DOE/ER-0089
Dist. Category UC-20C

Environmental Assessment for the Satellite Power System Concept Development and Evaluation Program - Nonmicrowave Health and Ecological Effects

November 1980

Prepared for:
U.S. Department of Energy
Office of Energy Research
Solar Power Satellite Project Division
Washington, D.C. 20585

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DOE/NASA
Satellite Power System
Concept Development
and
Evaluation Program

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SUMMARY

The office of Energy Research of the Department of Energy (DOE) and the National Aeronautics and Space Administration (NASA) are jointly carrying out a Concept Development and Evaluation Program for a proposed Satellite Power System (SPS) (1). The SPS Concept is being evaluated for its potential as an alternate energy source.

For purposes of this evaluation, NASA has developed a preliminary reference system (2). SPS, as described in the reference system, would collect solar energy on satellites in geosynchronous orbit in space. The energy would be converted to microwaves and beamed to an earth-receiving antenna (rectenna). At the rectenna the energy would be converted to electricity and fed into power grids for public use.

The DOE has responsibility for societal, comparative, and environmental assessment of the impacts of the reference system. One task in the environmental part of the program is the assessment of the non-microwave effects on health and the environment. These effects would result from all phases of SPS development and operation. This report covers the current knowledge regarding these effects, and is based on the reference system. The following tables summarize this assessment.

Table 1 - THE PUBLIC

SUMMARY OF NONMICROWAVE SPS IMPACTS ON HEALTH AND SAFETY OF THE PUBLIC

Cause/Effects	SPS Activities Involved	State of Knowledge
Air Pollution/ Respiratory disease, cardiovascular impairment, skin, eye irritation	Mining Construction Manufacturing Transport Launch Recovery	The potential for air pollution would be increased by all these activities. A prototype site rectenna study indicates that construction activities would cause air pollution in excess of existing standards if corrective measures were not taken. Quantitative studies have not been done for other activities, but it is expected that at least some of them would increase air pollution appreciably in localized areas, and that precautions would need to be taken to avoid exceeding state and federal standards.
Water Pollution/ Intestinal disease, skin irritation, other effects of ingestion	Mining Construction Manufacturing Transport Launch Recovery	Water pollution could be a potential hazard from these activities. Quantitative studies have not yet been done. It would be necessary to plan acceptable disposal of waste water in order to avoid impacts on public health.
Solid Waste/ Land use loss, illness	Mining Manufacturing Clearing and constructing launch and landing pads	It is clear that solid waste would be produced from all these activities. The impacts would depend on type of waste and methods of disposal. Land use might be lost to the public and, if disposal of toxic materials were not carefully carried out, there could be danger to the public health. An in-depth assessment of these impacts would be needed.
Noise/Psychological stress, hearing damage	Launch Recovery Construction	Launch noise might damage hearing of persons within 10,000 ft. of the launch pad, interfere with sleep at up to 100,000 ft., and interfere with speech and be highly annoying within 30,000 ft. Infrasound would be expected to be highly annoying at distances of 100,000 ft. due to low frequency vibrations of building structures or low frequency pressures in the middle ear. Sonic booms would not be expected to damage hearing. Because of startle, booms would interrupt speech and interfere with sleep. Part of the population would be highly annoyed within about 100,000 ft. of the center of pressure. Construction activities would increase noise levels, both in transportation corridors and in the vicinity of sites. The sites and transportation corridors selected and their nearness to populated areas would determine whether there was a public impact.
Safety/Accidental injury, fatality	Transport Launch Recovery	The public might be subjected to the hazards of accidents in the transport of SPS materials. The materials would include some which are highly toxic, flammable and explosive. Corridors for and means of transportation have not been defined. This would need to be done before hazards could be compared to those of conventional activities. There might be dangers to the public from accidents at launch and recovery, i.e., explosion on launch pads, launch abort or recovery landing accidents. The hazard would be dependent on the sites chosen and the corridors used. No quantitative assessment of accident probability has yet been made.

Table 1 - THE PUBLIC (continued)

Cause/Effects	SPS Activities Involved	State of Knowledge
Toxic Materials Exposure/Illness	Mining Manufacturing Transport Launch Recovery	The public might be subjected to increased amounts of toxic materials from various processes used for making and transporting components for SPS. Most of these would be conventional processes, and the usual methods of avoiding the release of excessive amounts would be used. There would be some unusual materials used, e.g., gallium arsenide and, in these cases, procedures for protecting the public would need to be developed. Launch and recovery of spacecraft would involve the release of some toxic materials from fuel burning, e.g., hydrocarbons. The effects on the public would depend on launch and landing sites. No quantitative estimates of the effects of these materials have yet been made.
Reflected Light/ Eye damage, crop and domestic animal impacts	Satellite Operation	There is a possibility that light reflected from the satellite to earth could damage human vision and disturb plant and animal cycles. A study of the characteristics and timing of the light is underway. When this study is complete, the effects on vision, animals and plants will be examined by experts in these fields.
Ozone Reduction, Ultraviolet increase/Skin cancer	Launch and Landing of Space Vehicles	Estimates of ozone reduction, as a result of SPS spacecraft activities, are very low compared with other activities which affect ozone. If those estimates are approximately correct, SPS would increase skin cancer by less than 0.01%,which would be undetectable due to variability of other factors affecting the ozone layer.
Acid Rain/ Crop damage, eye and skin irritation	Launch and Landing of Space Vehicles	Acid rain caused by effluents from fuel burning of spacecraft could affect crops and be a skin and eye irritant. Based on current studies, this effect would be expected to be highly localized and to be small compared to other terrestrial activities (e.g., fossil fuel power plants).
Weather Modification/ Crop damage, adverse weather effects	Launch and Landing of Space Vehicles Rectenna Operation	The rectenna prototype study team concluded that waste heat from the rectenna would not modify weather. However, there are other possible effects of the rectenna and of space transport which might modify weather. The group studying atmospheric effects of SPS has studies underway on this problem.
Electromagnetic Field Exposure/ Illness	Rectenna Operation Power Transmission	It is not expected that the fields from rectenna would impact the public, i.e., the fields should not extend beyond the buffer zone. The public might be exposed to fields in the vicinity of power transmission lines, but it is currently expected that the fields would be no different from those from conventional transmission lines. Research is in progress on the biological effects of electromagnetic fields. Thus far it appears that the effects are very subtle and would not be expected to be a danger for members of the public.
Lasers:Infrared Irradiation/ Eye, skin injury	Transmission of energy to earth	The transmission of energy to earth by microwaves is the option considered in the current reference system. The option of using lasers for this is being considered. The preferred type of laser has not been selected, and hazards to the public have not been studied.

Table 2 - TERRESTRIAL WORKERS

SUMMARY OF NONMICROWAVE IMPACTS ON HEALTH AND SAFETY OF TERRESTRIAL WORKERS

Cause/Effects	Activities Involved	State of Knowledge
Air Pollution/ Respiratory disease, cardiovascular impairment, skin, eye irritation, other occupational illness	Mining Construction Manufacturing Launch Landing	The workers involved in all these activities could be subjected to increases in air pollutants with consequent hazards to health. The prototype assessment of rectenna construction found that air pollutants might exceed standards if mitigating procedures were not used. Most of the pollutants would be the same as those encountered in conventional activities. Federal and state regulations and the usual safety standards would apply. It is currently assumed that by using known mitigating procedures, SPS activities could be carried out without unduly exposing terrestrial workers to noxious air pollutants.
Water Pollution/ Skin, eye irritation, occupational illness	Manufacturing Spacecraft Recovery	There would be the possibility of hazards for the terrestrial worker from water pollution. The extent of these hazards has not been assessed.
Noise/ Hearing impairment, stress; psychological and physiological	Mining Manufacturing Launch Landing	The noise hazard from conventional types of manufacturing (e.g., cement plants) construction and transportation noises would prevail, and it is expected that they could be dealt with, using conventional safety regulations. The unique noise hazards of SPS would be the noise from launch and landing of spacecraft. Hearing protection would be necessary for personnel in or near these sites. There might also be psychological effects from annoyance and startle for workers near these sites.
Safety/Accidental injury, fatality	Mining Construction Manufacturing Transport Launch Recovery Rectenna Operation	Workers would be subjected to the occupational hazards ocurring in the conventional mining, manufacturing, construction and transport activities. The ground transportation of large amounts of toxic, flammable and/or explosive materials for SPS might call for special precautions to prevent excessive injuries. No quantitative study has been made of these hazards pending knowledge on transport methods and quantities of hazardous materials to be moved. Workers at launch and landing sites could be injured by launch and landing accidents and by fuel fires or explosions. No assessment of the extent of these hazards has yet been made.
Toxic Materials Exposure/Illness	Mining Manufacturing Transport Launch and Landing	There would be toxic materials used in the manufacture of SPS components. Most of these would be materials used in conventional processes, but there might be toxic materials, e.g., for the gallium arsenide solar cell if that option were chosen, which would be used in much larger amounts than in current processes. When material lists become firm, an assessment of the hazards associated with these exotic materials will be needed.

Cause/Effects	Activities Involved	
Electromagnetic Field Exposure/ Illness	Rectenna Operation	There will be electromagnetic fields induced by rectenna operation. The worker will be exposed to these fields. Research on the health effects of these fields has not yet defined the effects thoroughly. When the magnitude of the fields is defined, assessment will be needed, using the then current findings of research.
High Voltage/ Electric Shock, Injury, Fatality	Rectenna Operation	Rectenna workers will be exposed to the hazards of high voltages. The design of rectennas is not specific, as yet, regarding these hazards. It is assumed, currently, that they will be comparable to conventional power plants and that current safety regulations will suffice. This hazard will be assessed as design of rectenna facilities progresses.
Lasers/ Eye, Skin Damage	Rectenna Operation	Lasers are being considered as an alternative method for transmitting energy from satellites to earth. If this option becomes viable, the rectenna workers may be subject to spurious radiation (currently assumed to be in the infrared part of the spectra) from the beam. Hazards, particularly to the eyes and skins, will need assessing if/when a preferred type of laser is chosen.

Table 3 - SPACE WORKERS

NONMICROWAVE SPS IMPACTS ON THE HEALTH AND SAFETY OF SPACE WORKERS

Cause Effects	Activities Involved	State of Knowledge
Prolonged Weightlessness/Vestibular problems, Calcium loss: Bone decalcification Muscle atrophy Hormone, fluid, electrolyte imbalances Anemia Cellular immunity changes Cardiovascular changes	Space transportation Space construction Space operation	There have been changes in earlier spaceflights from preflight baseline values in all the parameters listed under effects. Some of the changes were probably due to an adaptation process of the body to the zero-g environment, expected to have an effect on future health. Other variations from normal may affect work efficiency and future health. NASA Life Sciences personnel expect that, prior to SPS contruction and by use of both ground-base and space based research and experience, the cause and effect relationships will be explained, and methods of ameliorating the unwanted effects will be found. Research is needed to solve these problems.
Radiation Exposure/ Cancer Genetic changes Cataracts Central nervous system damage Life shortening Infertility	Space transportation Space construction Space operation	There are a number of uncertainties in the information used to make preliminary estimates of radiation dose and of the health risks from radiation for space workers. Using the current reference system the best estimate is that a 90-day tour in GEO (where a majority of workers would spend their time) would result in a radiation dose of approximately 40 rem. This is in a range which would result in increased cancer incidence, and a possibility of increases in genetically-related ill health, developmental abnormalities of the newborn, cataract and temporary decreases in fertility. Possible unique effects of high-energy, heavy ions, present in galactic cosmic radiation, may be of consequence. Research is needed on the biologic effects of these particles. The probability of serious health effects due to space ionizing radiation could be minimized by increases in and/or changes in the character of shielding. Research and modification of SPS design are needed. Age, sex and length of tours in space will also modify radiation effects. Decisions on radiation limits for space workers are needed. The precision of dose estimation needs improving by more precise measurements of flux and energy of ionizing particles in space and by improvements in the models used for predicting dose due to flux. It is thought that with research and system design changes the radiation dose could be reduced to one which might be acceptable on a risk/benefit basis. Every effort should be made to minimize ionizing radiation as the design of SPS proceeds.

Table 3 - SPACE WORKERS (continued)

NONMICROWAVE SPS IMPACTS ON THE HEALTH AND SAFETY OF SPACE WORKERS

Cause/Effects	Activities Involved	State of Knowledge
Space Transport Accident/Injury, Fatality	Launch Recovery Orbital transfer Satellite maintenance	There would be the possibility of injury or fatality connected with space transportation. There could be launch or landing accidents and/or life support failures. No quantitative studies of the probability of these emergencies have yet been made.
Extended Confinement/ Psychological stress	Space construction Space operation	The effects of prolonged confinement in other remote working situations have resulted, in some cases, in psychological stress and a high turnover in personnel. A system of screening for adaptability, resilience, dedication, etc., would need to be worked out. Also, recreational facilities in space, and needs of families and friends on earth would have to be considered.
Life Support Failure/ Illness, fatality	Space transportation Space construction Space operation	NASA has previous experience with life-support systems, and is continuing to improve these. The SPS module, living conditions and working stations would differ greatly from those of previous space activities. Designs of modules and work stations are underway, and some aspects of these may be tested in the planned Space Shuttle and Space Operations Center activities.
Spacecraft Charging, Environmental Interactions/ Electric shock, injury, fatality	Space construction Space operation	The phenomena is being studied in a number of laboratories as well as by NASA and the Air Force. One theoretical study has been done for SPS, but on an early version. The extent of the problem would depend on the material in the space structures, so new studies would be needed, not only on the extent of the build-up of charge but on methods to reduce it.
Electromagnetic Field Exposure/ Illness	Space operation	Space workers near the solar energy panels and antenna would be working in electromagnetic fields. The intensity of these fields has not yet been defined. Research programs are underway to assess the biological hazards of these fields but, to date, results are limited. When the strength of fields is defined, a study of potential effects, using the then current literature, would be needed.
High Voltage/ Electric shock, injury, fatality	Space operation	Space workers would be in the vicinity of high voltages, and would have the same risks as those working in power plants, etc., on earth. The hazard might be compounded by the awkwardness of working in the weightless state. Proper precautions and safety regulations would be necessary.
Meteoroid, Space Debris Collisions/Injury, fatality	Space travel Space construction Space operation	The probability of collisions of spacecraft and space structures with meteoroids and space debris has not been studied. NASA has information and computer programs applicable to this problem. The large size of the satellite would make it more vulnerable to this hazard than previous space vehicles.

Table 3 - SPACE WORKER (continued)

Cause/Effects	Activities Involved	State of Knowledge
Occupational Hazards/Injury	Space construction Space operation	The usual occupational hazards associated with construction work would apply to space workers. These might be accentuated by the awkardness of working in the weightless state. Proper design of work stations might alleviate this situation. When specific tasks are detailed, a study of hazards will need to be done.
Emergency Medical/ Dental problems	Orbital transfer Space construction Space operation	Though space workers would be screened for medical and dental problems prior to space travel, there could occur some problems with this many people in space. Health care facilities and personnel are included in SPS planning, and these should be able to handle all except the most complicated emergencies. In the unexpected case, where the facilities were not adequate and the patient would need complicated hospital care, it might be difficult to obtain transportation to earth at the appropriate time.
Space Environment/ Infectious diseases	Living and working in space environment	The closed system and limited living areas in space modules might be conducive to outbreaks of infectious diseases. NASA Life Sciences personnel are looking at methods to both challenge the workers immune system (thereby increasing resistance) and to keep outbreaks of this kind from occurring by designing facilities and life-support systems so that buildup of micro-organisms would not occur.
Acceleration(G-loads)/ Cardiovascular and respiratory effects	Space transportation	Experience with acceleration effects in space travel is very limited, but cardiovascular and respiratory effects would be expected to be the most important. It is known that the length of time spent in the weightless state affects the tolerance of acceleration forces, and more research is needed on this effect. NASA expects that effects could be ameliorated by tradeoffs between g-loads and duration; by proper body positioning of personnel,and by counter-pressure suits. Research is needed to avoid adverse consequences.
Extravehicular Activity (EVA)/ Injury,fatality	Space construction and maintenance	Space-suit activity (outside of work and living modules) is not a planned part of space construction and maintenance activities. However, it would need consideration for emergency purposes, i.e., repairs to machinery, etc. There would also be EVA of some kind in movement from the living module to work stations. Failure of life-support systems for these activities could result in injury or fatality.

Table 4 - ECOLOGY

SUMMARY OF NONMICROWAVE SPS IMPACTS ON THE ECOLOGY

Cause/Effects	Activities Involved	State of Knowledge
Air Pollution/ Ecosystems damaged	Mining Manufacturing Construction Launch Transport	The effects of air pollutants on wild and domestic animals are uncertain. It is probable that, if mitigating procedures were followed to meet current standards for humans, adverse effects on animals would be avoided. Some adverse effects of air pollution on plants have been found, but again conformance with current standards would probably avoid adverse effects with the possible exception of acid rain. Acid rain would be highly localized but might change soil acidity and damage leaves and crops. The potential adverse effects of pollutants from manufacture and/or use of unconventional toxic materials would need study.
Water Pollution/ Ecosystems damaged	Mining Manufacturing Construction	Water pollution would affect both animals and plants in the areas where this occurred. No definitive assessment of the extent of water pollution from SPS activities has been done. Care would have to be taken to avoid damage, especially in areas where there were endangered species. Federal and state water quality standards would have to be complied with. Where unconventional toxic materials were used, studies of effects might be required.
Solid Waste/ Ecosystems damaged	Mining Manufacturing Construction	Solid waste from these activities would destroy ecosystems in areas of its placement. Plants and animals in adjacent areas might be affected if materials leached out of the waste piles. Studies would be needed of the effects on rare or endangered species in the areas of disposal of solid wastes.
Land Use/ Ecosystems destroyed and damaged	Mining Manufacturing Construction Launch sites Transport Rectenna siting Power distribution system	In areas where land would be cleared for SPS activities, the local ecosystems could be destroyed. Areas on perimeters of these cleared areas might be damaged by traffic, waste and drainage changes. Depending on the type of ground cover and type of continued use, some peripheral areas might repair and wildlife return; others might not. Each site would need impact assessment to avoid, where possible, irreparable damage to ecosystems, especially where rare and endangered species were involved.
Noise/Wildlife disturbance	Launch Recovery Construction	The unusual noise associated with these activities might startle and otherwise disturb wildlife. Animals might adapt to certain of the noises, but this is not certain. Space shuttle studies might clarify some of these effects. If rare and endangered species were involved, care would need to be taken.

Table 4 - ECOLOGY (continued)

Cause/Effects	Activities Involved	State of Knowledge
Reflected Light/ Plant and animal cycle changes	Space operations	Light would be reflected to earth from surfaces of space-craft and space structures. A study currently being completed will characterize the expected intensity and timing of this light. Experts on effects of light on plants and animals, using this information, will determine whether there might be impacts on plants and animals.
Ozone Reduction, Ultraviolet Light Increase/Damage to plants and animals	Launch Landing of space vehicles	It is probable that appreciable changes in ultraviolet light caused by ozone reduction would impact certain plants and animals. However, current estimates of ozone reduction from SPS activities indicate that the change would be so small that it would be undetectable due to large variations in ozone concentration naturally and from other current impacts. If the current estimates are found to be reasonably accurate, it is expected that the impacts on ecosystems would be negligible.
Electromagnetic Field Exposure/ Plants, animal disturbance	Rectenna operation Power transmission	There would be electromagnetic fields in the vicinity of the rectenna site and the power transmission lines. These are expected to be no greater than those near conventional power transmission lines. Research is being carried out (funded from sources other than SPS) but is not advanced enough to determine specifically effects on animals. Some effects on certain types of plants have been found. When the intensity of fields resulting from SPS activities are determined, a study will be needed.

1.0 INTRODUCTION

The possibility of collecting large quantities of solar energy in space, converting it to microwaves, transmitting it to earth, and converting it to electricity is being studied by the Department of Energy (DOE) and the National Aeronautics and Space Administration (NASA). This joint program, described in the SPS Concept Development and Evaluation Program Plan (1) will generate the information needed to make a rational decision regarding development of the Satellite Power System (SPS) program after 1980. NASA is conducting systems definition (i.e., engineering) studies of the SPS. The DOE is evaluating potential environmental impacts; examining economic, international, institutional issues and other social issues; and comparing SPS with selected existing energy sources and alternative power sources for the future.

A SPS "reference system" is described by NASA in the SPS Concept Development and Evaluation Program Reference System Report (2). This reference system provides the technical and operational information DOE needs to conduct preliminary environmental, socioeconomic, and comparative assessment studies. The reference system is only an engineering concept, and NASA's current systems definition work is developing a more complete understanding of the satellite power system. Societal and environmental impact studies can also be expected to influence evolving system designs. The principal characteristics of the reference system are listed in Table 5.

Also required for the satellite power system would be construction bases in space, launch and mission-control bases on earth, and fleets of space vehicles to support the construction and maintenance of the satellites. These transportation vehicles would include heavy-lift launch vehicles, personnel launch vehicles, cargo orbit-transfer vehicles, and personnel orbit transfer vehicles. The earth launch site would be the Kennedy Space Center, pending further study.

The key environmental issues associated with the SPS concern potential effects on human health, ecosystems, climate, and electromagnetic interference. In order to address these issues in an organized manner, five tasks have been established:

Task I	Microwave Health and Ecological Effects
Task II	Nonmicrowave Health and Ecological Effects
Task III	Atmospheric Effects
Task IV	Effects of Ionospheric Heating on Telecommunications
Task V	Electromagnetic Systems Compatibility

This report covers Task II: Nonmicrowave Health and Ecological Effects

2.0 SCOPE

This assessment is intended to identify and evaluate (quantifying where possible) the nonmicrowave-related health effects and ecological impacts which might reasonably be expected to accompany the construction and operation of the satellite power system as defined in the current reference system concept (2). The assessment covers effects which would arise from SPS activities including:

- Mining raw materials
- Processing materials and fuels
- Manufacturing components
- Transporting materials on the earth and in space
- Packaging materials for transport into space
- Manufacturing space vehicles
- Launching space vehicles
- Traveling in space
- Living and working in space while constructing and maintaining satellites
- Siting, constructing and operating rectennas (ground-receiving station)

Included in the assessment are potential hazards and impacts to the space worker, the terrestrial worker, the public, and the ecology.

Table 5

SPS SYSTEM CHARACTERISTICS

System Generating Capability at Utility Interface	- 300 Gigawatts total - 5 Gigawatts per station
Number of Satellite-Earth Stations	- 60 Satellites - 60 Earth rectenna stations
System Design Life	- 30 Years
SATELLITE CHARACTERISTICS	
Satellite Mass	- 35×10^6 Kilograms (gallium aluminum arsenide photovoltaic cells) - 50×10^6 Kilograms (silicon photovoltaic cells)
Satellite Dimensions	- 10 x 5 x 0.5 Kilometers
Structural Material	- Principally graphite composite
Satellite Location	- Geosynchronous earth orbit (GEO); 35,800 Kilometers altitude above earth
ENERGY-ELECTRIC SYSTEM CHARACTERISTICS	
Energy Collection	- Gallium aluminum arsenide photovoltaic solar cells with concentration ratio of 2; or silicon photovoltaic cells with concentration ratio of 1.
Solar Cell Efficiency	- 20% for gallium aluminum arsenide; 17.3% for silicon
Energy Conversion	- Solar to DC electric to microwave
Electric System	- DC to microwave by 10^5 klystron tubes (per satellite) - Microwave radiation by 1-kilometer diameter antenna array (per satellite) - 1.2 Arc-minutes beamwidth - 6.72 Gigawatts microwave radiated power - 2.45 Gigahertz fundamental operating frequency - 22 Kilowatts per square meter power density (center) to 2.4 kilowatts per square meter power density (edge) at transmitting antenna
RECEIVING SYSTEM (RECTENNA) CHARACTERISTICS	
Microwave Receiving Elements	- Half-wave rectifying diodes - 98% Collection efficiency - Series of tilted, serrated steel panels - 2% Reflected microwave power upward and toward Southern horizon - 1% Leakage loss
Power Available at Utility Interface	- 5 Gigawatts (per station) at utility electric frequency
Rectenna Dimensions	- 78.5 Square kilometers total active panel area - 10 x 13 Kilometers (ellipse) total area (not including control and support facilities area needs) - 11.4 x 14.4 Kilometers (ellipse) exclusion area
Terrestrial Power Densities	- 23 Milliwatts per square centimeter at 2.45 gigahertz at center of rectenna - 1 Milliwatt per square centimeter at 2.45 gigahertz at edge of rectenna - 0.1 Milliwatt per square centimeter at 2.45 gigahertz at exclusion boundary
System Control	- Fail-safe pilot beam control to satellite from earth (0.003 milliwatts per square centimeter peak power density by beam spreading)

Source: Reference 2

3.0 METHODOLOGY

There are two categories of effects of SPS development. First, there are impacts which would result from increased use of conventional processes (e.g., increased public exposure to air pollution from steelmaking or processing fuels). SPS activities would increase these impacts in some cases by large amounts; in others, minimally. The second category consists of impacts unique to SPS (e.g., effects on the space worker of weightlessness or unique types of ionizing radiation). Though impacts due to conventional processes have been identified, the major emphasis during the Concept Development and Evaluation Program has been on the impacts which would be unique to SPS. The reference system has been used as a baseline and, with the exception of one research study, current knowledge from the literature and previously performed research have been used as input information for the assessment. A few SPS-supported in-depth studies have been performed by contractors/consultants. Most impacts are described in a general way pending more precise information on systems design.

4.0 IMPACTS OF TERRESTRIAL DEVELOPMENT

4.1 Production of Materials, Components, and Fuels Needed for SPS

All the activities involved in mining, processing, manufacturing and transportation of the materials and components needed for SPS implementation have potential for adverse environmental effects (See Table 6). Air, water, and solid-waste pollution might be increased. There would be the possibility of land disturbance, safety hazards, noise pollution and toxic material hazards.

Many of the impacts of these activities would be incremental to environmental situations which already exist. In some cases the increment would be so small as to be almost negligible. In other cases appreciable increments in environmental hazards could be realized.

Tables 7 and 8 tabulate some preliminary estimates of some of the impacts that SPS material requirements might have. The data were taken from an early version of the SPS Reference System, and the estimates are rough. They are used here only to illustrate the potential for impacts in the absence of mitigating strategies. Some materials would require only an exceedingly small increase in production, and add minimal pollution to the environment. Other materials would be needed in amounts approaching or exceeding 50% of annual U.S. production. Production of these materials would increase impacts greatly unless practical ameliorating strategies could be developed. In Table 8 the increments to existing pollutants appear reasonably small. However, this is an average for the U.S.; and, in fact, the pollutants would occur in localized areas. In these locales increases could be sufficient to exceed national standards for some pollutants. Federal and state regulations and standards exist for most of the pollutants and for some of the toxic materials which would be generated. When some of the design parameters for SPS have been worked out more precisely, studies will be needed to determine actual levels generated and the ameliorative measures which would be needed for compliance with standards and regulations. It can be stated tentatively that these preliminary analyses indicate that SPS would produce measurable increases in air, water, and solid waste pollution, and in use of water, materials and land.

The potential health risks to the public and the terrestrial workers would be increases in respiratory, cardiovascular, kidney, urinary tract, or digestive diseases; and in skin and eye irritation. When the materials processed were flammable or explosive, fire and detonations might occur. There would be all the conventional occupational hazards for terrestrial workers, e.g., mine accidents, electrical hazards, chemical burns. Table 9 gives tentative estimates of occupational illness and injury for mining, construction, and manufacturing. Federal and state safety regulations would apply to these SPS-related activities. In most instances it is probable that conventional safety procedures would be adequate, but for some hazards more stringent procedures might be necessary.

Ecosystems near SPS-related activities would probably suffer some damage. They could be affected by air, water, solid waste, and noise pollution; by loss of habitat from land use from such activities as mining and building new factories; and by increases in human populations in areas where increased activities might occur.

4.2 Ground Transportation of Materials and Equipment

Transporting materials and equipment would involve moving SPS supplies between mining sites, construction locations, manufacturing facilities, launch and recovery areas, and rectenna sites. Again, most

Table 6

POTENTIAL IMPACTS OF MATERIALS ACQUISITION

Extracting, Processing, Fabricating Materials and Equipment			
Mining	Constructing New Facilities	Manufacturing	Transporting Materials and Equipment
o Land Disturbance (strip-mining, subsidence, spoil piles) o Air Pollution (fugitive dust) o Water Pollution (leaching, drainage modification) o Toxic Material Hazards o Safety Hazards o Noise Pollution o Solid Waste Disposal Effects	o Land Disturbance o Air Pollution (fugitive dust) o Water Pollution o Safety Hazards o Noise Pollution	o Air Pollution (stack emissions) o Water Pollution (process effluents) o Solid Waste Disposal Effects o Safety Hazards o Toxic Material Hazards o Noise Pollution o Water Resource Depletion	o Air Pollution (vehicle exhausts) o Waste Pollution (spills) o Accidents (conventional, catastrophic) o Toxic Material Spills o Noise Pollution

Table 7

INCREMENTAL MATERIAL REQUIREMENTS OF SATELLITE POWER SYSTEM

Material	Portion of U.S. Annual Production, %[a]	
	Silicon Design[b]	Gallium Arsenide Design[b]
GFRTP[c]	NA[d]	NA
Stainless steel	NA	NA
Glass	NA	-[e]
Silicon	NA	-
Copper	0.94	0.66
Aluminum	7.3	7.4
Silver	6.9	170
Molybdenum	0.007	0
Mercury	22	22
Tungsten	48	48
Steel	2.6	2.6
Concrete[f]	4.0	4.0
Gallium arsenide	-	NA
Titanium	0.044	0.044
Ceramics	NA	NA
Misc. and organics	NA	NA
Argon	7.8	1.9
Hydrogen	66.7	42.0
Oxygen	18.9	11.7
Methane	NA	NA
Sapphire	-	NA
Teflon	-	NA
Kapton	-	NA

[a] Material requirements are from Ref. 2, and U.S. production figures are from Ref. 3. Values assume that two satellites are constructed each year.

[b] The two reference system options for photovoltaic solar cells (See Table 5 and Ref. 2).

[c] Graphite-fiber-reinforced thermoplastic.

[d] NA = Not available.

[e] Not applicable.

[f] Production measured as cement.

ENVIRONMENTAL EFFECTS OF SPS DEPLOYMENT

Type of Impact	Annual SPS Emissions[a]	U.S. Annual Total
	10^6 metric tons	
Air Pollutant Emissions[b]		
Particulates	0.11	14
Sulfur dioxide	0.013	30
Carbon monoxide	0.042	88
Hydrocarbons	0.010	22
Nitrogen dioxide	0.0010	20
Ammonia	0.00027	NA[c]
Water Pollutant Effluents[d]		
Bases	0.012	NA
Biological oxygen demand	0.00083	NA
Chemical oxygen demand	0.031	NA
Dissolved solids	0.017	NA
Suspended solids	0.022	NA
Organics	0.0056	NA
Water Resources Requirements[e]		
Nonrecoverable water use	3.4	1366
Solid Waste Generation[f]		
Waste material	1.6	229
	10^3 km^2	
Land Requirements		
For rectenna sites only	10.56	9363[g]

[a] Source: Ref. 4. Based on early version of SPS configuration (Scenario A). Does not reflect more recent designs. The SPS annual figures were derived by averaging the total system impacts over a 30-year construction period.

[b] SPS data from mining, processing, fabrication. U.S. total data for all sources from Ref. 5, 1973.

[c] NA - Not available.

[d] From steel, aluminum, copper, cement processes.

[e] SPS data from propellant manufacture, launch pad cooling, construction. U.S. total from Ref. 3, 1977.

[f] SPS data from aluminum and steel processes. U.S. total data from Ref. 6: residential, commercial, industrial wastes.

[g] U.S. total land area.

DISTRIBUTION OF OCCUPATIONAL ILLNESS AND INJURY

Activity	10^6 Person-Days Lost[a] Occupational Injuries	Occupational Illnesses
Material Acquisition	14.63	0.45
Ground Construction	9.04	0.29
Ground Operation and Maintenance	1.48	0.08
TOTAL:	25.15	0.82

[a] Data are for conventional mining, construction, manufacturing only, and are totals over the 30-year life of the satellite power system.

Source: Ref. 2, based on early version of SPS configuration. Does not reflect more recent design concepts.

of the impacts would be conventional (See Table 6), and the issue of interest for these impacts is the incremental effect. Quantitative studies of the increments and their specific impacts have not been made.

Potentially very serious impacts might result from transporting toxic, highly flammable and potentially explosive materials. An example of a toxic material which might be used in large quantities is arsenic if the gallium arsenide solar cell becomes the preferred option. This is an extremely toxic and possibly carcinogenic material, and spills of this material could be very dangerous. With regard to flammable and explosive materials, a large quantity of rocket propellants would need to be transported to the launch site. One of the most serious concerns is liquid hydrogen, which is currently transported by tank truck to launch sites but is under consideration for transport by barge or rail car. Reference 7 describes some of the problems with accidental hydrogen release, based on projections for the space shuttle program. Liquid hydrogen spills can ignite immediately or have a delayed ignition. Upon immediate ignition, there is a flash as the gaseous hydrogen is consumed, followed by a burning of the liquid pool. The flash from a 3200 m^3 (850,000 gal) spill can produce enough heat to cause first-degree burns and ignite light combustibles such as paper at a distance of 300 m. Thermal radiation from a liquid pool fire is about one-fifth that of a flash. This size spill is based on a launch-pad accident of the space shuttle. A ground transport accident would probably not involve as much liquid hydrogen in one incident.

If immediate ignition did not occur, Ref. 7 indicates that the cloud of gaseous hydrogen could disperse downwind and be ignited by some remote spark. However, this possibility is limited by the lower flammable limit (the lowest concentration for which ignition could occur), and by the fact that an accident would likely involve some violent event sufficient to cause immediate ignition.

Other explosive or highly flammable materials include monomethylhydrazine, hydrazine, and nitrogen tetroxide used in chemical liquid propellants. These would be of more concern for their highly toxic effects than for their flammability.

Spills of liquid oxygen could also create significant local impacts, primarily on ecosystems. The extreme cold would be the principal cause of damage.

Although data are available on the results of transportation accidents, these have not been translated into actual health and safety effects, i.e., injury rates. To do so would require an analysis of accident probability and an evaluation of probable transport corridors to determine public exposure to these hazards and to compare the hazards with those of conventional activities.

Thus, transporting materials might add to pollution effects on the health of the public and terrestrial worker and to degradation of ecosystems. Transport accidents could seriously harm members of the public and certain categories of terrestrial workers, and destroy ecosystems in the vicinity.

4.3 Construction of Launch and Landing Pads

Construction of facilities for launch and landing would require material acquisition and transportation to the sites. The associated impacts of these activities would be the same as are outlined above. The site(s) would require clearing and removal of vegetation; grading; excavating for foundations and underground utility lines; preparing surface drainage systems; preparing and pouring concrete; erecting associated structures; road building; possibly fencing; constructing water and sewage facilities; revegetation where this had been destroyed by construction activities (A prototype study has been done for the impacts of rectenna construction, see Section 7.0. Many of the impacts will be comparable.). Table 10 lists effects which might affect the environment.

If these facilities were built near populated areas, the public might be exposed to increased air and water pollution, noise, and traffic hazards. These might affect health and safety. Workers at the site would be exposed to greater risks than the public; in addition, they would be exposed to the occupational hazards associated with heavy construction. Quantitative studies of these impacts have not been made.

The ecology at the site and in its vicinity would also be impacted. Habitats at the site would be completely destroyed in graded and paved areas. Nearby habitats could be degraded from air and/or water pollution; from soil compaction caused by vehicular and foot traffic. If drainage and underground water patterns were changed, this might modify habitats for both plants and animals. Noise from vehicles and human activities could interfere with animal breeding, nesting, and feeding activities. If night work is required, the lighting and noise might affect diurnal cycles. Particular care would need to be taken if there were rare or endangered species in or near the site area. Kennedy Space Center (KSC) was selected as the prototype site for launch and landing for SPS vehicles. Environmental impact studies (EIS) have been done for KSC for purposes of Space Shuttle and Space Transportation Systems (STS) (Refs. 7,8). Small areas of wildlife habitat will be destroyed for building purposes for Shuttle and STS. Should this site eventually be chosen for SPS, the environmental impact would be smaller than if an entirely new site were chosen. However, there would be increased impact on the area since the existing facilities would be expanded. The EIS for KSC lists rare, endangered and threatened species of flora and fauna in the area. There are many of these; however, it was concluded that there were no impacts which might be expected to jeopardize these species. Whether KSC or an entirely different site is chosen, in-depth studies of the impacts would be needed.

Table 10

IMPACTS FROM CONSTRUCTING LAUNCH AND LANDING PADS

Air Pollution (fugitive dust, vehicle exhaust	Noise (vehicular)
	Land Use
Water Pollution (cement production, fuel spills)	Ecology Habitat Destruction and/or Modification
	Solid Waste (spoils from vegetable materials; from excavating and grading; debris from construction)

5.0 LAUNCH AND RECOVERY OF SPACECRAFT

Launch and recovery of spacecraft would produce environmental effects. Table 11 lists possible impacts from these activities. As mentioned above, the reference system uses Kennedy Space Center as the prototype site for launch and recovery activities. So far this site has been used for baseline studies. Other sites (e.g., ocean) are being considered, and environmental effects would differ appreciably.

Table 11

IMPACTS OF LAUNCH AND RECOVERY OF SPACECRAFT

Launch	Recovery
o Air Pollution (vehicle exhaust, ground cloud)	o Air Pollution
o Water Pollution (launch pad cooling)	o Water Pollution (residual propellant spills, ablative material removal)
o Noise (acoustic, sonic boom)	o Noise (sonic boom)
o Launch Emergency (abort, off-trajectory failure)	o Recovery Emergency
o Toxic Materials	o Toxic Materials
o High Acceleration/Deceleration for space personnel	
o Ozone Depletion	
o Acid Rain	
o Explosive Hazards	
o Effluent Deposition in the upper atmosphere	

5.1 Air Quality

Launch and recovery would affect air quality. SPS launch activity would produce air pollution from the exhaust products of the launch vehicles and from the formation (at the launch platform) and dispersion of a "ground cloud" made up of exhaust gases, cooling water, and some sand and dust. Because of launch trajectory and vehicle speed, the majority of the exhaust products would be emitted in the troposhere (0-11 km altitude), although a sizeable quantity would also be emitted in the stratosphere (11-50 km) (4). The ground cloud, on the other hand, would develop at the launch pad and rise to 0.7-3 km, where its bouyancy would be neutralized by cooling of gases.

The ground cloud has been the subject of extensive research, particularly with regard to the space shuttle (8). The ground cloud could expose the public to air pollutants because of its low altitude. A mathematical model has been developed to estimate the maximum concentrations of various pollutants in the ground cloud as a result of a space-shuttle launch. These results would not be directly applicable to SPS operations because of the probable use of liquid-fueled rockets (vs. solid-fueled for the shuttle) and the significantly larger launch-vehicle size.

As a result of previous work, ambient concentration limits can be identified for various launch-related air pollutants. Standards used for the space-shuttle program are based on the National Ambient Air Quality Standards promulgated by the U.S. Environmental Protection Agency (9) and exposure limits recommended by the Committee on Toxicology of the National Academy of Sciences (NAS)/National Research

Council (NRC) (as referenced in 8). The NAS/NRC recommendations include a short-term public limit (STPL) designed to avoid an irritation of the moist mucous membrane of the upper respiratory track and a public emergency limit (PEL) related to accident conditions that might result in some irritation but with reversible effects. It is thought that SPS ground-cloud concentrations would probably be below the STPL and PEL values, but quantitative information is not yet available. The group working on atmospheric effects of SPS is generating some information with regard to the pollutants from spacecraft.

Test flights and the testing of rocket engines, orbital maneuvering systems, and reaction control systems would also produce air pollutants.

5.2 Water quality

The water quality effects of the launch and recovery of SPS vehicles have not been assessed; however, some information is available for the space shuttle (8). Pollutants could enter the water through contamination of the launch-pad cooling water with engine exhaust products, removal of ablative insulation from reentry vehicles, and residual propellant spills if the launch vehicles were recovered from the ocean. The first two conditions could be controlled by onsite water-treatment facilities, and would not normally present a public health problem. Maximum allowable concentrations of propellants in water have been suggested for Shuttle (8). These could be used as a starting point for assessment of the impacts for SPS which would need to be done when these activities were better defined.

5.3 Noise

A preliminary evaluation of the noise impact of SPS vehicles on the community and ecology at the launch and landing site has been performed (10). The tables, figures and conclusions in this section are from that study. Also see Ref. 10 for sources of information and methods of computer data. This study used Kennedy Space Center (Cape Canaveral) as the prototype launch and landing site.

5.3.1 Launch Noise: Since the heavy-lift launch vehicle (HLLV) would have more impact and many more launches than the personnel launch vehicle, the study emphasizes the HLLV launch impacts. Though other noise mechanisms might be present in a rocket engine, most of the noise produced would be the result of turbulence in the exhaust. Thus, only the exhaust noise was considered in this study. For some calculations information was sparce, and conclusions are therefore tentative. The findings of this study with respect to impacts are summarized below.

Calculations of the noise levels produced by HLLV during launch are given in Figs. 1 and 2. These figures provide the maximum spectra at several distances from the launch point. Table 12 shows some information contained in Figs. 1 and 2, supplemented by determinations of A-weighted sound level, overall sound-pressure level L_{eq} for a 24-hour period; and SIL (see Table for definitions).

Hearing Damage: The OSHA requirement for maximum exposure is 115 dB(A). Thus, from the values given in Table 12, a potential hearing hazard would exist within 1500 m (5000 ft) from launch point. This assumes that a daily exposure would exist and that all people exposed would be outdoors. Using the more stringent technique employed by EPA, wherein the L_{eq} for 24 hours should not exceed 70 dB(A), the range of potential hearing hazard extends to 3000 m (10,000 ft). Thus, all space center personnel would require hearing protection devices if they were within 3000 meters of the point of launch. See Fig. 3 for the approximate region bounded by the 3000 m radius at Cape Canaveral.

Speech Interference: The speech interference effects of the launch phase would be minimal since the duration of the intense noise is not great. However, during launch itself and for at least 2 minutes thereafter, some speech interference would be present, even at distances as great as 9000 m (30,000 ft). It is felt that the duration of the noise, which would occur about twice a day, would not be great enough to severely impact the community surrounding the space center from a speech interference viewpoint.

Sleep Interference: Figure 4 shows the results of noise studies on sleep. The possibility of sleep disturbance does exist for distances as great as 30,000 m (100,000 ft) from the launch site. As seen from Fig. 4, this effect will vary depending on the person. Also, such things as the level of background noise will influence the degree of sleep interference.

Annoyance: The percentage of people estimated to be highly annoyed may be obtained using Fig. 5. There is some question as to the appropriateness of extrapolating an event occurring once per day to a 24-hour sound exposure. However, this technique probably provides as accurate an estimation of the response as any available at this time. Table 13 shows the percentage of people highly annoyed at

Table 12

SOUND LEVELS OF LAUNCH NOISE

Distance / Frequency		300 m 1000 ft	1500 m 5000 ft	3000 m 10,000 ft	9000 m 30,000 ft	30,000 m 100,000 ft
		Octave Band Levels dB re 20μPa				
16 Hz		146	133	127	117	107
31.5		143	130	124	114	104
63		140	127	121	111	96
125		136	122	115	101	77
250		132	117	109	91	53
500		128	112	102	76	30
1000		124	105	92	60	-
2000		119	98	82	36	-
4000		114	89	68	-	-
8000		108	78	54	-	-
Measure						
A-level	dB	130	114	105	89	71
L_{eq}	dB	89	78	70	56	41
Duration	sec	12	42	54	77	77
OASPL	dB	149	136	130	120	109
SIL	dB	121	101	86	43	8

Octave Band Level: The sound power level or sound pressure level for a frequency band one octave wide. The upper frequency f_u of the band is twice the lower frequency, f_ℓ, and the center frequency is given by $f_c = \sqrt{f_u \cdot f_\ell}$. Analysis of a sound in octave bands is a convenient means of describing the frequency distribution of the noise.

A-Level: A-Weighted Sound Level - Sound pressure level which has been filtered or weighted to quantitavely reduce the effect of the low frequency noise. It was designed to approximate the response of the human ear to sound. A-weighted sound level is measured in decibels with a reference of 20μPa.

L_{eq}: Average A-Weighted Sound Level - The average A-weighted sound level, or equivalent sound level, is the average (on an energy basis) of the A-weighted sound level integrated over some specified amount of time.

OASPL: Overall Sound Pressure Level - The overall sound pressure level, or sound pressure level, is 20 times the logarithm to the base 10 of the ratio of the measured root-mean-square pressure to a reference sound pressure. The reference sound pressure is 20 micro pascals (20μN/m^2).

SIL: Speech Interference Level - The speech interference level is a simplified method of quantifying noise in terms of its interfering effect on speech communication. It is calculated from the arithmetic average of the octave band sound levels for the four octave bands centered at 500, 1000, 2000 and 4000 Hz.

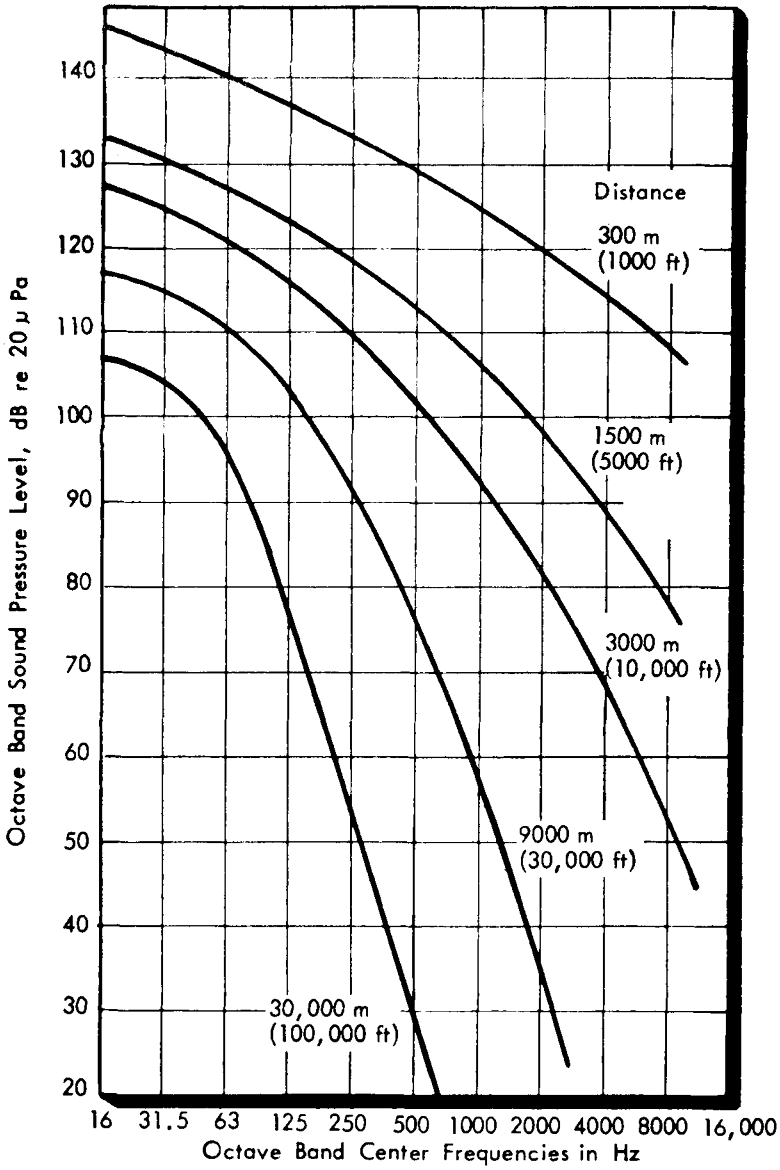

FIGURE 1. MAXIMUM SPECTRUM LEVELS FOR HLLV ROCKET NOISE AT DIFFERENT DISTANCES FROM LAUNCH SITE (See Table 12 for Definitions)

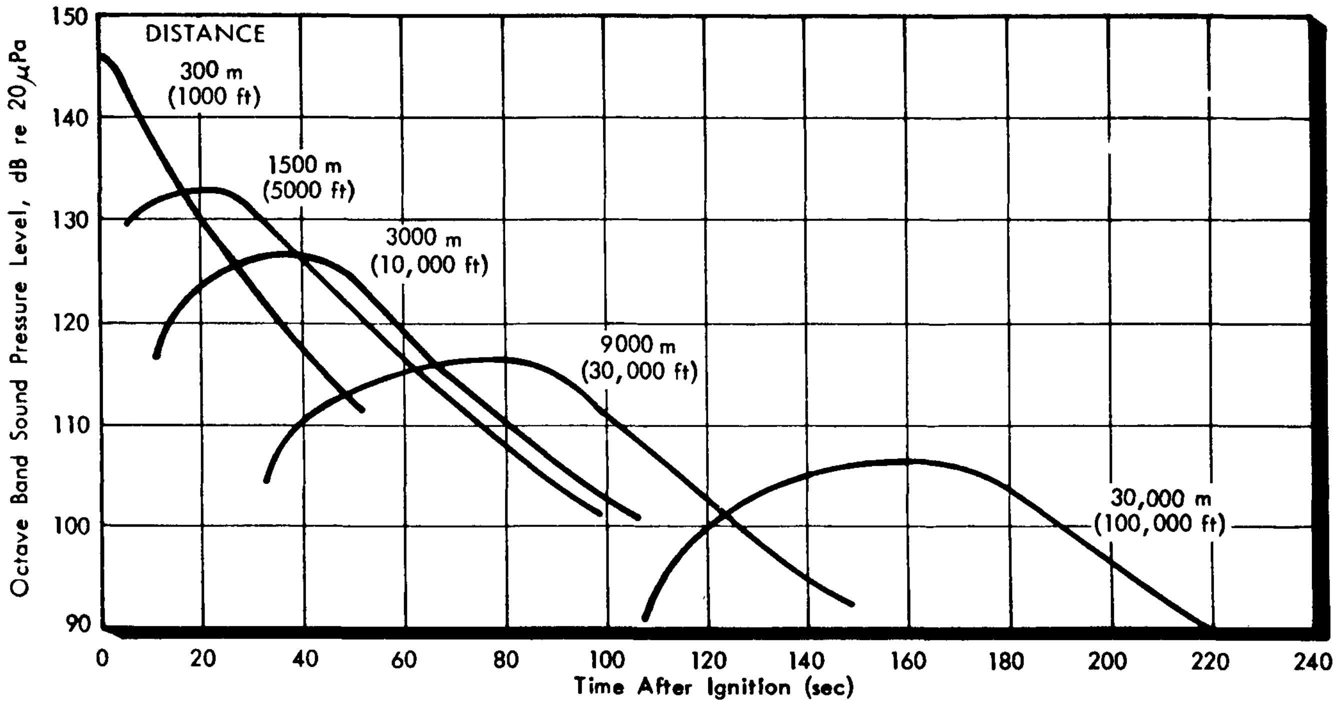

Figure 2. TIME HISTORY OF 16 Hz OCTAVE BAND LEVELS FOR HLLV ROCKET NOISE
AT DIFFERENT DISTANCES FROM LAUNCH SITE
(See Table 12 for definitions)

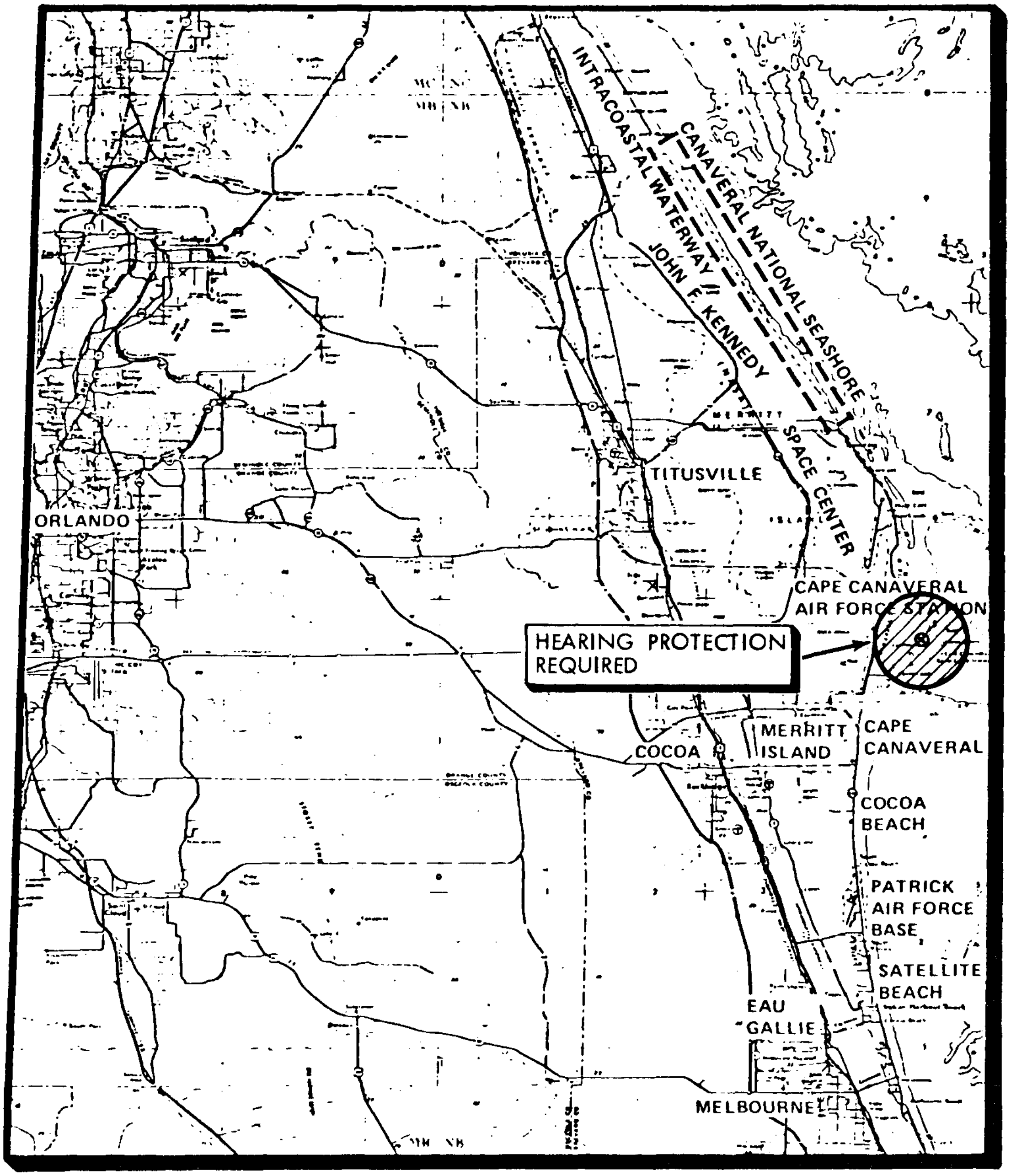

Figure 3. PREDICTED REGION AT CAPE CANAVERAL FOR WHICH HEARING PROTECTION WILL BE REQUIRED FOR LAUNCH NOISE

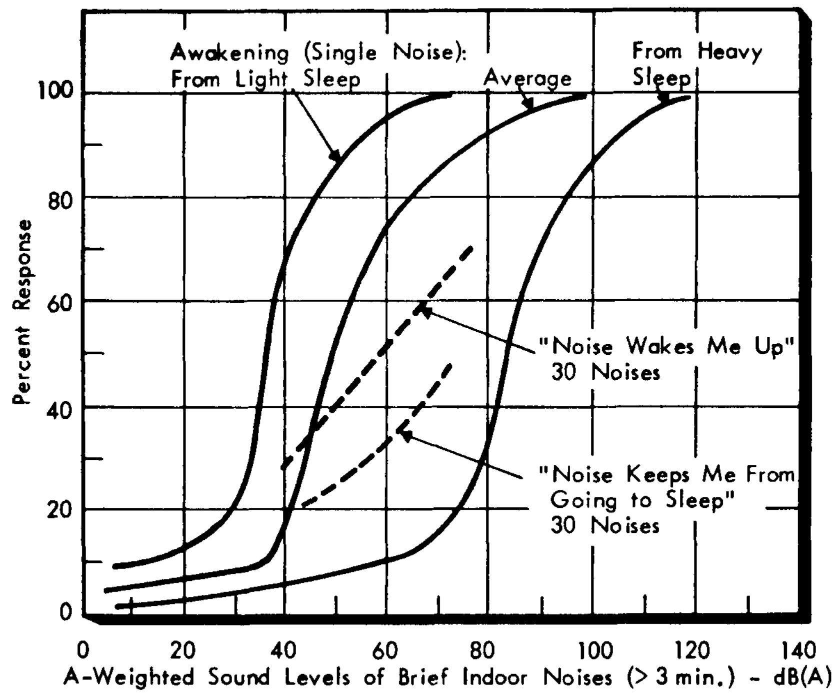

Figure 4. AWAKENINGS TO SOUND FROM VARIOUS LABORATORY AND QUESTIONNAIRE STUDIES

(See Table 12 for definitions)

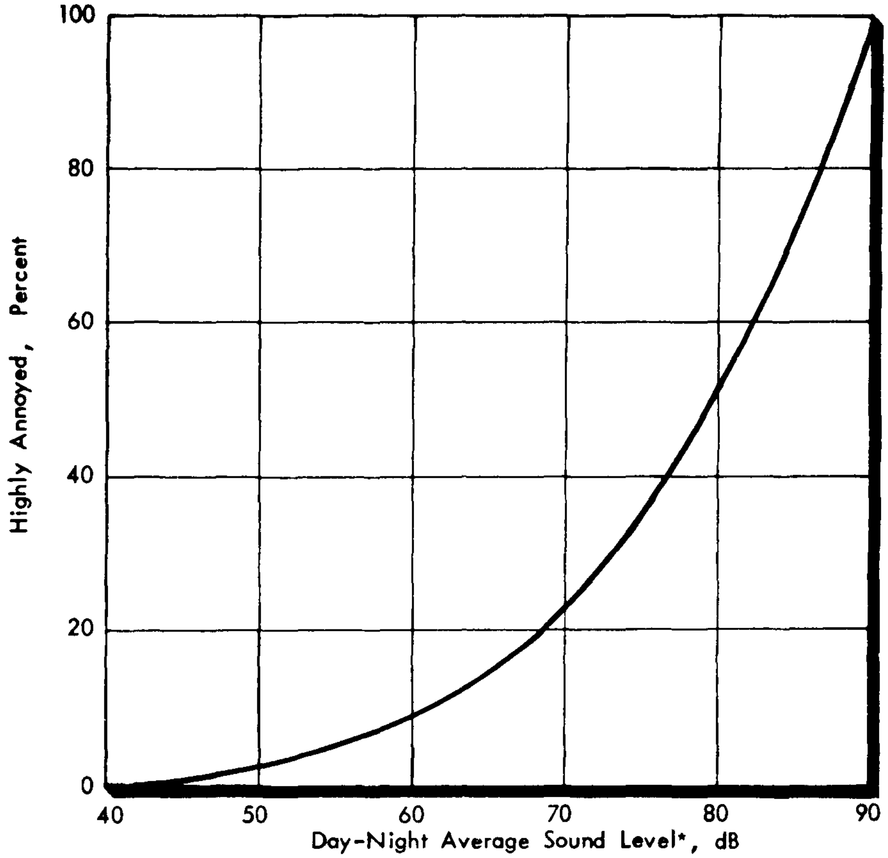

Figure 5. PERCENTAGE OF PEOPLE HIGHLY ANNOYED AT DIFFERENT NOISE LEVELS

*Day-Night Average Sound Level (L_{dn}): The average, on an energy basis, of the A-weighted sound level integrated over a 24-hour period, with appropriate weightings applied for noise levels occurring in the daytime and nighttime periods. A 10 dB adjustment is applied to nighttime (2200-0700) sound levels to account for the increased annoyance to noise during the night hours.

Table 13

COMMUNITY REACTION TO LAUNCH NOISE

Distance from Launch Point: Meters	Distance from Launch Point: Feet	Percent of People Highly Annoyed
300	1,000	90%
1500	5,000	45%
3000	10,000	24%
9000	30,000	5%
30,000	100,000	1%

different distances from the launch point. Even at 3000 m (10,000 ft) from the launch point, 24% of the people would be highly annoyed. It is anticipated that at distances greater than 9000 m (30,000 ft) from the launch point where less than 5% of the people would be highly annoyed, little impact would occur. As an illustration, the areas around the Cape Canaveral launch site associated with these annoyance values are shown in Fig. 6. At distances closer than 9000 m (30,000 ft) from the launch point, however, more and more people would be highly annoyed, and for distances closer than 3000 m (10,000 ft), more than one-quarter of the population would be highly annoyed.

Infrasound Effects: The special effects possibly produced by infrasound (relating to a frequency below the auditory range of the human ear, i.e., 20 Hz) are unclear because of the lack of criteria in this area. However, if one uses data from Fig. 7 and assumes that the levels reported are spectrum levels, then the octave band level below which no adverse physiological effects should occur is 10.5 dB higher than that shown in the figure at 16 Hz. Thus, below an octave band level of 132 dB, no physiological effects should exist. This means that at locations greater than 1500 m (5000 ft) from the point of launch, no physiological effects should occur. Furthermore, the criterion for astronauts is 145 dB, which means that even as close as 300 m (1000 ft) from the point of launch, no physiological effects should occur for 2-minute exposures. Even though there may be no physiological effects, it is likely that there would be annoyance at distances as great as 30,000 m (100,000 ft) from the point of launch due to low frequency vibration of building structures or low frequency pressures in the middle ear. Building vibrations can directly affect humans or, through nonlinear effects, cause rattles, etc., in the audio frequency range. With respect to the Cape Canaveral launch site, the area in which there would be annoyance from infrasound effects is shown in Fig. 8.

Effects on Animals: Since the literature is not explicit in a dose/response relationship for the various effects of noise on animals, it is impossible at this time to provide accurate estimates of the effects of the launch noise on hearing damage, communication interference, sleep interference or startle effects. Startle effects could occur at points as far away as 30,000 m (100,000 ft) from the launch site. However, it is possible that the animals would adapt to the launch noise. The 30,000 m radius is related to the specific launch site of Cape Canaveral in Fig. 9.

5.3.2 Sonic Boom: Estimates of sonic boom pressures are presented in Table 14.

Maximum boom pressures of 1197 N/m^2 (HLLV first stage booster) and 766 N/m^2 (PLV first stage booster) would cause significant startle effects characterized by gross body movements. However, people have experienced booms of up to 6800 N/m^2 without evident injury. These launch booms would occur over the ocean at the Cape Canaveral site if KSC were used, so they would not impact humans except on watercraft in the area (see Fig. 10). Similarly, the sonic booms generated by the reentry of the boosters would also occur over the ocean and not over populated areas. The sonic booms which will occur over land are those associated with the return of the HLLV and PLV orbitors to the launch site (see, for example, Fig. 11). The maximum overpressures associated with these booms would be less than 15% of those at launch. They would occur over populated areas, so these effects are described in some detail below.

Hearing Damage: It is anticipated that even for booms with overpressures of 200 N/m^2(4.2 psf or 140 dB peak SPL), no hearing damage would occur. The modified limit for 100 booms per day proposed by EPA would be 140 dB peak. Translating this to a one-boom per day exposure would allow the boom to be as great as 169 dB if an equal energy rule were used, and 150 if the original 5 dB for each factor of

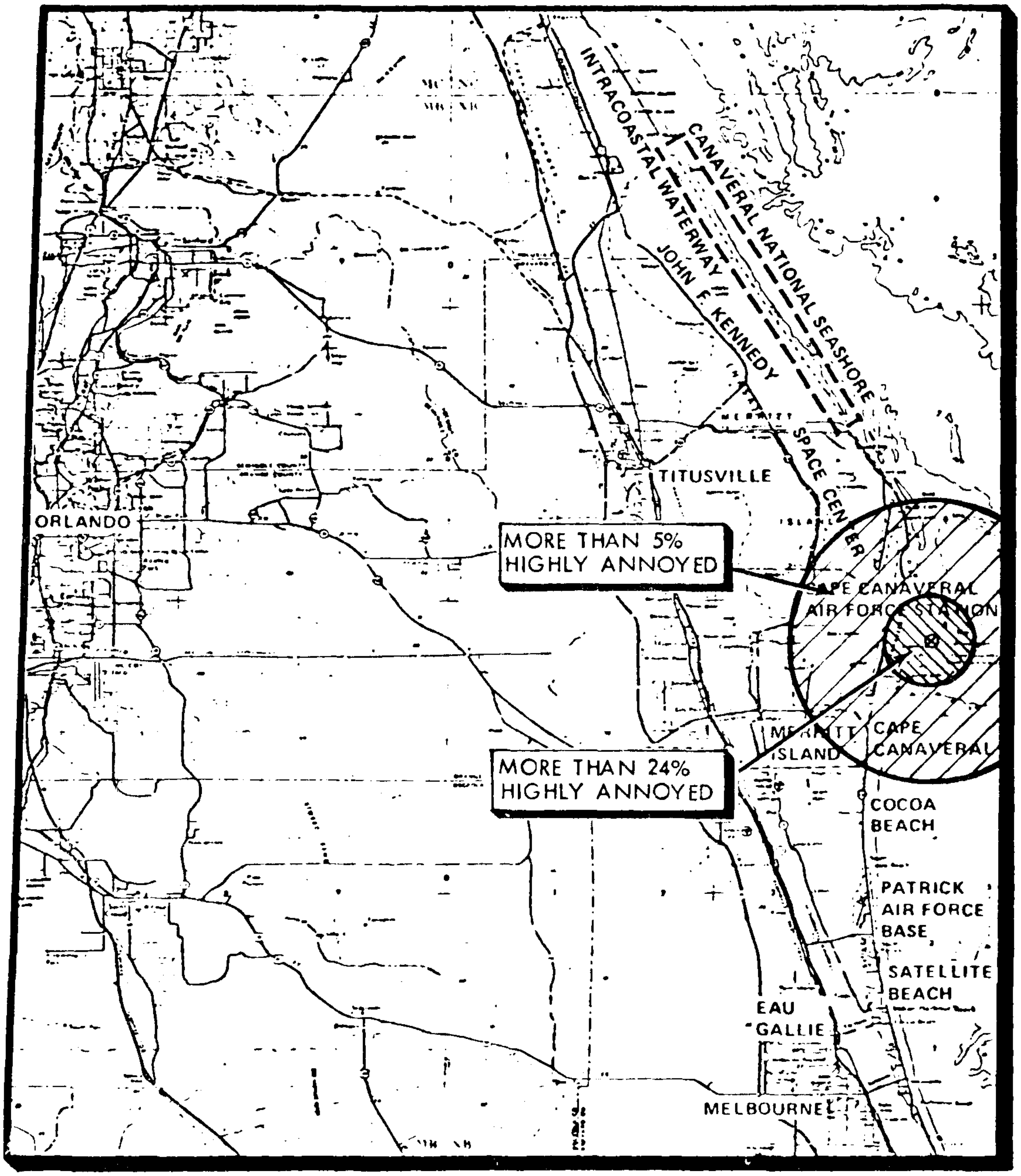

Figure 6. PREDICTED REGIONS OF ANNOYANCE AT CAPE CANAVERAL FOR LAUNCH NOISE

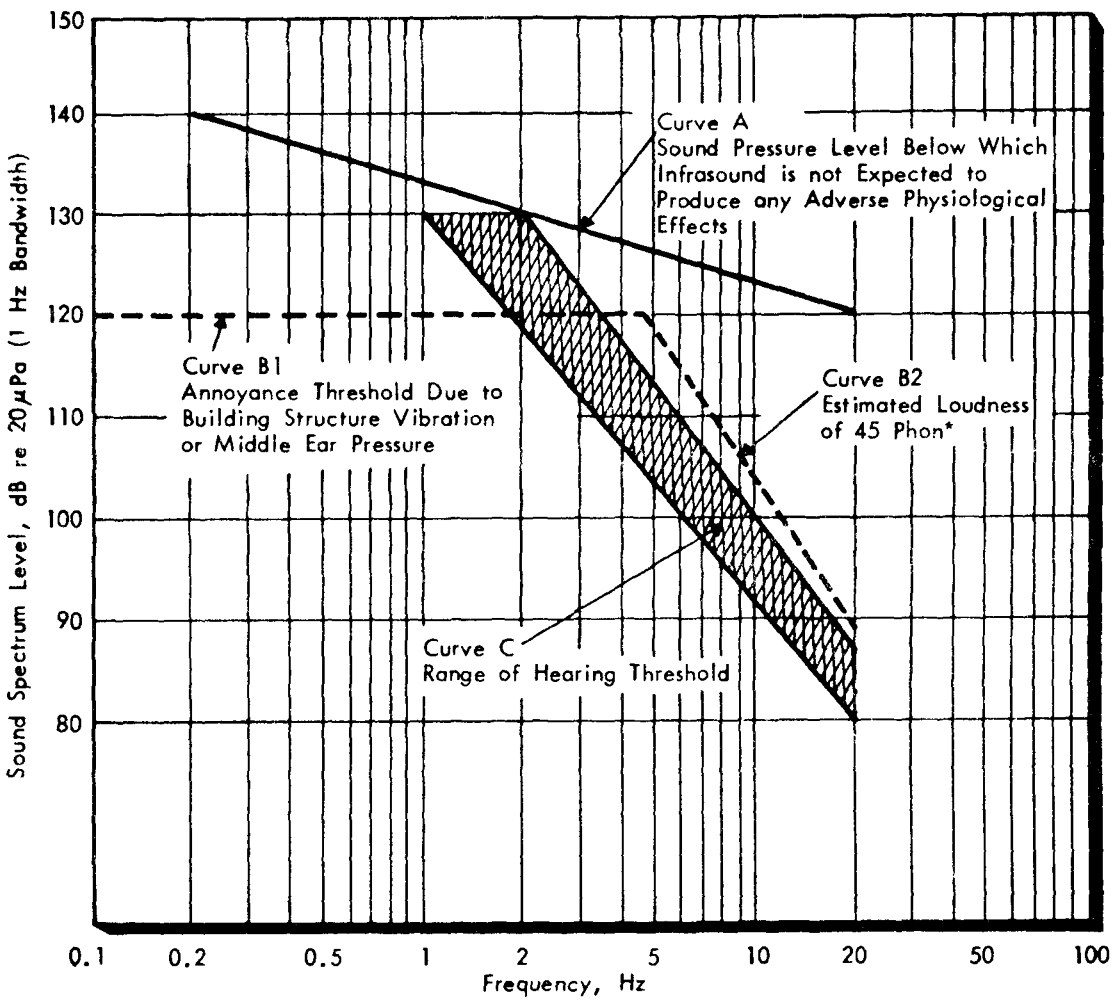

Figure 7. INFRASOUND CRITERIA FOR ONE-MINUTE EXPOSURE

*Phon: A calculated unit of loudness level designed to be equivalent to the sound pressure level of a 1000 Hz tone judged as loud as the measured sound.

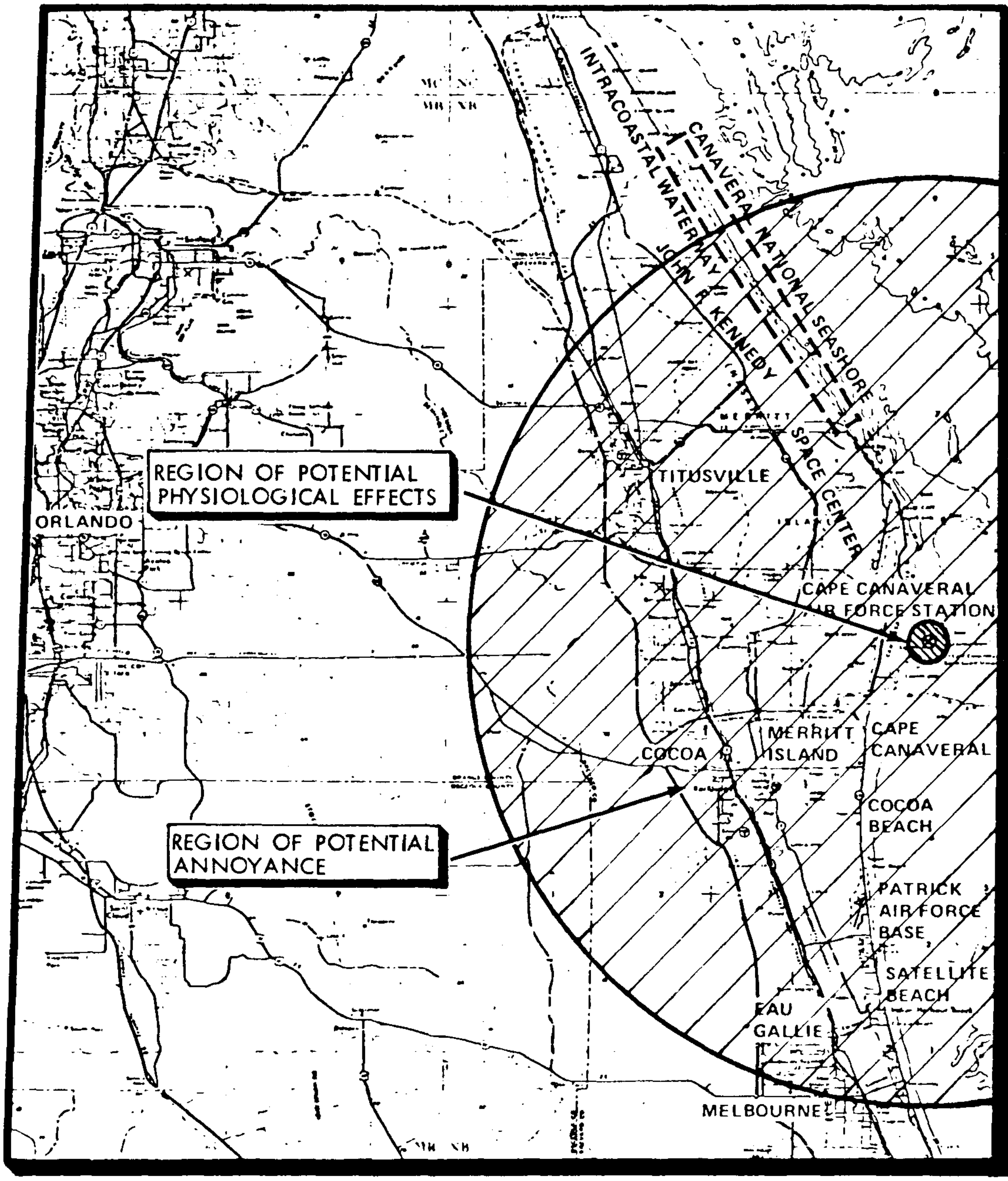

Figure 8. PREDICTED REGIONS AT CAPE CANAVERAL
AFFECTED BY INFRASOUND AT LAUNCH

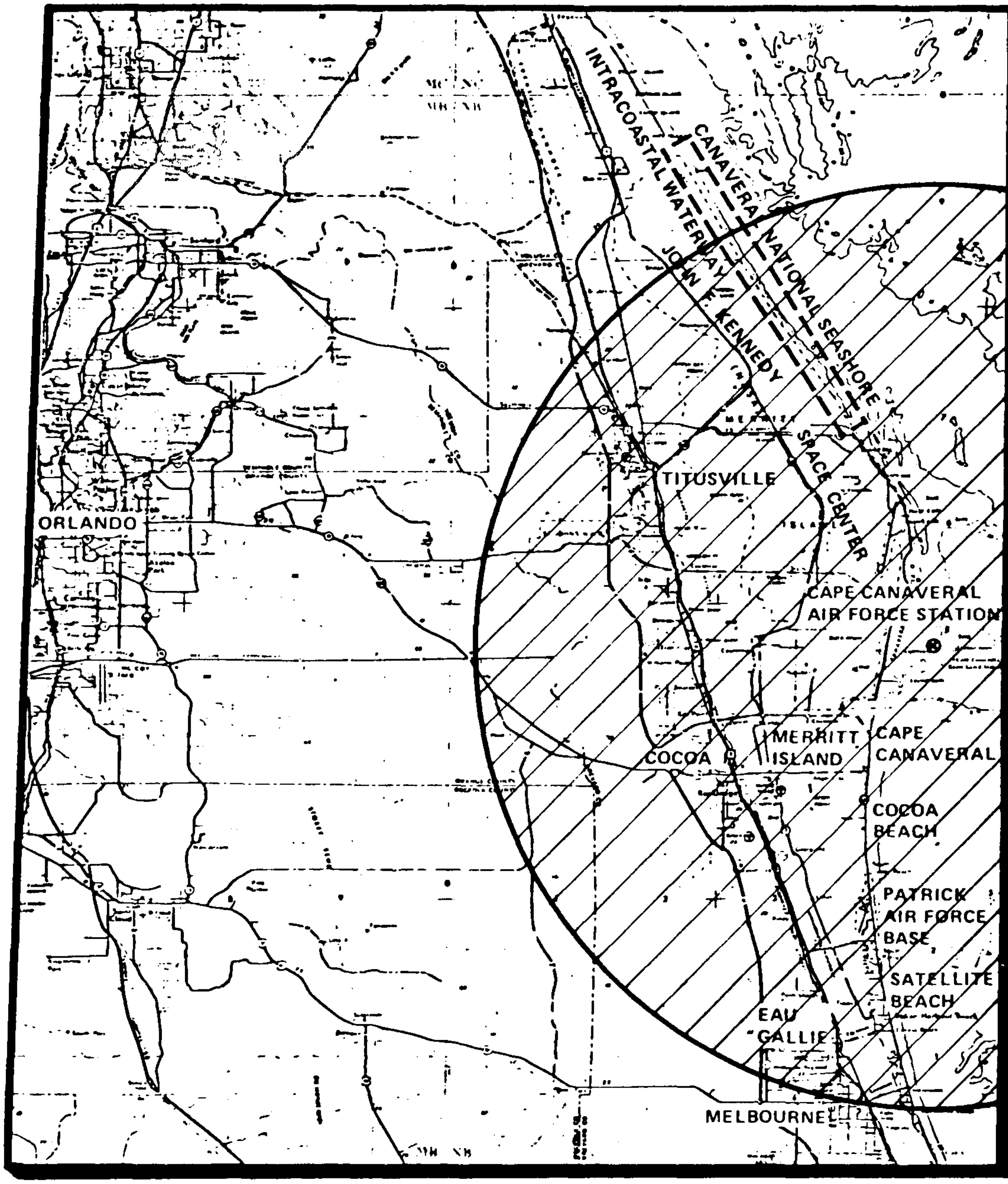

Figure 9. PREDICTED REGION AT CAPE CANAVERAL IN WHICH ANIMALS WILL BE STARTLED BY LAUNCH NOISE

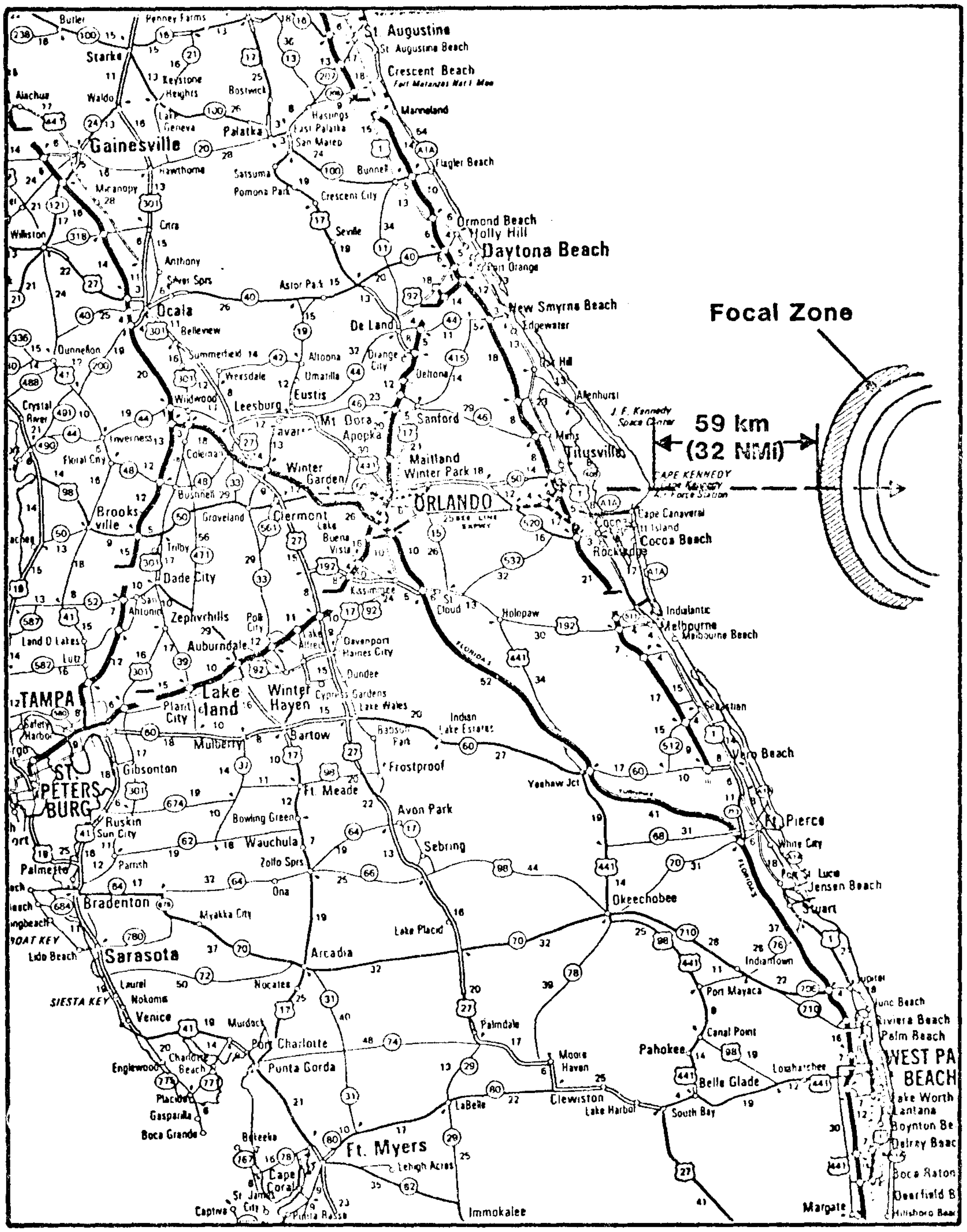

Figure 10. HLLV LAUNCH SONIC BOOM FOOTPRINT

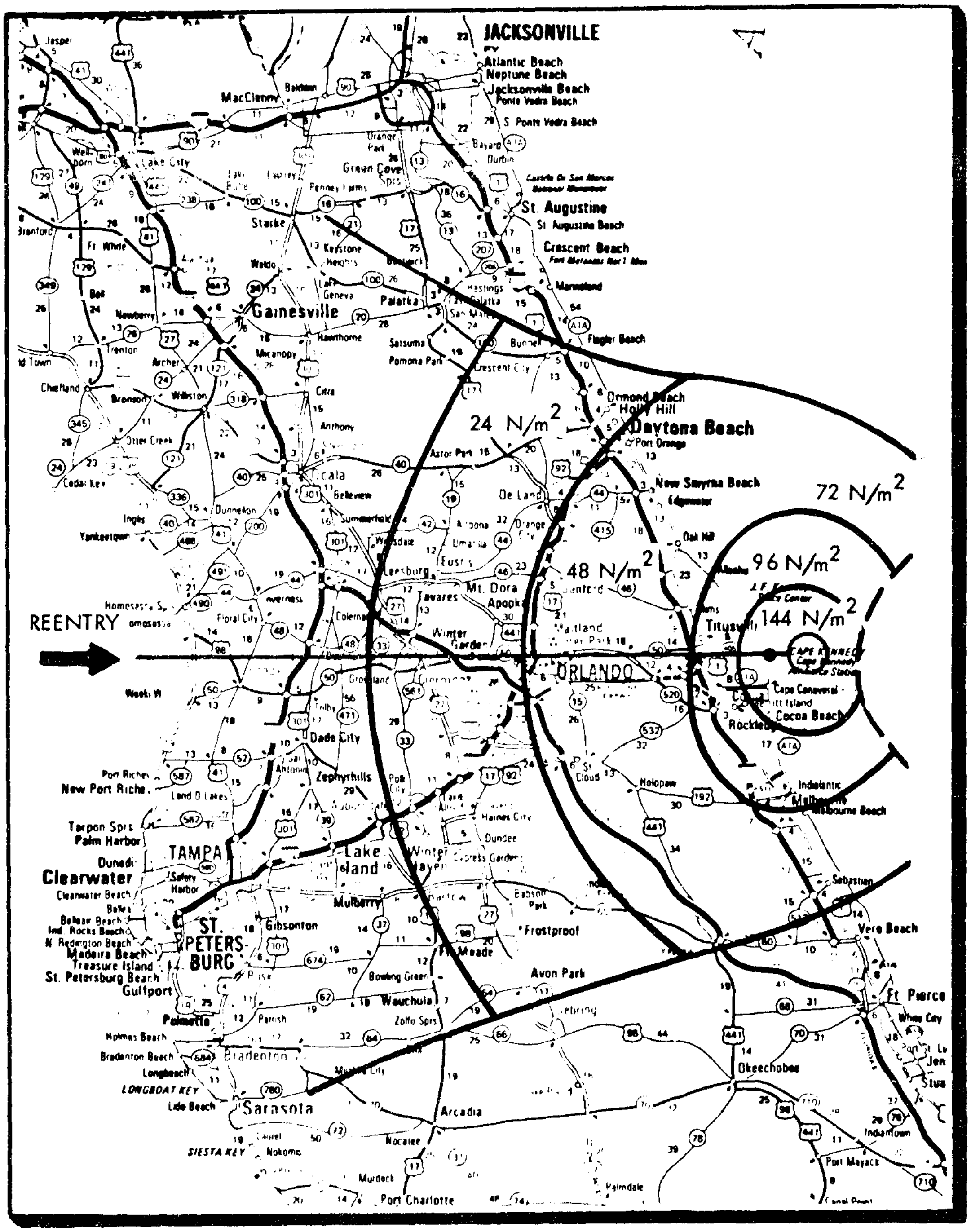

Figure 11. SONIC BOOM OF HLLV ORBITER ON RETURN TO LAUNCH SITE

Table 14

SONIC BOOM SUMMARY

	HLLV Booster	HLLV Orbiter	PLV Booster	PLV Orbiter
LAUNCH				
Strength	1197 N/m^2 (25 psf)		766 N/m^2 (16 psf)	
Frequency per year	375		30	
RE-ENTRY				
Strength	192 N/m^2 (4 psf)	144 N/m^2 (3 psf)	144 N/m^2 (3 psf)	72 N/m^2 (1.5 psf)
Frequency per year	375	375	30	30

HLLV: Heavy-lift launch venicle
PLV: Personnel launch vehicle
N/m^2: Neutrons per square meter
psf: Pounds per square foot

10 reduction in events were employed as suggested by a National Academy of Science committee.

Speech Interference: Since a sonic boom would last for only about 1.2 to 1.5 seconds, no speech communication problems should result. An interruption in speech could occur because of the startle due to the boom. However, if the booms occurred on the order of once or twice a day, it is anticipated that the startle effect would become minimal.

Sleep Interference: Sonic booms would probably interfere with sleep within the affected area. At this time, no dose/response data exist to quantify the magnitude of this effect.

Annoyance: Two different schemes were employed to assess the reaction of the community to sonic booms during reentry. The first utilizes information in Table 15 which was based on a 10- to 15-boom exposure per day. The second technique utilized the reaction of people to other forms of environmental noise, and applied the results to sonic booms with the same day-night average sound level. See Ref. 10 for details. Figure 12 shows the predicted regions of annoyance in the vicinity of KSC. The inner area was predicted to have a pressure of 96 N/m^2 (1.5 psi). The percentage range in each case is associated with uncertainty in predicting the effect of duration of the sonic booms.

Effects on Animals: The major effect on animals would be that of startle, and therefore observance of animal behavior during booms should be noted during the reentry operations to insure that no detrimental effects were indeed taking place. The animals probably would adapt to these procedures since they must have adapted to loud thunder claps which, although at a lower level than sonic booms, are somewhat similar in character. The short-term startle effects probably would have no lasting effect on animals. However, the frequency of the boom (an average of 1.1 per day) is the main reason for concern about possible long-term effects associated with startle.

Uncertainties with Respect to Noise: Some of the tentative conclusions on noise effects of SPS necessarily involved assumptions about noise levels, propagation phenomena, and human and animal responses. Studies of noise from Space Shuttle may remove some of the uncertainties. Additional research may be needed for determining SPS noise levels and effects with more precision than was possible in this preliminary study.

Table 15

EFFECTS OF SONIC BOOM

Overpressure (N/m^2)[a]	Effect of Simulated Boom on Test Subjects
International Civil Aviation Organization Results	
< 24	Not rated as annoying.[b]
48	10% of sample rated this as annoying.[b]
144	All considered this as annoying.[b]
48-144	Nonprimary structures (plaster, windows, brick-a-brac) sustained some damage.
< 950	Primary (load-bearing) structures of acceptable construction, and in good repair, showed no damage.
Federal Aviation Administration Results	
16	Orienting, but no startle response. Eyeblink response in 10% of subjects. No arm/hand movement.
30-111	Mixed pattern of orienting and startle responses. Eyeblink in about half of subjects. Arm/hand movements in about a quarter of subjects; no gross bodily movements.
130-310	Predominant pattern of startle responses. Eyeblink response in 90% of subjects. Arm/hand movements in more than half of subjects; gross body movement in about one-fourth of subjects.
340-640	Arm/hand movements in more than 90% of subjects.

[a] 1 newton per square meter (N/m^2) = 0.021 pound per square foot (psf).

[b] Based on 10-15 booms per day.

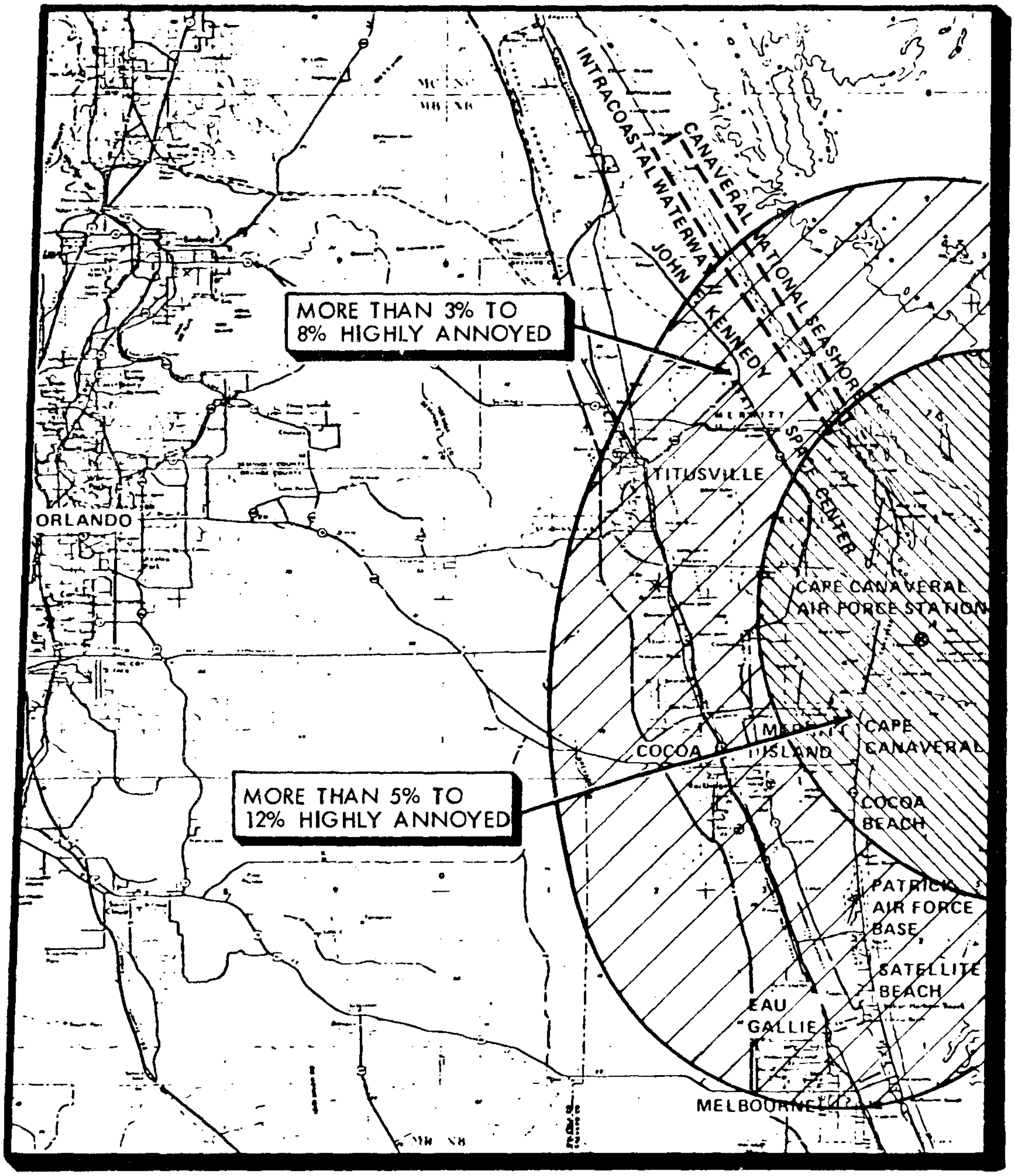

Figure 12. PREDICTED REGIONS OF ANNOYANCE AT CAPE CANAVERAL ASSOCIATED WITH SONIC BOOMS FROM HLLV ORBITER

5.4 Ozone Depletion

The depletion of ozone in the stratosphere has caused concern in recent years mainly because of the potential for increases in human skin cancer. There is also concern that plants and animals may be affected. Ozone absorbs some of the biologically harmful ultraviolet light (BHUV) from sunlight. As ozone decreases, more of the BHUV reaches earth and impinges on humans and ecosystems.

There is a very strong relationship between the flux of BHUV and nonmelanoma skin cancer, and indications are that melanoma incidence is also related to BHUV, though other unknown causative factors are thought to be involved (11).

The major cause of ozone depletion in recent years appears to be the industrial and domestic use of halocarbons. There are a number of uncertainties in calculations of the effects of halocarbons, but the best estimate of a recent National Academy of Sciences' study (12) is that if chlorofluoromethane release is continued at the 1977 rate, ozone may be reduced by about 8% during the next 30 years.

The ozone concentration would be affected to some extent by SPS spacecraft activities. The group working on the atmospheric effects of SPS have done preliminary studies of possible changes in ozone concentration (13). Rocket exhaust emission studies led to an estimate of a 0.01 to 0.02% decrease in ozone when a steady state is reached. An independent study (14) estimated a decrease of 0.03% due to SPS launch activities. Considering the uncertainties in the models used, these estimates are remarkably similar and are at levels which would be undetectable with current instrumentation.

There is a possibility that the decrease in ozone due to launch effects might be offset by the effects of nitric oxide which would be generated when the second stage of the heavy-lift launch vehicle reenters the atmosphere. The estimate of this effect gave a probable increase in ozone of 0.02% (13). However, there are a number of uncertainties in this prediction, and thus there is a possibility that there would be no change or a very minute decrease in ozone.

Thus, current knowledge indicates that SPS effects on ozone would be minor compared to effects from other human activities, and would not appreciably change skin cancer incidence or affect ecosystems.

5.5 Accidental Injury

Several situations could contribute to accidental injury or death during launch and recovery operations. These include the possibility of fire or explosion on the launch pad, aborted launchs, and landing accidents. Figure 13 depicts a preliminary analysis (15) of the explosive potential of the heavy lift-launch vehicle (HHLV) compared with data for the Saturn V rocket. The conclusion was that all personnel should be cleared from the area of radius approximately 4300 meters (approx. 2.8 miles) within which the blast pressure would be greater than 0.4 pounds per square inch (psi). In Titusville, the nearest town to KSC, where psi would be .28, there might be doors and windows blown out with consequent danger of public injury.

Effects of various blast-wave pressures are shown in Table 16.

Table 16

Effect	Threshold blast wave pressure, N/cm^2 (psi)
Glass breakage	0.34 (0.5)
Penetrating missiles	1.4 (2.0)
Eardrum rupture	3.4 (5.0)
Lung injury	6.9 (10.0)
Lethal	21.0 (30.0)

From Ref. 8

The potential dangers from launch-pad fires and the consequent air pollution for SPS have not been analyzed nor have launch abort and recovery landing accident. The assessment for space-shuttle operation concluded that these incidents would be analogous to conventional aircraft accidents and that, in the case of launch abort, they would occur over controlled range areas and thus present no unusual problems (8). An evaluation of accident probability would be required to estimate SPS effects. The

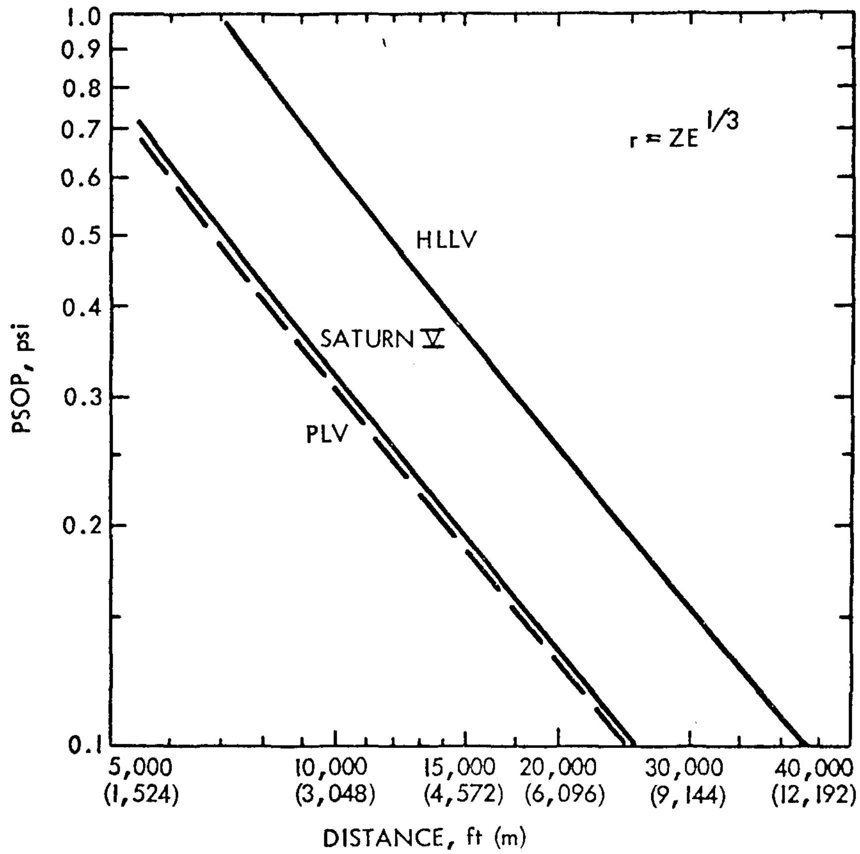

Figure 13. Variation of Peak Side-On Overpressure with Distance for Catastrophic Explosion

r = distance from explosion in ft
E = weight of equivalent TNT exploded at sea level
HLLV = heavy lift launch vehicle
PLV = personnel launch vehicle
Z = (ft/lb TNT)$^{1/3}$

hazards to the public and the ecology will depend on the site(s) eventually selected for launch and landing of spacecraft.

5.6 Acid Rain: Effluents from the fuel used by SPS spacecraft might add to the acidity of the atmosphere and thus increase impacts from acid rain. In the previous SPS Atmospheric Effects (16) assessment it was tentatively concluded that the contribution from HLLV rocket exhaust emissions to regional- or continental-scale acid rain would be negligible, taking into account the magnitude of these emissions in comparison with the total SO_2, NO, and NO_2 emissions from industrial and other sources in the southern United States. However, a highly localized and temporary acid rainfall might occur in the vicinity of a launch site due to raindrops falling through a ground cloud. The effect would be similar to the effect of rain falling through a plume of a power plant, although on a much reduced scale, since it would be due to a single cloud rather than to an extensive continuous plume. The SPS Atmospheric Effects personnel have an investigation of the expected magnitude of this effect underway.

Some research is being carried out on the effects of acid rain on vegetation. A recent workshop (proceedings to be published) was held at Brookhaven National Laboratory. The workshop was titled: "Effects of Acid Precipitations on Vegetation Soils, and Terrestrial Ecosystems". The findings and reccommendations of this workshop will assist in determining the ecological effects of acid-rain from SPS activities.

Acid rain from SPS could impact vegetation, soil and water quality in a localized area. If acidity is high enough, it could also cause skin and eye irritation.

6.0 SPACE ACTIVITIES

Space workers would be transported to low earth orbit (LEO) by the personnel launch vehicle (PLV) which will be similar to space shuttle. They would then be transferred to the personnel orbital transfer vehicle (POTV) and transported to geosynchronous orbit (GEO) where the satellites would be constructed. Return to earth reverses this procedure. The effects of zero-gravity, acceleration, ionizing radiation in space, and the possibility of accidents are the main considerations in the transport phase. Accident probability has not yet been studied.

Some personnel would stay at the LEO staging base for work there, but most would work at GEO. In both LEO and GEO there would be weightlessness, ionizing radiation, life support, occupational hazards, and the general effects of living in a unique environment to be considered. Some of these problems are considered in this section.

6.1. Health Effects of the Space Environment

The Life Sciences personnel at NASA Johnson Space Center, with assistance from the Boeing Company, have prepared a report on the possible health consequences to SPS space workers which would result from living and working in the space environment (17). They conclude that SPS space workers would not suffer any long-term adverse effects on health from this exposure. This conclusion is based on the expectation that prior to SPS spaceflights, both ground-based and space (shuttle and Space Operation Center) experimentation will assist in solving some of the problems which have been encountered by the human in space.

Thus far, experience for humans in space has been limited to U.S. and Russian astronauts. These have been highly trained, highly motivated persons. Their tasks have been very different from those projected for the majority of SPS space workers. The tentatively suggested schedule for SPS space workers is a 5-year career, with 90 days in space alternated with 90 days on earth. The longest flight of U.S. astronauts has been 84 days, and these have not been repeated. Russian cosmonauts have had longer tours but information about their physical condition in space is sparce. Charts taken from Ref. 16, illustrating some of the differences between the past missions and the conceptual SPS missions, are reproduced in Figs. 14 and 15. It is pointed out that space workers could be in a deviate physical condition for a majority of the 5-year career if the currently proposed SPS schedule were adopted.

6.1.1. Weightlessness (zero-gravity, null-gravity): There have been a number of deviations from normal (or baseline) physiological parameters noted in astronauts. Many of these effects appear to be adaptations to the lack of gravity, and they returned to normal either during the mission or very shortly after returning to earth with no apparent adverse consequences to the astronauts. However, some of these deviations might be problems if flights were repeated at regular intervals. The NASA/ Boeing report summarized effects as follows:

FIGURE 14
(from Ref. 16)

Factors Involved in Comparing Past and Future Missions

Crew (Space Workers)	Habitat
Type of personnel	Environments
Preparation and training	Shielding
Pre-, in-post flight activities	Recreation and rest
Regimentation and discipline	Food and nutrition
Etc.	Privacy
	Etc.
Mission Flight Parameters	**Career***
Orbits	Total time in space
Accelerations	Cumulative psychological/physiological effects
Solar activity periods	Job fatigue
Etc.	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 3-1/2 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 15
(from Ref. 16)

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	Skylab Astronauts
Shorter preparation time and training, limited primarily to job-related activity, with minimum spacecraft physics & systems, habitability, etc.	Several years of broad-based 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	Skylab Astronauts
Broad variety of specilized manual, clerical, staff skills (with minimum professional engineering & scientific skills).	Each crew member capable of all scientific, technical & management requirements.
Work at peak efficiency for maximum safe period during mission. Return to space in shortest safe & practical time.	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.

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, certainly 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.

3. There is a fluid shift, particularly from the legs to the head and upper torso, and some fluid is lost, probably primarily from the blood plasma with some contribution of interstitial fluids from leg musculature. The fluid shift to the upper regions causes engorgement of veins, puffiness of distensible regions of the face and neck, sinus and oropharyngeal congestion. These changes possibly contribute to the development of untoward vestibular responses including nausea and vomiting.

4. Cardiovascular adaptability or competence (orthostatic tolerance) is prejudiced as determined by stress tests (including lower body negative pressure) and return to an erect posture in normogravity following space exposure.

Less Important Effects: Less obvious changes that may be secondary or teritiary levels effects include:

1. Skin infections which might be a result of defense system change or depression, inadequacy of provisions for maintaining hygiene, increased virulence of microbial invaders, or other causes.

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

3. Changes in neuroendocrine activity as measured in blood and urine specimens, with special reference to electrolyte and water balance, electrolyte losses, and plasma volume loss.

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

5. A catch-all category that produces the readout that bioenergetic control has been compromised; maximal work performance capability is reduced, and the calibratable responses among energy output, heart rate, and oxygen uptake lose their quantitative interdependence.

Organ Systems That Have Suffered Minimal or no Functional Changes During Space Exposure Include:

1. Reproductive
2. Digestive
3. Respiratory (in zero acceleration)
4. Lymphatic
5. Nervous (especially psychomotor, behavior, judgment, problem-solving ability)
6. Sensory (except vestibular)
7. Excretory

More detailed discussions regarding effects of weightlessness on the various human organs, as a result of previous spaceflights, are contained in Ref. 17. A shortened version of this, a discussion of acceleration/deceleration, and the NASA Life Sciences proposals for future research are in Appendix A of this report.

Extensive research on the effects of weightlessness is needed in order to protect the health of the SPS space worker.

6.1.2 Acceleration/Deceleration: While there is much information available on the effects of acceleration on humans, most of this is ground-based or from experiments in aircraft. NASA has very limited information with regard to spacecraft and the interaction of weightlessness effects with those of acceleration. They have intentionally kept the exposure of astronauts to acceleration and deceleration to the lowest possible levels in order to maximize the yield of data on zero-gravity exposure. They propose to limit launch and landing levels to less than 3 g. See Appendix A for further discussion on acceleration/deceleration. Research is needed to provide the following:

1. Definition of the effects of various durations in a null-gravity environment on subsequent tolerance to force fields in all axes.

2. Definition of the range of acceleration forces resulting in physiological effect and of tolerance in the population that may fly in space.

3. Optimization of countermeasures that may be used under high-force field conditions.

6.1.3. Habitat Environments: The various environments of the habitat area can present a broad spectrum of potentially adverse physiological or psychological effects. These environments frequently influence habitat design or operational approaches, and almost always the cost of optimizing their condition for the space workers' well-being results in maximum cost and weight penalties. Many trade studies will be necessary to derive final design of habitat environmental ranges. Habitat environments include:

Atmospheric compositions and pressures
Temperature
Noise
Light
Vibration
Odor
Bacteria
Toxic Elements
Particulates (ingestibles and inhalation)
Humidity

Life Support Systems in Habitat and Work Areas: A number of systems would be needed to accommodate the ordinary daily needs of SPS space workers to insure physiological and psychological health, safety and general well being. These systems include:

Food and nutrition	Water (potable, cleaning, industrial)
Hygiene	Sleep
Rest and recreation	Exercise
Privacy	Waste and trash management
Clothing	Architectural design
Entertainment	

Health Care System: A very important element in the maintenance of health and safety of space workers is the provision of a health care program which would effectively deal with the prevention as well as treatment of medical contingencies in space. The health care system would provide the following elements:

Preventive Programs - Selection of healthy workers,periodic multiphasic screening, maintenance of health trend analysis, health training and indoctrination, physical fitness, etc.

Treatment Program - Equipment and protocols for probable routine or emergency medical contingencies, and medical personnel (paramedics, physicians' assistants, physicians, and specialists' consultants) for rescuing, stabilizing, transporting, and hospitalization of workers.

Therapy - Equipment, personnel and protocols for providing physio/psycho/pharmaceutical corrective therapy.

6.1.4. Altered Biorhythms and Diurnal Cycles: Space workers would be subjected to altered rhythms of many types - from cellular and glandular internal body rhythms to daily habit routines. These altered rhythms might be consequential enough to warrant identification and analysis to determine their contribution to physiological or psychological problems.

6.1.5. Amelioration of Potentially Adverse Effects: Preventative Actions: Selection of workers would be aimed at maximum productivity over a currently presumed 5-year career. Considerations would be good physical condition, resilience, adaptability to stress, dedication, and the intelligence to understand not only their job requirements but the actions that must be taken to remain healthy in space. The exact criteria for selecting workers must be worked out.

Most of the space workers in SPS would have very different work assignments (e.g., construction, food preparation, clerical, etc.) from those of the astronauts. Space workers would require extensive training and indoctrination prior to their initial spaceflight and sustained training and indoctrination on a continuing basis throughout their career. Proper indoctrination in the importance of food, exercise, hygiene, and other health-sustaining regimens were responsible for minimizing potentially adverse physiological effects of previous space missions. The nature and extent of this effort must be defined and suitable programs developed prior to the initial SPS missions. The Shuttle (STS) and Space Operations Center (SOC) programs of the 1980's will provide an opportunity to gain insight into the requirements for space-worker training and indoctrination.

Motivation will be critical. A 5-year career as a SPS worker in space could place a severe physiological and psychological stress on the space worker and psychological stresses on his or her family or associates.

Experiences with various programs involving the long-term assignments to remote and stressful environments have shown that good training and high salaries are not necessarily sufficient to maintain a steady work force. Off-shore drilling companies, as an example, are experiencing 100% annual turnover in personnel who are extensively and expensively trained and highly paid.These companies are desperately seeking better methods for selecting, preparing, and sustaining a dependable work force. In contrast, the Skylab, Tektite, and our nuclear submarine programs found the crews to be highly motivated and productive. Careful studies of the effects of repeated missions for the Shuttle crews, and repeated long-duration (90-day) missions for the SOC crews would hopefully provide guidance for selecting SPS workers motivated to serve an effective 5-year space career.

Maintaining good physical condition of the SPS worker would certainly be a very significant factor in the amelioration of adverse effects of the space environments. This would require good regimens of nutrition, exercise, rest and hygiene, coupled with a good food system and enjoyable recreation. These requirements would have to be met between missions as well as during spaceflight, and be tailored to the needs of the individual. The individual's needs would be dependent on the type of person involved, the type of work being done, and the levels of environmental stresses involved. NASA has learned a great deal about these needs for astronauts and cosmonauts from previous space missions, but much needs to be learned about the individual and collective needs for the types and numbers of workers who would be employed in space for SPS.

Living and working conditions would be very important. The physical and psychological well-being of SPS space workers would be affected by environments that would be controllable as well as those that would be inherent in spacecraft. The living and working conditions of the space worker would need careful consideration in order to make long and repeated missions attractive. Some of the obvious of the controllable elements are listed below:

- Lighting
- Temperature
- Toxic and noxious elements
- Architecture
- Humidity
- Breathing environment (pressures and constituent gases)
- Noise
- Clothing
- Time structuring (eat, sleep, work, play structures)
- Social and management structure

Treatment and curative actions would be needed. It is expected that, with many hundreds of space workers involved, some would be adversely affected by the environments of space missions. Some of the possible actions would be: task reassignment or schedule modifications; variation in physical conditioning regimens (possible supervision to prevent neglect of necessary exercise, nutrition, hygiene, etc.); medical treatment; and altered living conditions.

Much research and planning would be needed to minimize the stresses of living and working in the space environment. Reference 17 outlines the planning and research needs and proposals for future work. This information is also included in Appendix A of this report.

6.2 Ionizing Radiation

SPS space workers will be exposed to ionizing radiation in all phases of space transportation and in living and working environments in space. Radiation in free space will vary depending on which space environment is considered and will vary with time within an environment. The radiation, to which an individual space worker is exposed, will vary with the amount of shielding provided in the transportation, work and living environments and the amount of time spent in each of the three space environments to which workers will be exposed. The biological effects of the radiation will be somewhat dependent on the age and sex of the worker.

The space workers will be transported to Low Earth Orbit (LEO) where a minority of workers will spend their space tours. The majority of workers will then be transferred to orbital transfer vehicles and be transported by way of 5.25 hour transfer ellipse (TE) to geosynchronous orbit (GEO) where they will spend their entire tour. The tentative work schedule suggested in the reference system is for 90-days in space alternated with 90-days on earth for a five year career (i.e., ten 90-day tours over a five year period).

There are many uncertainties involved in the estimation of radiation dose and in predicting the biological effects of these doses for space workers. A detailed report is being prepared on the SPS radiation environment and the biological hazards for that radiation (19). The following is abstracted from that report.

6.2.1 Radiation Environment and Estimated Dose for SPS

Low Earth Orbit (LEO): In LEO ionizing radiation consists of very low energy electrons and high energy protons in the radiation belts of the South Atlantic Anomaly (SAA). The electrons will be stopped by very minimal shielding. Thus the protons are the major source of radiation. The flight paths in LEO are such that some orbits will pass through the SAA and some will not, i.e., 60% of the orbits and 86% of the time will be essentially flux-free. Thus extra-vehicular activity, if required, could be carried out during these radiation-free periods.

The flux of radiation in LEO varies with solar activity, i.e., will vary by a factor of about two between solar minimum and solar maximum. The dose estimates (averaged for time-in and time-out of the radiation belts) for LEO at solar minimum, when doses are higher, range from 14 to 28 rem and at solar maximum range from 7 to 14 rem for a 90-day mission.

Transfer Ellipse (TE): Dose calculations for the one-way 5.25 hour TE going from LEO to GEO vary between 1.0 rad due primarily to protons and 0.018 rad due primarily to bremsstrahlung (these are the estimates for dose equivalent in rem as well). The large difference in these calculations is due to different assumptions with regard to the trajectories to be used for the orbital transfer. Selection of a specific trajectory for SPS will, at least in part, resolve these large differences.

Geosynchronous Orbit (GEO): In GEO geomagnetically trapped electrons, trapped protons, galactic cosmic rays and solar particle events contribute to the radiation environment. The trapped protons are of such low energy that they will not present a health hazard to workers at nominal shielding thickness.

There are two large temporal variations in the electron flux at GEO. These are diurnal variations due to geomagnetic substorms. The radiation in free space is due to the primary electrons; behind at least 3 gm/cm^2 of aluminum shielding radiation, it is due primarily to the secondary bremsstrahlung (photons) produced by interaction of the electrons with the shielding. Thus, behind shielding of at least 3 gm/cm^2 of aluminum, dose from bremsstrahlung is an important component of the radiation environment.

The galactic cosmic rays (GCR) consist primarily of high energy nuclei with origins outside our solar system. Approximately 88% are protons, 10% are helium nulcei, 1% are heavy nuclei with a charge greater than 2 (high-energy, heavy-ions: HZE).

Solar particle events (SPE) are caused by large upheavals on the solar surface which accelerate protons, and to a lesser extent heavy nuclei, to high energies. These events can increase radiation in GEO to high values for several hours or days. Retreat to heavily shielded storm shelters would be required should a large SPE occur.

The majority of the radiation in GEO will come from the bremsstrahlung at an aluminum shielding thickness of 3 gm/cm^2 (as specified in the reference system). The contribution to the dose from HZE in GCR is very uncertain due to unknowns regarding the biological effectiveness of HZE. HZE probably have very different biological effects than do other ionizing radiation particles.

The best current estimate of the SPS worst case radiation dose in GEO is 0.43 rem per day, and about 40 rem per 90-day tour. These estimates do not account for large solar particle events. The largest SPE yet measured suggested a radiation dose of as much as 25 rem behind 40 gm/cm^2 of aluminum shielding, or as little as 2.5 rem. Recall that the SPS assessment presumes only 3 gm/cm^2 aluminum shielding.

Summary of Radiation Dose Estimates: As stated above, there are uncertainties in the radiation dose estimates which need to be resolved. Given these uncertainties the current best estimates of dose in the three environments are:

Mission phase	Dose equivalent (rem*)
LEO:	
Average daily dose equivalent at solar minimum**	0.15 0.30
at solar maximum**	0.08 0.15
TE:	
Average one way trip from LEO to GEO	~1 ~0.2
GEO:	
Average daily dose equivalent at solar minimum (excluding solar particle events) assuming a "worst" case longitude of 160 W.	0.43

** estimates of 2 different investigators
* rem and rad are assumed equivalent for the relavent ionizing particles.

6.2.2 Biological Effects of Space Ionizing Radiation

The biological effects of ionizing radiation are generally classified as either acute (early) or late (delayed) effects.

Acute Effects: Acute effects result from high doses of radiation received over a relatively short time period. It is very unlikely that these would occur for SPS workers. The exceptions might be the occurrence of unexpected nuclear detonations in space or of large solar particle events. In these two cases, if workers were on extra-vehicular activities and unable to reach storm shelters quickly, they might be acutely irradiated. If that did occur radiation sickness, depletion of bone marrow, etc., might follow. Workers acutely irradiated would need to be transported to earth as quickly as possible for therapy. Their future radiation exposure would need to be severely limited.

Late Effects: Late effects of ionizing radiation are those of most concern for space workers. The late effects which can be caused by the conventional types of ionizing radiation which occur in the space environment include cancer induction, developmental abnormalities in newborn, genetically related ill health, lens cataracts, shortened life-span and impairment of fertility. In addition to the generally known effects of ionizing radiation, there may be unusual biological effects from the high-energy, heavy-ions (HZE) which are a component of the galactic cosmic rays present in GEO. HZE energy is such that it would be very difficult, if not impossible, to stop these particles with shielding.

Cancer: Cancer arising in the various organs and tissues of the body, such as the female breast, the thyroid gland and the bone marrow is the principle late effect in individuals exposed to radiation and thus the major health hazard from the types of radiation expected to be encountered in space. The induction of cancer is influenced by age at the time of irradiation (i.e., latent period influence), sex and by the physical characteristics of the radiation received. With high doses of radiation the amount of cancer induction can be fairly easily predicted; with lower doses, projection of increase in cancer incidence, per unit of radiation, is more difficult and the models used currently involve a great deal of uncertainty. Using these models for cancer prediction it was estimated that, for each 10,000 workers who were exposed to 10 missions of 40 rem each, between 320 and 2000 additional cancer deaths (in excess of normal expectation of cancer mortality) might occur in later life. The wide range of this estimate stems from the choice of risk-projection model and of the dose response model.

Other Effects of Ionizing Radiation: The dose estimated for GEO is large enough that it might also cause genetically related ill health, developmental abnormalities of the newborn, cataract and temporary decreases in fertility. The probability that these effects would occur is lower than that for cancer and, of course, would diminish if the radiation dose were reduced for purposes of minimizing cancer.

The biological effects of the unique HZE particles are largely unknown at this early stage of research in that field. Based on some preliminary findings on the densely ionizing tracks of these particles, it is predicted that they may be very effective in inducing mutations, cancer and cataracts.

6.2.3 Uncertainties Regarding Space Ionizing Radiation and It's Biological Effects

There are many areas which need more work in order to clarify and more specifically quantify the ionizing radiation hazard for space workers. With regard to dose estimation, measurement of the radiation environment in free space needs to be done more precisely and a model developed specifically for SPS for simulation and study; short term variations of dose rate need better understanding; an instrumented satellite needs to be placed in GEO to measure dose rate, particle spectra and variations in the radiation field at depth in phantoms; shielding transport codes need precise evaluation. With regard to the biological hazards, age and sex profiles of space workers need to be specified; the most up-to-date information for estimating health risks of ionizing radiation must continually be reviewed for application to SPS; the effectiveness of various methods of shielding for minimizing radiation dose must be studied; the possible effects of HZE particles need further research; the possible synergism of ionizing radiation with other physcial and chemical agents in the space environment must be studied.

6.2.4 Mitigation of the Ionizing Radiation Problem

In spite of the uncertainties in radiation dose and risk estimation, the current estimates indicate that the unmodified reference system would probably lead to significant health problems. There are modifications which could be made in SPS design, e.g., changes in shielding, which would reduce radiation. Reassessment of the risks will be needed as better information becomes available for their prediction. Every effort should be made to minimize the ionizing radiation in the environment to which the space worker will be exposed.

6.3 Electromagnetic Exposure

SPS space workers would be exposed to electromagnetic energy (EM fields) which would occur across a wide range of frequencies and characteristically exhibit a large range of intensities. Some EM fields occur naturally in space; and in the case of SPS, others would be generated at the satellites in GEO.

The most intense EM field would be produced at the microwave transmitting antenna. The biological implications of microwave EM fields is being assessed under a separate task (20).

Much more work is necessary to develop a comprehensive evaluation of the potential for biological effects of an adverse nature on space workers due to EM fields other than those produced by the antenna. This evaluation cannot be done at this time for several reasons. First, equipment designs must be further developed before EM frequencies and intensities can be characterized adequately. Second, shielding for personnel must be better defined. Finally, more information regarding the effects of EM fields on biological systems is needed.

Appendix B contains a general discussion of EM fields expected from SPS and a brief discussion of the status of biological research on the effects of EM fields.

There might be difficulty in the future in extrapolating knowledge about EM-field biological effects for terrestrial settings to the much more complicated working environment in space. Currently, it appears that the effects of the EM fields on the space worker would be minor relative to other hazards, but an assessment will be needed as SPS design progresses.

6.4 Spacecraft Charging and Environmental Interactions

Electrostatic charges could build up on spacecraft and on construction equipment used in GEO and possibly present hazards to workers from electric shock. Electric discharges between structures might be possible, and could cause accidents of substantial magnitude. There is research in a number of laboratories and by NASA and the Air Force aimed at understanding these phenomena and finding mitigating strategies for avoidance of problems. Though one theoretical study has been done for SPS, there have been changes in the reference system which change the physics (personal communication, John Freeman, Rice University). Thus, the dangers from this situation cannot be assessed until further study has taken place.

6.5 Occupational Hazards (SPS Space Construction)

A detailed description of exact activities of the workers involved in building the space structures has not been generated. It is expected that the heavy construction would be done with man-manipulated machinery (beam-builders, etc.). The hazards involved would be the same as those using heavy construction equipment on earth except that these hazards would be increased due to problems with life-support (exterior to the space module) and problems of manipulation in the weightless condition. Considerable planning needs to go into the designs of work stations to minimize these problems. Workers would also need eye protection from the extreme brightness of the sun and temperature control to protect from the extremes between noonday sunlight to complete darkness.

Extravehicular Activity (EVA) in a spacesuit would not be expected as a routine part of space construction; however, it must be planned for in the case of emergency procedures, i.e., machinery might need external repairs, etc. There would probably need to be some trade-off between ideal atmospheric pressure in the space station and a pressure which could be used in spacesuits and which would allow mobility. If the space station pressure and that used in spacesuits were very different, then prolonged periods of decompression would be needed in order to avoid bends. The NASA life scientists are studying this problem in relation to Space Shuttle. Spacesuits would also have to be designed with ionizing radiation protection in mind.

The workers might be in the vicinity of high voltages, particularly during maintenance. This hazard would probably be no greater than that found in conventional power plants, but again, because of the awkwardness of working in the weightless state, special precautions would probably be necessary.

6.6 Toxic Materials

Space workers might be handling toxic materials, but the extent and types have not yet been defined. Evaluation of the possible hazards will be done when the design and expected worker activities have progressed further.

6.7 Meteoroid and Space-Debris Collisions

No work in this area has been done specifically with respect to SPS. Computer programs are available for examining this problem, and have been used for previous space missions. The size of a SPS satellite would make it more vulnerable to collisions than vehicles and satellites which have been put in space to date. While it currently appears that the probability of collisions would be small, these collisions, if they occurred, could be catastrophic. The amount of space debris is increasing at a fairly rapid rate. The problem of SPS collisions with meteoroids and space debris thus needs definitive studies.

6.8 Reflected Light

A possible hazard to the public and ecosystems from space operations is the light reflected from space structures. This could affect human vision (especially if viewed with binoculars or a telescope), and disturb the duirnal rhythms of plants and animals. A study is in progress to characterize this light and estimate its probable intensity and timing. When that study is completed, assessments will be made of the potential effects on the human eye, plants and animals.

6.9 Laser Hazards

An option being considered for transmitting power from the satellite to earth is the use of lasers. This study has not progressed far enough to permit evaluation of hazards to space workers, but see "Laser Hazards" under Rectenna below for a general discussion.

7.0 CONSTRUCTION AND OPERATION OF RECTENNA (GROUND RECEIVING STATION)

7.1 Environmental Assessment

Ideally, locations for SPS rectenna sites would be characterized by relatively clear, dry weather throughout the year; topography with little relief (i.e., flat or very gently rolling land) would have little or no socio-economic development; would contain no particularly sensitive or extensive populations of wildlife or vegetation; would have few, if any, economically-important natural resources; would have no particular aesthetic, recreational or conservation value; and would be reasonably close to some major electric load center. It is unlikely that any site in the US could be found which would satisfy all these idealized criteria. Moreover, electric load centers in the U.S. are geographically diverse with wide-ranging natural and man-made attributes.

An analysis of the impacts of rectenna siting is important for future planning, i.e., for illustrating the types and extent of effects which might be anticipated if SPS were fully developed. Many impacts would be site-specific, and results from one site cannot be easily projected to vastly different environmental settings. Nevertheless, the value of even one example is instructive and helpful. Thus, in order to analyze impacts in detail, an environmental assessment of the nonmicrowave impacts arising from construction and operation of the SPS rectenna was done by Environmental Resources Group (21).

Desert-like sites most nearly approximate the ideal rectenna site. The prototype site selected for this study was the Ross Valley/Coso area in the California high desert. This is not a site expected to be used for a SPS rectenna but has many characteristics that are considered currently to be optimal for siting. This particular site was selected for the study because environmental studies are being done there for the Bureau of Land Management in anticipation of geothermal development. Thus, much baseline data on the characteristics of the area are available. The group performing this assessment was instructed to use the current SPS Reference System Design (2). However, it was found that much of the detail needed, especially with respect to construction, was not yet specified in the Reference System. Thus, other sources of information (detailed in the report) regarding heavy construction had, of necessity, to be used, and many assumptions had to be made. These are described along with a detailed description of the site in Ref.21 . Three maps of the site are included in Figs.16 to 18 .

7.1.1 Rectenna Construction: The requirements for rectenna construction which would cause impacts on the environment are briefly described below.

Labor Requirements: It was estimated that rectenna construction would require 10 million man-hours and an average work force of 2,500 persons over a 25-month period, with a peak of 3,200 during Months 16 through 24 of the construction schedule.

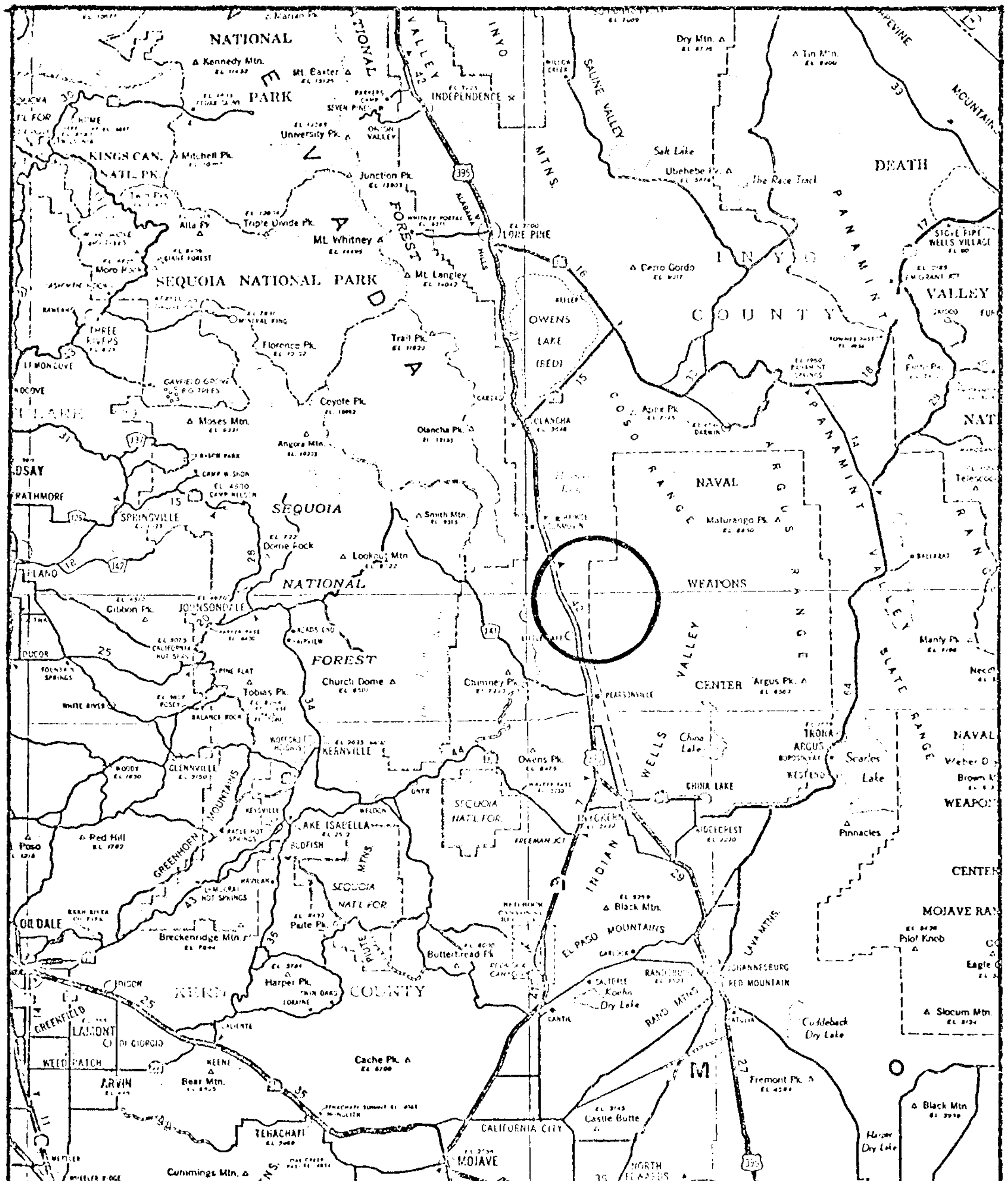

FIGURE 16. Location of Coso Study Area

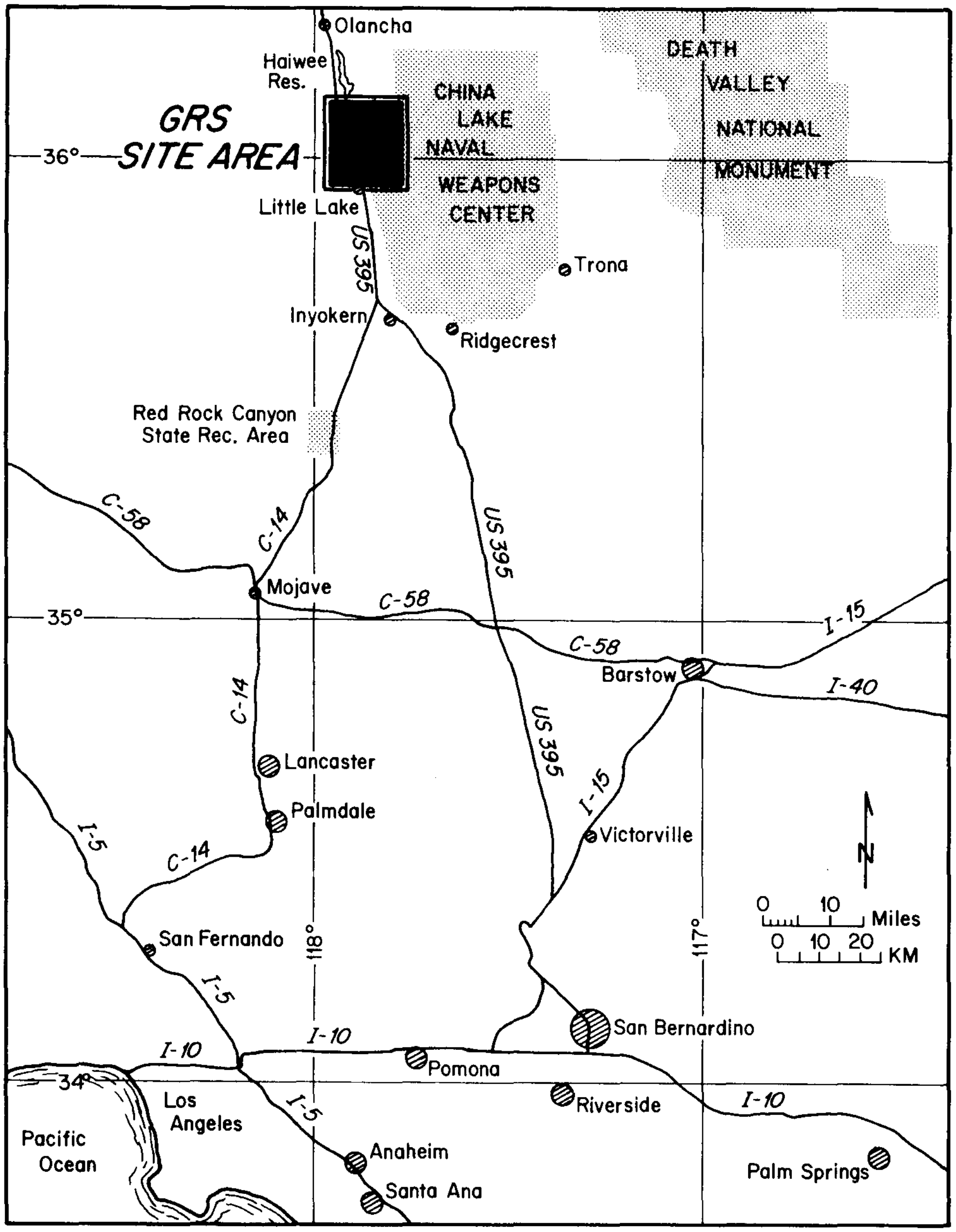

Figure 17. LOCATION OF GRS STUDY AREA

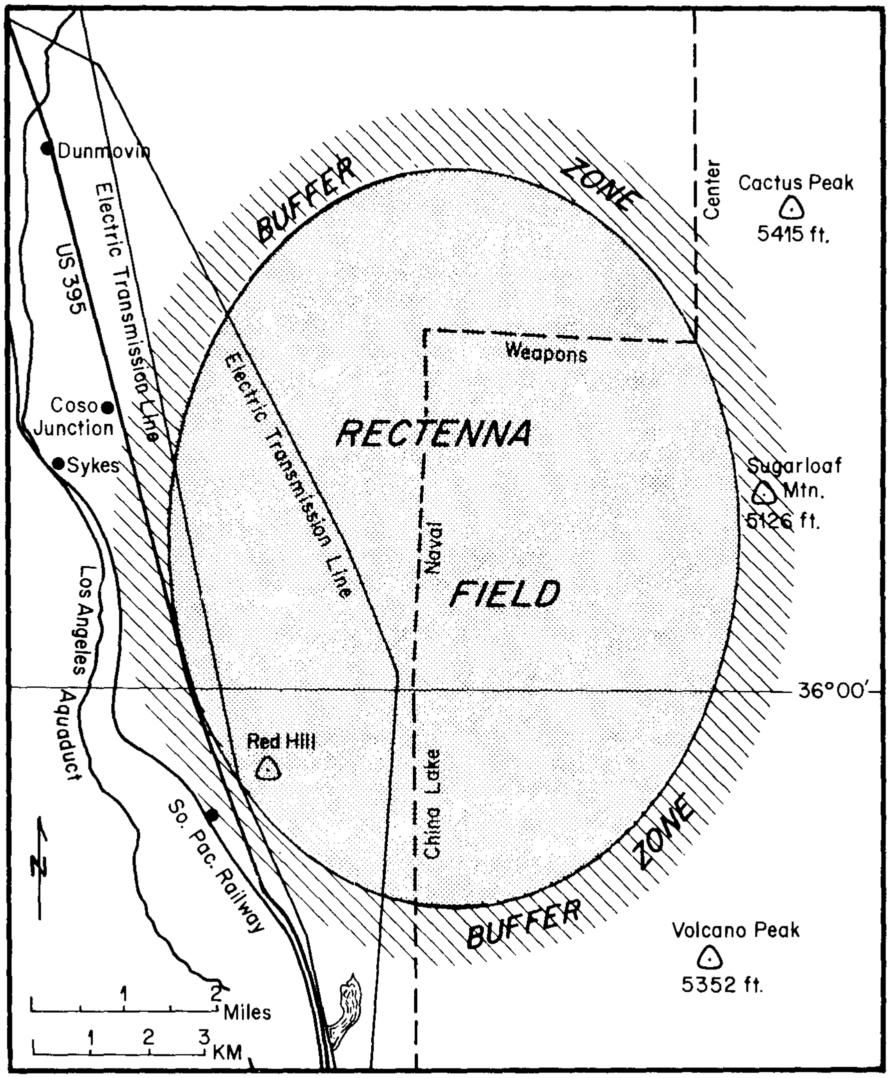

Figure 18. RECTENNA PLACEMENT WITHIN ROSE VALLEY

Material Requirements: Estimates of material requirements are shown in Table 17. It was estimated that 6.2 unit trains (100 cars each) per day or 2,400 truck trips per day (or a combination of trains and trucks) would be needed during Months 9 through 15 and 0.6 unit trains per day for Months 16 through 24.

Utility Requirements: A maximum annual water demand was estimated to be between 2.7 and 14.9 million cubic meters. The broad range is due primarily to uncertainty regarding means of control of fugitive dust.

Vehicle and Equipment Requirements and Fuel Consumption: Fig. 19 presents these requirements for months 3 to 24 of the construction period.

Solid and Liquid Wastes: Rectenna field-site preparation (Months 3-11) would produce roughly 1,800 tonnes per day of vegetative waste which would require disposal. Rectenna panel manufacture and installation (Months 16-24) would produce about 5 tonnes of solid waste -- primarily metals -- per day. The construction related population would produce a maximum of 18 tonnes of domestic solid waste/day and a maximum sewage flow of 2,800 cubic meters per day.

Air Polluting Emissions: Air polluting emissions were determined for each activity associated with construction activities. An example of the type of breakdown which was done is shown in Table 18. A summary of the emissions is given in Table 19.

Land Use for Rectenna: An ellipse of length 13.4 km and width 10 km would have to be completely cleared of vegetation and graded for rectenna panels. A buffer zone, also with a width of 1.35 km on each end and 1 km on each side, would also be required. The buffer zone might or might not need to be cleared, depending on fire hazard, drainage characteristics, etc. In addition to the rectenna panel area, there would be many other impacts on the land, i.e., ancillary roads and buildings.

7.1.2 Environmental Impacts:

Air Quality: Table 20 compares the incremental concentrations of pollutants predicted for rectenna construction activities with the existing ambient air quality and federal and state Ambient Air Quality Standards (AAQS). It is seen that ameliorative measures would have to be taken in order to comply with standards.

Climatology: This study concluded that waste heat from the rectenna did not appear to have potential for climatology changes, i.e. the waste heat rejection would be less than that of large coal and nuclear installations. However, there are other possible effects of rectenna on climate. These are being assessed under a separate task (13).

Noise: Table 21 shows typical noise levels associated with construction equipment and operations needed for rectenna construction. Table 22 shows permissible noise exposures in occupational settings. It is apparent that for construction workers some of the occupational standards would be exceeded. Mitigation procedures might include mufflers whenever possible on machinery and equipment, special insulation for noisy operations such as on-site concrete plants, and ear protection devices for workers.

Table 17

MATERIAL REQUIREMENTS FOR CONSTRUCTION OF HYPOTHETICAL SPS RECTENNA SITE IN THE CALIFORNIA HIGH DESERT

Items	Material Requirements							
	Aggregates & Ballast (1,000 tonnes)	Cement (1,000 tonnes)	Concrete (1,000 cu.yds.)	Steel (1,000 tonnes)	Aluminum (1,000 tonnes)	Plastic (1,000 tonnes)	Ceramic (1,000 tonnes)	Diodes (Number)
A. Preliminary Construction								
Main Access Road (16 km)	97*	1*	22+					
Railroad (16 km)	130			0.96				
Perimeter Fencing & Gravel Roads (45 km)	100			0.093				
B. Rectenna Field Site Preparation								
Gravel Roads (45 km)	100							
C. Rectenna Construction								
Support Manufacture and Installation								
Foundations	6,500†	900†	4,200			3.8		
Arches	3,300†	450†	2,100	370				
Grouting	300†	70†	200					
Panel Manufacture and Installation								
Manufacture				1,200	57	1.3	5.8	$7.5x10^9$
Installation & Wiring				110	110	11	0.06	
D. Electric Power Collection								
Electric Power Collection	4.6†	0.6		5.3	0.2			
TOTAL:**	11,000	1,400	6,500	1,700	170	16	6.	$7.5x10^9$

* Cement and aggregate for asphaltic concrete not included

\+ Asphaltic concrete.

† For non-asphaltic concrete.

** Other construction and pre-operation activities are not applicable to these requirements

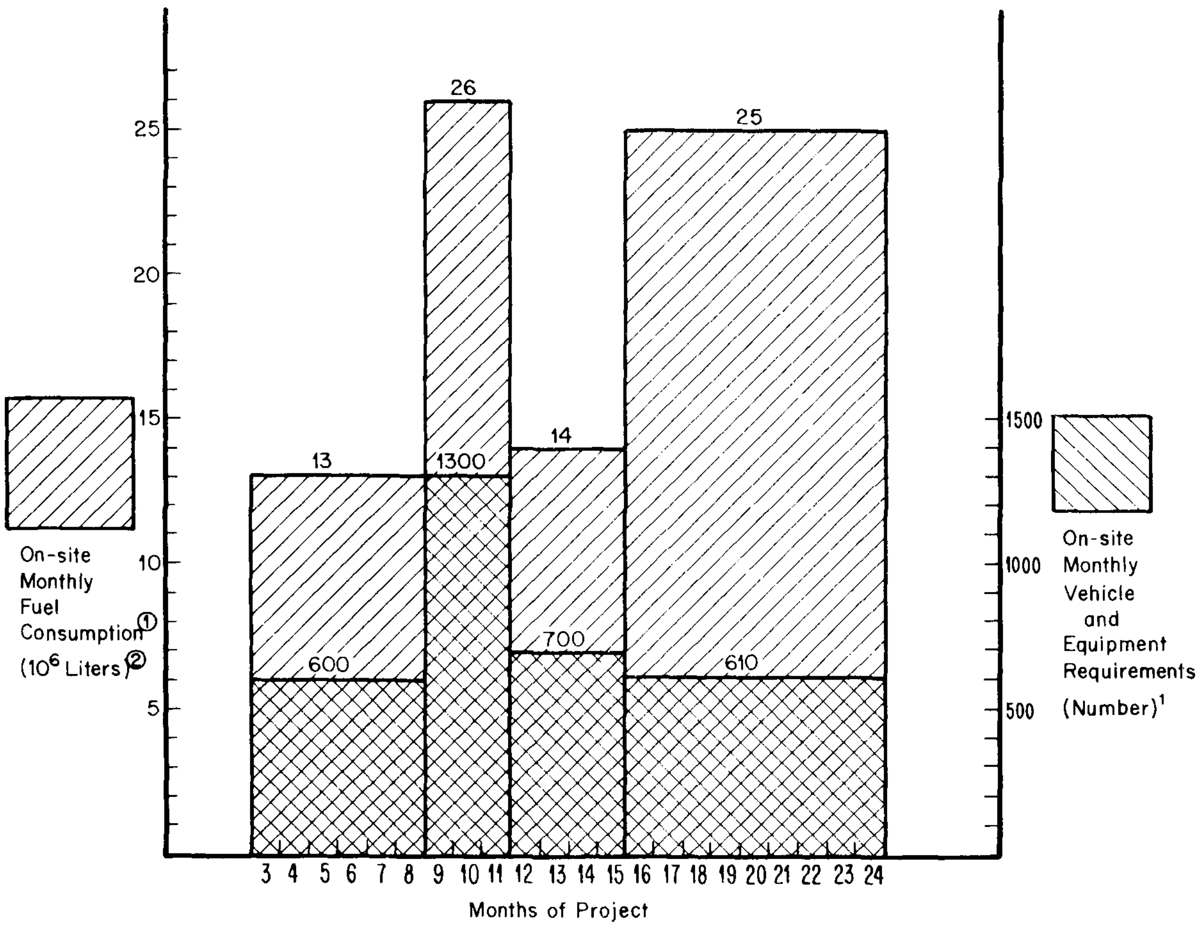

Figure 19. GRS MONTHLY CONSTRUCTION VEHICLE AND EQUIPMENT REQUIREMENTS AND ASSOCIATED FUEL CONSUMPTION

(Based on General Electric, 1979)

[1]Excludes Transmission Line Construction

[2]A Specific Gravity of 0.85 is Assumed

Table 18

ESTIMATED AIR POLLUTION EMISSION FACTORS FOR HEAVY-DUTY CONSTRUCTION EQUIPMENT FOR BUILDING A SPS RECTENNA

Source	Emission Factors ($kg/10^3$ liters of fuel) THC*	NO_x	SO_x	CO	TSP**
Bulldozer	2.5	53.9	3.7	7.9	1.8
Grader	2.1	44.8	3.7	9.4	2.7
Dump Truck	3.6	62.8	3.7	11.1	2.1
Crane	4.2	59.2	3.7	11.8	3.6
Backhoe	4.2	59.2	3.7	11.8	3.6

Source: U.S. EPA AP-42 (January, 1975).

*THC: Total hydrocarbon

**TSP: Total suspended particulate matter

Table 19

SUMMARY OF ESTIMATED MAXIMUM DAILY (AND HOURLY) AIR POLLUTION EMISSIONS ASSOCIATED WITH RECTENNA CONSTRUCTION (Months 9-11)

Source	Emissions kg/day (kg/hr) THC	NO_x	SO_x	CO	TSP
Rectenna Site Cleaning and Grading	1,300(163)	23,480(2,935)	1,600(201)	4,307(538)	79,365(9,921)
Support Structure Manufacture and Installation	1,389(232)	20,039(3,338)	1,266(210)	3,961(661)	2,527(338)
Delivery of Construction Material	238(22)	2,923(176)	260(25)	616(48)	136(12)
Power Generation	86(4)	962(40)	36(2)	238(10)	58(2)
Worker's Vehicles	182(78)	366(157)	15(7)	2,072(891)	33(14)
TOTAL:	3,195(499)	47,770(6,646)	3,177(445)	11,194(2,111)	82,119(10,287)

Table 20

ESTIMATED AIR QUALITY IMPACTS OF RECTENNA CONSTRUCTION

Pollutant	Averaging Period	Concentration Increment ($\mu g/m^3$)	Maximum Background Concentration ($\mu g/m^3$)	Net Ambient Concentration ($\mu g/m^3$)	California AAQS ($\mu g/m^3$)	Federal Primary AAQS ($\mu g/m^3$)	Federal Secondary AAQS ($\mu g/m^3$)
Hydrocarbons	3-hour	243	N/A	243	--	160	160
Nitrogen Dioxide	1-hour	4,365	N/A	4,365	470	--	--
Sulfur Dioxide	1-hour	267	N/A	267	1,310	--	--
	3-hour	267	N/A	267	--	--	1,300
	24-hour	89	N/A	267	131	365	--
Carbon Monoxide	1-hour	774	N/A	774	46,000	40,000	--
	8-hour	774	N/A	774	--	10,000	10,000
	12-hour	516	N/A	516	11,000	--	--
Total Suspended Particulates	1-hour	155	N/A	155	--	--	--
	24-hour	52	110	162	100	260	150

Table 21

TYPICAL NOISE LEVELS ASSOCIATED WITH CONSTRUCTION EQUIPMENT/OPERATIONS NECESSARY FOR RECTENNA FIELD SITE PREPARATION AND SUPPORT STRUCTURE MANUFACTURE AND INSTALLATION

A. Rectenna Field Site Preparation:

Equipment	Noise Level at 15 Meters (dBA)
Bulldozer[1]	87
Road Graders[2]	80-94
Dump Trucks[2]	82-93
Cranes[2]	76-87
Backhoes[2]	72-92

B. Support Structure Manufacture and Installation:

Equipment	Noise Level at 15 Meters (dBA)
Auger-Jackhammer[2]	82-98
Rock Drilling Machine[2]	82-98
Concrete Pouring Machine[2,3]	82-85
Concrete Trucks[2]	82-93
Trailer-Trucks[2]	82-93
Cranes[2]	76-87
Concrete Plant[4]	69
Arch-Making Factories[4]	69

[1] Source: Federal Register 39:121 (June 21, 1974).

[2] Source: U.S. Environmental Protection Agency (EPA), "Noise from Construction Equipment and Operations", EPA Report PB-206-717 (1971).

[3] Noise levels shown to approximate concrete pouring machines are those for concrete pumps.

[4] Noise levels shown to approximate the concrete plant and arch-making factories are those for outside the turbine building of a power plant.

Table 22

PERMISSIBLE NOISE EXPOSURES IN OCCUPATIONAL SETTINGS[1]

Duration (hours/day)	Sound Level (dBA)
8	90
6	92
4	95
3	97
2	100
1-1/2	102
1	105
1/2	110
1/4 or less	115

[1] Source: Federal Register, 34(96 (May 20, 1969).

The public would not be affected by noise since the local residents are at a distance which would result in a large decrease in noise levels.

Noise could alter roosting, feeding, reproductive patterns for bird species, particularly raptors, and disturb other fauna such that they would avoid areas with project-caused elevated noise levels. Noise of off-road recreational vehicles, used by personnel in their spare time, might also impact local wildlife.

Geology and Soils: Geologic/soils constraints (e.g., earthquakes and soil variability) on rectenna construction and operation at this site would be a larger problem than impacts. The only possible geological impact is subsidence, which could result from groundwater withdrawal if withdrawal for rectenna construction (along with that of other local water consumers) were to severely lower the water table. Landslides and triggering earthquakes appear very unlikely. Natural earthquakes could, of course, severely damage the rectenna.

There may be significant soil impacts. Removal of vegetative cover might allow wind and water erosion. There would be potential for compaction of some soils. Once disturbed, some also would be difficult to revegetate. Soils from excavation for footings would probably be left on the soil surface. This soil is usually low in fertility and does not support vegetation; thus it would cause visual scars and might induce accelerated wind and water erosion. The existing topsoil, which might have value in revegetation efforts, would be disturbed by construction activities. There would also be impacts from spills of gasoline and lubricating materials, litter, parking of personal vehicles, etc. Loss of wildlife habitat would be an indirect impact related to surface disturbance of soils.

Hydrology and Water Quality: Table 23 gives estimated water consumption during rectenna construction. It is more difficult to estimate water use during the operation phase where water would be required for labor-force related consumption and for dust suppression and/or irrigation if revegetation were carried out for soil restabilization purposes. No surface water is available in this area, so water would have to be piped in from outside or pumped from local groundwater. If local groundwater was used, it is estimated that there would be an overdraft of the groundwater and that the water table would be appreciably lowered. This lowering of the water table might result in a reduction of the quantity of groundwater in storage, a reduction of the quantity of underflow into Indian Wells Valley to the south, lowering of the water level in Little Lake, surface vegetation degradation, and a degradation of natural water quality.

Table 23

ESTIMATED ANNUAL WATER CONSUMPTION DURING RECTENNA CONSTRUCTION

Activity	Estimated Quantity Cubic Meters[1]
Concrete Production	910
Dust Suppression	75 - 11,000[2]
Labor Force and Domestic Use	850
TOTAL:	1,800 - 13,000

[1] One acre-foot = 1,233 cubic meters.

[2] Wide range depends on type of chemical used for dust suppression.

Degradation of Natural Water Quality: Natural water quality could be degraded by groundwater drawdown, sewage disposal, increased sedimentation, and soil stabilization programs.

The magnitude of the impacts of groundwater drawdown would depend on: 1) the degree of subsurface hydraulic communication among reservoirs of useable and nonuseable water, 2) the precise location of and extent of nonuseable water, 3) the hydraulic relationship between known geothermal reservoirs and the adjacent groundwater reservoirs, and 4) location and rates of groundwater extraction. There are not sufficient data available to permit a precise estimate of either magnitude or probability of such impacts. It is clear that groundwater use would have to be very carefully planned and monitored to provide protection for water quality.

The main source of liquid waste would be from sewage from the project workforce which was estimated to be 3.4 million liters/day. Other potential sources of liquid waste include concrete production, arch fabrication, aggregate washing, surface runoff (which could include dust suppression agents), and the disposal and leakage of oils and greases from vehicles and machines. A septic system does not appear practical, but sewage treatment might be an acceptable means of disposal.

Increased sedimentation could be a problem, although it is deemed unlikely except in the event of an unusually large storm.

Effects of soil stabilization could not be evaluated without a program being defined. If chemical methods were used, the adverse effects of the chemicals selected and the intensity of water use would have to be considered. If revegetation were employed, there would be initial intensive water use, and the potential for fire hazard and the effects of creating new "unnatural" biological habitats would have to be considered.

Surface Runoff: Construction activities would result in extensive soil and vegetation disturbance and dust emissions which would alter surface runoff patterns and increase soil erosion and sediment load. An appropriate erosion control plan would have to be an important part of preconstruction planning.

Impacts on Plant Communities: Rectenna siting would involve direct impacts on floral communities stemming from the disturbance of the land surface on the site, as well as from the development of access roads, railroads, ancillary facilities, etc. There would also be the potential for indirect impacts on plant species due to changes in hydrologic conditions (e.g., drawdown of the groundwater table), air and water pollution emissions, as well as casual and recreational activities by project personnel.

The major direct impact would result from cleaning and grubbing of 10,500 hectares of land for the rectenna field. Additional land disturbance, which would affect plant communities, would include development of the main access road to the site, the required rail spur, temporary construction phase facilities (e.g., storage areas, construction of personnel housing, shop areas), the electric power collection system, permanent ancillary facilities (e.g., control center and administrative facilities), and the perimeter fence and patrol road. These activities would disturb roughly 400 additional hectares of land-surface area. The impacts on plant communities resulting from these various land allocations would differ between construction and operations.

Because of the soil disturbance during site preparation and the subsequent rectenna construction activities, no significant naturally-occurring revegetation would be expected during the rectenna construction period. During the operational phase, in the absence of efforts to prevent it, some natural revegetation of the rectenna field site would occur. However, soil compaction, due to vehicular and equipment use during construction, might prevent or delay reestablishment of vegetative cover. In desert shrub communities, natural regeneration of disturbed areas is very slow - 30 to 40 years, under the best of circumstances, and often 100 years or more. Revegetation, when it does occur, is generally initiated with the appearance of short-lived pioneer species which can colonize areas of disturbed soil. Succession then may occur as these pioneer species are followed by longer-lived perennial species.

Regeneration of the naturally-occurring vegetation would be affected by: 1) measures taken to control erosion, 2) continued disturbance/compaction of the soil by maintenance vehicle traffic, 3) wind and water erosion, 4) changes in the pattern of natural infiltration of sunlight and precipitation, 5) displacement of naturally-recurring plants by weedy and nonnative species, and 6) microclimatic changes under the rectenna panels.

There could be impacts on sensitive floral areas and rare and endangered species in the vicinity of the rectenna (off-site) due to reduction of water levels, changes in water quality, inadequate control of liquid wastes, and deposition of windblown dust and sand.

Impacts to Faunal Communities: Rectenna siting would involve direct impacts on faunal communities from the disturbance of the land surface on the rectenna site, as well as from associated developments such as access roads, railroads, etc. Indirect impacts also might occur due to hydrologic changes, air and water pollutant emissions, noise, and other disturbances related to the presence of the project construction and operations workforce.

The removal of vegetation from the site would completely modify the existing faunal habitats and result in virtually complete destruction of animals which were unable to flee to nearby similar habitats. Only bird species and relatively large mobile mammals would be expected to escape when threatened.

Significant losses of rabbits, rodents, ground squirrels and other small mammals would be expected, as well as losses to reptile species (most of the 31 species found in the study area would suffer population losses). No significant faunal recolonization would be expected during the construction period because of the extensive soil disturbance and the subsequent construction activities.

Some degree of faunal recolonization would occur on the site during operations, although the recolonized faunal communities might be different from the preconstruction communities. Within the rectenna field, faunal recolonization would depend on the nature and extent of revegetation, altered soil and microclimatic conditions, the direct effects of the rectenna structures, and the degree of continued human activity and disturbance during operations.

The rectenna structures themselves could directly affect faunal recolonization. Locomotion or flight (particularly the large species) could be restricted, and the panels could serve as perching sites, shade or rest areas, or nesting sites for various species. The entire rectenna field itself could visually resemble a body of water to bird species which could attract them to the rectenna site.

Human activity and vehicular use during operation could serve to inhibit or even prevent recolonization by some faunal species. This could stem from vehicle-caused mortality, as well as by species' reaction to the noise, movement, and mere presence of men and vehicles.

Some faunal recolonization would occur during operations in the areas disturbed by development other than the rectenna field. The nature of the impacted soils in these areas and the floral succession that occurs would be key determinants of faunal recolonization in these areas. Because these disturbed areas would be relatively small (and undisturbed areas nearby) and because no significant microclimatic changes or extensive continuous disturbance would occur, faunal recolonization would be expected to be more rapid than in the rectenna field.

Amphibians could experience indirect impacts because of water quality degradation or reduction in surface water supplies, since these species breed in water and their larvae grow there. In addition, spade-foot toads could emerge from burial too early because of their reaction to construction noise.

Extensive off-road vehicle use by project personnel or a significant reduction in the productivity of aquatic systems in the area could indirectly affect some reptilian species.

Bird species that use the rectenna field site as feeding areas would be adversely affected; raptors and other birds that require large areas for foraging would be most affected. Some of these species might be able to use the rectenna field for foraging areas during operations, depending on the extent of floral and faunal recolonization that occurred. Many bird species -- particularly migrating or wintering avifauna -- would be adversely affected by any loss or degradation of water supplies. Raptors, as well as other bird species, also could be severely affected by project-caused noise and human intrusion in previously isolated areas. These factors could disrupt reproductive behavior; this problem would be of greater concern during rectenna construction.

Mammals which range widely for feeding would suffer a significant loss in foraging areas because of construction; some of these mammals might be able to use the area again during operations. In addition, mammals such as bats and carnivores would be severely impacted if local surface water resources were lost or degraded. Mammalian denning and reproductive behavior also could be affected by project noise and human intrusion.

There are several rare and/or protected animal species in this area (See Ref. 21 for full details). Planning of construction and operation activities would have to take these into account to avoid, whenever possible, endangering these species.

A Summary of Environmental Impacts: Impacts of rectenna construction and operation, along with suggested procedures for mitigation of impacts, are listed in Table 24 . This table is taken from the Reference 21.

7.2 Other Impacts of Rectenna Construction and Operation

7.2.1 Rectenna Construction Impacts: The construction worker would be exposed to the same occupational hazards as those occurring in other conventional heavy construction, steel-making and concrete manufacturing activities. No accident probability studies have been done specifically for rectenna construction. With the possible exception of plastics, toxic material handling would not be expected to present a health hazard for construction workers.

The public and the ecology in the vicinity of the rectenna would be impacted by increased amounts of transportation activities and the associated hazards of accidents and increases in air pollution.

Table 24

SUMMARY OF RECTENNA CONSTRUCTION AND OPERATIONS PHASES ENVIRONMENTAL IMPACTS

Technical Area	Rectenna Construction	Rectenna Operations	Mitigation
Air Quality/ Climatology	Probable standards violation for nitrogen oxides, particulates and hydrocarbons No climatic impacts	No significant air quality impacts Unknown, but possibly significant microclimatic effects at/near ground surface	Adequate dust suppression program during construction would mitigate particulates impacts Extending construction schedule would reduce emission peaks for hydrocarbons and nitrogen oxides Pending further research, project modifications might be needed for ground surface microclimate impacts
Noise	Substantially elevated noise levels, but few human noise receptors in the area Possible impacts on noise-sensitive species	No significant impact	Improved noise control technology by rectenna implementation timeframe for vehicles, equipment and processes (e.g., arch and panel fabrication) would mitigate construction phase impacts During construction noise sensitive habitats should be avoided to maximum extent possible during breeding/nesting seasons
Geology/ Soils	Geologic impacts less important than geologic constraints Study area very active seismically, but within normal range for Southern California Soils impacts significant: large disturbed areas; compaction, wind/water erosion Soils constraints: diversity of soils types implies variability in engineering properties (e.g., shrink/swell potential, corrosivity to metals/concrete)	Seismicity has potential for facility destruction or loss of efficiency (alignment vs. satellite) Soil productivity impacted for project life: depends on extent and degree of construction phase and ongoing operations disturbance	Thorough seismic and soil studies required as part of site-specific engineering Careful soil stabilization/drainage/erosion control programs required

Table 24 (continued)

Technical Area	Rectenna Construction	Rectenna Operations	Mitigation
Fauna	Land disturbance would completely modify site faunal communities Possible indirect impacts on fauna from hydrologic changes, air and water pollutants, personnel activities and loss of feeding areas for nearby fauna Surface water sources for migratory water and land birds would be lost (playas) and jeopardized (Little Lake) One protected species (Mohave ground squirrel) found in Rose Valley	Impacts similar to construction phase Impacts closely related to flora impacts Microclimate changes at ground surface a key issue for severity/mitigability of fauna impacts	Reestablishment of pre-existing faunal problematic; closely linked to strategy/success of floral mitigation Careful placement of ancillary facilities needed to minimize impacts on sensitive habitats Careful planning, design, construction and construction scheduling needed to avoid indirect impacts and to avoid sensitive habitats during breeding/nesting seasons
Land Use	Total displacement of existing site uses (e.g., farming, grazing, recreation) Minor loss of mineral resources (cinder, pumice) Minor indirect (growth-related) impacts Potential land acquisition/use conflicts with Navy (China Lake MWC), energy (geothermal), wilderness, archaeological resources, Native American use/access in cultural/religious sites	Same as construction phase	Major impacts not mitigable

Table 24 (continued)

Technical Area	Rectenna Construction	Rectenna Operations	Mitigation
Hydrology/ Water Quality	Project requirements= 2-14 million cubic meters (depends on dust suppression methods used) Meeting project needs from groundwater would lower water table 0.2 to 1.5 meters/year; would reduce underflow to adjoining valley; could lower water level in nearby lake; might contaminate usable water through hydraulic connection with unusable groundwater	Project requirements minor unless major revegetation program undertaken. Revegetation could require 27 million cubic meters/year for 3 years, which could cause water table drawdown	Careful soil stabilization/drainage/erosion control program required Groundwater withdrawal impacts mitigable by importing water from outside study area Proper sewage control program necessary during construction to prevent water quality degradation
Flora	Land disturbance would completely modify site's floral communities Possible indirect impacts on flora from hydrologic changes, air and water pollutants and personnel activities No endangered species present at Rose Valley/ Coso; one rare species present	Impacts similar to construction phase Microclimate changes at ground surface a key issue for severity/mitigability of floral impacts	Reestablishment of pre-existing flora problematic; major and difficult revegetation program required Careful placement of ancillary facilities necessary to minimize impacts on sensitive habitats Careful planning, design and construction/operations practices necessary to minimize indirect impacts (e.g., water quality degradation)

At more remote sites the increases in manufacturing, etc., as outlined in Section 4.1, would have impacts.

7.2.2 Rectenna Operation Impacts:

High Voltages: The workers at the rectenna site during operation would be exposed to the hazards of high voltages. Currently, it is assumed that these would be of the same character as those of conventional power plants and that safety regulations now in use would be applicable. This will need reviewing as system design progresses.

Electromagnetic Fields: The rectenna worker would be exposed to electomagnetic fields. The intensity of these fields is as yet undefined. See the general discussion of this problem in Section 6.3 and Appendix B.

The public and the ecology might also be exposed to these fields in the vicinity of the power transmission lines (which currently are expected not to differ appreciably from conventional transmission lines). The discussion in Section 6.3 would apply to the public and animals. There are some research programs in which plant damage has been found in electric fields, for example, see Refs. 22 and 23. The extent of damage appears to depend on the shape and height of plants (plants with rounded leaves do not seem to suffer as much, if any, damage as those with pointed leaves). The impacts would appear to depend on the type of native or agricultural plants in the vicinity.

Laser Option: The October 1978 Reference System Design uses microwaves as the mode of beaming energy from the satellite to earth. The impacts of microwaves are being studied by another SPS task group. The system designers are now looking at lasers as a possible option for beaming energy to earth. No decision has been made regarding which specific laser technology would be the preferred (most efficient) option,so the following discussion is a generalized one.

There would be health hazards associated with laser use. The factors which would have to be taken into account with regard to human injury are: 1) wavelength of the transmitted light, 2) tissue spectral absorption, reflection, and transmission, 3) strength or irradiance of the incident beam, 4) size of the irradiated area, 5) duration of exposure, and 6), for eye damage, the pupil size and the site on the retina which is irradiated. Tissue damage may result from thermal effects, photochemical action, and acoustical transients (24,25).

There are laser-associated hazards (i.e., not from beam) which depend on the type of laser used. These include electrical shock, airborne contaminants, cryogenic liquids, noise, ionizing radiation, nonbeam optical radiation, explosions, and fire.

The types of lasers which have to date been suggested as possibilities for SPS all irradiate in the near- or far-infrared (IR). The two tissues which are most susceptible to laser beam damage at these wavelengths are the eye and the skin.

Eye damage is the most likely health effect of laser use. Near-IR radiation is transmitted through the cornea, aqueous humor, lens, and vitreous humor, with significant quantities absorbed at the retina and choroid. Retinal damage can occur at these wavelenghts. Far-IR is absorbed in the cornea and the aqueous humor and corneal damage can occur. In the transitional zone between near- and far IR there may be both corneal damage and retinal damage and, in addition, there is the possibility of damage to intermediate eye structures such as the lens and iris. The area where the light is absorbed is the area susceptible to damage. Depending on the intensity of the irradiance, the length of the exposure, the size of the exposed area, and the location in the eye where the energy is absorbed, there may be minimal lesions which do not affect vision, cataract-type consequences, or severe and permenent loss of vision due to retinal damage in the foveal area.

Skin damage from lasers is of somewhat less importance than that to the eye, since skin is more easily reparable. However, there is a possibility of skin damage which can range from milk reddening to blisters and charring. Depigmentation, ulceration and scarring of the skin, and damage to underlying tissues may occur from extremely high-powered laser radiation. Latent and cumulative effects of laser radiation have not been adequately studied.

When a preferred type of laser for consideration for SPS use is selected, more definitive assessment of the health and safety hazards will be made. Effects on the terrestrial worker, the public, and the ecology will all need assessing. Research may be required to assess latent and cumulative effects of laser irradiation.

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APPENDIX A

WEIGHTLESSNESS, ACCELERATION/DECELERATION, NASA LIFE SCIENCES RESEARCH PLAN

(Abstracted from Reference 16)

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1.0 WEIGHTLESSNESS: Effects of Zero or Null Gravity

NASA's Life Sciences group has followed the medical/physiological condition of all the American astronauts, pre-, during, and post-flight. They also have on-going ground based research for purposes of better understanding the effects of weightlessness and of finding methods of ameliorating those effects which might affect health and efficiency. Their knowledge has been summarized for SPS in Ref. 16. The following description of the effects on various organ systems is taken from that report.

1.1 Musculoskeletal System

Loss of calcium from the body has been continuous throughout stays in space in all astronauts. No reversal of this trend has been seen even up to 175 days in the Russian mission. Three of the Skylab crewmen exhibited loss of heel-bone material averaging 3.9% per month. One had regained bone loss by the 87th day postflight, the other two had not regained their losses by the 95th day. Urinary calcium and phosphorous loss were high in all Skylab crewmen, and fecal calcium was frequently higher than urinary calcium. Excretion of these minerals returned to normal in less than one week after return to earth, but bone structure had not been rebuilt. The loss of total body calcium was about 0.4%. Exercise (up to 90 min/day in Skylab and 150 min/day in Salyut-6) did not prevent calcium excretion and bone demineralization. There are many factors that influence mineralization of bone that can be manipulated. However, means that have been tested in bed rest and in space have met with little success. Perhaps a part of the causation has not been considered. The report states that there is reason to expect that a novel exercise program can be synthesized that will more nearly duplicate the natural loads (of earth's gravity) on the skeleton, and maintain skeletal integrity perhaps when augmented by nutritional factors, drugs, longitudinal compression of skeletal members, or other techniques short of providing artificial gravity. The conclusion is that without remedial measures, missions of 8 to 9 months would not be precluded, based on present understanding of skeletal dynamics in weightlessness. Very lengthy missions would be precluded because of the belief that serious degradation to trabecular bone represents a morphological change that cannot be corrected. The effects of repeated missions, as would be required for SPS, have not, of course, been studied.

Muscle mass was lost and muscle strength was slightly reduced in Skylab. During postflight testing, work capacity was severely reduced, but this was thought to be caused by reduced cardiac output (see below). Postflight changes in muscle excitability, fatigueability, tension capability, and electrical efficiency were noted. Changes in muscle after prolonged spaceflight indicate that absolute muscle integrity has not been achieved by the exercise regimes used. However, the rate of muscle degradation became so low in Skylab 4 that it is assumed that there should be no concern for operational factors in stays of 90 to 180 days.

1.2 Cardiovascular System

In the zero-gravity environment there is a blood and fluid redistribution, as well as a loss of plasma and red blood cells (see Hematology below), and a change in the property of blood vessels to expand. The fluid shift is from the legs towards the upper part of the body and the head. Small changes in the electrical and mechanical properties of the heart, as well as a reduced heart-rate response to exercise, were seen in flight. Lower body negative pressure-stress tests were performed pre-, in-, and post-flight in Skylab. On some astronauts in- and post-flight tests had to be terminated early due to presyncopal responses (e.g., dizziness and pallor, fall in systolic and diastolic blood pressure and heart rate). Upon return to earth, the normal tolerance to the stress of upright posture (orthostatic tolerance) is temporarily reduced. In postflight the cardiac area showed reduced dimensions by x-ray and reduced cardiac muscle mass by echocardiogram. There was a reduction in ventricular and diastolic volume and in stroke volume. Most of the heart abnormalities had returned to preflight values by about a month postflight, but the capacity for maximum levels of exercise was depressed for about two months. The orthostatic intolerance encountered upon return to earth causes dizziness, weakness, transient instability on standing, decreased heart rate and decreased pulse pressure. These symptoms last for up to two weeks postflight.

The investigators attribute most of these signs and symptoms (including orthostatic tolerance) to the fluid shifts. They conclude that cardiac function was unimpaired as a result of spaceflight. The headward fluid shift -- at least in early orbit -- may degrade performance because of malaise, headache, sinus congestion, and a sensation of headfullness. The fluid shift may also contribute to inflight space sickness (see Neurophysiology).

There is a special concern when accelerative (decelerative) forces are applied on the long axes of the body during crucial task, e.g., re-entry, as tolerance may be exceeded. It is expected that this problem can be ameliorated by counterpressure devices.

1.3 Hematology

There was a marked and progressive loss of blood plasma volume throughout the Skylab flights (see Fig. A-1, reprinted from the NASA-Boeing report). The red blood cell (RBC) mass decreased until about 30 to 60 days into space when it appears that regeneration is in progress. About 7% of the RBC changed shape near the end of Skylab 4. Recovery on re-entry from these abnormalities was rapid. The plasma volume returned to normal in 1 to 4 weeks postflight; RBC values return to approximately normal in about 100 days from the beginning of flight (i.e., the kinetics of recovery were identical whether or not the subject remained in flight (Fig. A-1). The abnormally-shaped RBC disappeared in the first day after recovery, and the shape changes were thought to be without apparent significance or handicap to the space worker. It is postulated that the disappearance of RBC is due to trapping (and destruction) by the spleen, and that recovery is delayed due to inhibited bone marrow. Since postflight recovery is relatively fast, it appears that for single flights of the duration of Skylab these deviations are not a hazard to postflight health (See Fig. A-2 for postulated mechanisms). The effects of repeated inhibition of bone marrow, as might be the case in SPS, are unknown.

1.4 Immunity and Infectious Disease

There were some changes in results of laboratory procedures designed to test the capabilities of the immune system in the Apollo and Skylab astronauts, but other tests showed normal results. The exact cause and possible impact of the changes in immune system parameters are currently unknown.

Some skin infections have occurred in space (boil, sty, and presumed fungal infection), but no outbreaks of infectious diseases have occurred. However, considering the fact that three is the maximum number of people in prior spacecraft, this is not a good test of the situation in SPS where there may be as many as 500 people working in and out of a space module. The microbiological threat is not abated in space inasmuch as conditions are favorable for multiplication, transfer among workers, and transfer to workers from the space vehicle and stores and equipment. For SPS, this problem would need concentrated study and effort in order to avoid the possibility of epidemics of infectious disease in space.

1.5 Nervous System

The central nervous system has not been evaluated by quantitative tests in space; however, control of respiration and temperature, registering of senses (sight, hearing, etc.), cognitive functions, problem solving, and sleep were carried out with no apparent problems.

The autonomic nervous system is intimately concerned with maintaining homeostasis and regulating adaptive changes. It appears to have functioned adequately in most respects but may in some way (biochemical, humoral changes) be involved in the calcium and muscle loss syndromes.

The peripheral nervous system is not known to be affected by weightlessness. However, weightless effects on other systems, for example, those which alter calcium-potassium ratios, could significantly affect nerve thresholds and recovery, thus producing alterations in nerve function.

The achilles-tendon reflex time was affected by spaceflight. At postflight, it was at first shorter and then longer than preflight values. The time sequence of recovery to preflight levels was coincident with the return of muscle tone, so these abnormalities may have been more dependent on the state of musculature than on nerve transmission.

It appears that the nervous system has, in general, maintained its stability in transitions between one-g and zero-g. Mental, behavioral, and physical performances have been good. Some changes in the various organ systems, which appear adaptive in nature and appear to help attune the body to a challenging transition, have taken place. There are exceptions which should be regarded with caution, however, e.g., potassium loss, reduction in immune competence, demineralization, muscle atrophy, and vestibular performance pattern changes. These may be desirable adaptations to a new environment; when they aren't, it may be that the sensors which supply information to the central nervous system (such as blood oxygen, blood CO_2, blood volume, posture) are at fault rather than the nervous system itself.

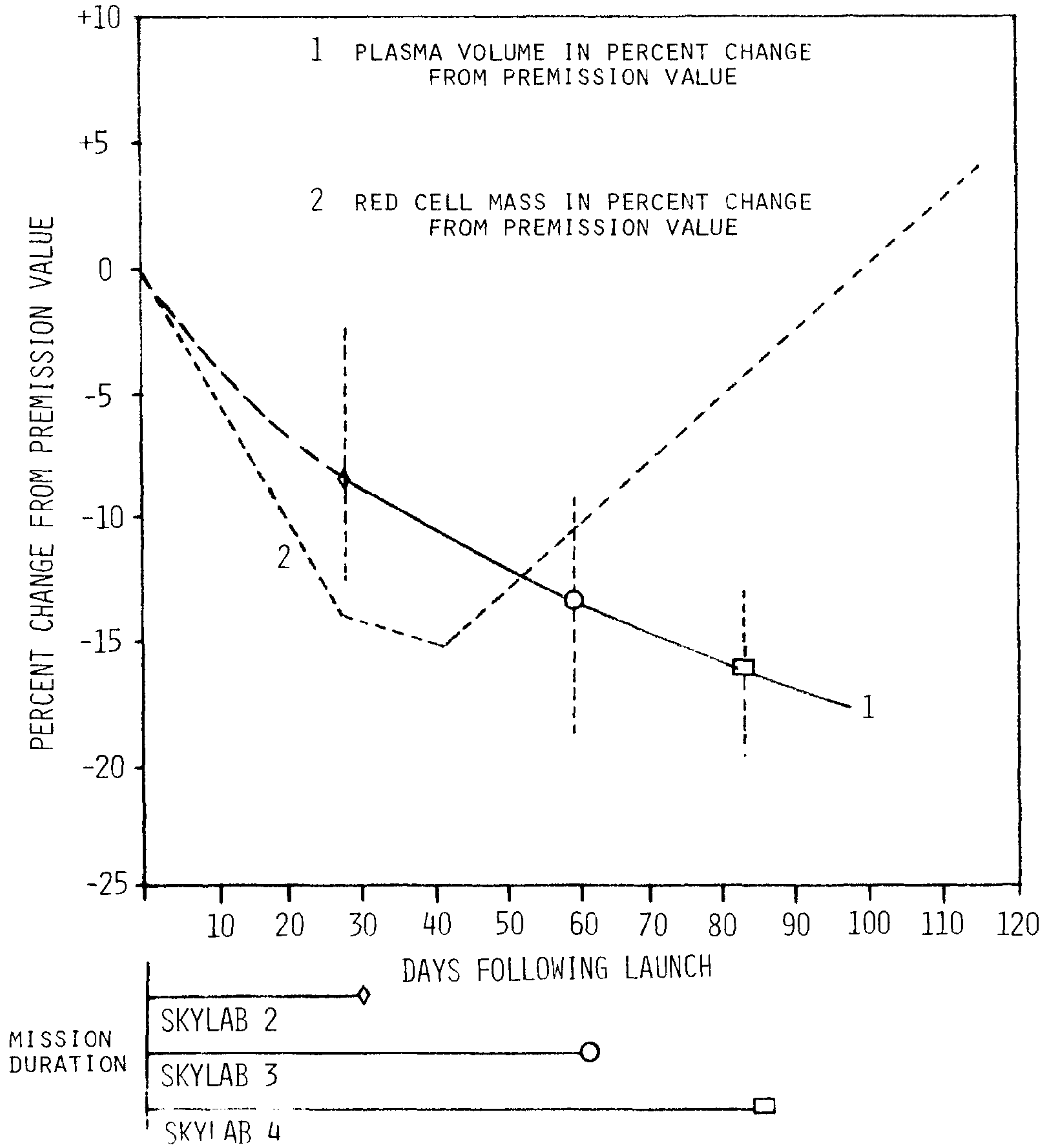


Figure A-1. BLOOD VOLUME CHANGES IN SKYLAB

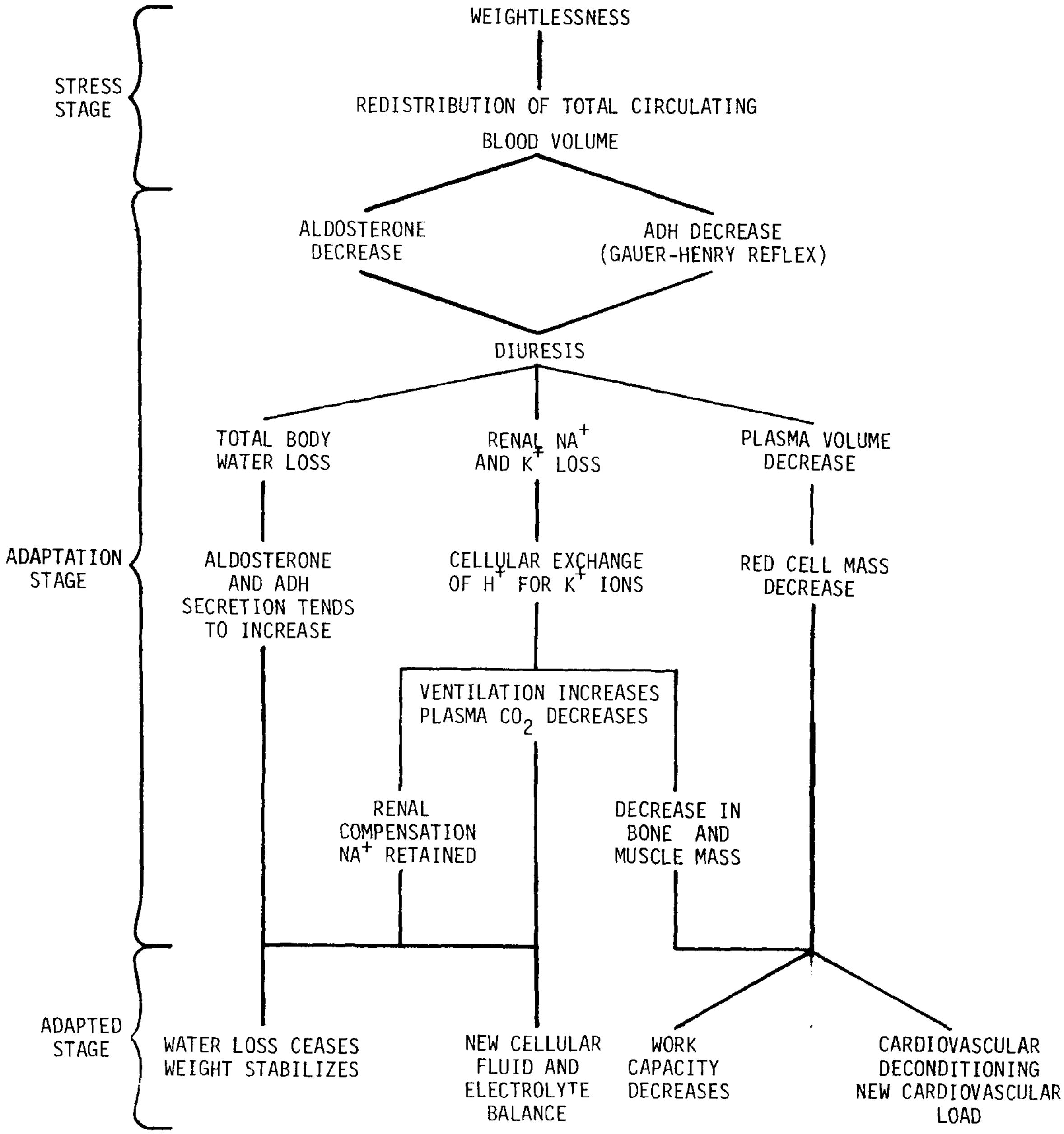


Figure A-2. ADAPTIVE FLUID AND ELECTROLYTE RESPONSE TO WEIGHTLESSNESS (PRESKYLAB HYPOTHESIS).

1.6 Neurophysiology

In Skylab there were a variety of symptoms including sensations of rotation, nystagmus (oscillation of the eyeballs), dizziness, vertigo, and postural illusions. There were also motion sickness symptoms and signs including pallor, cold sweating, nausea, and vomiting. The otolith, which is a part of the vestibular apparatus (having to do with balance),is a gravity sensor. It would be able to detect accelerations and decelerations in zero-g but would lose its one-g stimulus, i.e., orientation with respect to gravity, in zero-g would not be sensed normally but would depend on visual and tactile clues. Misfits in information inputs are assumed to be responsible for the symptoms listed above (other than those associated with motion sickness). The motion sickness is assumed to arise from problems in the linkage between the vestibular system, the position and motion analyzers and the autonomic nervous system. The motion sickness symptoms in Skylab disappeared by the 6th day. Some of the other sensations persisted longer. For SPS workers these symptoms might present problems for work efficiency, especially since they will have to adapt to movement through relatively long distances and work and live in a variety of positions and environments.

There is also the possibility that the otolithic particles, which contain calcium, could be resorbed by the body when calcium is mobilized during weightlessness (similar to bone degradation), and they might not regenerate upon return to one-g.

The NASA researchers hope to develop screening processes which will determine susceptibility to motion sickness and also hope that drugs will be developed which will be more effective for avoiding the symptoms. They conclude that vestibular responses appear not to limit stays in the weightless condition.

1.7 Respiratory System

The vital capacity (greatest volume of air that can be expelled from the lung after a maximum inspiration) was decreased early in flight and for the duration of flight. It returned to normal two hours postflight. The decrease was attributed to fluid shift to the lung circulation which may have limited deep inspiration. No effect on exercise capability could be attributed to pulmonary function. It was thought that pulmonary function suffered little or no decrement in zero-g.

1.8 Biochemistry

A number of changes were seen in the blood and urine levels of biochemicals. Most of these changes were attributed to adaptation to the weightless condition and thus of no long-term consequence. However, elevations in phosphorous and calcium in blood and increased secretion in urine are related to bone demineralization, and potassium excretion may be related to muscle function (see Musculoskeletal System above).

1.9 Endocrine System

There were some significant changes in levels of hormones, some of which had been predicted (Fig. A-2), but others were not. Thus, there appear to be some mechanisms involving hormone balance which are unknown or as yet imperfectly described. It was concluded that the changes were, for the most part, indicative of a successful adaptation by the body to the combined stresses of weightlessness and flight. Levels returned to normal shortly after return to earth, and inflight changes are not expected to limit exposure times of space workers.

1.10 Metabolic Activity, Work Capacity, Exercise Tolerance

The physiological responses to exercise in flight showed differences that could not be generalized over all crewmen. These included decreased responses of heart rate, decreased systolic and diaslotic blood pressure, increased resting respiratory minute volume, increased pulmonary ventilation, decreased or increased oxygen consumption and carbon dioxide production, decreased pulmonary efficiency and decreased mechanical efficiency. These changes did not degrade the capability to perform submaximal exercise, but did show that the quantitative relationships between cardiovascular, respiratory and musculoskeletal systems, that were obtained during preflight testing, were not maintained in flight.

Ergometry (exercise test) carried out on Skylab astronauts postflight showed severe decrements in capacity, though astronauts showed efficiency on inflight ergometry tests. Hence, the problem was in re-adapting to one-g conditions. There were decrements in strenuous exercise capability for approximately two months.

Work capacity in zero-g has not been carried to maximum effort. In Gemini, mobility did not suffer, but EVA activities were compromised by lack of restraints to the extent that seemingly simple tasks caused overwork. These findings caused a shift of emphasis in work situations from mobility devices to stabilizing and restraint systems.

It was found that exercise tolerance was maintained quite well in zero-g by a program of exercises that employ antigravity muscles and weight-bearing bones.

The conclusion was that work can be carried out efficiently in a properly designed task and that man's stay time in the weightless condition will not be limited by bioenergetic considerations.

1.11 Physiological Limits

No hard limits have yet been established for continuous or cumulative exposures to the weightlessness of spaceflight. However, several physiological effects mentioned in the previous discussion could ultimately impose limits on zero-g exposure. Bone demineralization is the most apparent effect of weightlessness that could limit flight durations in the SPS program. Degeneration of gravity receptors is another potential limiting factor for spaceflight duration; however, the nature and time course for the development of this effect remain speculative. Both of these effects are only realized with reappearance of gravitational or other external forces. Other physiological effects of weightlessness, such as cardiovascular deconditioning, loss of plasma volume, and immunosuppression, may not be current limiting factors to spaceflight duration, but will require monitoring and deployment of appropriate countermeasures.

Motion sickness appears to be an annoyance that temporarily interferes with performance. However, it appears to be time limited. The fluid shift and spinal lengthening also appear to have nuisance value so that they interfere with fitting and wear of emergency equipment and with physical comfort at work station equipment. These problems may be overcome by better bioengineering designs.

Exposure limits must be derived through further experimentation and/or progressively increased exposures to zero-g. When established, these limits will likely be a function of the availability of effective countermeasures. Moreover, with sufficient progress in these countermeasures, weightlessness as such may not be the most critical factor for limiting long-duration spaceflights.

Experience with spaceflight to date has shown that man can live and work in space for periods of as long as 84 days for American astronauts and 175 days for cosmonauts. It has also shown that the most deleterious effects of zero-g exposure may not be realized until return to one-g and subsequent readaptation. Also, from physiological evidence amassed through extensive experimentation in cardiovascular, hematological, endocrinological, vestibular, and musculoskeletal systems, it can be stated that the tentatively allowable exposure period to zero-g can be safely extended to six months. This may not apply to re-exposures to zero-g after a recovery period in one-g, i.e., a cumulative problem that is more serious than an initial exposure to weightlessness may appear.

Physiological measurements and performance parameters should be monitored during these extended missions to detect debilitating changes that might occur. This approach of systematically increasing exposure times can be continued until physiological limits are approached or until operational goals are realized.

2.0 EFFECTS OF ACCELERATION/DECELERATION

Physical forces act on the body to cause acceleration and displacement of the whole or some part of the body. The extent and circumstances of the response of the body to force may result in a range of physiological responses from a level at which no effect can be perceived to a level resulting in massive tissue destruction.

NASA has very limited information on the effects of acceleration/deceleration in spaceflight (as opposed to "ground-based" testing on subjects residing in one-g environment), and is thus unable to provide substantial information on these environments until further research is accomplished. The duration of exposure to weightlessness is known to influence the extent to which the response of the body to acceleration is altered and also the length of time to readjust to normal preflight response characteristics. NASA has intentionally kept the exposure of astronauts to accelerations and decelerations to the lowest possible levels in order to maximize the yield of data on zero-gravity exposure. They propose to limit launch and landing accelerations to levels of less than 3 G.

The magnitude of the force acting on the body and the mass of the body determine the magnitude of the body determine the magnitude of the effects. The duration of the acceleration is a significant factor in the response of the body, particularly at the shorter duration exposures approaching impact (duration < 0.2 sec). Also significant are the direction of the force vector, the resultant direction of acceleration with respect to orientation of the body, and the specific body position. The restraint and support systems for the human body in an accelerating vehicle determine the manner in which forces are transmitted from the vehicle to the body, and thereby strongly influence the physiological response to the acceleration.

The cardiovascular and respiratory effects are generally the most significant. A chart and graph taken from the NASA report are reprinted in Figs. A-3 and A-4. Figure A-3 depicts the basic mechanisms of accelerative action on the organism. Figure A-4 shows the effect of body position on tolerance to acceleration. The heavy solid line is a plot of the required acceleration to achieve earth orbit against the required duration of that acceleration. This plot illustrates the physiological trade-off that must be made between short-duration, high-G loads and much longer duration, lower G loads. Maximal peak forces for the Apollo spacecraft reached approximately 6 G on entry, with lesser values for launch and orbital maneuvers. Mercury (Fig. A-5) and Gemini spacecraft operated at slightly higher values. No acute operational problems, significant physiological deficits, or clinical sequelae related to the cardiovascular and musculoskeletal systems are known to have resulted.

The Space Shuttle vehicle (prototype for SPS personnel launch vehicle) will impose a quite different acceleration environment on the crew. The G loads will be lower but will have a longer duration (Fig. A-6). Visibility requirements during landing necessitate an orientation of the crew couches that results in an acceleration during entry that is primarily in the $+G_z$ vector. The effects at various G-loads of acceleration in this vector are shown in Table A-1. An anti-G garment covering the legs and lower torso is being made available for use during entries to reduce the effects of this acceleration.

Table A-1

Subjective Effects of Acceleration

Magnitude, G	Effects
	Positive acceleration ($+G_z$)
1	Equivalent to the erect or seated terrestrial posture.
2	Increase in weight, increased pressure on buttocks, drooping of face and soft body tissues.
2.5	Difficult to raise oneself.
3 to 4	Impossible to raise oneself, difficult to raise arms and legs, movement at right angles impossible; progressive dimming of vision after 3 to 4 sec, progressing to tunneling of vision.
4.5 to 6	Diminution of vision, progressive to blackout after approximately 5 sec; hearing and then consciousness lost if exposure continued; mild to severe convulsions in about 50% of subjects during or following unconsciousness, frequently with bizarre dreams; occasionally paresthesias, confused states and, rarely, gustatory sensations; no incontinence; pain not common, but tension and congestion of lower limbs with cramps and tingling; inspiration difficulty; loss of orientation for time and space as long as 15 sec after acceleration.

Since the physiological effects of an acceleration force field are many, the potential for modification of these effects by a number of environmental factors should be considered. The primary limiting effects are a loss of oxygenation due to effects on the cardiovascular and respiratory systems. Temperature can be expected to interact when it results in vasodilatation and decreased cardiac return. Any other environmental factor that might affect the cardiovascular or respiratory system would be expected to influence acceleration tolerance. There is also a large individual variation in tolerance of acceleration.

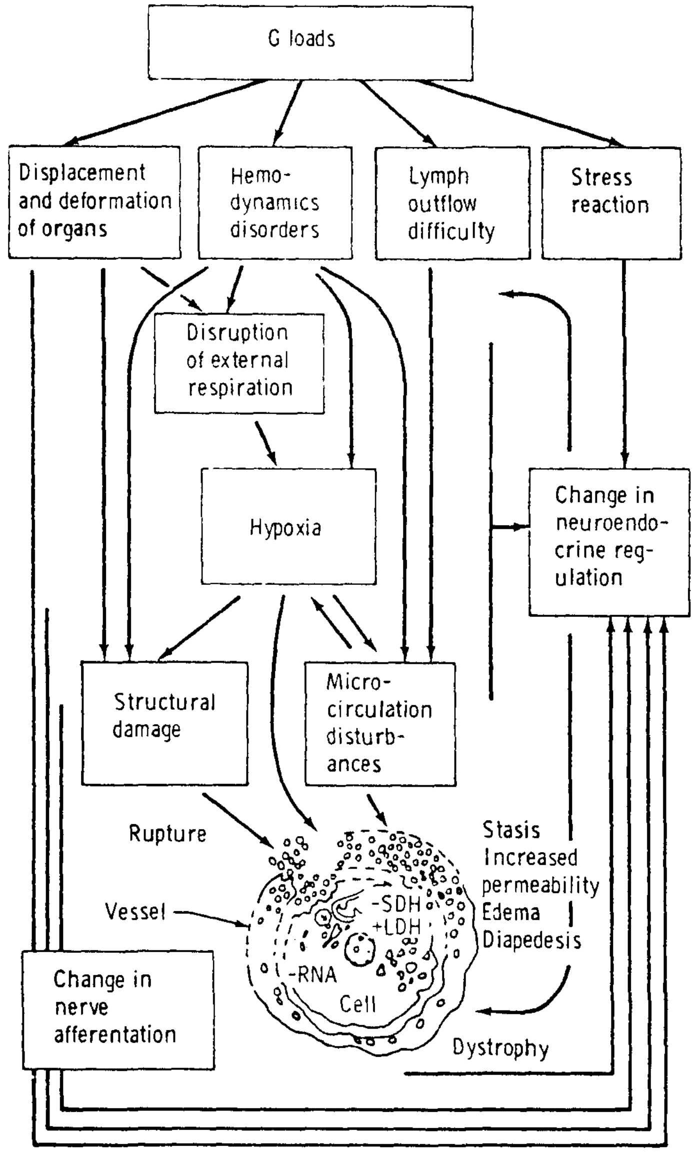


Figure A-3. BASIC MECHANISMS OF ACCELERATIVE ACTION ON AN ORGANISM. CELL CHANGES CONSIST OF INCREASED ACTIVITY OF LACTATE DEHYDROGENASE, (+LDH), REDUCE ACTIVITY OF SUCCINATE DEHYDROGENASE (-SDH), AND REDUCED QUANTITY OF RIBONUCLEIC ACID (-RNA) IN CYTOPLASM.

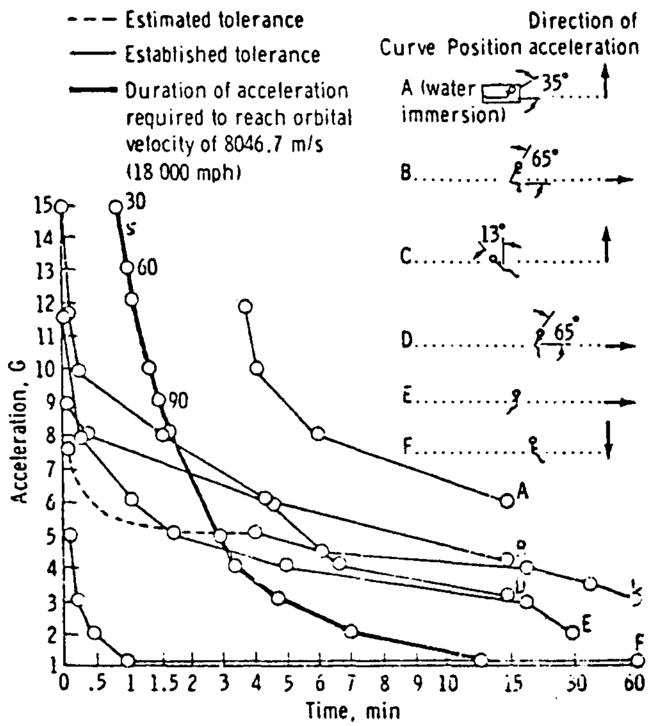


Figure A-4. EFFECT OF BODY POSITION AND POSTURE ON TOLERANCE TO ACCELERATION. THE TIME SCALE (ABSCISSA) IS LINEAR BUT NONPROPORTIONAL.

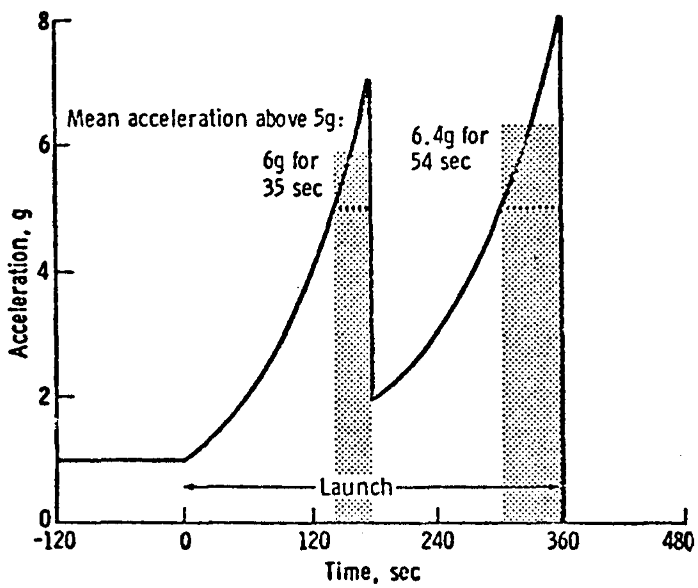
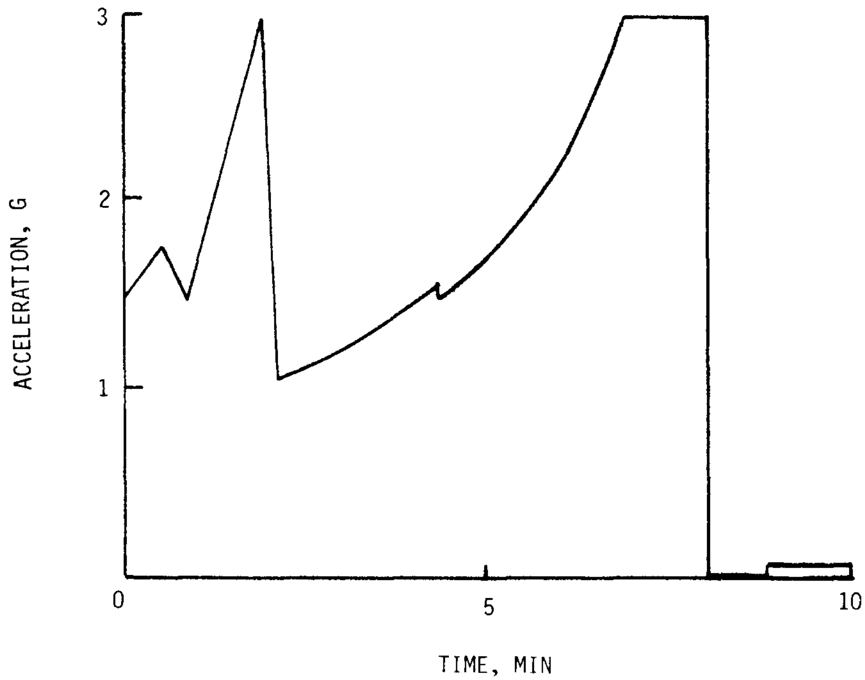
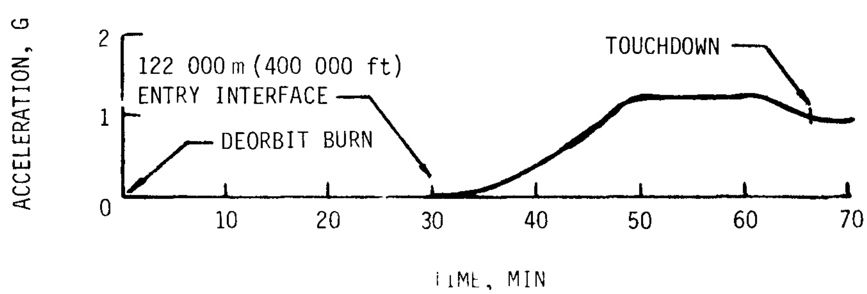


Figure A-5. ACCELERATION PROFILE OF LAUNCH PHASE OF THE MANNED MERCURY-ATLAS 6 ORBITAL FLIGHT. STIPPLED AREAS SHOW PERIODS OF ACCELERATION GREATER THAN 5g.



(a) LAUNCH.



(b) ENTRY AND LANDING

Figure A-6. ACCELERATION PROFILES OF THE SPACE SHUTTLE VEHICLE AS A FUNCTION OF TIME.

Research is needed to provide the following:

1. Definition of the effects of various durations in a null-gravity environment on subsequent tolerance to force fields in all axes.
2. Definition of the range of acceleration forces resulting in physiological effect and of tolerance in the population that may fly in space.
3. Optimization of countermeasures that may be used under high-force field conditions.
4. Effects of repetitive G exposure and cumulative G effect.

3.0 RESEARCH PLAN

Currently, only ground-based research is being carried out under the auspices of NASA Life Sciences, but it is anticipated that two major space programs in the 1980's and 1990's -- the Shuttle/Spacelab and the Space Operations Center (SOC) -- will provide opportunities for research in space. The Life Sciences organizations will be conducting research in support of these programs. This research can be designed to yield information needed to identify potential adverse effects of SPS-type space operations and suitable countermeasures. The general objectives of NASA Life Sciences during the next few years are:

- To determine effects of space environment on life systems.
- To gain greater understanding of life processes and systems.
- To extend crew health-care capabilities for space utilization and exploration.
- To develop improved life support and protection systems for people working and living in space.
- To develop crew operations and equipment design to enhance crew/space-system integration.
- To develop processes that exploit the advantages of space for bioprocessing.
- To determine advantages of space to help support clinical research on earth, and
- To apply space technology to health care for people on earth.

This research will be conducted on the ground in various laboratories throughout the nation and in space aboard the Shuttle/Spacelab.

Currently on-going, ground-based research includes:

- Operational laboratory
- Crew health maintenance
- Cardiovascular deconditioning
- Bone/muscle alterations
- Fluid and electrolyte changes
- General research
- Extravehicular systems
- Food production
- Program definition
- Medical selection creteria
- Systems habitability verification
- Space-motion sickness
- Blood alterations
- Radiation effects and protection
- Life-support systems
- Nutritional requirements
- Man-machine systems

Each of these general topics usually includes a number of research programs.

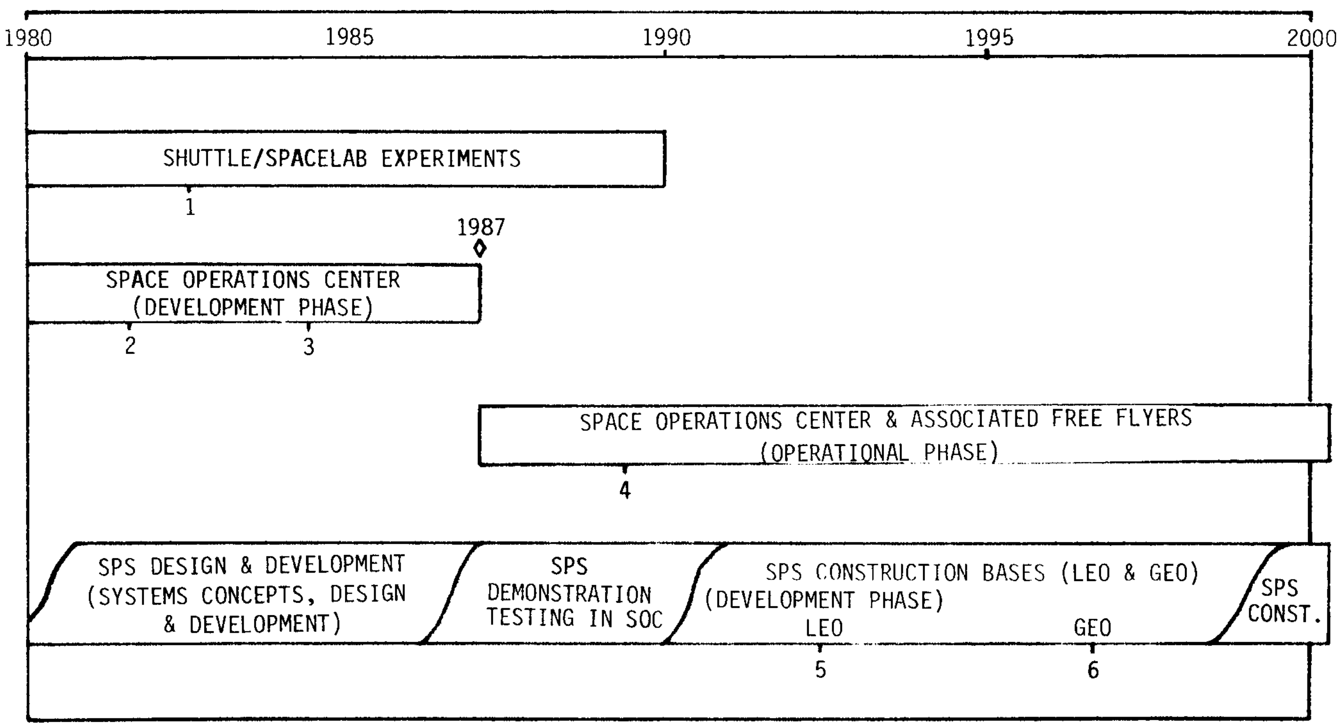
Shuttle and SOC will present opportunities for space-based investigations, and a number of proposals have been made for these investigations. Most of the results of the proposed investigations will be directly applicable to SPS. Also, the operational experience from SOC will be important for SPS planning. This program will involve 4 to 16 space workers living in modular 4-man habitats for periods of 90 days. The space activities, work schedules, and mission cycles will be similar to those expected in SPS. For the first time crew members will be making repeated missions into space and working at "routine" jobs. The long-term and accumulative effects of repeated missions into space will be explored. There are, however, several characteristics of the SPS program that will require research directed specifically at SPS. These features include:

- The large number of people -- 500 in space
- The large variety of tasks (construction, maintenance, housekeeping, health care, etc.)
- The large number of female workers -- 25% of total work force
- Repeated long-duration missions over a 5-year career span
- Workers in GEO habitats and work areas (Shuttle and SOC will be in LEO)

The significance of these unique features is that every life support, protective, habitability, and health-care system developed for previous programs will require a major redesign or replacement with a new system concept. In addition, the operational environments will introduce new psychological and sociological situations that may impact the worker and his family and earth-based associates. These will introduce new areas of research for NASA.

A schedule for providing information relating to the health and safety of space workers has been formulated which is based on consideration of the needed date for finalizing SPS workers' schedules -- about 1995 -- and the currently anticipated manned space program proceeding or concurrent with SPS space missions. This is shown in Fig. A-7. The circled numbers show milestones at which new information, applicable to SPS, will become available.

The NASA evaluation of the effects of the zero-gravity environment and acceleration effects brings them to the conclusion that SPS planning can proceed with reasonable confidence that there will be minimum adverse effects on career SPS members due to living and working in the space environment. This is based on the assumption that research and space operations between the present and the SPS projected date for starting construction will lead to ways to solve or ameliorate problems.



SCHEDULE POINTS 1 THRU 6 REPRESENT TIMES AT WHICH INCREMENTALLY IMPROVED INFORMATION ON CREW HEALTH, SAFETY AND WELL-BEING WILL BE AVAILABLE

Figure A-7 COMPARATIVE SCHEDULES FOR THE SHUTTLE/SPACELAB, SOC, AND SPS PROGRAMS

APPENDIX B

ELECTROMAGNETIC FIELDS

1.0 Electromagnetic Fields at the SPS Satellite

2.0 Electromagnetic Fields at the Rectenna

3.0 Biological Effects of Electromagnetic Fields

4.0 References

1.0 ELECTROMAGNETIC FIELDS AT THE SPS SATELLITE

Workers in space would be exposed to electromagnetic energy (EM fields) which occur across a wide range of frequencies, and characteristically exhibit a large range of intensities. Some EM fields occur naturally in space, and in the case of SPS others would be generated at the satellites in GEO.

The EM fields produced at the satellites would occur across a frequency spectrum extending from the steady electric condition (direct current) to the high microwave region. Electrostatic fields would occur near high voltage equipment. Inductive electromagnetic fields would be produced near current-carrying conductors and current generators. Low intensity energy would exist across the frequency spectrum, and higher intensity peaks would be evident at fundamental operating frequencies with less pronounced peaks at their harmonics. Some intermodulation of operating frequencies would also be expected.

The most intense electromagnetic field would be produced at the fundamental operating frequency of the transmitting antenna. The frequency is 2.45 GHz for the current reference system, but could change as system design evolves. Another SPS assessment group is studying and evaluating the biologic implications of microwave EM fields (Task 1 - Microwave Effects on Health and Ecology), and their findings are being reported separately.

Little if any EM energy would be produced by equipment during satellite construction. The principal risk of EM-produced health effects would therefore be faced by satellite maintenance workers, and then only if satellites remained operational during maintenance and repair periods. Moreover, workers would have to be shielded against ionizing radiation. That shielding would offer at least some protection against the lower intensity equipment-generated EM fields.

2.0 ELECTROMAGNETIC FIELDS AT THE RECTENNA (Earth Receiving Station)

Electromagnetic (EM) fields would be produced at various frequencies and intensities over practically all of the rectenna site.

Microwave energy received at the rectenna from space would be converted to conventional electricity by the dipole-diode receiving elements. The conversion could be limited to the so-called steady electricity (direct current), could include processing to alternating current (ac), or could involve a combination of the two forms. In any event, voltages would progressively be built up to higher and higher levels in a number of "power blocks" as the electricity is transferred to on-site substations and subsequently delivered in one or more directions to consumers by power transmission lines and distribution circuits. The process is not dissimilar to that used at switchyards at conventional power plants.

Electromagnetic fields would be produced throughout the rectenna site during operations. Magnetic fields (or forces) would be produced in a known proportion to current flow in electric conductors. They would be very localized, with their strength decaying rapidly as distances from the conductors increase. Electric field components also would be produced at intensities in known porportion to both voltage and current. The electric intensities would not decay rapidly with distance, so their influence could be quite widespread. There would also be EM fields in the vicinity of power transmission lines. These are currently not expected to differ appreciably from conventional transmission line fields.

3.0 BIOLOGICAL EFFECTS OF ELECTROMAGNETIC FIELDS

There is a great deal of uncertainty about the biological effects of EM fields at this time. Extensive research is in progress (independent of SPS) by the military services (e.g., Refs. 1 and 2) the Electric Power Research Institute (EPRI) (e.g., Ref. 3) and the Department of Energy (DOE) (e.g., Ref. 4).

A symposium (5) held in 1978 covered much of the recent research. Epidemiologic studies have been done in several countries (6,7,8) on persons exposed to electric fields at power-generating facilities and in the vicinity of high-voltage transmission lines. While some researchers felt that they found adverse effects, the studies suffer from lack of proper controls, exclusion of other factors such as small shocks and noise, and statistically significant numbers of subjects. Further studies, with significant numbers of subjects and which include matched controls and exclude such associated factors as mini-shocks and noise, need to be done in order to determine the effects of electric fields on humans.

Since research on humans is difficult, research programs on animals are in progress to determine the effects of electric fields on animals. The most extensive program is being carried out at Battelle Northwest Laboratories, partly supported by the Department of Energy and partly by the Electric Power

Research Institute. These experiments have so far been on rodents, but a swine exposure unit is being developed. In these studies there is an effort to exclude such associated factors as elevated ozone concentration, noise, spark discharges, and mini-shock. A number of studies are being done including biochemistry, physiology, growth, reproduction, and behavior. Thus far, in most experiments the animals exposed to electric fields do not differ significantly from nonexposed matched controls. The exceptions are that there is evidence that electric fields may increase nerve excitability (replicate studies are currently underway) (9), possibly elevate platelet and white blood cell counts (10), and induce a behavioral preference for areas shielded from the field (11).

Other investigators have reported that electric fields are biological stresses (12), cause an increase in white blood cells (13), increase pituitary and adrenal weights (14), cause transitory enhanced growth rates (15), cause reduced growth rate (16), increase mortality and rate of growth (14), have effects on hematological and serum chemistry (14 to 20), slow electrical conduction in the heart (21). It is possible that some of these findings were due to secondary influences of the electric field, i.e., spark discharges, corona, noise and ozone. Further experimentation will be necessary to better define electric field effects and their potential for human health effects.

The public and the ecology might also be exposed to EM fields in the vicinity of the power transmission lines. The discussion above would apply to the public and animals. There are some research programs in which plant damage has been found in electric fields (e.g., see Refs. 22 and 23). The extent of damage appears to depend on the shape and height of plants (plants with rounded leaves do not seem to suffer as much, if any, damage as those with pointed leaves). The impacts would appear to depend on the type of native or agricultural plants in the vicinity.

Very little is known about the effects of chronic exposure to low-level magnetic fields on humans (24). Some research is underway (e.g., Refs. 25 and 26) which may generate some answers. Currently, it is anticipated that if there are effects from magnetic fields they will be very subtle and not of great (if any) consequence to SPS workers.

As yet, the strength of these fields in the work areas of space and rectenna personnel has not been defined. When these values are defined, an in-depth study of the current literature will be needed for assessing the possibilities of health hazards.

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