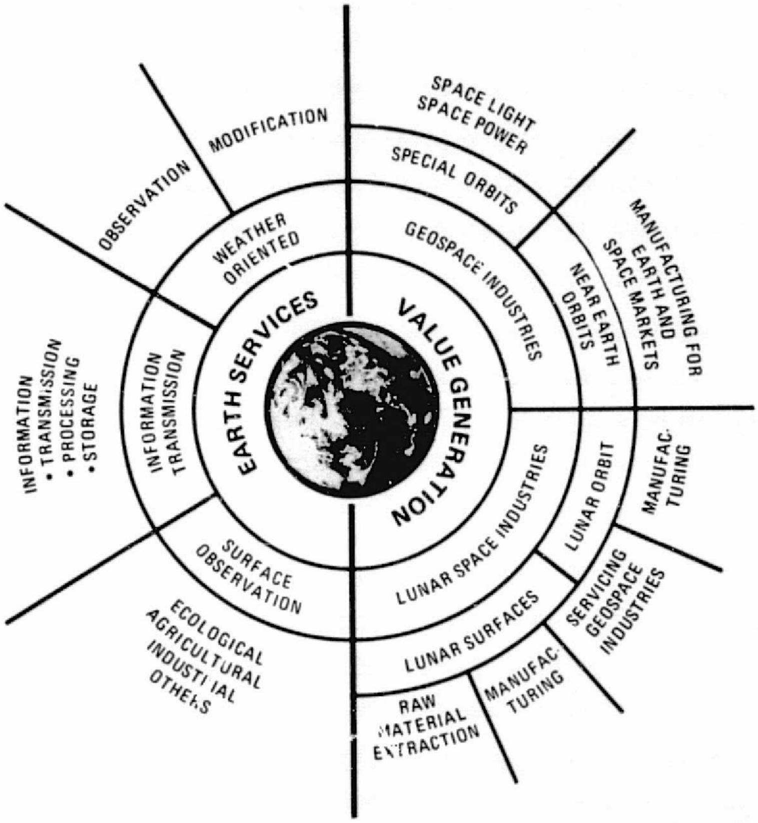
SD-78-AP-0055-2

Space Industrialization



SPACE INDUSTRIALIZATION BACKGROUND, NEEDS, AND OPPORTUNITIES

FINAL REPORT

Rockwell International
Space Division

(NASA-CR-150721) SPACE INDUSTRIALIZATION. VOLUME 2: SPACE INDUSTRIALIZATION BACKGROUND, NEEDS, AND OPPORTUNITIES Final Report (Rockwell International Corp., Downey, Calif.) 268 p HC A12/MF A01

N78-25108

Unclas
G3/12 21610

SD 78-AP-0055-2

Space Industrialization

Final Report

Volume 2. Space Industrialization Background, Needs, and Opportunities

April 14, 1978

Contract NAS8-32198

Rockwell International
Space Division

Rockwell International
Space Division

FOREWORD

This $190,000 Space Industrialization study was performed under NASA Contract NAS8-32198 for Marshall Space Flight Center from September 1976 through April 1978. The study was in two parts: Part 1 identified the potential goals for space industrialization and developed and assessed evolutionary program options for realization of those goals; Part 2 defined program support demands, evaluated and defined the leading program options, and developed recommendations for program implementation. The study results are documented in four volumes:

1. Executive Summary
2. Space Industrialization Background, Needs, and Opportunities
3. Space Industrialization Implementation Concepts
4. Appendixes

The Rockwell study manager was Mr. C.L. Gould. Other key Rockwell participants were A.D. Kazanowski and T.S. Logsdon. Additional support was provided by D.B. Anderson, C.R. Gerber, and T.A. Sackinger. Many others helped in various ways. They included the following key consultants:

- Dr. Krafft Ehricke
  Space Global, La Jolla, CA
- Dr. Reed Powell
  California Polytechnic University,
  Pomona, CA
- Dr. Charles Cheeseman
  General Electric,
  Valley Forge, PA
- Dr. Ernst Stuhlinger
  University of Alabama,
  Huntsville, AL
- Dr. Gerard O'Neill
  Princeton University, Princeton, NJ
- Dr. Delbert Smith, J.D., Space Law
  Madison, WI
- Dr. Kerry Joels
  NASA/Ames Research Center, CA

The study was performed under the technical direction of C.C. Priest, Marshall Space Flight Center. Mr. J. von Puttkamer was the overall program manager at NASA Headquarters, Office of Space Transportation Systems. Major contributions were also made at special working group meetings by the following:

- Andrew Adelman
  IBM
- Dr. Bertrand Chatel
  United Nations
- Debbie Donahue
  President, Student Chapter of AIAA,
  University of California at Irvine
- Bonnie Dunbar
  Rockwell International
- Fredrick Durant III
  Smithsonian Institution,
  Air and Space Museum
- Clarence Hill
  Rockwell International
- Barbara Marx Hubbard
  Committee for the Future,
  Washington, D.C.
- Walter Morgan
  Comsat Corporation

Inquiries regarding the study should be addressed to the following:

- Claude C. (Pete) Priest
  NASA-Marshall Space Flight Center
  Attention: PS04
  Huntsville, AL 35812
  Telephone: (205) 453-2796
- C. L. (Chuck) Gould
  Rockwell International
  12214 Lakewood Boulevard
  Downey, CA 90241
  Telephone: (213) 594-3560

CONTENTS

	Page
INTRODUCTION	1
BACKGROUND SCENARIO	3
Fundamental Considerations	3
Three Basic Scenarios	5
Scenario Assessment	13
NEEDS SUMMARY	47
SPACE OPPORTUNITIES - SERVICES	49
Information Transmission Opportunities	51
Data Acquisition Opportunities	107
Terrestrial Alternatives	135
Bibliography	158
SPACE OPPORTUNITIES - PRODUCTS	161
Introduction	161
Space Processing of Organic Materials	161
Space Processing of Inorganic Materials	174
References	199
SPACE OPPORTUNITIES - ENERGY	201
Space Light	201
Lunetta	202
Soletta	216
Space Fusion Power	231
The SPS	235
References	254
SPACE OPPORTUNITIES - HUMAN ACTIVITIES	257
Therapeutic and Recreational Possibilities	257
Science-Intensive Space Activities	259

PRECEDING PAGE BLANK NOT FILMED

ILLUSTRATIONS

Figure		Page
1	Background Scenario: State Parameters	4
2	Open World Growth	12
3	Critical Period in World Demographic Scenario	20
4	Profiles of Population Change Determinants (Schematic)	23
5	Profiles of Population Changes (Schematic)	24
6	Population Scenario - Ranges of Population Changes, 1975-2000	26
7	Illustrative Example of an Extraterrestrial Demographic Projection	29
8	Grain Production Potential	42
9	Land Food Production - Investment and Value Increase Potential	43
10	Information Transmission - Anchor Opportunities	50
11	American Educational Attainments	52
12	Earnings Versus Educational Attainments	54
13	Electronic Education: Cost Parameters	55
14	Broadcast Education - LCD's	57
15	Electronic Education in the Underdeveloped Countries	58
16	Electronic Telecommuting	64
17	Electronic Telecommuting: A Practical Experiment	66
18	Savings Through Improved Communications	68
19	Electronic Telecommuting	69
20	Current Personal Communications Activity	73
21	Personal Communications Systems	74
22	National Information Services	78
23	Electronic Mail	81
24	Mail Delivery Methods	82
25	American Health Care Statistics: Annual Expenditures	96
26	The Causes of Death	97
27	Public Health Care Delivery	98
28	Public Health Care Delivery	101
29	Offshore Limit Monitor	105
30	Data Acquisition	108
31	Ocean Resources and Dynamics System	112
32	Earth Observation Complexity Inversion	114
33	Resource Depletion	120
34	Potential Exhaustion of Selected Materials	122
35	Geologic Clues to Mineral Location	123
36	Sensitivity of Diagnostic Computer System Annual Unit Cost to Number of Installations	156
37	Electrophoretic Separation of Urokinase-Producing Kidney Cells	165
38	Biological Processes Facility Equipment Organization	166
39	Anatomy of the Renal System	168

PRECEDING PAGE BLANK NOT FILMED

Figure		Page
40	Electrophoresis Concepts and Parameters	170
41	Polycrystalline Rod Being Transformed (by Localized RF Heating) into Single Crystal (Floating Zone Method)	176
42	Sensor/Computer Trace of Silicon Crystal Doped With Boron	180
43	Development of Spiral Step Produced by Intersection of Screw Dislocation With Surface of Crystal	183
44	Growth Pattern From Single Dislocation on Single Crystal of Paraffin η-$C_{36}H_{74}$	183
45	An Edge Dislocation EF in the Glide Plane ABCD	184
46	Structure of an Edge Dislocation	184
47	A Dislocation in a Two-Dimensional Bubble Raft	185
48	Potential Beneficiaries From Space Production of Silicon Crystals for Medical and Electric Power Application	189
49	Image Diameter Versus Reflector Distance From Image	202
50	Lighting Levels and Lunetta Sizes	203
51	Lunetta Performance in Perspective	203
52	Lunetta Applications	204
53	Average Cloudiness	206
54	Multi-Track Lunetta Illumination Mode	208
55	Three-Dimensional View of Three-Track Mode	208
56	Example: Illumination of Boswash Megalopolis	209
57	Lunetta Illumination Pattern: New York	210
58	Effect of High Limiting Elevation Angles on Lunetta Illumination Pattern and Applicability to Multi-City Lighting	211
59	Clear Night Illumination Profiles for Three American Cities	212
60	Effect of Limiting Elevation on Lunetta Capacity to Serve Several Cities Within a Longitude Band of 25 to 45 Degrees	213
61	Sample Cost Breakdown of Shuttle-Compatible Lunetta System in Sun-Synchronous 3-Hour Orbit	214
62	Geometry of Focal Area Reduction of Reflectors in Circular Orbits	216
63	Use of Retro-Reflection for Powersoletta to Enhance Daytime Power Generation	218
64	Soletta Power Stations for Western Europe, U.S.S.R. and North America	219
65	Solar and Powersoletta Overall Energy Input at Three Locations	220
66	Characteristics Data of Three-Hour Orbit Powersoletta System	222
67	Marine Life Productivity Areas	223
68	Biosoletta Orbit for Seafood Production	224
69	Biosoletta - Oceanic Food Production	228
70	Comparison of Three Transportation Alternatives for Biosoletta	229
71	Powersoletta System Cost Distribution	232
72	Electric Energy of Powersoletta System (Sun-Synchronous 3-Hour Orbit)	232

Figure		Page
73	Central Importance of Controlled Fusion for Space Industries	233
74	The Solar Satellite Power System Concept	236
75	Initial Concepts Matrix	237
76	Concepts Selected for Trade Studies	238
77	Solar Photovoltaic System Characteristics	238
78	Advantages of GaAlAs Solar Cells	240
79	Selection of Flight Conditions	241
80	Solar Thermal Major Trade Areas	242
81	Solar Thermal System Characteristics	243
82	Microwave Radiation Problem Areas and Approaches	245
83	MWPTS Cost Trades Comparison	245
84	Stripline Rectenna Module (High-Density Area)	246
85	GEO Satellite Construction Scenario	247
86	LEO-GEO Satellite Construction Scenario	248
87	Photovoltaic Point Design Evolution	248
88	Comparison of Transportation System Options	251
89	Therapeutic and Recreational Activities in Space	258
90	Science-Intensive Space Activities Serving Basic Terrestrial Needs	260

TABLES

Table		Page
1	Input Parameters	14
2	Global Effects Monitoring Funding Schedule	147
3	Crop Measurement Program Funding	151
4	Powersoletta Characteristic Data for Several Orbits and Limiting Elevations	217
5	Cost Differences for Geosynchronous and Combined-Altitude Construction	249
6	Additional Trade Study Results	250
7	Transportation System Options	252

PRECEDING PAGE BLANK NOT FILMED

INTRODUCTION

This volume of the *Space Industrialization* study deals mostly with the preliminary background material that was gathered to lay the foundation for the subsequent hardware studies. Thus, in general, the material deals with three separate topics:

1. The Background Scenario
2. The Needs of Man
3. Space Opportunities

The Background Scenario is essentially a summary of the status of the family of man at this point in time. It also includes reasonable extrapolations to indicate the probable status of the world in future years. Population level, minerals, food, fuels, public safety and education are all given careful consideration. So are the various projections devised by computer simulations and other means. The fundamental conclusion is that the status of man is not as bleak as many have supposed, but that grossly increased personal prosperity and societal stability can be attained via the systematic industrialization of the space frontier.

The needs of man were derived from careful readings of the Background Scenario and other published materials. These needs were, at first, compiled in an unstructured manner, but later they were grouped into five relatively broad categories. The primary aim of this grouping was to stimulate further ideas and more rational evaluations.

The Needs Lists were used to trigger ideas on any attractive new space opportunities. At this point in the study an *opportunity* was defined as any technologically viable enterprise that promised to fulfill an identifiable need. Later in Part 2, the various opportunities were to be subjected to a series of filters. The purpose of this filtering process was to eliminate any apparent opportunity that was not actually viable for a number of reasons. These included excessive cost, societal impacts that were too small to be worthy of the required effort, and the existence of terrestrial alternatives that were more practical and attractive than other proposed solutions in space.

BACKGROUND SCENARIO

1. Fundamental Considerations
2. Three Basic Scenarios
3. Scenario Assessment

BACKGROUND SCENARIO

Planning is management of the future. Unfortunately, the real future is a function of innumerable rational and irrational factors — too many to be considered in any practical forecasting method. Any practical projection that is made, therefore, must be derived from a selection of key factors. These factors are referred to as *determinants*, and their effect on key manifestations — or *state variables* serve as descriptors of future conditions. Different state variables are of particular importance to different regions of the world, but many are of comparable importance. It is possible to identify a network of state variables of reasonably general validity. Such a network is presented in Figure 1.

FUNDAMENTAL CONSIDERATIONS

The four primary state variables that were taken into account in this study are population, energy, production and living standard. Everything, including military strength, can be traced back to one or more of these four state parameters. These primary state parameters are interconnected by a set of communicating tubes through which dedicated resources are transferred. Directly or indirectly, resources are dedicated to meeting investment requirements. Since the sum of all desirable investments almost always exceeds the store of available resources, not enough resources can be dedicated. Therefore, priorities must be set.

Ideally, the individuals who set these priorities should balance near-term needs against long-term objectives. Unfortunately, this is rarely achieved in practice because it requires an astute sense of proportion, of balance and perspective. Planning is as much an art as a science.

Population

Birth and death rates obviously have a crucial influence on a country's population trends. But births and deaths do not occur in a vacuum. They are influenced by life styles based on traditions, on scientific developments, on socio-economic conditions, on wars, revolutions and on socio-political conditions. In highly industrialized countries, low birth rates have been induced by the particular socio-economic climate of the industrial life style. In the non-communist developing world, population climbs rapidly because of particular improvements transplanted from western achievements, but not integrated into the developing socio-economic framework, such as reduced maternal and infant mortality and increased average life span. In communist countries, birth rates are low by state fiat or resignation of the population.

Production and Energy

Determinants influencing production levels and energy parameters are social discipline, a degree of work ethic human development, and, of course, available capital. If these favorable factors are present, resources can be

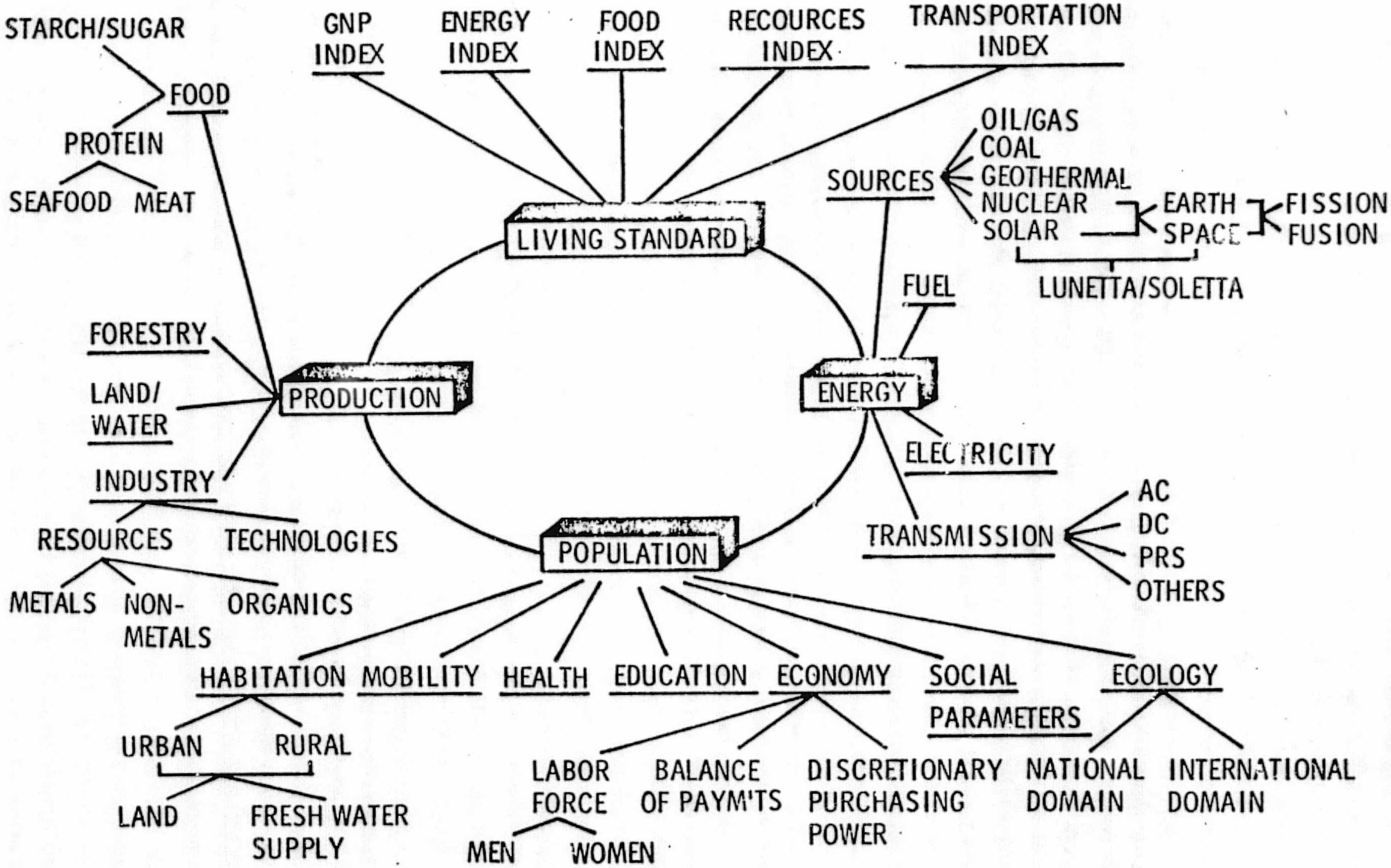


Figure 1. Background Scenario: State Parameters

developed or acquired, except in cases where the paucity of resources offers no starting base at all. This, however, is practically never the case. For example, the *Fourth World Countries* of the sub-Sahara region may seem to lack a resource base but, in fact, they own vast resources of solar energy; similarly, many of the poorly fed countries on the African continent have millions of acres of unused farmland.

For global development, steps need to be taken to improve the marketability of these resources. However, the envisioned improvements may conflict with the other goals of the western world. For example, developing the solar energy in the Sahara may conflict with America's stated goals for energy independence.

Living Standard

The living standard of a particular country is strongly impacted by population, production, and energy, but it transcends these and has an essence of its own. A large population, *per se*, cannot be construed as being unequivocally detrimental to a high living standard. Determinants (often subjective) associated with the quality of life often exert a far more important impact on the living standard.

The physical location of the people in a particular country has an important impact on the quality of their lives. One way they express this is through the continuing migration from rural areas into metropolitan areas which is largely driven by desires for the higher standard-of-living found in metropolitan areas. In these urban areas a diversity of sporting, cultural and service opportunities exist that require a relatively large and dense population for their economic feasibility.

THREE BASIC SCENARIOS

In the past 10 years, three basic scenarios for the future have been devised. Two of these remain within the conventional framework of earth as the only available *world* to man. The third was based on the assumption of an expanding *world* beyond the limits of earth, beginning in the last quarter of this century. The terrestrial scenarios entail many variants. But the two boundary cases are represented by the pessimistic assessment provided by the Club of Rome (Forrester-Meadows), and the Hudson Institute (Kahn, et al.)

The Club Of Rome Scenario

The Club of Rome approach examined five basic factors: population increase, agricultural production, non-renewable resources depletion, industrial output, and pollution generation. The authors asserted that these five factors alone determine and, in their aggregate eventually limit, growth on this planet. These variables were fed into a computer model under different sets of assumptions, all resulting in gloomy predictions offering a choice of disasters from which to perish. Even the so-called *message of hope* in the Limits To Growth study consisted of a classic violation of human nature — the recommendation that world leaders should distribute future scarcities, to live in happy docility on the reservation earth, to submit to carefully regulated statism and to surrender the human birthright of exercising new options and surpress mankind's innate growth potential.

It is interesting that the first two of the above five factors (population increase and agricultural production) were the basis of Malthuse's concern. Moreoever, his conclusions were roughly as gloomy as those envisioned by the Club Of Rome and his *solutions* for avoiding the ultimate catastrophe similarly unrealistic, even bizarre.

In the Limits To Growth study, no substantiation is offered for the assertion that the five selected factors are indeed the basic determinants. In particular, the power of human ingenuity and resolve is omitted from the list. Thus, the five non-human factors fed into the computer developed a life of their own, unrelated to human reactions. The eventual result was that man was locked into a vise between destruction and submission.

The Hudson Institute (The Next 200 Years) Scenario

In the Hudson Institute approach, two perspectives of the future were developed. The first assumed that over the next 200 years the major activities would be earth-centered, and that extraterrestrial activity will be limited to modest levels of space exploitation. The second perspective was space-oriented. It assumed a high level of extraterrestrial activity, including the establishment of large space colonies involved in manufacturing and energy production. The book repeatedly challenges the Club of Rome hypothesis that mankind has no alternatives to either limits to growth or eventual catastrophe.

The Hudson Institute authors are convinced that the terrestrial resources are sufficient to meet the requirements of both a growing world population up to stationary level and the associated expected economic growth. They countered those who warn of the consequences of population explosion with the proposition that the rapid growth is in its final stage. They reject, in effect, the notion that mankind's present situation on the globe equals that of a large rat population crowded into a small cage. From this they draw an optimistic outlook concerning rationality — by and large — in Man's future social behavior.

Ehricke-Miller (The Extraterrestrial Imperative Scenario)

The third scenario, The Extraterrestrial Imperative, transcends the conventional terrestrial environment to include a progressively wider range of extraterrestrial environments. Mankind's future for the next hundred years is carefully analyzed and it is asserted that, for reasons associated with basic physical principles, life on a small (terrestrial) planet must resort to an extraterrestrial energy source in order to survive.

A book entitled *The Extraterrestrial Imperative* by K. A. Ehricke and E. A. Miller presents new insights in evolutionary processes of life and extrapolates these insights to space developments. The time span selected for the scenario was 1970 to 2070. Three fundamental anchor points were selected: Man, Earth and Space.

Man

Man represents a life form with new metabolic capability — information metabolism — enabling him to interact more strongly with the environment than photosynthesis, and as directly as photosynthesis with primordial matter and energy (in contrast to oxygen metabolism).

In the view of the authors, new metabolic capabilities always foster a new technological capability plateau. Since living matter evolves negentropically.* A new metabolism means greater concentration of information and energy, greater complexity and superior material-processing capabilities. Through the new and different abilities and methods of interacting with the environment, the rise of a new metabolism disturbs the previously established equilibrium between environment and preceding metabolic activities. The elasticity of the old system is capable of tollerating an incubation period; but thereafter the impact of the expanding disturbance provokes a confrontation which can be overcome only by environmental expansion and the establishment of a new equilibrium.

Earth

Relative to earth, man today plays the evolutionary role occupied some three billion years ago by the early photochemical autotrophs and their successor, the chlorophyll molecule. At that time, chemical energy was replaced by solar energy as primary energy source for living beings. The result was more complex biological processes which produced the inorganic waste products that destroyed the early life-generating atmosphere and replaced it with the oxygen atomsphere known and cherished by Man. Confinement of the bio-population to earth made material recycling an absolute necessity. This contributed to the destruction of the earlier environment and necessitated the development of a secondary technology based on *waste* (oxygen metabolism), which furthermore stimulated the expansion of life into new terrestrial realms.

Thus, an infinite energy environment and a quasi-infinite material environment were generated. These two infinities constitute an Open World. Both are indispensible for a work-performing system (such as life), because such system must be an open system to function and be stable within the requirements of the *Second Law of Thermodynamics*.

The authors of *The Extraterrestrial Imperative* have analyzed the fundamental characteristics and metabolic correlations of the Open World. The pre-photosynthetic world of earth was not open and, therefore, could not last if life was to endure. The biosphere is an Open World, in equilibrium with the greater primordial environment. Once Open World equilibrium is reached by a metabolism capable of interacting directly with primordial matter, the population of the particular open system must — and, indeed, does — cease to grow.

Space

The Open World of Man, called *Androsphere* by the authors, meets the above-mentioned requirements. In contrast to biotechnology, information metabolic technology is capable of expanding into space environments. Thereby, one of the most important prerequisites for Open World development can be met. Moreover, by following the extraterrestrial imperative, a fundamental threat to the biosphere can be removed. The biospheric environment need not share the fate of the first environment. To the contrary, the *Androsphere* will surround the biosphere and not only protect it, but distribute its seeds throughout space.

*In the direction of negative or decreasing enthophy — greater order and increasing contrast to inanimate matter whose entrophy increases — increasing disorder and energy distribution.

Information metabolism is capable of interacting directly with primordial resources (matter and energy) on a much wider basis than photosynthesis. Man's information processing capability far exceeds that of earlier metabolic technologies. Primarily for these two reasons, extraterrestrial environments can be made productively useful. This is the truly novel aspect of the information metabolic revolution. The need to interact with primordial matter and energy — both indispensible for establishing Open World equilibrium — can be met without affecting the biosphere at all.

Years before the Club Of Rome publications, the authors recognized the threat posed by different possible forms of disaster. All of these are merely different forms of entropy death.* But in the evolutionary context of the extraterrestrial imperative and its underlying physical laws, the logic of, and confidence in disaster makes their avoidance become quite apparent.

To avoid disaster it is not necessary to stop everything on earth and exit into space *en masse*. The process of turning space into a productive asset will be a gradual one, but the authors postulate that it will have reached giant proportions by 2070, progressively accelerating on the basis of its preceding successes.

The authors devoted considerable attention to demonstrating that not only mankind, but also the biospheric environment would suffer grievously if techno-scientific progress and its translation into industrial productivity would cease to be pursued vigorously, since mankind has grown too large to *feed* on the biosphere in pre-industrial fashion. In such fashion, the biosphere could sustain not much more than about one billion people, roughly the world population at the dawn of the industrial revolution.

Information metabolism is capable of technologies whose applications and continued advances can vastly improve human productivity, but which can be applied safely on a large scale only outside the confines of the biosphere and of a heavily populated earth.

The key technologies are: fusion and the application of processed fusion energy to mobility, to the processing of primordial materials for industrial purposes, and to the creation and sustanance of exobiospheres.

Space conditions facilitate the attainment of steady-state fusion in several respects. Specifically, space provides capabilities for very large volume high-vacuum enclosures which would be virtually unattainable on earth. It also provides favorable conditions for superconductor technology; and the application of very strong magnetic fields using special space-manufactured alloys for maintaining superconductivity at high current densities.

*For example, if we take the low-entropy product of biological industries, oil and coal, and turn them into a maximum entropy mixture of atmospheric gases and heat in which we perish, then this is a form of entropy death. If, on the other hand, we sustain low-entropy conditions in the atmosphere after combustion or avoid burning by nuclear, solar, etc., power or by spending energy outside the biosphere then we are compatible with the *Entropy Law*.

Fusion is a cheaper and more versatile energy source than solar energy for a number reasons. It is more compact; it is independent of eclipses and solar distance; it can be installed above or below a surface; it is a more effective means of propulsion; it offers a greater variety of energy forms; it is the only energy source that can provide economically the strong magnetic fields required to shield exposed human settlements against most particle radiation.

The book assumes that fusion will replace solar energy as principal energy source between 1995 and 2010. Thereafter, the value of goods produced in space will climb rapidly because of greater possibilities and superior economy.

As a second key factor, the authors considered the proximity of the Moon as a material resource base. Goods and materials can and will be transported into space from earth. But the prospect for benign advancements (as distinct from technological advancements such as increased I_{sp}) are very limited for launch vehicles. Hydrogen powered or even gaseous core reactor powered air-breathers generate polluting nitrous oxides. O_2/H_2 drives inject water into the presently dry outer atmosphere. And all conventional space drives release large amounts of thermal energy, especially into the lower atmosphere with doubtful ecological consequences. The Saturn V was a highly efficient carrier (because it was large and expendable which permitted a very low mass fraction). However, it injected about 41,000 thermal kwh (kwht) into the troposphere per ton of payload into low orbit.* For the space Shuttle, this value is over 100,000 kwht/ton payload. Even for large aerospace freighters of 1,000 to 2,000 tons payload, the demand for reusability is likely to preclude figures below 40,000 kwht/ton. Transportation of lunar products to earth involves no significant burden in terms of material injection or ecologically relevant thermal burden. The bulk of the energy is dissipated between 200,000 and 100,000 feet.

Thus, metals and metal products can be delivered to earth orbit from the lunar domain with virtually no detrimental effects. Space structures and facilities can be supplied from the Moon with no effect on the biosphere. Lunar oxygen also can be made available to aerospace freighter stages returning to low orbit from geosynchronous or circumlunar orbits at great savings in propellant and energy released into the atmosphere because the oxygen does not have to be lifted from earth.

For these reasons, the Moon is expected to become a major materials supplier both to earth and space installations. Growing amounts of energy will be dissipated outside the biosphere on the Moon. The small amounts of fuel for fusion (about five tons per Gwe-year) can readily be supplied from earth, until delivery from Mars becomes practical.

Comparison of the Three Scenarios

In its terrestrial optimism, *The Extraterrestrial Imperative* far exceeds the conclusions of the Club Of Rome's original scenario (which, meanwhile, has

*Ehricke, K. A., Philosophy and Outline Of Long-Range Space Planning For The Needs Of This Nation and Mankind. Presentation before the NASA Deputy Associate Administrator (Planning), Dr. W. von Braun. North American Rockwell (now Rockwell International) Report PO 71-16 (July 1971), pp. 122-123.

been revised considerably in a more optimistic direction). The terrestrial outlook is not as optimistic, however, as that offered later in *The Next 200 Years*, for several compelling reasons.

Moreover, a terrestrial solution does not alleviate the need for Man to establish an Open World. Restoration of compatibility with the *Second Law Of Thermodynamics* cannot be avoided. Because of size and conditions of the terrestrial environment, the open energy flux (which determines the ultimate living standard) is necessarily restricted to a lower level than in a larger *Androsphere* that includes extraterrestrial environments. A terrestrial solution leaves no alternative to the exploitation of ever-poorer mineral grades at a rising energy burden compounded by further rising energy burdens to avoid increases in environmental pollution. The exploitation of poorer minerals is unavoidable because recycling alone cannot meet the demands of a growing population.

Obviously, the gap between rich and poor will not narrow if only terrestrial resources are used. Decline of living standards in developed countries and frustration in the developing world over the seemingly unalterable confinement to steerage both can grow intolerable because of loss of hope that things will change for the better. Grace periods, meanwhile, have been squandered away and the neglect to invest in new options — a neglect that cannot be remedied overnight — can be very costly. An option-poor polluted future suddenly can become a bitter presence.

Consequently, there is little reason to assume that the second phase will be peaceful and cooperative. If confinement to steerage is not to be a permanent condition, the need to coordinate its particular weapons will bring developing world nations closer together. The weapons against the first class passengers on space ship earth will be combinations of expropriations and trade block trade formations with a strong dose of defensive policies, greater shares in the processing, transportation, and marketing of raw materials, enlarged territorial seas with attendent neutralization of strategic straits and gulfs and similar measures not conductive to a free world trade that the industrialized nations need.

With the exception of some extreme scenarios of little significance, an optimistic technological and benign industrial implementation strategy can be applied (with terrestrial limits); indeed, many problems can be reduced or eliminated. However, the optimistic line necessarily presumes certain idealizations, especially in the socio-behavioral sector which, in turn, introduces a disquieting sensitivity of the scenario to whether certain critical assumptions actually will be realized.

On the other hand, the prospects for attaining the key goals can be improved by introducing the potential of the extraterrestrial imperative. In addition, they can be *desensitized* (i.e., made more *forgiving*) in the case of failure of an optimistic terrestrial expectation to materialize.

The final argument, then, for the extraterrestrial imperative is a very practical one: Extraterrestrial environments are productively accessible environments. They do offer significant improvements to every terrestrial scenario, many needed improvements for optimistic forecasts in the terrestrial sector possible in the first place. This being so, why should one not utilize them? Why should one substitute all-out terrestrial optimism for more solid ground of less optimism, but more options in the Open World of earth and space?

Why Industrialize Space?

The authors found the question *"Why Not Space?"* far more difficult to answer than the question *"Why Space?"* Of course, not any space activity will do. The need for a rational strategy of space industrialization is discussed beginning with early, appealing achievements in the 1980's focusing on projects of value to both industrialized and developing countries, and emphasizing intensive research in space fusion as the key to truly large-scale industrialization in space.

The socio-political conditions for the next 100 years are projected on the basis that, on earth, nation-states and governments will remain a principal fact of international life. However, it is considered possible that major projects (as would be undertaken in utilization of oceanic resources, in earth orbit, and on the Moon) are at least based on international agreements, if not international participation.

The Results Of Space Industrialization

Figure 2 depicts some key state parameters of a 2070 global scenario considered attainable, by the authors, as a result of Open World development with extraterrestrial fusion power being introduced in various capacities on a large scale. Comparative data are presented for 1900 and 1970.

The industrially utilized *Androsphere* comprises the Moon, Mars, and the asteroids, except some in the upper regime of orbital energies. The world population numbers between 11- and 12-billion. The population doubling time has risen from the 1970 values of about 25 years (2.8 percent annual growth rate) for the then developing countries and 45 years (1.5 percent) for the then industrialized countries to a fairly narrow range around 160 years (0.43 percent) corresponding to the estimated value in 1750, shortly before the industrial revolution.

With 9.5 billion, the *"Haves"* amount to some 80 percent of the world population. Extraterrestrial operations have greatly broadened the global middle class through need for scientists, engineers, technicians, and much skilled labor, as well as new businesses and the stimulation of trade through the influx of extraterrestrial products and services. This compares favorably with about 30 percent *"Haves"* in 1970 and represents a reversal of the trend in our time (1975: western industrial countries [750M] and socialist states without China [250M] amount to 25 percent).

Correspondingly, the minimum average wealth of 2070 lies close to the maximum in 1970 — an average per capita GNP of about $2,000.00* for the then poor countries. The average per capita GNP of then wealthiest countries would be about $3,500.00.* Thus, the gap is significantly reduced compared to the 1970

[1]All values in 1970 dollars. At an average annual inflation rate of 2 percent, the 2070 value would be roughly seven times higher.

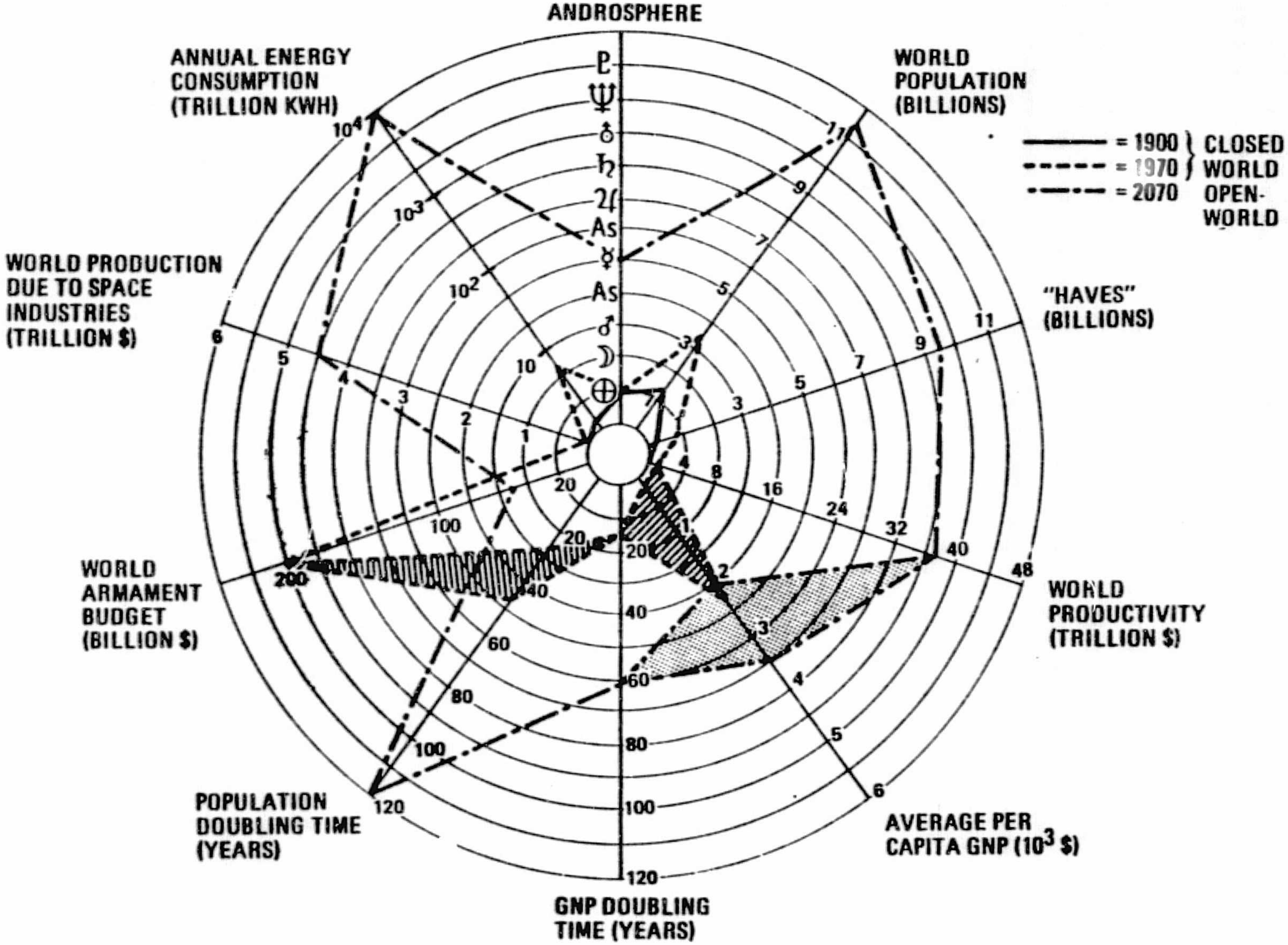


Figure 2. Open World Growth

situation ($50.00 to $2,900.00). The per capita values for 2070 represent an enormous increase in global wealth, a rise in annual world productivity (from about $1.5 trillion in 1970 to $37 trillion in 2070) will occur. The value of world production due to space industries could conservatively be $4.5 trillion. While this is *only* 12 percent of the overall *Androspheric* world productivity, it should be noted that at most only 1/1000 to 1/5000 of the world population (5 to 10 million people) are expected to actually be involved in space industrial productivity of goods and services. This implies that the individual productivity in the extraterrestrial sector of the *Androsphere* in between 160 and 600 times as high as the per capita productivity of terrestrials.

From the annual energy consumption, it follows that the world average per capita value has increased by a factor of about 770 (from 0.13 kw-year to 100 kw-year). Over 90 percent of this energy is spent in the form of fusion and solar energy in the extraterrestrial sector: production, heavy load transportation, and high-speed interplanetary mobility. Terrestrial energy consumption is up by a factor of 200, much of it solar energy.

Perhaps the most hopeful corrollary to the above picture is that the world armament budget of 2070 might be reduced to 25 percent of the 1970 value. Since the world population has grown by a factor of about four, this reduction means that the per capita defense burden is lowered to about 6 percent of the 1970 value. This is consistent with the assumed emergence and expansion of a prosperous and enlightened middle class from many nations on all continents of the globe, cooperating in operating the productive and distributive infrastructure of mankind (the human *chlorophyll molecules* of that time). Then, at their productive commercial efforts, underwrite a three-dimensional civilization inner world where there is no practical limit to energy, resources and space to progress; in a world where the inner solar system is interlinked by weeks of travel time and by near instant holographic communication planet-to-planet, and in which the outer solar system awaits incorporation into the *Androsphere*.

In conclusion, the third scenario has two distinct components — the terrestrial and the extraterrestrial. The transition from one basic environment to several environments in the early stages of space industrialization is one of the more critical determinants affecting the real scenario later in the 21st Century.

SCENARIO ASSESSMENT

On the foundations of Figure 1 , a set of inputs can be defined and, for the future scenarios, a number of time derivatives of these inputs. Later they are treated (according to requirements) as dependent, independent, and as discretionary parametric variables.

Methodology

Table 1 lists the relevant input parameters that represent or affect the static parameters shown in Figure 2 . They are organized into ten groups. Each group represents one of the major concentrations of power and influence — demographic, social, socio-economic, technological, etc., and each group is powerful enough to act as an independent determinant. Yet, anyone viewing the

Table 1. Input Parameters

POPULATION	DEMOGRAPHIC (D)	SOCIAL (S)	SOCIO-ECONOMIC (SE)	COMMUNICATION/ MOBILITY (CM)
	D.1 Population Size	S.1 Food Supply (cal/pd)	SE.1 Labor Force	CM.1 Mail
	D.2 Population Density D.1 Area	S.2 Protein Supply (% of S.1)	SE.2 Females of Childbearing Age in Labor Force	CM.2 Voice Communication
	D.3 Urbanization (% of D.1 in Cities > 10^5)	S.3 Habitation (Quality, Light, Energy)	SE.3 Unemployment	CM.3 Video Communication
	D.4 Number of Households (Rural, Urban)	S.4 Public Health Services	SE.4 Per Capita GNP	CM.4 Non-Road Transportation (Train, Ships, Air)
		S.5 Education	SE.5 Income Distribution $\frac{\text{Av. per Capita Income of Bottom 25}}{\text{Av. per Capita Income of Top 10\%}}$	CM.5 Road Transportation (Road Lengths, Buses, Cars)
		S.6 Public Safety		CM.6 Tourism (Into a country, out of a country, into Space)
		S.7 Lifestyle & Cultural Factors		
	D.1^1 Population Projection $\partial D.1/\partial t$	S.1^1 Food Supply Protection ($\partial S.1/\partial t$)	SE.1^1 Projection of Job Requirement ($\partial SE.1/\partial t$)	PROJECTIONS
	D.3^1 Rate of Urbanization $\partial D.3/\partial t$	S.2^1 Protein Supply Projection ($\partial S.2/\partial t$)	SE.2^1 Projection of Females in Work Force ($\partial SE.2/\partial t$)	CM.X^1 = $\partial CM.X/\partial t$
	D.4^1 Number of Households Projection = $\partial D.4/\partial t$	S.3^1 Habitation Projection ($\partial S.3/\partial t$)	SE.4^1 Projected Economic Wealth ($\partial SE.4/\partial t$)	
	D.5^1 Xtraterrestrial Demographic Projection = $\partial D.1X/\partial t$	S.4^1 Public Health Service Projection ($\partial S.4/\partial t$)	SE.5^1 Projected Change in Income Distribution ($\partial SE.5/\partial t$)	
		S.5^1 Education Projection ($\partial S.5/\partial t$)		
		S.6^1 Public Safety Projection ($\partial S.6/\partial t$)		

PRODUCTION & ENERGY	INDUSTRIAL PRODUCTION (IP)	FOOD PRODUCTION (FP)	ENERGY (E)
	IP.1 Material Resources (Metals, Non-Metals, Organics)	FP.1 Land, Water, Climate and Agricultural Production	E.1 Energy Consumption
	IP.2 Extraction Technologies (Earth, Moon)	FP.2 Forestry	E.2 Fossil Sources
	IP.3 Recycling Technologies	FP.3 Aquatic Resources and Fishery Production (Marine and Inland)	E.3 Primordial Sources (Earth, Space)
	IP.4 Substitution Technologies		E.4 New Technologies (Earth, Space)
	IP.5 Material Consumption for Domestic Industries & Exports	FP.1^1 Projected Agricultural Production ($\partial FP.1/\partial t$)	E.5 Economic Factors (Earth, Space)
	IP.6 New Processing Technologies (Earth, Space)	FP.2^1 Projected Wood Production ($\partial FP.2/\partial t$)	E.6 Social and Environment Factors (Earth, Space)
	IP.7 Economic Factors (Earth, Orbits, Moon)	FP.3^1 Projected Fishery Production ($\partial FP.3/\partial t$)	E.7 Political Factors
	IP.8 Social & Environmental Factors		E.8 Fuel Production
	IP.9 Political Factors		E.9 Electric Power Generation
	IP.10 Projected Industrialization (Earth, Orbital, Moon)		E.10 Power Transmission
	IP.5^1 Projected Material Consumption ($\partial IP.5/\partial t$) (Domestic and Exports)		E.1^1 Projected Energy Consumption ($\partial E.1/\partial t$)
			E.8^1 Projected Fuel Consumption ($\partial E.8/\partial t$)
			E.9^1 Projected Power Consumption ($\partial E.9/\partial t$)

POLITICAL/ ECONOMIC/ ENVIRONMENTAL	NATIONAL (N)	INTERNATIONAL (I)	GLOBAL
	N.1 Balance of Payments	I.1 U.S.A.	G.1 Oceans
	N.2 Urban/Rural Development	I.2 Other OECD Countries	G.2 Land
	N.3 Surveillance of Territorial Waters	I.3 U.S.S.R.	G.3 Earthquakes/Volcanic Eruptions
	N.4 Border Surveillance	I.4 China	G.4 Atmosphere
	N.5 Ecology/Environment in the National Domain	I.5 Developing World (Third and Fourth)	G.5 Weather
		I.6 New Economic Power Centers (Trade Centers, Multinational Corporation)	G.6 Climate
		I.7 International and Space Law and Institutions	

ORIGINAL PAGE IS OF POOR QUALITY

present state and future developments needs to keep in mind the interplay between various groups. Mankind's evolution has reached a point where few events on this globe occur completely without human involvement.

Another reason for the grouping, as presented, is that it serves to make the consequences of introducing discretionary parameters more visible. Any major new decision or new development creates a consequence world that is basically different, at least in some respects, from the preceding *world*. This applies equally well to political development, to economic decisions, or technological developments.

Each power and influence group is divided into static and dynamic state parameters. For the sake of simplicity, only the partials with respect to time are listed. Of course, there are other partials and their overall total is very large. It would require a computer program for simultaneous consideration of all transfer functions (partials and even second derivatives), since almost everything depends on almost everything else. Such computer analysis would result in somewhat more deeply understood (and perhaps somewhat more realistic) background scenario projections than the conventional story-teller method. Since a complete treatment exceeds the framework of the present contract, only the interactions considered most relevant are taken into account.

The demographic, social, socio-economic, and communication/mobility groups are self-explanatory. The same is true of the productive infrastructure. The national inputs are based on the assumption that sovereign states are a fact of life that will not change significantly in the relevant projection period.

While all the before-mentioned groups contain intrinsic uncertainties as far as future scenarios are concerned, there are some major potential disturbance factors that can be isolated. They are listed in the international and global input groups.

International Interactions

The international group contains elements that represent major agglomerations of power. The actions and interests of the United States are a continuing major determinant in the geopolitical and geo-economic arena. The future expectations of the other Organization for Economic Cooperation and Development (OECD) countries, in general, run parallel to those of the United States for obvious reasons. But, at the end of World War II, few leaders in the United States recognized their future importance as America's allies.

Their need to export, to assure reliable long-term access to foreign raw materials, forces them to pursue an aggressively competitive economic policy. This situation has repeatedly had a divisive effect on their relations to the United States. There is some danger that this trend is magnified as economic and raw material needs inexorably push the United States into a competitive posture on the world market. There are many justifications for the assumption that joint technological ventures can provide the necessary cohesiveness to lessen the danger of deterioration of relations of which the U.S.S.R. would be the main beneficiary. From this follow needs for joint energy development projects, seabed mining development, and joint ventures in space industrialization.

These joint ventures would require great skill and coordination since they must take the competitive free enterprise characteristics of their national economic systems into account.

The *surprise potential* of the U.S.S.R. and China is rooted primarily in their different, hostile ideologies and the primate of these ideologies in their domestic and international policies. But there are important differences between the two countries, affecting their *surprise potential.*

The developing world does not act in unison; but collectively its countries are so much worse off than the industrialized and most communist countries that they constitute a cohesive factor. It is in the interests of the United States and the other OECD countries, which provide about 80 percent of the world's foreign aid for developing countries, to maximize the effectiveness of their aid in terms of economic growth and demographic slowdown, while also developing new markets for their products by enhancing trade relationships. Most of the world trade presently takes place between the industrialized nations. The incentives provided by space industrialization and their terrestrial spin-offs are important for many developing nations.

As long as the specter of secular resource declines dominate the minds of political and economic leaders, the evolving trading system may be seen as characterized by dealings between large concentrations of economic power.

The arena of dynamic sociological and economic change is shifting rapidly to the Pacific Ocean area. There is a heightened sense of regional consciousness. The Pacific Ocean area trade center may span the Pacific from Canada to Australia and from New Zealand to Japan; or it may also involve smaller areas independent of the *grand Pacific design*, such as Association of Southeast Asian Nations (ASEAN). There is also growing self-awareness among South American countries

In each case, the trade areas are vast. They command many resources in large quantities and vast stretches of ocean (if the 200 mile management limit is accepted). They can benefit from a large array of space industrial tools (information transmission, resources satellites, Lunetta, reverse teleoperation from GSO space station — to name only a few).

Finally, the international group contains international and space law and the corresponding institutions. Some of the as yet unresolved legal areas (e.g., remote sensing of earth resources by satellites and international treaty relating to the Moon) are bound to affect space industrialization one way or another.

The Factors That Affect Population Growth

The increase in world population is slowing down to some extent, but too many factors still favor high birth rates. Excessive population growth is almost exclusively a problem in the developing nations. The most important determinants are:

- Standard of Living
- Level of Industrialization
- Health Standards and Mortality
- Urbanization
- Population Density and Religious Beliefs

Standard of Living

Poor and little-educated people all over the world want more children than those that are more highly educated and prosperous. Since poor, uneducated people predominate in many developing countries, birth rates in these regions are high. Moreover, children provide old-age security in developing countries where social security, pensions, and other forms of aid to the elderly are lacking. Thus, it can be concluded that education without economic growth to raise prosperity and provide other forms of old-age security, can have only limited success in curbing birth rates in the underdeveloped world. This means that educational satellites alone can have only limited success, unless supported by other measures designed to raise consumption and living standards.

Level of Industrialization

In the industrializing societies, a growing number of women join the work force. In the United States, a highly industrialized country, 75 percent of couples under 35 years of age consist of earning husband and wife. Naturally with increasing numbers of job-holding wives, the number of births tend to decrease.

Health Standards and Mortality

In developing countries, infant mortality is particularly high. This drives up the birth rates because the poor people of the world breed enough offspring to be assured of male heirs and offspring that will support them in their old age. As improved health standards cut down infant mortality, the birth rate does not automatically follow suit unless accompanied by other developments that depress the birth rate. As a result, the population growth rate shoots up.

Urbanization

Most of the world's poor live in rural areas. More children mean more workers for the land. But the cities lure. Today and in the decades ahead, a large number of people in developing countries will be born in a rural area and then migrate to a city, swelling the ranks of the unemployed and the unemployable. But in the city, even in city slums, the birth rate tends to decline. In this context, large cities have some effect in curbing population growth.

Population Density and Religious Beliefs

Factors affecting both developed and developing countries include population density and the religious beliefs of the local inhabitants. The high population density of Western European nations and Japan influences public attitudes toward smaller families. By contrast, the high population density in India and Indonesia, for example, has not been a birth rate reducing factor so far (Indonesia plans to reduce the growth rate of 25 percent before 2000). On the other hand, undercrowded developed nations (Canada, Australia) and Brazil (on a lower level of economic development) favor an increase in population. Religious persuasions play some role in determining the desired family size, but it is not often a decisive factor.

Population Growth Rates in Various Regions

Among the industrialized nations and those of the communist economic (COMECON) bloc, population growth is slower or even negative in some cases. The process of population slow-down became accelerated in all countries of Europe, North America, and the Soviet Union and its satellites around 1965. The growth rate of the United States population is expected to be 0.8 percent between 1975 and 1995 (corresponding to an increase from 213.6M to 252M), down 0.2 percent from the average growth rate in the decade 1965 to 1975, and even more from earlier periods. In France and the Federal Republic of Germany the birth rates are no longer sufficient to guarantee the continuation of present population size. The Federal Republic of Germany has the lowest birth rate among the major western nations. Based on extensive public opinion polls, the desire for children amounts to an average of 1.8 per family. This is distinctly below the level of 2.2 to 2.5 children per family needed to sustain present population size under German conditions of infant mortality and mean life span, which are similar to those in other highly industrialized countries.

A *Gallup Poll* found that in the United States and Canada, 57 percent of those questioned believe the ideal number of children to be 0, 1, or 2 (i.e., at most barely enough to sustain the present population size). In Western Europe, the figure is 63 percent, suggesting an even slower population growth, if any, in the future. In contrast, while in the United States and Canada 18 percent prefer four or more children (9 percent in Western Europe), 33 percent expressed this preference in South America, 31 percent in the Far East (except Japan: 14 percent) and 79 percent in Africa.

Reading the Trends

It appears the following realistic conclusions can be drawn from the demographic scenario assessment:

1. The population will continue to grow, albeit at a slowing growth rate. But the slowing process is too gradual to prevent at least a tripling of the world population in the next century. The factors supporting growth are lack of higher living standard, lack of industrialization, and lack of education.

2. In pre-industrial times, mortality peaks *skimming off* excess population at fairly regular intervals were the rule. These mortality peaks were caused by starvation, disease, or both. The longer the interval between mortality peaks, the higher the peaks. This cycle was interrupted by the advent of the industrial revolution. Even the worst wars have never been a sufficient substitute for *nature's* corrective methods.

   Today, a natural mortality peak is suppressed by aid in food and medicine. Thus, during the past 150 years the historical interplay between growth and growth correction has ceased to be operative. A period of 150 years is a very long *moratorium.* But the old rule that the longer the moratorium the higher the peak still applies. Thus, with every decade of further population growth, it becomes progressively more important to assure that the moratorium never ends; because even now a *natural* mortality peak would assume fantastic proportions, even by the standards of a nuclear exchange.*

3. Assuming that this moratorium can be sustained, mankind already now is committed to a *level-off* size of about 7.5$\overline{B}$, even assuming that family sizes for zero growth rate in all countries could be achieved immediately. This level-off state would occur around 2030 to 2040. If a worldwide net reproduction rate of 1.0 is reached by 2025, a stable population of 13$\overline{B}$ would be achieved about a century later. The maximum annual increase in world population occurs in this case in the 1985/95 time period and exceeds 100$\overline{M}$ annually. Thereafter, the annual increase will decline slowly to a level around 30$\overline{M}$ annually by 2100 → a value that should be readily absorbed, assuming the moratorium will have continued and the industrial civilization advanced to its higher techno-scientific potentials (see Figure 3).

   The most critical demographic influence is in the period ahead — to about 2020 when the annual population growth should have fallen below 100$\overline{M}$ and new terrestrial and extraterrestrial industrial developments will have reached maturity. If the moratorium can be made to hold through this period, the probability that it can be perpetuated appears to be extremely good.

4. The disparity in population growth will produce a shift in global population composition, aggravating the minority status of the North American-European-Russian-Japanese populations. As the rest of the world industrializes, the combination of manpower, resources, and industrial productivity is bound to produce new economic power centers. The pressure will be especially great on the Japanese-Western European-North American

*Treated in more detail in The Extraterrestrial Imperative by K. A. Ehricke and E. A. Miller.

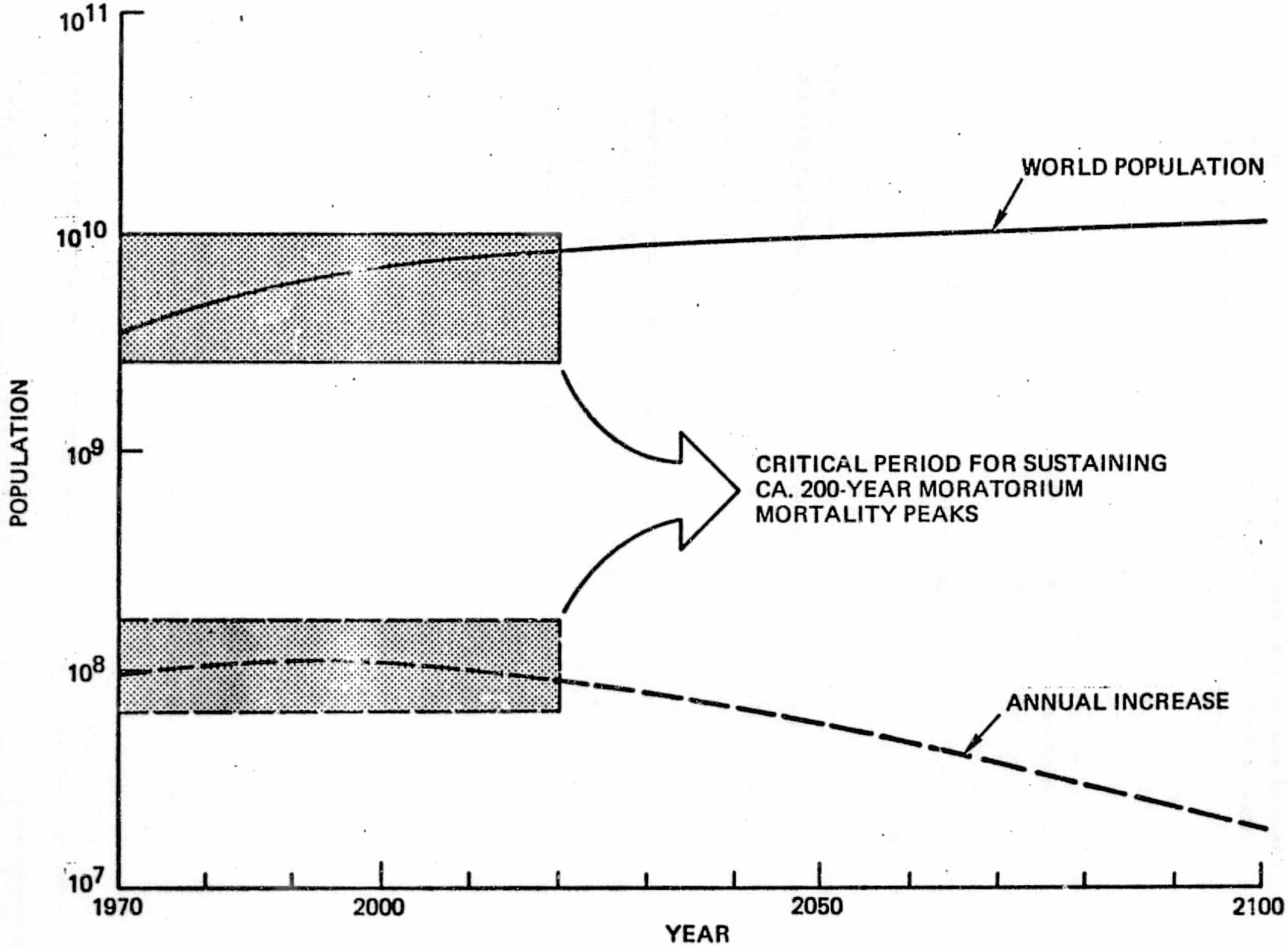


Figure 3 . Critical Period in World Demographic Scenario

populations (in the order of decreasing pressure), since the Soviet Union is fairly self-sufficient, except in food, and since the wealth, technological know-how, *historical guilty conscience* and *softness* appear particularly prevalent in the latter two population groups. But the long biological time constants of demographic changes, which permit somewhat greater freedom of extrapolation than in other areas, suggest that all three population groups will be pushed toward the position of islands that cannot afford to make the sea their enemy. Neo-environmental technologies, fusion energy, and scientific breakthroughs are strong elements of assurance in the future. They must remain — and this is meant in historical context — or regain their position as mankind's leaders in rational conceptualization as well as in science and technology. This requires the revival of consciousness of the grand concepts of Western Civilization which created world history and global civilization and national thought. It furthermore requires to erect on these massive foundations new rational concepts of progress in science and technology, in solving the socio-psychological problems of a new, much larger mankind, and in opening new horizons of creative productivity to meet the requirements of a much more consumption-oriented humanity within the constraints of keeping this <u>the</u> planet of life in this solar system.

5. The fact that the most active parts of mankind are a minority that apparently continues to shrink may also have another consequence. If the present shrinkage of the Federal Republic of Germany continues, the population will be reduced from some 60 million to 20 million in 2076. The French and other Western European populations will have declined also. All of Western Europe may be reduced to some 100 million people by 2100 and, like North America, become underpopulated.

   While this is not very likely, it has clear consequences, should it occur. Western Europe would lose its position as an economic superpower. Its financial basis would shrink. Its capacity to remain a lender in many increasingly capital-intensive areas of research and development would be reduced seriously. A Western North America would become more isolated.

6. It follows, from the timing of the most critical period for holding the moratorium, that no significant break can be expected from any attempts, however successful, to reduce the net birth rate (the birth rate after correction for infant mortality). Reduction in birth rate, therefore, cannot be the <u>first line</u> crisis prevention objective. It has to be food production <u>and</u> trade in different mixes for different countries.

7. Meanwhile, it is important to gradually reduce the birth rate. There is an optimum course; but this course does not coincide with the fastest possible reduction. This becomes clear when analyzing three different types of population reduction — birth rate reduction, *natural* catastrophes and nuclear war.

A change in population has different socio-economic consequences, depending on the type of change, because it affects differently the three main determinants of population composition: birth rate, life expectancy, and infant mortality. Figure 4 shows three distinct examples. Slowing down population growth by industrial life-style evolution involves a decline in birth rate whose effect on population stabilization is delayed by a simultaneous decline in infant mortality and increase in life expectancy, due to improving living standards.

Case (B) illustrates the classical way of reducing excessive populations. It was a regular occurrence in pre-industrial ages. Birth rate and life expectancy decline and infant mortality rises. Following the disaster, the processes are reversed, except that the rise in life expectancy tends to be slow because the disaster leaves behind a *crop* of weak and disabled. The rate of growth after the disaster is lower than before for some time.

Case (C) illustrates the far more devastating effect of a demographically incisive man-made catastrophe — nuclear war.

Figure 5 depicts the change in demographic profile resulting from the changes shown in Figure 4. In Cast (A), birth rate decline first leads to a percentage reduction in the 0 to 20 year age group. Subsequently, the economically active age group of 21 to 64 years declines. The percentage of the generally retired age group above 64 years rises. Thus, a too rapid drive toward zero population growth has undesirable socio-economic consequences. The natural disaster, Case (B), at least leaves behind a healthier and more stable demographic profile, whereas Case (C) creates a heavy economic burden because of a disproportunately high percentage of severely and permantly disabled.

8. Ameliorating the effects of the moritorium is best accomplished by contributing to world food production and trade rather than by direct contributions from space in which communication satellites attempt to educate the public in family planning methods. This is true because effective family planning is seldom successful in the developing world unless the population is to first experience living standard gains.

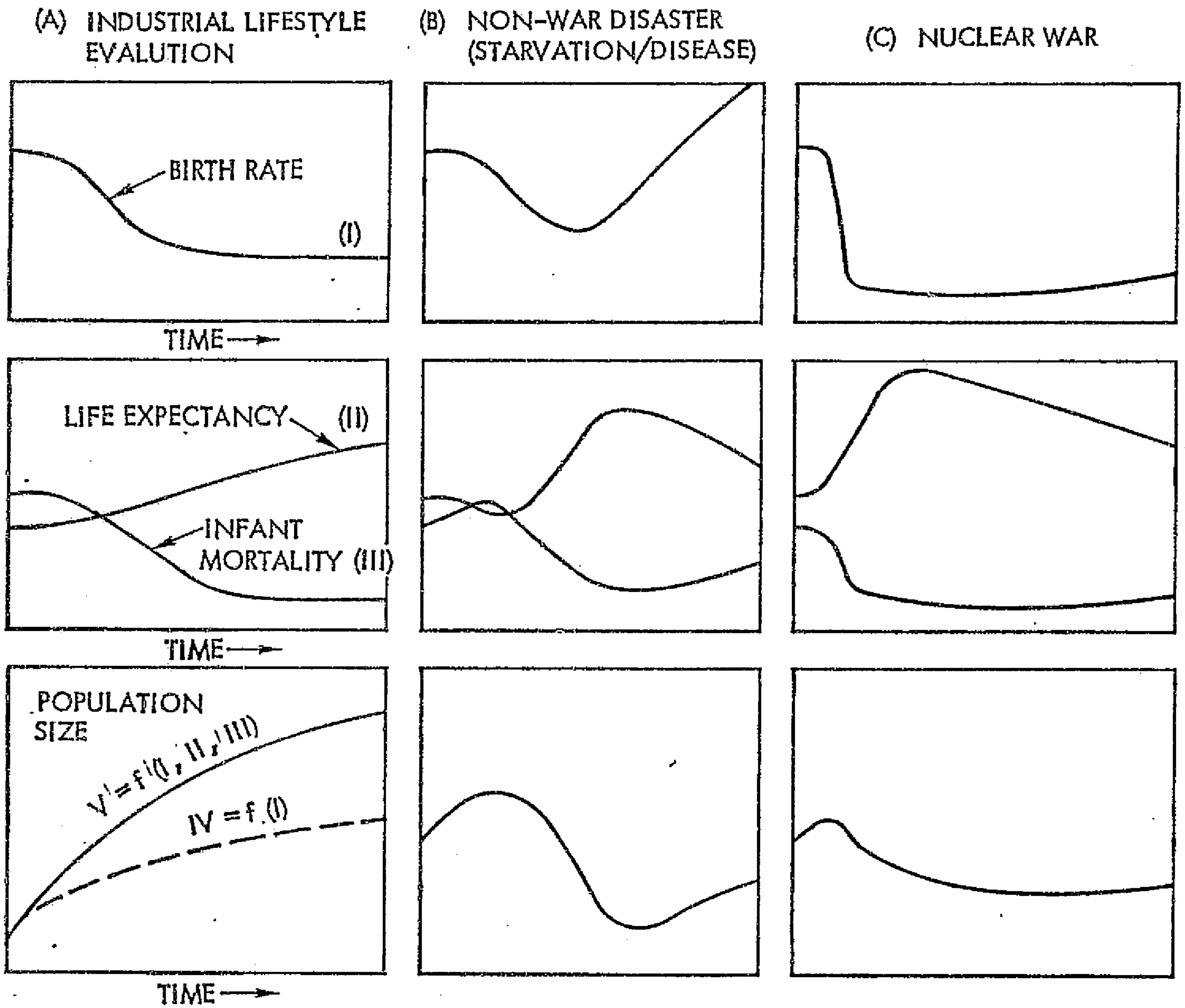


Figure 4 . Profiles of Population Change Determinants (Schematic)

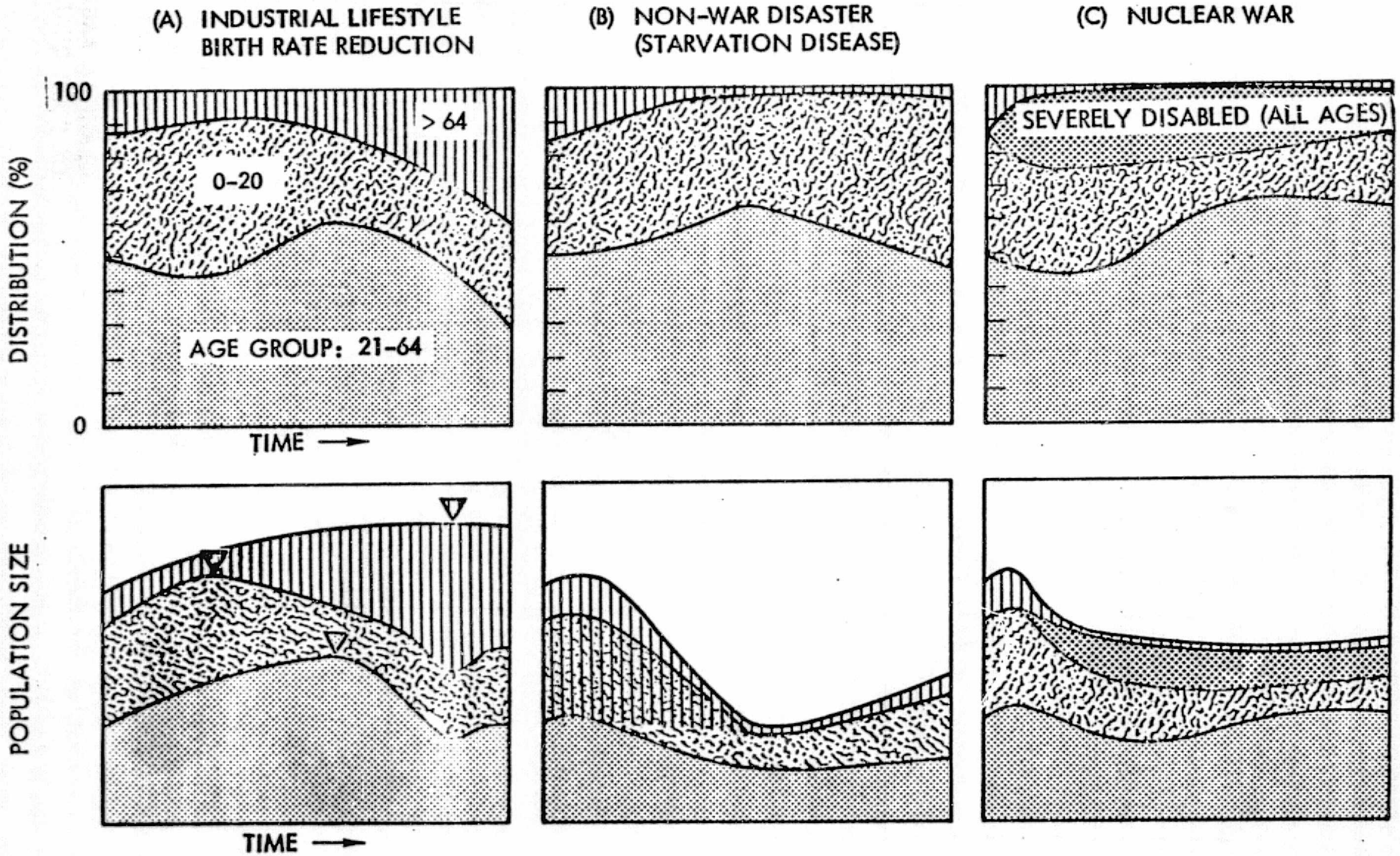


Figure 5 . Profiles of Population Changes (Schematic)

Specific Demographic Projections

Figure 6 depicts four population change rates and their effects during the 1975 to 2010 time period. One extreme case occurred in the Federal Republic of Germany. In 1971, this country began to fall below a net reproduction rate of 1.0 and, hence, its population actually began to decline. The negative growth rate was minus 0.65 percent per year. Other Western European (and Eastern European) nations have change rates around minus 0.4 percent to 0 percent (stationary population).

Indonesia has the highest population growth rate among the largest developing nations (Sudan, Bolivia, Iran, Dominican Republic have higher rates). Indonesia makes a conscientious effort to reduce its growth rate, which, in the 1960's was still about 2.5 percent. The average value between 1975 and 2010 should be in the order of 1.96 percent, higher in 1975 and lower in 2010.

The population growth rate of the United States assumes an intermediate position. Having been 1 percent between 1965 and 1975, the projected growth rate for 1975 to 1995 is 0.83 percent. For the period 1975 to 2010, the growth can be expected to be in the order of 0.63 percent.

In the Soviet Union, the population growth rate declined significantly after 1973 (from 0.92 percent between 1967 and 1973, to 0.55 percent between 1973 and 1976). Apparent causes include high urbanization rates, housing shortage, social strains, and easy *no fault* divorce. If present conditions presist, the average growth rate between 1975 and 2010 will be 0.42 percentage. It is possible that the growth rate will decline further. However, in view of its low population density, the Soviet Union can reasonably be expected to at least maintain present rates of growth.

Europe's population already is close to being stationary. It appears likely that the population of the United States will follow suit in the first half of the next century, or practically so. An average growth rate of 0.63 percent corresponds to a population doubling time of 110 years. A growth rate reduced to, at most, 0.35 percent can be expected around 2025. The ensuing doubling time of 200 years no longer represents a problem.

The Soviet population growth rate may not reach 200 years' doubling time before the end of the 21st Century; and even then, the country will not be densely populated, nor will it suffer from a shortage of important resources.

In the developing world, Africa and South America still are not densely populated, on the average. The problem, especially in Africa, is one of food and resources, particularly energy. Africa's solar energy resources need to be developed. On both continents, average population growth rates are high. Near-stationary demographic conditions on these continents may not be reached until some time in the 22nd Century.

China's population seems to be leveling off. India, Indonesia, the Phillippines, and the Middle East countries also are not likely to reach near-stationary* conditions prior to early in the 22nd Century.

*Meaning $\lesssim$ 0.5 percent (140 years' doubling time).

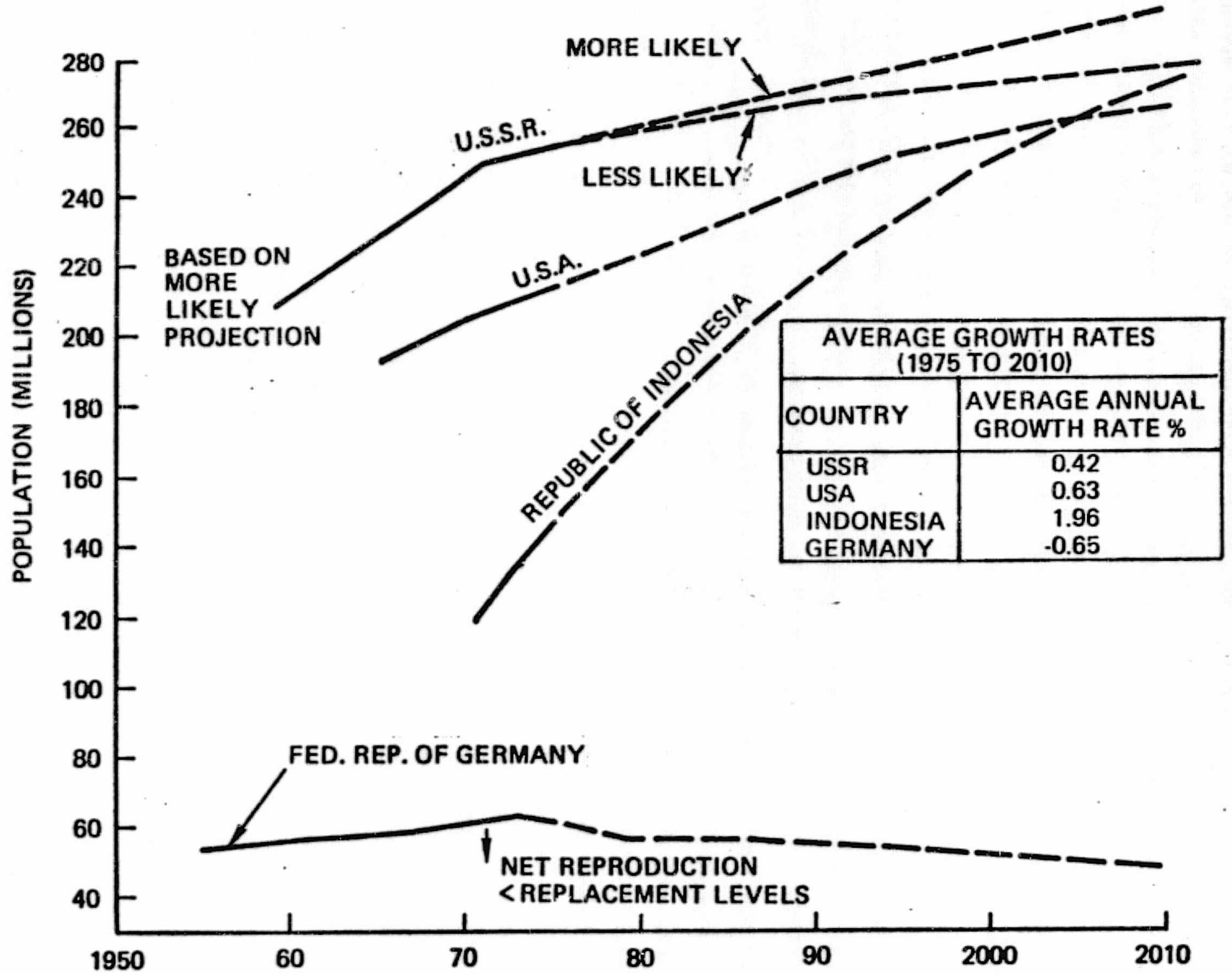


Figure 6. Population Scenario - Ranges of Population Change 1975 - 2010

Trends Toward Urbanization

In the highly industrialized countries of Western Europe and in the United States, a move away from city cores to suburbs and to smaller cities and towns is underway, altering a century-old pattern of nuclear urbanization that saw the rise of the great cities of Europe and North America.

But the process of urbanization as such is not reversed. Rural development has made it possible to find even in smaller towns conveniences and luxuries not available in big cities half a century ago. Thus, the trend toward urbanization appears to continue in different form — sprawling metropolitan areas with local *small town atmospheres*. In the small countries of Western Europe, the gap between rural and urban living conditions most likely will continue to be reduced, giving way to an emulsion of closely intertwined rural, industrial, and *bedroom* zones. These will be interrelated by urban-type services in communication, power, conveniences, and interconnected by high-speed mass transportation, the way suburbs are connected with urban core today in cities such as New York, London, Paris, Berlin, etc. Private residential transportation will be relatively short range, opening a growing market for electric automobiles.

Such a trend means new services, demands cleaner industries, high levels of industrial and agricultural production and an all-around efficient management of environmental resources as well as of waste. Clean and abundant energy is of fundamental importance.

In large Western countries and in the U.S.S.R., cities in climatically and industrially favorable regions are likely to grow and merge into large megaloplitan areas (although there are opposite trends where particularly attractive surroundings may be blocked from free urban expansion, such as around San Diego and certain other Pacific coastal communities). The megalopolitan areas will be separated by large agricultural zones or by quasi-wilderness territories.

In the developing countries of South America, Africa, and much of Asia, the trek into cities, as it took place earlier in the new industrialized nations, continues at a growing rate. Conditions in rural areas are so poor that even city slums become attractive by comparison.

According to a recent United Nations' estimate, 819 million, or 30 percent of the people in developing countries, lived in urban areas of 20,000 inhabitants or more. By the year 2000, the number of urban dwellers is expected to rise to 2200 million. This constitutes an average growth rate of 4 percent per year for 1975 to 2000, and it corresponds to a growth equivalent to 138 metropolises of 10 million people each. In this era, the Indonesian Government expects all of Java to be an *island city* with 146 million being domiciled in Java and Madura. The corresponding population density in density in these islands would be some 1100 per square kilometer, exceeding the most densely populated and urbanized centers of Western Europe.

Extraterrestrial Population Projections

Today the number of personnel living in space for 0.5 percent of their normal life span (70 years) is zero. In the 1980's, the number will begin to climb and longer space habitation intervals will gradually be added (for reasons of economy) consistent with an advancing technology of protection and fitness to return to earth.

The rise of space population will be determined by the space industrial projects pursued and by the average duration of the extraterrestrial *tour of duty*. Measuring this duration in percent of a normal life span, the true factors result in a chart of which Figure 7 is an illustrated example, not a specific extraterrestrial demographic projection. It shows the type of chart which would be associated with space industrial program evolutionary alternatives.

Initially, short periods (on the order of four or five months) will dominate the scene. Because of the cost of frequent personnel turnover, this group will have disappeared before 2000. The 1990's may be dominated by the *one percenters* (about three-quarters year tour of duty). But they too will be short-lived and, in the first decade of the 21st Century, a period of about 3.5 years may be the norm.

The relatively rapid extension of in-space time (from some four months to almost four years in a span of some 20 years) represents an intrinsic increase in per capita productivity for several reasons. Therefore, the number of space personnel need not rise as fast as would be the case in shorter-stay times in space, unless the workload is rising rapidly. However, to be industrially efficient, the supporting equipment designed to enhance the per capita productivity should advance faster than the need for more people.

This situation changes somewhat with the advent of the 10-percenters to 50-percenters. Here, major investments are required. For economic reasons, they should be used by larger numbers of people and it is presumed that this goes hand-in-hand with more tasks in space to provide jobs for these people.* Thus, as the stay time beyond earth rises above ten percent, and eventually reaches 100 percent (complete extraterrestrialization), the extraterrestrial demographic growth rate is likely to increase faster. But that pertains almost certainly to the period following the period of space industrialization proper.*

The Quality of Life

The social scenario deals primarily with basic requirements — food, habitation, health, education, and public safety aspects. Life styles and cultural factors cannot be expressed in quantitative terms, but they can be expressed in terms of attitudes which, in turn, affect the demand elasticity (hence, the price elasticity) thereby representing a method of tying non-economic, non-quantisable factors into the *needs picture*.

Total Food Supply

As was emphasized earlier, the most effective means of encouraging birth rate reductions is to increase the standard of living and to modify traditional

*Astropolis and Androcell — The Psychology and Technology of Space Utilization and Extraterrestrialization by K. A. Ehricke. Paper presented at the International Space Hall of Fame Dedication Conference, Alamagordo, New Mexico (October 1976).

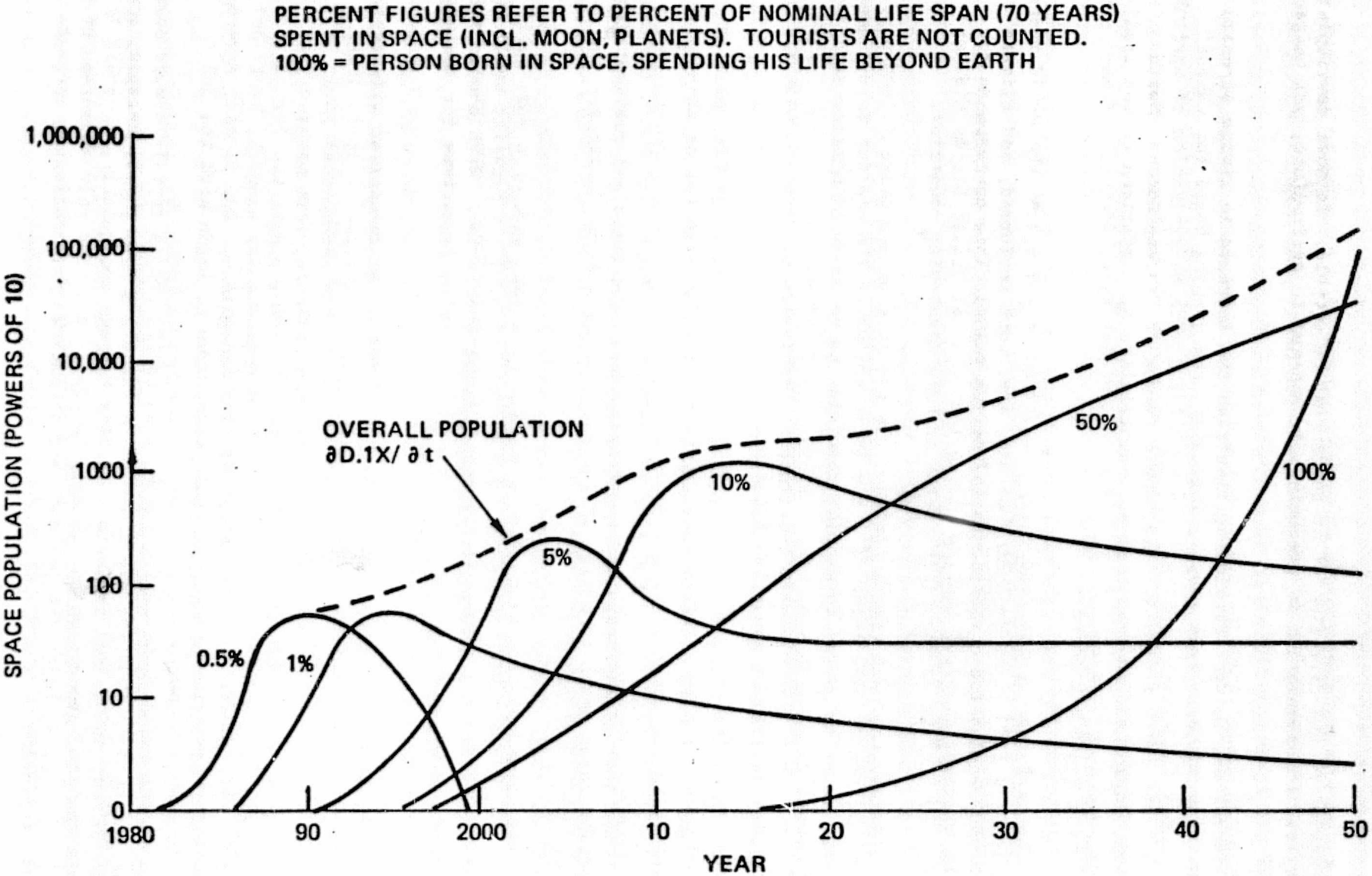


Figure 7. Illustrative Example of an Extraterrestrial Demographic Projection

Rockwell International
Space Division

life-styles in the direction of an industrial life-style. In most developing countries, the population is predominantly engaged in agriculture, yet hunger rules.

Therefore, in most developing countries the increase in living standard begins with adequate food supply; logically, the jumping board for takeoff into a more industrial life-style is associated with modernization of agriculture and its infrastructure. The modern farmer of Western Europe, North America, Japan, and Australia is an industrialist by comparison to the traditional farmer in Southeast Asia, India, the Middle East, Africa, and many parts of Central and South America.

The daily per capita food energy requirements throughout the world range from 1700 to 3300 kcal, depending on age, sex, work performed, and climate (with 2500 kcal being a representative medium value). This corresponds to 0.7 kg of wheat or rice, i.e., 0.117 hectare (ha) at United States Midwest yields, or 0.45 ha at the yield factor in many developing countries.

Population growth exerts considerable pressure on the present food supplies. The United States Department of Agriculture estimates the present import needs of wheat and rice by the developing countries to be 55 to 60 million tons (of which about 30 million tons are supplied by the United States). The International Food Policy Research Institute in Washington projects a wheat and rice deficiency in 1985 of about 100 million tons.

The United Nations has identified 43 *food priority countries*, most of which are located in a central African belt extending from the south-Saharan countries in the north to Zaire, Malawi, and Madagascar in the south. The second largest group stretches from Afghanistan, Pakistan, and India through Southeast Asia to Indonesia and the Philippines. The third and smallest group comprises three small countries in Central America and the Caribbean, and one in northern South America.

More abundant food production would not only take care of a very basic need in many developing countries; its social and economic benefits would also be likely to reach a predominently agricultural population. With abundant food supplies, these people would have far more persuasive incentives for the adoption of birth control on a wider scale.

This tendency is strengthened by the advent of an industrial life-style. Increased food production above all rests on modernization of agriculture. Modernization requires an agricultural industry that encompasses power generation, irrigation and other water construction projects, farm machinery and its maintenance, roads and transportation, manufacturing plants for fertilizer and pesticides, a communication and information transmission network, banks and other credit institutes, and efficient farm management. But in many developing countries, education of many peasants would have to begin with the 3-R's.

As the standard of living rises, food habits change rapidly toward more meat and corn consumption associated with switching from wheat, cereals, and rice to meat and animal products. If this happens too quickly, progress in grain and food production can quickly be wiped out. The only advantage of this cycle is that it keeps the pressure and incentives for continuing increase in food production.

According to United Nations Food and Agriculture Organization statistics, pigs (with 42.5M tons) provided most of the meat in 1974; followed by beef and veal (42M tons) and poultry (20.7M tons). Unfortunately, beef and pork are among the most inefficient converters of crude protein to edible protein (4 percent and 14 percent conversion efficiency, respectively), whereas poultry yields 23 percent, milk 25 percent, and eggs 25.5 percent. On this ground, chromosome separation in orbit would be desirable to maximize the number of milk cows wherever milk and milk products are compatible with established dietary preferences (which are surprisingly difficult to change).

Protein Supply

Protein needs are strongly dependent on age. Babies and children have the greatest need for protein, not only for body building and disease resistence, but for the brain development as well. Here lies an important crossing between today's nutritional scenario and tomorrow's social and political scenario. Babies need about 3.5 grams of protein per kilogram of body weight, children 1.5 grams, young adults about 1 gram, and elderly persons 0.5 grams. This results in 7 to 14 grams/day for babies, up to about 45 grams for children, 60 to 80 grams for young adults, and 25 to 45 grams for elderly persons.

Fish, or seafood in general, is the principal source of high-grade protein whose production does not interfere with the productivity of land food, such as cereals and rice. This has made seafood the traditional source of protein for poor countries and the desirable protein supplement for industrialized nations with an inadequate domestic agricultural base. The largest seafood consumers are the Asian countries.

The world fish catch has more than doubled since 1953. In that year the catch (live weight) was 27M tons, in 1964: 51M tons, in 1966: 57M tons, in 1967: 60.5M tons, and in 1970: 70M tons. Since then, the catch has remained essentially constant (with some reduction in 1972 and 1973). The quoted figures include inland catches (approximately 11 percent to 13 percent). From the remainder, about 30 percent must be deducted to account for the difference between live weight and edible weight. This 30 percent is not lost; most of it is used, after processing, as animal fodder and reappears as meat, milk, and eggs. But the protein losses that occur in this conversion vary from 75 percent (milk, eggs) to 77 percent (poultry) to 86 percent (pork) to 96 percent (beef).

The primary reason for the growth of fish protein in the past decades have been technological — modernized ships with on-board processing and refrigeration facilities enabling them to engage in longer trips and fish even in poor weather, more efficient nets and catch methods, etc.

These technological innovations were capital intensive and lead to far-reaching infrastructural changes from fishery to transportation and processing industry. Only wealthy and technologically advanced nations could make use of these options. Now, these possibilities have largely run their course. The new fishing areas (that were brought within reach by the new methods) are also fished to the maximum degree. Unfortunately, environmental considerations and rising fuel costs threaten even some reduction in future catches. The hope has been expressed that information gained from ocean-monitoring satellites will help to further raise the economically realizable catch. Moreover, the attention now turns to small sea animals such as the krill (a small shrimp).

Habitation

In a previous subsection, the number of households was discussed, but not the quality of the associated habitats. The quality is judged by the sturdiness of construction, the availability of light, the availability of energy for heating and cooling, and the availability of fresh water. In the developing countries, the quality of construction is mostly poor. Most of these countries are located between the Tropics of Cancer and Capricorn, in basically warm climates, with little seasonal variations. However, the structures offer inadequate protection against heavy rainfall.

Improved quality of construction would use either wood or wood and plaster material. The wood would have to be provided by the country's forest resources, and may require modernization of forestry as well as monitoring by satellite. The material must be transported to the construction sites, which requires fuel.

Lighting is not available in many habitats, because electricity is not available. However, night illumination by Lunetta can provide sufficiently bright outdoor lighting directly before the habitats to allow families to sit in front of their houses, reading and studying, in the same way in which today the luminaires on the median of a modern highway are used in developing countries by peoples living in habitats without electricity beside the highway.

The principal energy sources are wood, inedible crop residues, or animal dung. The required amounts of electric power for electrification can be estimated as part of a country's residential power requirements. The use of low-cost solar cells for daytime power in many areas should be investigated as part of a potential future market.

With a growing population and expanding industries in the larger metropolitan areas, the demand for land will increase over the next 20 to 40 years. This requires zoning and spatial planning. The housing needs are most acute for the lower-income groups in the urban areas. Public policy must set aside low-cost land for construction of the dwellings and other amenities for these groups. These dwellings should meet minimum adequate standards of habitation in terms of sanitation facilities, water supply, and low-cost transportation. Low-cost land is usually found at the fringes of metropolitan areas. Transportation to the city and to places of work, therefore, require low-cost means of public transportation.

With land becoming scarce and increasingly expensive, construction of high-rise units will become necessary in many urban areas. This may entail a major change in cultural patterns and individual preferences. Location close to new industrial parks (as they evolve as part of zoning and spatial planning efforts) would reduce the transportation problem and the associated traffic problems in certain times of the day. The high-rise dwelling units should be made viable by associated shopping centers, schools, and other community facilities.

As to the average living space per household, a minimum standard of living would dictate about 60 m^2 of roofed space on a 100 m^2 plot per household of six members. In high-rise dwellings, the same floor space would be required, associated with adequate grounds and facilities surrounding the high-rise.

The need for water supply calls for building a network of water reservoirs all over the country in urban and rural areas. For a minimum adequate standard of living, the available water supply should be 85 to 90 liters per capita per day (i.e., about 21 to 23 gallons) in urban areas. Present worldwide average urban household consumption ranges from 100 to 250 liters per capita per day.

But even a target of 85 to 90 liters requires a large investment program in reservoirs and purification and distribution systems. During the next 30 to 40 years, many existing cities and all the new cities in the developing world will have to construct elaborate water conservation systems capable of controlling underground as well as surface flows of water. The metropolitan water demands might compete with needed irrigation for agriculture.

In areas where increasing demand for water will cause the water to become progressively more expensive, other measures must be taken. Water may have to be economized, but this is the least desirable alternative, unless obvious waste is taking place. Another option is the recycling of water. Water recycling systems are expensive, but with rising water prices, the investment will eventually become economical. Finally, there is the option of salt water conversion — at least in the many developing countries with coastlines. This too may involve expensive investments which must be judged against tomorrow's water costs. Moreover, much depends on the cost and availability of energy. Indonesia, for example, has considerable geothermal energy sources on Java, geographically close to the coast. India, Africa, and the Arab countries have lengthy shorelines. Iran plans to use the excess heat from atomic power plants, in addition to solar energy, for fresh water production from the sea.

Public Health Service

Taking the number of physicians per 10,000 people as the indicator for availability of health personnel (doctors, pharmacists, nurses), the average ratio in developing countries lies far below that in industrialized countries, namely, 0.3 to 0.6 per 10,000. Moreover, this average does not reveal the wide gap between regions, the highest ratios being at urban areas, the lowest ratios in remote rural areas. A minimal acceptable standard for health services should provide a larger number of physicians.

The situation is similar with hospital beds and associated medical facilities. Average values in developing countries are 5 to 10 hospital beds per 10,000 people. The ratio should be closer to 50 to 100 beds per 10,000 people.

The need to raise the standards of health services to these more adequate levels requires substantial investment in the training of physicians, dentists, pharmacists, nurses, and paramedics, as well as in the expansion of training institutes for these people. The cost of training a physician ranges from $50,000 to $100,000; that of a paramedic (a fraction of this amount) $15,000 to $30,000. If seven physicians are to be provided for 10,000 people, which would be a minimum standard of health service, then, for a population of 200 million, 140,000 physicians will have to be trained, at a total cost of about $7B (at $50,000 per physician). If seven paramedics per 10,000 people are provided at $15,00 per paramedic, the cost is $2.1B. By raising the number of paramedics (for example by 50 percent to 10.5 per 10,000, and reducing the number of physicians to five per 10,000), more medical personnel would be available to the population sooner at lower cost. The impact of reducing the number of doctors can be minimized if the paramedics can serve as a closely-connected extension of the physicians. This requires a communication system which, for large area and archipelago, can be provided only by domestic information transmission satellites. The capacity of these medical satellites should be large enough to permit person-to-person voice communication, or at least require a network of only small transmitters and receivers between remote villages and the doctors in towns, or the specialists in cities and urban centers.

Hospital beds are also very expensive. At 75 beds per 10,000, a population of 200 million requires 1.5 million beds, at an effective cost of $10,000 per bed, the required investment outlay is $50B. The use of lower-cost remote hospitals connected by a satellite to a fully-equipped central hospital could reduce this cost.

A steady improvement in the provision of health services is an important ingredient of a rise in living standard of the people in developing countries. If the heavy unemployment that characterizes the present economy of these countries can be overcome, better health services will also become economically beneficial. Improved health conditions improve productivity. The investment outlays are high, but it appears that they can definitely be reduced for large countries, such as many African, South Asian, and Southeast Asian nations, by using suitable, or perhaps even specialized, domestic medical information transmission satellites.

Education

Requirements for advances in educational facilities exist in both the large-area industrial countries, including the United States and the Soviet Union, and in developing countries.

In the socialist countries, education is centrally planned, centrally financed, and proceeds within ideological guidelines. In the United States, education is largely kept under local control and is also financed locally. The use of direct broadcasting educational satellites is potentially more effective in countries with a centralized educational program. Nevertheless, educational satellites could play an important role in two areas: Supplementary programs for the enrichment and broadening of local school curricula (particularly in poorer states or in remote areas such as in many parts of Alaska); and specialized courses for adult education. In view of the high rate of technical, scientific, managerial, etc., progress, the knowledge base of the young adult at termination of formal education is soon obsolete. This holds for physician, the businessman, the stockbroker, the automobile mechanic, as well as for the engineer and the farmer. At this time, the person attempts to keep on top of the changes by experience, by continuing on-the-job learning, by exchange of information in professional group meetings, by reading books, special professional periodicals or trade journals, or in some cases, by attending refresher courses at suitable institutions.

An educational direct broadcasting satellite network could provide several specific courses in parallel on different wavelengths to keep members of large and important skill groups up-to-date more thoroughly and consistently.

These programs must be pragmatic and to the point, but not shallow. To entice a faithful audience they must convey to the viewer the conviction, subsequently borne out by experience, that participation in this form of continuing adult education is economically advantageous. To enable the viewer to watch the programs, there must be plans for suitable time periods. Many detailed problems in organizing such a system must be overcome. To assess the worth of large investment outlays, experience should be collected in carefully-selected test areas; for instance, one involving a large urbanized region; another, a number of agricultural communities; and a third, a combination of large city (such as Houston or Los Angeles) with a surrounding region of smaller towns and agricultural communities.

The educational demands of a growing and developing society call for educational opportunities on both ends of the spectrum — the child and the adult. In the 7 to 13 year age group, school attendance in many developing countries is still far below 100 percent; perhaps 60 percent (boys - much less for girls) and falls off progressively faster in the 14 to 16 and 17 to 20 age groups (which are ready to enter the labor force in rural areas or migrate to the cities in search of jobs).

The first goal in educational services for these young people is, logically, to strive for 100 percent enrollment in the 7 to 13 age group; subsequently escalate attendance in the 14 to 16 age group, perhaps to 70 percent to 80 percent, and by the 17 to 20 age group: 50 percent to 60 percent or better. Not only would this prepare more people for productive jobs — and the best people for medical, engineering, legal and scientific professions — it would also reduce the pressure of unemployment in the 17 to 20 age group and associated antisocial phenomena such as crime and radicalization.

Raising the school attendance to such a large extent over a period of 20 to 30 years also calls for expediting the output of teachers and associated teachers' colleges rapidly. Schooling for the 7 to 13 age group will most suitably occur on a local basis, with a student/teacher ratio of typically 30/1 for the primary school phase. At the junior and senior high school levels, the ratio increases to typically 20/1 and 15/1. At these levels, at which also vocational training takes place, educational satellites can play a cost-reducing and educational quality increasing role.

Investment outlays for the expansion of educational facilities, including educational satellites, are on the multi-billion dollar level. The young people reaching working age will double in many Asian countries in the next 15 years. With 44 percent of the population in Southeast Asia under 15 years, the problems of education are reaching staggering proportions. In the Philippines, 73 percent of the 7 to 13 age group were enrolled in 1957. To reach 100 percent attendance by 1980 involves a threefold increase in enrollment. In Indonesia, the factor would be 2.2, in Pakistan a sevenfold increase would have to be absorbed for 100 percent attendance and increase in schooling to five to eight years by 1981.

Studies on the sources of economic growth in industrialized as well as developing countries have shown that the payoff of investment in developing human resources is well worth the investment. However, this is true only if the opening of the job market by labor-intensive developments is being coordinated and keeps in step with the release of better-educated young people into the work force.

If, on the other hand, both growth processes go hand-in-hand. Spreading educational opportunities evenly among the broad layers of the population is essential for spreading economic opportunities more evenly. This improves equity in the participation of growth in general and in the distribution of wealth and income in under present conditions (which show a wide gap between the wealthy and the poor in most developing countries).

Public Safety

Public safety involves the control of crime, fires, storms, floods, droughts, earthquakes, and terrorism — especially terrorism in which nuclear weapons are used.

Weather satellites, earth- and sun-monitoring satellite-supported climatological research will provide improved early warning against storms, floods, and droughts. Crop inventory satellites will contribute to early warning against crop failures and incipient food shortages, or worse, in the following years. The rash of severe earthquakes in 1976 has once again emphasized the need for earthquake prediction in critical areas of the American west coast, Far East, and Near East.

The police in different countries employ widely varying methods of fighting crime. In the principal western countries, different judicial practices hold than in socialist or in many developing countries. The police in large countries (with unimpeded freedom of movement such as the United States and Canada) and the police of many nations (working together in *Interpol*) can utilize information transmission satellites for rapid data exchange. The developing countries, which face enormous investment outlays and important socio-economic projects, are not likely to see a need in the immediate future for satellites to aid in crime control.

Terrorism is essentially an urban or quasi-urban phenomenen. Most terrorism, so far, has occurred in the free countries of the west. None could be identified as such in the socialist countries and little in the developing countries, with the exception of the Middle East and the activities of Cuban terrorists in several parts of South America.

Whether in western cities or in the cities of the developing world, the danger is that the flash point of violence seems to be getting lower. (with growing readiness for revolutionary challenge to authority) especially by the potentially volatile 15 to 29 year age group — the potential urban guerrilla. He needs leadership and weapons technology. Both may readily be provided by frustrated and jobless members of the intelligentsia.

Short of theft from a nuclear arsenal, the terrorist or guerrilla can come into possession of crude nuclear weapons only by gaining access to Pu-239. Several options are available to protect against this possibility:

1. Perfect control of the plutonium stock. Ivan Bekey and his co-workers at the Aerospace Corporation have suggested a possible approach for achieving this through the use of monitoring from satellites.

2. Development of converter and breeder reactors based on the thorium cycle (in which Pu-239 or any other bomb-ready material is not generated). This option is largely negated by the choice made so far and the investments associated with it; but it should not be written-off by the United States, since other countries are likely to develop it.

3. Combination of electric power transmission in lieu of exporting nuclear power plants using the power-relay satellite for transmission (from the United States to Egypt or Iran, from France to Pakistan, and from Germany to Brazil), and of solar or nuclear power generation satellites in geosynchronous orbit. While removing the possibility of P-239 theft, this option has several disadvantages. One is timing; the second is cost compared to direct nuclear power; the third — and relatively least serious — is space for transmitter areas and nuclear power stations in small countries such as France and Germany. All reactor building nations (including the Soviet Union) would have to agree to energy export by these methods, rather than by exporting nuclear power plants.

Thus, the control of plutonium stocks or the development of the thorium cycle appear to be the most promising methods for preventing the specter of plutonium theft without prejudicing the needed buildup of nuclear electric power generating capacity. The possibility of storing the plutonium in orbit until needed in reactors on earth does not appear to be economically viable. Roughly, one ton of Pu-239 is needed per gigawatt-year. The transport to and from orbit and orbital storage will cost in the order of $30M̄ in 1976 dollars, resulting in an extra charge of 8.22¢/kwhe for space storage.

Life-Style and Cultural Factors

A life-style is a pattern of emphasis of certain existential aspects of living and of neglect of others. Life-styles are shaped by cultural, ideological and socio-economic factors. In most countries of the developing world, old cultural patterns are integrated into modern ways of life rather than allowed to impede progress toward modernization. This was apparent in Japan and, later, in South Viet Nam. In Bali, Indonesia, one can see in the front of houses or in gardens fresh fruits and vegetables placed on the alters of protective local deities, while an Indonesian boy and his girlfriend emerge, mount a motorcycle, and take off with a roar that would impress the Hell's Angels. With the exception of India and some African nations, most countries in the world realize that their future is inexorably tied to economic growth and to technical and scientific progress. They eagerly partake of the advances of the west whenever they can.

The strongest and most profound changes in life-style in our time have been created by the communist countries, where the iron hand of government, intensive inculcation of ideological catechisms, and a socio-economic order subject to the dictates of the ruling party determine the life-style.

In the United States and Western Europe, many changes of life-style have resulted from the availability of contraceptives and the intense pressures of the environmental movement. The basic facts of economic and socio-political life — the need for growth, for enlarging the job market, for consumption, and for massive defense outlays — and the many manifestations of love of the good life — could not be altered significantly by the environmental movement. The enormous economic strength of the United States has made it highly resilient. In the past few years, this economy has been able to absorb the cost of the Viet Nam war, a 400 percent increase in oil prices, a flood of environmental regulations, and a recession.

But these events have left their mark. The space program, like other new scientific, technological efforts, will have to justify itself as never before. The days of grandiose projects proposed under a more or less thin veil of justification are a thing of the past.

Agricultural Production

Perhaps nowhere is the fashionable term *Spaceship Earth* more profoundly meaningful than in the area of food production. *Spaceship Earth*, on which mankind can sustain itself in large numbers, does not exist. Man has to build it; but there is plenty of potential around to make neo-Malthusianism look quite silly. Industries can be built on earth, in space, or on the lunar surface, but food production on a large scale requires this planet. This planet is the only one in the solar system whose *business* is life; the only one on which the necessary requisites — water, CO_2, nitrogen, and soil (with its living infrastructure) — abound. The growth potential of food production can meet the challenge of supporting 15 billion earthlings. Realizing the growth potential, however, is not so easy.

Two major food sources are available to mankind — land and sea. Of these two, land constitutes the principal food source.

In a nutshell, the issue of land food production is to achieve as high a utilization of solar energy by means of agricultural plants as possible. The most important parameters of this equation are known: The photosynthetic activity of the leaves, the rapidity with which the leaf surface grows for maximum intercept of sunlight, the position and arrangement of the leaves on the plant (short or dwarf plants are better than tall plants for reasons of spacing, as well as others such as producing too much cellulose), replacement of nitrogen and other nutrients (phosphorus) taken from the soil, proper irrigation, and pest control.

Expanded Cultivation and Intensified Farming

Two major options are available for increasing land food production: Expansion of cultivated area and intensification of farming. Expanded cultivation is obviously limited by the earth's size, climatic zones, topography, soil conditions, and local availability of water. Of the earth's surface of 13 billion hectare, 2.9 to 3.2 billion hectare can be cultivated, and about 1.2 billion hectare, or about 40 percent, are cultivated at this time. The largest growth potential is found in areas in which, ironically, people are presently undernourished, suffer from malnutrition and occasional starvation (especially in Africa, South America, and parts of Southeast Asia).

Major food production centers include the southern half of the Sudan (about 820,000 hactare), considered to equal present world food production, if and when fully developed; the south-Saharan savanahs, some African tropical forest regions, and some desert regions in North Africa and on the Arab peninsula and the grass plains in Argentina and in southern and northern Brazil.

In all cases, major obstacles lie in the path of realizing their food potential. In the southern Sudan, vast swamps created by the White Nile need to be drained — a process requiring perhaps 40 to 60 years. In the semi-humid savanahs south of the Sahara and in the desert regions, irrigation is a chief prerequisite. In all cases, research must be conducted to develop the locally most suitable plants and farming methods. An agri-industrial and rural infrastructure needs to be built, and the predominently farming population in these countries needs to be educated and trained in modern farming methods.

Even greater is the potential for increasing food productivity through intensification of agriculture. The *Green Revolution* is far from over. In fact, it appears that it has hardly begun, and that the next 100 years will see more yield improvements and related advancements of the biotechnology of cultivated plants than all the millennia since the first agricultural evolution.

There are three lines of intensification: Better off farm services (water management, fertilizer and pesticide production, low-waste storage); multiple croppings and crop interplanting (the interplanting of synergistic crops in the rotations between one main crop and the next); and improved plant and animal breeding.

Food production in virtually all developing countries can still profit from better off farm services. Even in India, which has made great strides in doubling its food production in the past 15 years, a 40 million hectare area is known to be extremely underutilized. The Indus-Ganges-Brahmaputra plane of India, Pakistan, and Bangladesh could yield three-quarters of the world's present cereal output if its rainfalls and glacier waters could be harnassed by flood control systems and irrigation canals, and if a more efficient agri-industrial infrastructure would be established.

In the tropics, up to three crops are feasible per year since seasonal variations are small. This would triple and annual yield per hectare. Of course, multiple cropping requires a correspondingly sophisticated irrigation and drainage system to provide proper conditions throughout the year, more intensive fertilizing, and highly effective pest and disease control measures. Moreover, the time for planting and harvesting and the time between harvesting one crop and cultivating the land for the next must be reduced below present levels (especially in the case of triple-cropping. The first and second lines of intensification (i.e., intensive multiple cropping) are estimated to offer the potential for raising the output of cereal grains in the tropics by a factor of five or six. Interplanting could raise this value by another 50 to 60 percent.

Improved Plant Breeding

The prospects for the third line of intensification, improved plant and animal breeding, show that the *Green Revolution* is far from over. The ascent of man has altered the slow environmental changes over geological epochs with their attendent selective effects on inherited characteristics and mutations which characterized the evolution of the species over the past two billion years. In the laboratories and test stations, selective effects of cross-breeding and of artificially introduced though not yet controlled mutations at higher-than-natural rates have accelerated the previous tempo a million-fold to a billion-fold.

The principal strategy of planned cultivation is the acceleration of natural evolution by isolation, i.e., differentiation of the genetic population and isolation of the desired genetic strain. In the past, this required at least one growing season. Several more seasons were needed for providing the seed stock. In a new technique, somatic-cell genetics, millions of cells are kept in test tubes. Selected cells can be cloned to provide large numbers of equal cells in a matter of weeks. Desired strains of carrots, corn, tobacco, and several other species can already be reproduced from selected cells and tissue clumps. It is expected that in the next decade it will be possible to introduce specific genetic material into cereal cells controlling the protein content and the composition, the ability to fix nitrogen, photosynthetic efficiency, and other characteristics.

Genetic Manipulation

It may even be possible, through genetic manipulation, to achieve somatic hybridization, for example, plants that grow tomatoes above ground and potatoes underground.

A new species can be generated only be mutation. By means of heat, chemicals, and radiation, the number of mutations can be raised well above the level in the natural environment. When a desirable new species is formed, then follows the last step, recombination, i.e., the combination of whole groups of genes for improved characteristics. This technique of recombinant genetics, thus, hybridizes the genes of mutations and existing species. It is a variant of somatic hybridization, in which also the genes of different species are hybridized.

The promise, then, is that within the next few decades, it will be possible to supply the different regions of *Spaceship Earth* with *tailor-made* cultivated plants that best meet local requirements in terms of cold climate resistance, pest resistance, reduced water consumption (through less evapotranspiration by taking up CO_2 at night) and photosynthetic efficiency (within limits).

The resulting world grain production potential could rise, in time, from present values of 1.2 to 1.3 billion tons to some 13 billion tons. The underlying assumption is based on multiple cropping in the subtropics and tropics, interplanting, the developing of locally-optimized high-yield strains, intensive agriculture, and efficient agri-industrial and rural infrastructure, and the extension of arable land by 50 percent of the maximum possible extension, i.e., by approximately 0.7 billion hectare.

Prognosis for the Future

Because of the lead times involved (up to three generations) and the large investments required, this condition is not likely to be reached faster than about 100 years from now. Even then human imperfections and the loss of initiative may mean that the indicated values may not be reached in the indicated time frame. The production curves are shown in Figure 8 . The dash-dot curve shows the required grain production level as a function of population size, if grain is to supply a daily food energy of 2,500 kcal. This is fictitious, of course, since other food sources are available. Nevertheless, it may be possible to achieve this production level between 2020 and 2040.

The solid production line is slow in taking off in the 1970's and 1980's because much research still needs to be done, more money is needed than is presently available in and to the developing countries, and mostly because of the political and social implications involved. Therefore, it is likely that the world deficit will increase in the next 15 years. Indeed, the present deficits of wheat and rice in the *Third World* of 55 to 60 million tons are expected to rise to about 100 million tons in 1985. In the 1990's, the upswing in world grain production should begin and reach its highest rate in the 2000 to 2020 period. It may be expected that the resulting economic upswing will provide the economic as well as socio-political basis for accelerating the more difficult and costly task of extending the arable land areas primarily in Africa and South America.

As the food production capacity is increased, crop monitoring, weather forecasting, the developing of regional climate forecasting, water management, disease and pest control, and refined harvest projections become increasingly important. These tasks will, to a large extent, be accomplished by earth-monitoring satellites. Information transmission satellites will also be needed to educate farmers and provide training in related agri-industrial professions, as well as for keeping the farmer informed about agricultural, biological, and economic aspects and changes in his business. Night illumination can reduce the time needed for harvesting one crop to prevent damage if inclement weather is predicted and for reducing the time needed for cultivating the land for the next crop in the case of multiple cropping. Figure 9 illustrates the fiscal aspect of the production increase depicted in Figure 8 . The investment per hectare for intensification, off-farm services, agricultural infrastructure, and extension of the arable land area vary greatly from virtually nil in Western Europe and the United States to $1,000 per hectare (for cases with an already reasonably well developed agricultural infrastructure — as in the Indus-Ganges-Brahmaputra area) to values as high as $25,000 to $30,000 per hectare for the southern Sudan and South Sahara territories (all values in 1976 dollars). Assuming somewhat perfunctorily a world-average investment in all arable land of

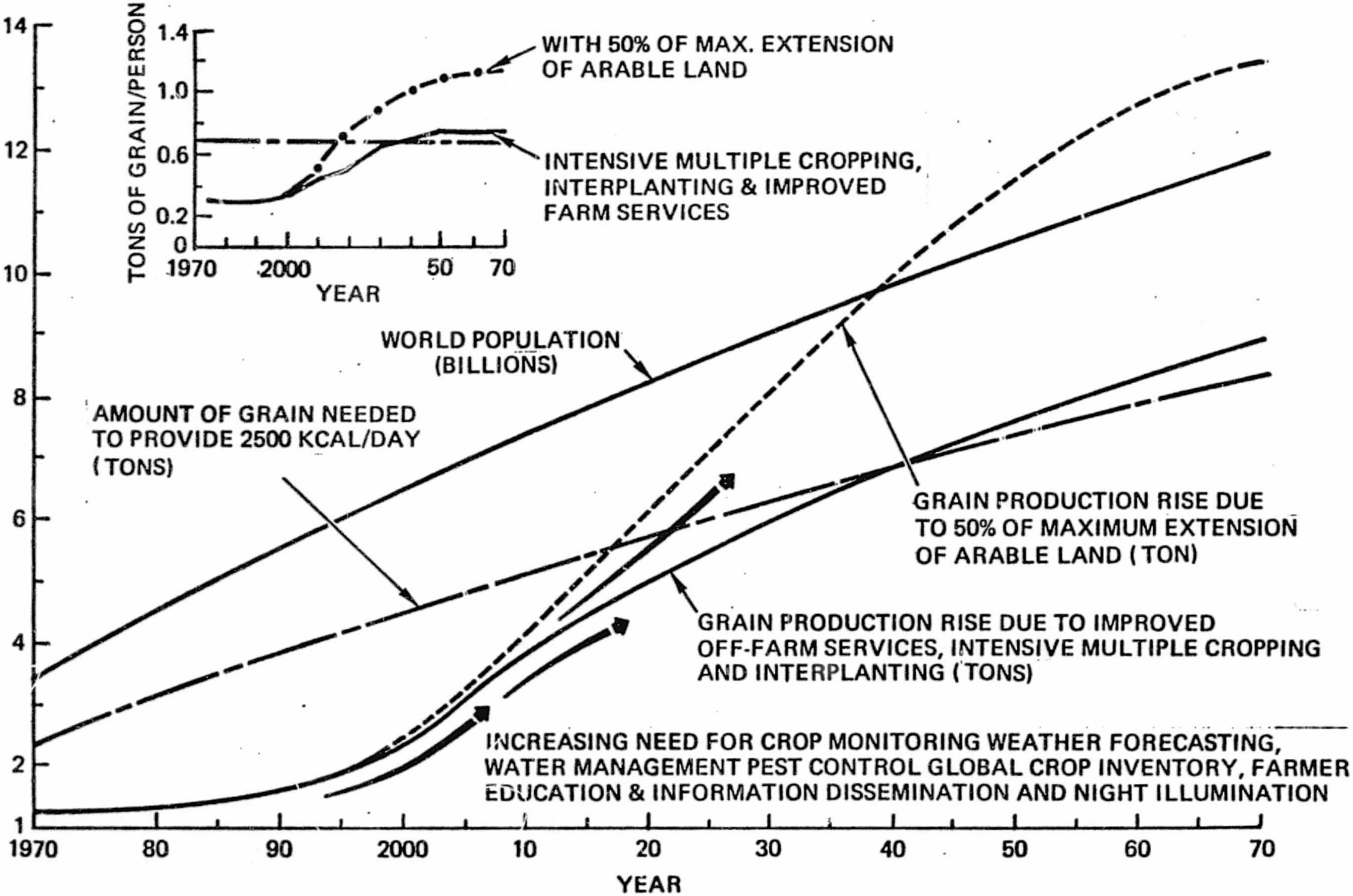


Figure 8. Grain Production Potential

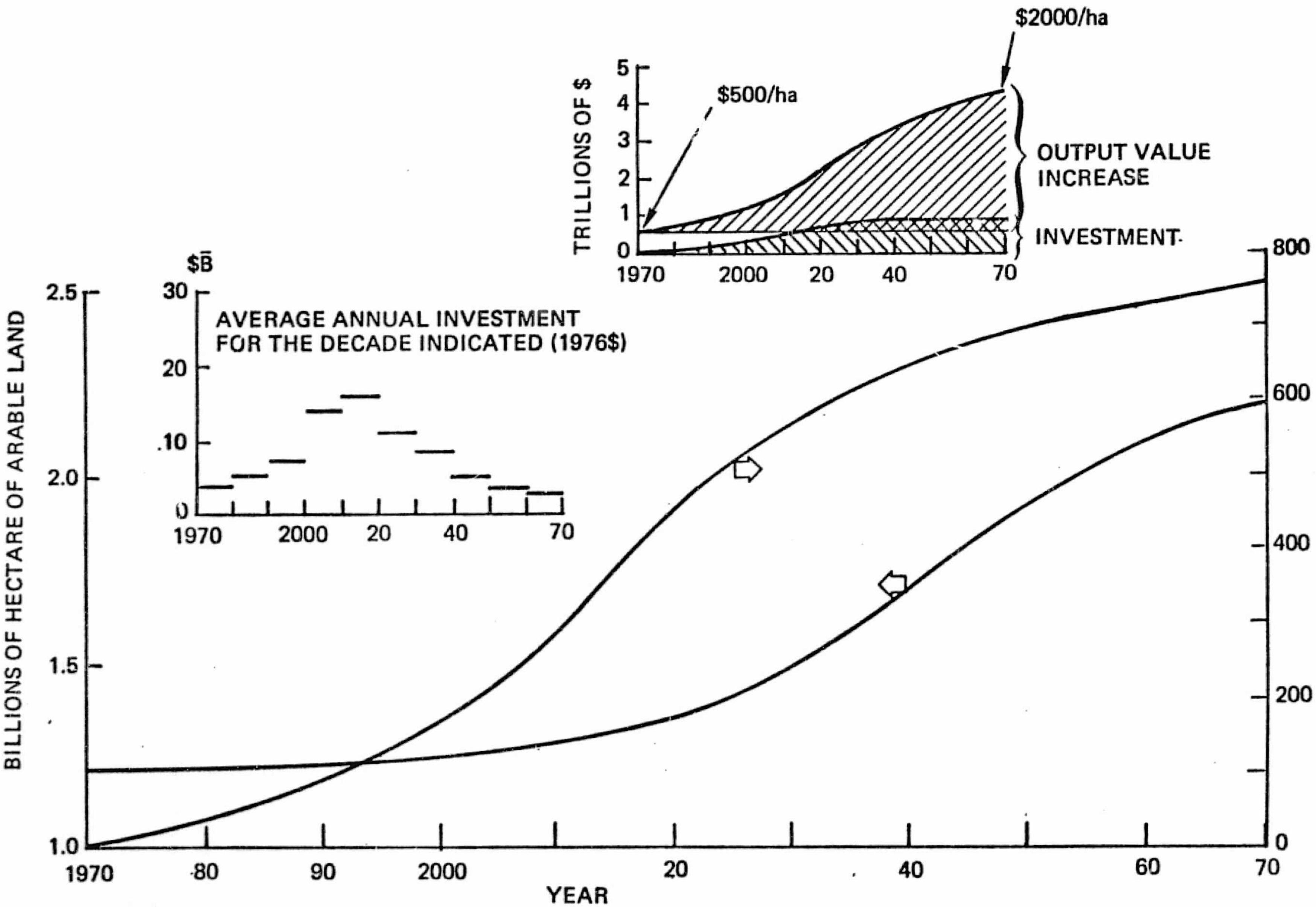


Figure 9 . Land Food Production — Investment and Value Increase Potential

Rockwell International
Space Division

$400 per hectare over the 1970 to 2070 time period, an investment approaching $800B in 1976 dollars is indicated.

The Required Investments

While the investments are staggering, they are relatively small compared with the potential returns. The second insert in Figure suggests a potential increase in output value by (1976) $3,800B. This is based on a somewhat pessimistic world average of $500 per hectare of grain in 1970, and a somewhat optimistic $2,000 per hectare in 2070.

While highly simplistic, these calculations and the curves in Figures and nevertheless *ballpark* production potential, investment and value generation potential in return. It is a gigantic endeavor, extending over two to three generations, but with the promise of measurable successes already in the 1990's and 2010's.

Satellite and space station functions (related to the many aspects of earth observation and information transmission) and spacelight (Lunetta) are indispensible parts of the overall effort. They will save billions of dollars — many times their own cost.

Food From the Sea

The possibilities for the increased production of seafood appear more limited than the production of land food, for a number of reasons. Ichthyculture has not passed through the equivalent of the first agricultural revolution and, therefore, is still largely on the prehistoric level of hunting wild animals and reliance for replenishment of resources on processes which take place outside the realm of human control.

Biologically, therefore, the analagous rules apply, to which already the primitive hunter was subjected: Phase 1: Livestock — low-intensity fishing, small overall catch, but catch by individual ships is reasonably large. Phase 2: Reduced stock — high-intensity fishing; overall catch is large, but the catch per ship begins to drop. Phase 3: Minimal stock — very high intensity fishing; overall catch is reduced; catch per ship is small. Beyond that limit of intensity of fishing the stock is threatened with extinction and the effort becomes uneconomical.

Only certain ocean areas show high productivity and provide an adequate payoff for commercial fishing. The stock in these areas tolerates only a limited catch rate. Short-term and medium-term environmental variations (in salt content and temperature due to small changes in currents) can cause significant shifts in breeding or feeding areas of commercial species. This introduces an important uncertainty factor for commercial fisheries. This uncertainty factor, however, may well be eliminated with the advent of satellite-based detailed monitoring and prediction of changes, and observation of shifts of schools of commercial fish.

These two factors are the main reason for the limitations on seafood production. Nevertheless, there are several ways to raise the production to twice or three times the present value of about 65 million tons live-weight ocean catches. Very briefly these are:

1. Extension of the catch activity to new species. One such species are sharks; another, and far more promising one, is small shrimp (krill) in the antarctic waters. Recently, this potential was explored by the Federal Republic of Germany, whose short shorelines threatened to limit its fishery activities in many fertile regions of the North Atlantic. An eight-month expedition by two German fishery research vessels was very successful. Estimates, based on extensive sonar measurements, place the annual krill production at around 200 million tons. Special sonar location devices and specially designed nets performed well, yielding catches of up to more than 60 tons per day. New processing methods are being developed, and krill pasta is said to be tasty. More problems remain to be solved; but inclusion of these small shrimp in the list of commercial catches may be one of the most promising steps at this time for an increase in seafood production.

2. Improvements in processing methods to reduce losses.

3. Increase of primary production by extending the circulatory system that carries nutrients from deep waters to surface waters, as it occurs naturally in the fertile and productive upwell areas. However, no effective (on a large scale) and economically attractive schemes for extending vertical circulation have so far been developed.

4. Raising young fish through their growth period of greatest vulnerability to natural predators and subsequent release. This method was successfully pioneered in Denmark on selected species, and subsequently adopted also in Great Britain and Germany. But the economically worthwhile possibilities are limited, because food supply for large numbers of small fish is costly.

5. Cultivation of salt water lagoons in the manner of fresh-water fish ponds. While quite successful in Japan and elsewhere in the Far East, this approach is not suitable for quantity production.

6. Intensification of controlled cultivation in lakes and ponds as it is applied in the Far East to scallops and oysters. Again, this method is effective, but only on a relatively small scale. Specifically, it is not applicable to the open sea, where the selection and breeding of closed communities of selected types is not currently possible.

One may add one other method which, understandably, does not occur to the fishery researcher and biologist:

7. Projection of solar energy (Soletta I) into natural global areas whose *fertilizing* effects of vertical circulation cannot be fully utilized because the other indispensible ingredient for growth, solar energy, is not available in adequate amounts. This is especially true for the Antarctic waters and the fertile areas in the Northern Atlantic and Pacific. During the respective winter months, thermal effects add to vertical circulation stimulated by currents. Heavy cold surface water sinks to the bottom causing lighter, deep water to rise and carry with it more nutrients to the surface. Without solar energy to stimulate carbon assimilation, however, the fertile waters cool off, unused, and sink back to greater depths. A Soletta I in geosynchronous orbit could *photon-fertilize* about 80,000 sq km. In spite of the magnitude of such a project, it appears comparatively much easier to *photon-fertilize* a chemically fertilized ocean area of this magnitude, rather than to chemically fertilize a comparable area by artificially inducing vertical circulation.

However, just on the basis of limited satellite aid to commercial fishery (to reduce fuel expenditure, but not to enable them to over fish) and extension of fishery to new species (such as the krill), the contribution to the world's protein supply could be raised to between 20 percent and 30 percent from the present 10 percent to 12 percent.

This is an important improvement for two reasons: It adds substantially to the protein diet of many developing countries, as well as industrialized countries with an insufficient land food base; It reduces the burden on the production of wheat and corn in having to sustain growing amounts of meat production as the standard-of-living in developing countries is raised.

On the other hand, modern fishery methods are capital-intensive, without being as labor-intensive as the modernization of agriculture. Industrialization associated with increases in seafood production is more specialized than the broader aspects of agricultural industrialization. Fewer people find jobs than in farming and off-farm services.

NEEDS SUMMARY

NEEDS SUMMARY

The purpose of *Space Industrialization* is to exploit the special environmental properties of outer space for the benefit of all mankind. It focuses on human needs and it promises to fulfill these needs often in ways that would be impractical or impossible using only terrestrial technologies. But what are the needs of mankind? There is no clear-cut way to develop an answer to such a mind-boggling question. The background scenarios discussed in the previous section were helpful in many respects, but the question does not, in any meaningful sense, lend itself to a definitive answer. The tables presented in Appendix B represent an attempt to list some of the more obvious needs of man. The needs listed are divided into five separate categories:

1. Population
2. Industrial Production
3. Food
4. Energy
5. Political/Economic/Environmental

These categories overlap to some extent and they are not all inclusive. Nevertheless, the items listed in the Appendix were crutial in reaching the goals of this analysis. In particular, these lists have stimulated numerous ideas for new methods to exploit the space frontier in economically viable ways. The items listed in the tables of Appendix B have also helped in structuring the various initiatives so that they can, in some cases, be fulfilled with common missions and with common hardware elements.

1. Information Transmission
2. Need for Information Services
3. Specific Information Transmission Opportunities
4. Data Acquisition Opportunities

SPACE OPPORTUNITIES – SERVICES

SPACE OPPORTUNITIES - SERVICES

The opportunities to provide services using space and ground facilities fall into two essentially non-overlapping categories:

1. Information Transmission
2. Data Acquisition

The first category includes, among many other examples, personal communications, off-shore limit monitoring, personal navigation, and sea-lane traffic control. The second includes all of the earth survey capabilities applied to known, specialized tasks for both governmental agencies and foreign countries. Because specialized knowledge is required to interpret the data, these services are seldom delivered directly to the ultimate user.

For the identification of opportunities, source data included many current publications (Business Week, Scientific American, U. S. News & World Report, The Wall Street Journal) as well as previous studies made available such as the Aerospace study, and reports from the National Science Council.

Well over 100 *opportunities* were identified by a descriptive title. Unfortunately, with so many that were similar except for the specific application, it was decided to select a few unusually attractive *anchor opportunities* as generic (see Figure 10) and describe and evaluate these in finer detail. A 12-point descriptive format, developed by Dr. Ehricke, was used for consistency, supplemented in the more promising cases by additional, unformatted discussion and elaboration.

Concurrent with the identification of these service opportunities was an effort to determine the national and global *needs* based upon recent books and other studies. Of course, it is not possible to separate *needs* and *opportunities* - every opportunity satisfies some real (or imagined) need, and every identified need immediately stimulates possible solutions (opportunities). The purpose of the *need* analysis was to screen out from the multi-fold opportunities these which were more fancied than real.

As the study progressed, more emphasis was placed upon immediately-achievable opportunities, particularly those that would have a direct and noticeable benefit to the ultimate user. It was found that a number of the expanded opportunities can be installed in the 1980-1990 era using the space Shuttle, with a *kick-stage* for lofting to geosynchronous altitudes.

A significant number of these near-term opportunities are extrapolation of existing trends, where the space element's contribution is more cost-effective than present ground-based elements. An example of this group is *electronic telecommuting*, in which inexpensive electronic communication is substituted for resource-wasteful commuting by automobile. A terrestrial alternative would be

A. COMMUNICATIONS

1. INFORMATION RELAY
   - DIRECT TV BROADCAST
   - ELECTRONIC MAIL
   - EDUCATIONAL BROADCAST
   - RURAL TV
   - METEOROLOGICAL INFORMATION DISSEMINATION
   - INTERAGENCY DATA EXCHANGE
   - ELECTRONIC COTTAGE INDUSTRIES
   - WORLD MEDICAL ADVICE CENTER
   - CENTRALIZED "DISTRIBUTED" PRINTING SYSTEMS
   - ENVIRONMENTAL INFORMATION DISTRIBUTION
   - TIME AND FREQUENCY DISTRIBUTION
   - ELECTRONIC TELECOMMUTING
2. PERSONAL COMMUNICATIONS
   - NATIONAL INFORMATION SERVICES
   - PERSONAL COMMUNICATIONS WRIST RADIO
   - VOTING/POLLING WRIST SET
   - DIPLOMATIC U.N. HOT LINES
   - 3-D HOLOGRAPHIC TELECONFRENCING
   - MOBILE COMMUNICATIONS RELAY
   - AMATEUR RADIO RELAY
   - "TELEGRAPHING" PERSONAL COMMUNICATIONS SYSTEMS
   - WORLDWIDE ELECTRONIC PING PONG TOURNAMENTS
   - CENTRAL COMPUTER SERVICE (FOR TRANSMITTING HAND-HELD CALCULATORS)
   - URBAN/POLICE WRIST RADIO
3. DISASTER WARNING
   - DISASTER WARNING RELAY
   - PRE-DISASTER DATA BASE (EARTHQUAKE)
   - EARTHQUAKE FAULT MEASUREMENTS
   - DISASTER COMMUNICATION SET

B. NAVIGATION, TRACKING, AND CONTROL

1. NAVIGATION
   - PUBLIC NAVIGATION SYSTEM
   - GLOBAL POSITION DETERMINATION
   - COASTAL NAVIGATION CONTROL
   - GLOBAL SEARCH AND RESCUE LOCATOR
2. TRACKING AND LOCATION
   - IMPLANTED SENSOR DATA COLLECTION
   - WILD ANIMAL/WATERFOWL SURVEILLANCE
   - MARINE ANIMAL MIGRATIONS
   - VEHICULAR SPEED LIMIT CONTROL
   - RAIL ANTI-COLLISION SYSTEM
   - NUCLEAR FUEL LOCATOR
   - VEHICLE/PACKAGE LOCATOR
3. TRAFFIC CONTROL
   - MULTINATIONAL AIR TRAFFIC CONTROL RADAR
   - SURFACE SHIP TRACKING
4. BORDER SURVEILLANCE
   - U.N. TRUCE OBSERVATION SATELLITE
   - BORDER SURVEILLANCE
   - COASTAL ANTI-COLLISION PASSIVE RADAR

Figure 10. Information Transmission - Anchor Opportunities

to install a conventional cable system. The satellite approach becomes more effective as the commuting distance increases, since the space platform eliminates essentially all geographical constraints.

There are other cases in which a space platform provides the only feasible solution to a particular societal problem; included in this group are most of the global monitoring needs, e.g., water management and border surveillance. In general, these are extensions of the LANDSAT technology and could be combined into a few multi-function space installations. One member of this group is of sufficient importance to require a dedicated satellite: a high-resolution earth-mapping radar. Even this, however, could provide other services, such as border surveillance, by a different interpretation of the data.

Another common characteristic of this group of earth-observing space elements is the need for training a large cadre of people to interpret and evaluate the acquired data. The satellite is a very prolific generator of data, and is certain to require generous allocations of the RF spectrum. The terrestrial bottleneck can be partially overcome by developing high technology data processing, but there will still be the need to train many thousands of full-time experts to interpret and communicate the results to the ultimate user.

Many of the service opportunities will be of greatest benefit to certain specific areas of the world. Broadcast education is, of course, extremely beneficial to a country like the United States, but can be priceless to lesser developed countries.

INFORMATION TRANSMISSION OPPORTUNITIES

The large-scale exploitation of space will most likely begin with national and international information transmission. As a matter of fact, these activities are already taking place on a large and growing scale. The INTELSAT series is experencing healthy growth; COMSAT is paying regular dividends; the ATS-6 and the CTS experiments show definite promise for future growth into new areas such as direct broadcast education and electronic teleconferencing.

Educational Broadcasting

Educational broadcasting provides an unusually promising opportunity to benefit both our own country and the rest of the world. Later we will consider that can be done in space in this area, but first we should examine some statistical background material on how well the American educational system works and how it might be improved.

Figure 11 shows the adult competence level in such ordinary tasks as reading, writing, holding a job, and balancing a checkbook. As shown by the

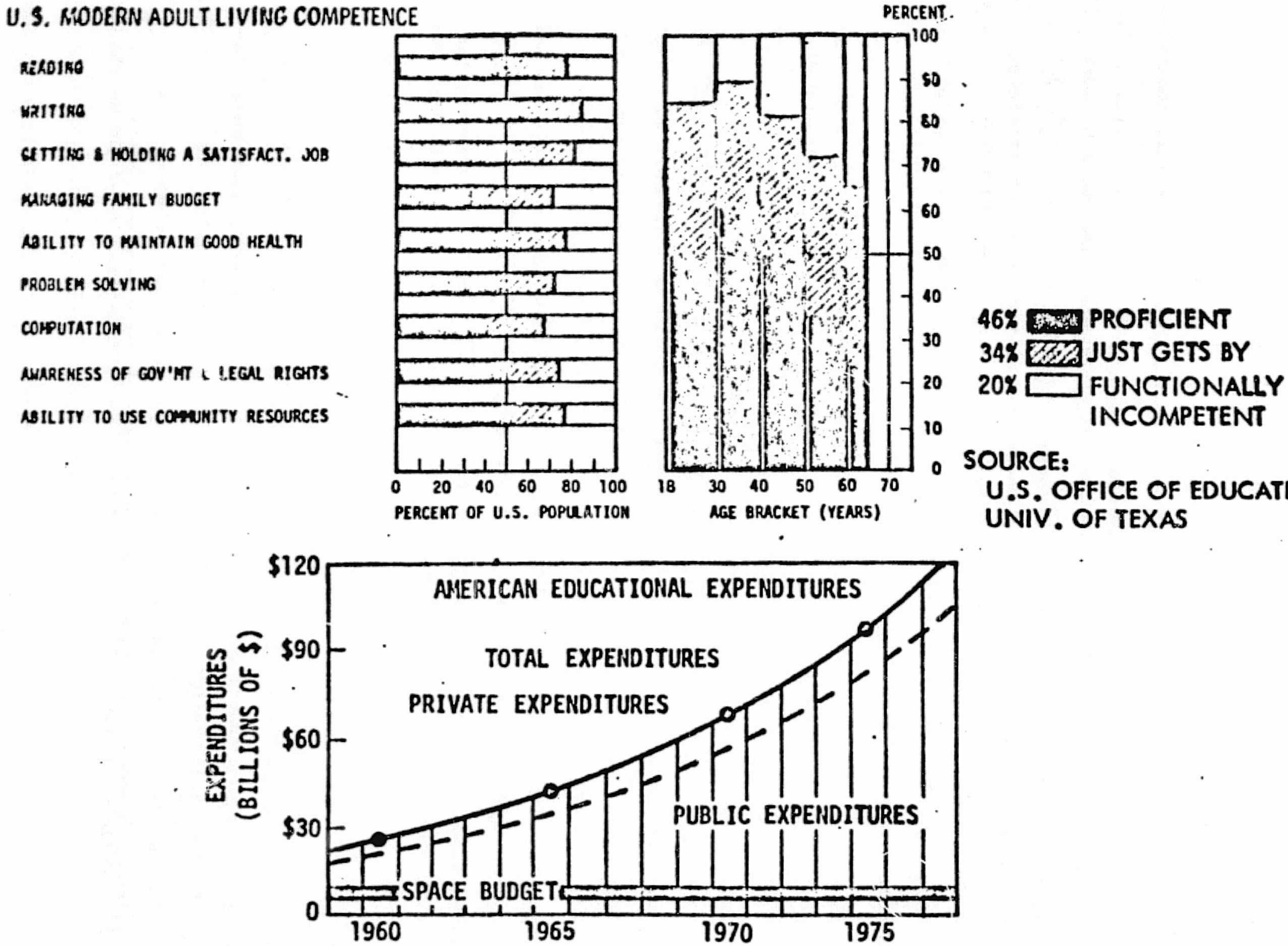


Figure 11. American Educational Attainments

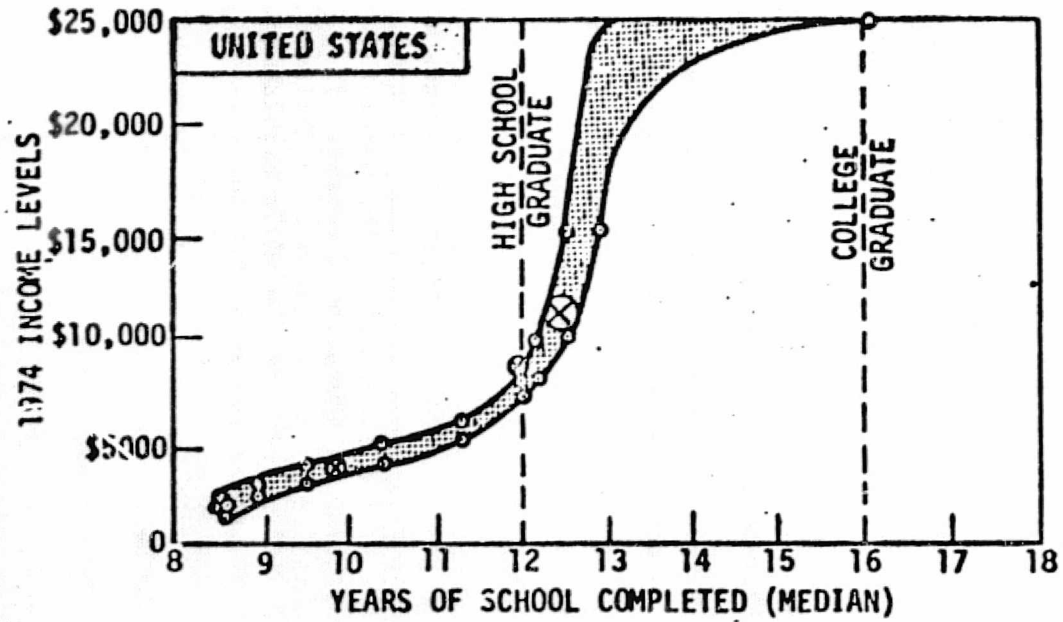
figure, only about 50 percent of the people in the United States are proficient in these simple areas of everyday living. Another 20 percent or so are just getting by, and approximately 30 percent are functionally incompetent even in these simple areas. Moreover, as the bar chart on the right-hand side of the figure shows, that portion of the American population between 30 and 40 years of age is significantly more competent than the more recent graduates from our school systems. This suggests that the quality of our educational system has been deteriorating in recent years.

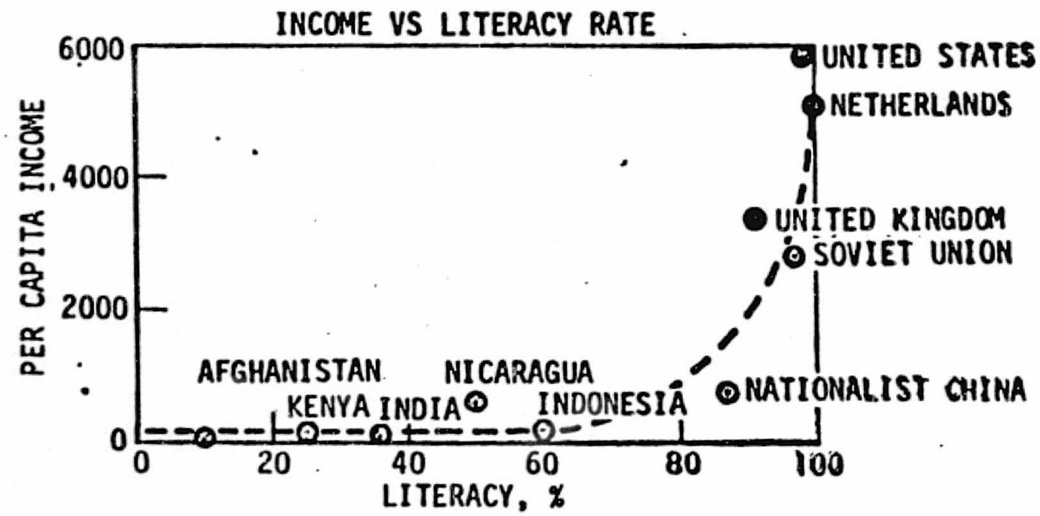
It might be suspected that this apparent deterioration has been caused by a reduction in funding levels. However, as the graph at the bottom of the figure shows, our expenditures for education have increased dramatically. In 1960, educational expenditures amounted to a little less than $30 billion per year. In the intervening years these expenditures have grown steadily. Today the total exceeds $120 billion per year. Moreover, the number of students in our school system has not grown substantially. In 1965, the number of students being educated was 55 million; in 1970 there were 60 million, Hence, it is clear that the per-student expenditure has increased by a significant amount over the past decade, but that there has been no corresponding increase in the quality of the graduates.

Many people suspect that the earning power of recent graduates has not kept pace with the increased earning power of laborers with lower skills levels. However, as indicated in Figure 12, there is a strong correlation between educational level and income on the job. For those families whose head had 12 years of schooling, the 1973 average income was between $7000 and $8000 per year. With just a few more years' education this value increased appreciably. In 1973, the average college graduate's family income exceeded $25,000 per year.

The per capta income of the other nations of the world is also strongly correlated with their average educational attainments. This is clearly shown by the graph at the bottom of Figure 12. Note that those countries with high literacy rates have correspondingly high income levels. Specifically, the literacy rates in the Netherlands and the United States exceed 99 percent, and the average per capita income is between $5000 and $6000 per year. In countries like Afghanistan and Kenya, where the literacy rates are 10 to 30 percent, the per capita income is only a few hundred dollars per year. Hence, it can be concluded that educational levels are strongly correlated with the ability to secure and hold a high-paying job.

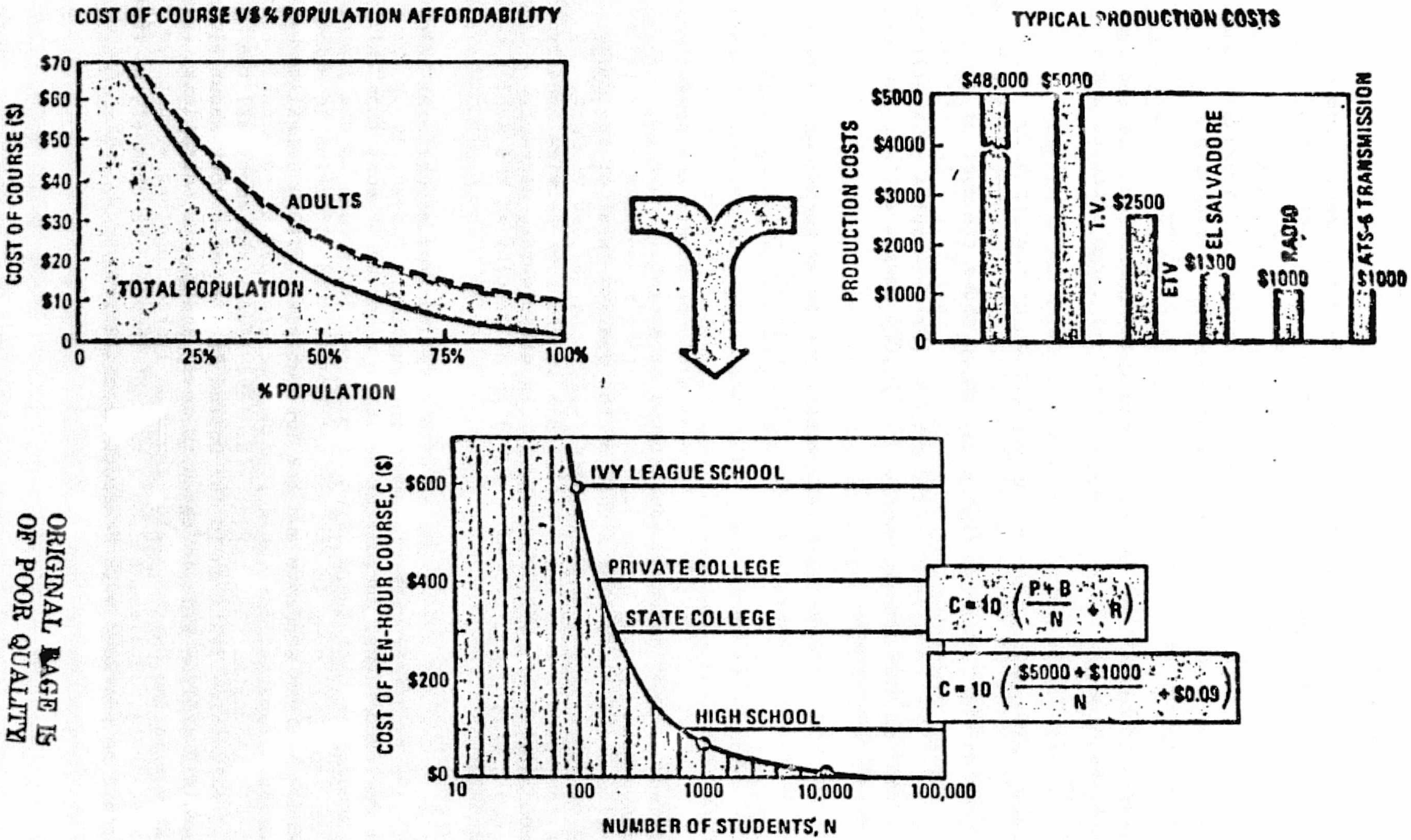
It has been asserted by some observers that the economics of broadcasting education from satellites is at best marginal. However, Figure 13 suggests that educational video programs broadcast from space can be highly economical. The graph in the upper right-hand corner of the figure shows the percentage of the population that is willing to pay to take an educational course. The information on this graph, which was compiled by our educational consultant, Dr. Kerry Joëls, shows that essentially 100 percent of the adult population in America would be willing to pay $10 to take a course within their special area of interest. As the price of the course increases, fewer and fewer people are willing to pay the fee. For example, if a course cost $70, only about 15 percent of the adult population would be willing to enroll — even if they have a specific interest in its contents.





*1977 CBS NEWS ALMANAC

Figure 12. Earnings Versus Educational Attainments*



*KERRY JOELS, CONSULTANT FOR THE SPACE INDUSTRIALIZATION PROJECT, JANUARY 1977

Figure 13. Electronic Education: Cost Parameters*

The total cost of a television course involves two crucial components: production cost and transmission cost. The production costs for a high-quality educational show like *Sesame Street* amount to about $48,000 per hour. Standard education television (of a lower quality) amounts to about $5000 per hour. Ordinary commercial radio production costs amount to about $1000 per hour. Hence, it seems reasonable that the cost of high-volume educational shows will probably range between $1000 and $5000 per hour. The transmission costs for the ATS-6 satellite amount to about $1000 per hour. Experience with the INTELSAT series of satellites indicates that this number could be reduced perhaps by a factor of 10 to 20 — particularly if large satellites are utilized in the broadcast operations.

Two values from this graph — the production of cost of $5000 per hour and transmission costs of $1000 per hour — were used in constructing a new graph, the one at the bottom of Figure 13, which shows the cost of a 10-hour educational course transmitted by an educational satellite. As this new figure shows, if 1000 or more students enroll, the per-capita cost will be less than a typical high school course. If 10,000 people enroll, the cost drops to only $6 per student.

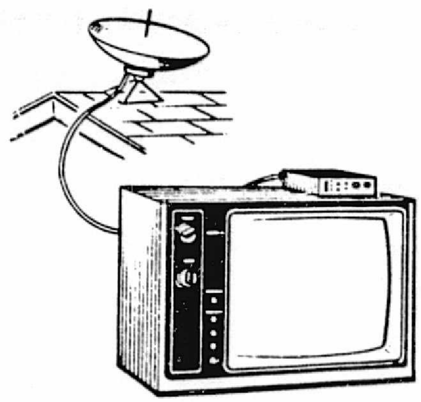
It is commonly believed that the general public is unwilling to watch educational television shows. However, Channel 28 (KCET-TV) in Los Angeles draws a generally favorable response. Their educational courses require 5000 to 6000 students to break even. A typical course on Channel 28 draws 7000 to 20,000 enrollees. Of course, many thousands of additional viewers watch the courses without enrolling. Exact audience counts are unavailable because ratings are not taken on educational broadcasts. However, Channel 28 does provide public service shows for which rating measurements are taken. Their experience indicates that a show of the quality level of the *Adams Chronicles* or *Civilization* *draws between 75,000 and 200,000 viewers*. By contrast, the non-network television broadcasts in the same service area typically draw between 120,000 and 300,000 viewers. In other words, non-network local TV is, at most, only about two to three times as popular as the public television channels.

Experience indicates that the results obtained from educational television usually compare favorably with classroom instruction. Indeed, it is the opinion of our educational consultant — after a survey of more than thirty published studies — that there is no significant difference in the learning level of the two media even in the present constricted situation in which there is no feedback between students and the instructors. With a satellite-based system, feedback capabilities could probably be provided at reasonable costs. A recent study indicates that terrestrial land-line links among all the educational television stations in the United States would cost about $10 million. If this same $10 million were invested in space links, the educational television stations in the United States could be linked together with three television channels, supplemented by a special interactive channel, so that the students could be provided with feedback capabilities.

Broadcast Education - Lesser Developed Countries

General Objective

The majority of the lesser developed countries tend to have widely dispersed populations and lack the infrastructure needed for adequate interpersonal communication and basic education. Yet, easy communication and widespread education is essential if these people are to emerge from a marginal-survival condition to produce a marketable surplus of goods and services. The essential key for development is not investment or relief, but education. A well-known quotation goes, "...*If I teach him how to fish, he can feed himself for the rest of his life.*"



- GROUND SETS MADE DURABLE INEXPENSIVE, AND EASY TO USE
- SETS SOLD IN SMALL COUNTRIES PICKS UP ONLY THE APPROVED PROGRAMS.
- TAILOR THE COURSES TO LOCAL SITUATIONS - EDUCATIONAL LEVEL, LOCAL JOBS, SPECIAL NEEDS

Figure 14. Broadcast Education - LCD's

Product to Earth

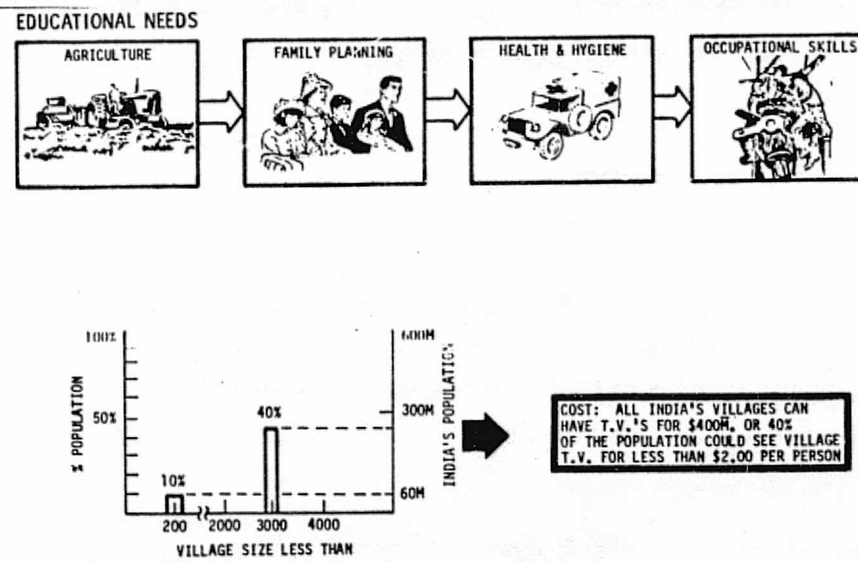
The primary product provided by this system is a means of communication linking those people who are now lacking the necessary facilities. In the general *first stage* case, two-way communication is not needed; but as the skills of the population improve, feedback for questions or opinions becomes much more desirable.

In the initial phase, local villages would be provided with a fixed-frequency television receiver. The receiver would be powered by locally generated electricity (wind, water or man-power). The receiver must be inexpensive, rugged and extremely reliable with a minimum of maintenance. Color transmissions are desirable, but not essential.

Each country would have a specific channel, 6 MHz in width at about 500 MHz frequency. The country itself would provide the necessary transmitter and the necessary programming facility. Channels would be assigned so that adjacent countries would be separated in frequency. The satellite would have one 52-foot reflector, with multiple feed assemblies to generate many spot-beams, each covering a circle about 1000 miles in diameter.

Key Objectives

To provide broadcasting facilities to aid lesser developed country's communication and educational needs, initiate productive efforts of peoples worldwide, and to stimulate markets for more advanced technological products.



*ADVANCES IN THE ASTRONAUTICAL SCIENCES, PROCEEDINGS OF THE AAS 19TH ANNUAL MEETING JUNE 19, 1973.

Figure 15. Electronic Education in the Underdeveloped Countries*

Principal Contribution

The principle contribution would be the development of worldwide capabilities for producing more food, material products, improved health education, and the other important benefits of communication that would result in areas that have not, and cannot afford, the cost of conventional methods. Each small country now has at least a few trained leaders who could, via satellite broadcast, share their knowledge with their people.

ORIGINAL PAGE IS
OF POOR QUALITY

Level of Contribution

The signals would be delivered to every small village, group or tribe that decides to watch and listen. Once installed, a single satellite could service an entire continent, such as Africa, at a cost that any nation could afford.

Uniqueness of Cont·ibution

Broadcasting from space eliminates geographical constraints and avoids the expensive alternatives of ground wire or radio installations.

Time Factor

The satellite design could be initiated immediately; no new technology is required. The ground receiver is based upon proven commercial designs and can be assembled by the resident population. The receiver is tuned to a single frequency, would have no external adjustments, and only one switch. Initial capability about 1980-ɔ5.

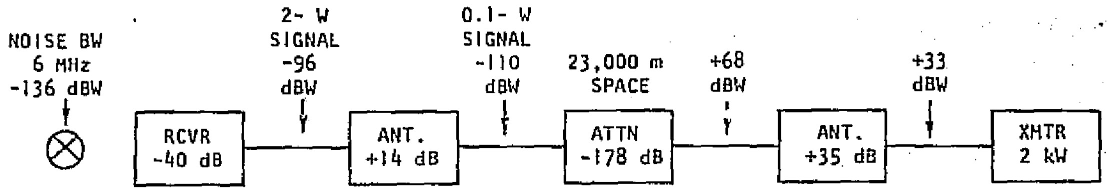
Principle Installation (Space Element)

Broadcast TV for lesser developed countries:

1. A single spot-beam 1000-mile diameter
2. A frequency of 500 MHz (lowest allocated frequency)
3. A noise-band width of 6 MHz (full-color TV)
4. Signal-to-noise ratio = 40 db for good TV picture, noise temperature = 300 degrees
5. Geosynchronous altitude

Space:

Antenna Beam Diameter	=	about 2.5 degrees (3 db)
Antenna Gain	=	35 db
Antenna Diameter	=	about 52 feet
Power, EIRP, per Channel	=	2 Kw
Transmission Efficiency	=	about 30 percent
Prime Power per Channel	=	about 7 Kw
Ground Antenna Diameter	=	5 feet
Receiver	=	fix-tuned at 6 MHz intervals



Principal Functional Units

Low-cost TV receivers with 5-foot parabolic antennas, powered by local generators. Central broadcast-preparation facility (one per country) and ground-to-satellite transmitter.

Principal Technologies

Medium size space antenna for UHF (500 MHz) transmission, plus necessary solar power assembly. One satellite may have 20 or more *spot beams*; however, only 3 or 4 may be in use concurrently. Thus, the prime power requirement may be no greater than 30 Kw.

Impact Spectrum

Technology	-	The necessary technology already exists
Economy	-	Great amount of wealth generated; much trade stimulated; greatly reduced foreign aid requirements
Environment	-	No impact
Social	-	Improved communication, government to people, would reduce inter-tribal rivalries and conflicts, stimulate productive competition
Political	-	Since each nation would control its own broadcast content, and each country has its own broadcast frequency, no conflict is foreseen. Widespread information should improve relationships between lesser developed countries and advanced countries
Scientific	-	No impact

Front-End Capital

Space element	-	About the same as one SBS satellite
Ground receivers	-	Assume 4M @ $100 each
Ground transmitters	-	About $100K each

Broadcast Education - USA

General Objective

To support and enhance the quality of our present educational system and to provide services for small, widely dispersed groups such as certain small businessmen and specialized hobbiests who find it difficult to obtain quality instruction in their specific area of expertise.

Product To Earth

Quality instructional programming in color broadcast directly to conventional TV receivers (with special antennas and adaptors) on several channels through most of the day.

Key Objectives

To provide supplementary instructional materials to aid classroom teachers in dispensing needed information to both general and specialized audiences.

Principal Contribution

A significant increase in the quality, timeliness, and impact of certain instructional materials. Because of the scale on which these materials would be broadcast and the electronic nature of the media, constant updating and correction of the broadcast material would be relatively easy to accomplish.

Level of Contribution

The material would be delivered directly to home receivers in every part of the continental United States. Our preliminary calculations indicate that approximately a half dozen continuous channels could be provided using a satellite system with relatively modest design characteristics.

Uniqueness of Contribution

Terrestrial networks could theoretically cover most of the country with similar broadcast materials. However, present cable and relay systems are significantly more expensive than space relay links. Moreover, many rural areas would not be adequately covered by a terrestrial network.

Time Factor

CONUS satellites available by 1987; extension to global area by 1995.

Principal Installation (Space Only)

Geosynchronous high-power, low frequency (UHF) multi-channel transmitter; each nation provides central preparation facility for own language, own culture, broadcasts.

Number of Beams per Satellite	=	100 for USA
Number of Channels per Beam	=	100
Bandwidth per Channel	=	25 kHz to 6 MHz
Power-Gain Product per Channel	=	30 db
Antenna Size	=	Approximately 60 feet
Prime Power	=	Approximately 150 kW
Orbit	=	Geosynchronous, Equatorial

Principal Functional Unit

Low-cost TV receivers, identical to existing sets, with simple 3-foot parabolic antennas pointed towards the zenith. Numerous course-preparation facilities (one per country). Commercial entrepreneurs prepare special-purpose courses, rent time on satellite (special unscrambler needed at receiver; sell courses to individual customers).

Talk-back requires adding small transmitter (audio) to user terminal, connected by wire to local center (urban and suburban) or by satellite to nearest center for rural areas. (One talk-back channel per broadcast channel.)

Principal Technologies

Large (space) antennas for UHF (100- to 400-MHz) transmission, plus necessary solar power assembly.

Impact Spectrum

Technology - Existing

Economy - Great reduction in property taxes as local schools are phased out of system. Improved trade with developing countries in global phase. Many jobs created to build ground system

Environment - No impact

Social - Great improvement in primary education; reassignment of many teachers/administrators to more productive roles; possible resentment of non-local school board control of subject matter. NEA and other teacher-union organizations may resist the implementation of the system and demand control of subject preparation

Political - Remove one source of racial conflict; improvement in international cooperation by interchange of subject material expands awareness of other nation's problems.

Scientific - No impact

Front-End Capital

About the same as one SBS satellite, plus ground terminal ($500M estimate).

Broadcast Education Discussion

In terms of technical feasibility, all the technology required in a broadcast education system has already been demonstrated. The only technical question is to determine what RF frequency allocations are to be allocated. One viewpoint is that the existing UHF TV channels, which are vastly underutilized, should be used. Only about 10 to 12 channels are needed, and every TV receiver must, by decree, be able to receive all these channels without modification. In this way, the burden upon the multi-million users would be minimized, with an increased cost at the satellite.

Another viewpoint is to select the most efficient RF channel, which is C-band, and develop an inexpensive down-converter (C to UHF) for the user's receivers. There are both positive and negative aspects for this approach.

Positively, it will generate a vast (about 100 million) market for a device to attach to the home TV receiver. Since many customers have shown a willingness to buy TV game attachments (about $65-$100), the cost may be bearable; but there are many families that cannot afford this much—this is the first negative aspect.

The second negative aspect is that this frequency allocation (C-band) is utilized by every existing communications satellite and all ground microwave relay terminals. The CCIR would have a great problem in achieving a selection of clear channels in this band for education. These are both technical and cost problems, but they can be resolved.

A full system would include the user feedback, and the quoted newspaper article indicates some of the potential. However, the initial system may be one-way, since its purpose is information dissimination to the ultimate user.

Adding the feedback capability at some later time need not include the satellite; more likely regional centers, each localized to a small community, would be developed. Here again, a large expansion of commercial activity is needed, but need not be charged to the user. Channels to display goods, materials, services would be leased to commercial enterprises, much as a newspaper or magazine displays advertisements. This alone should amortize the installation. Adding the feedback capability, orders for goods and services could be placed from the living room; add also, the electronic fund transfer capability, and credit transactions become possible. Again, accepting the concept of the initial installation, the expanding possibilities are staggering.

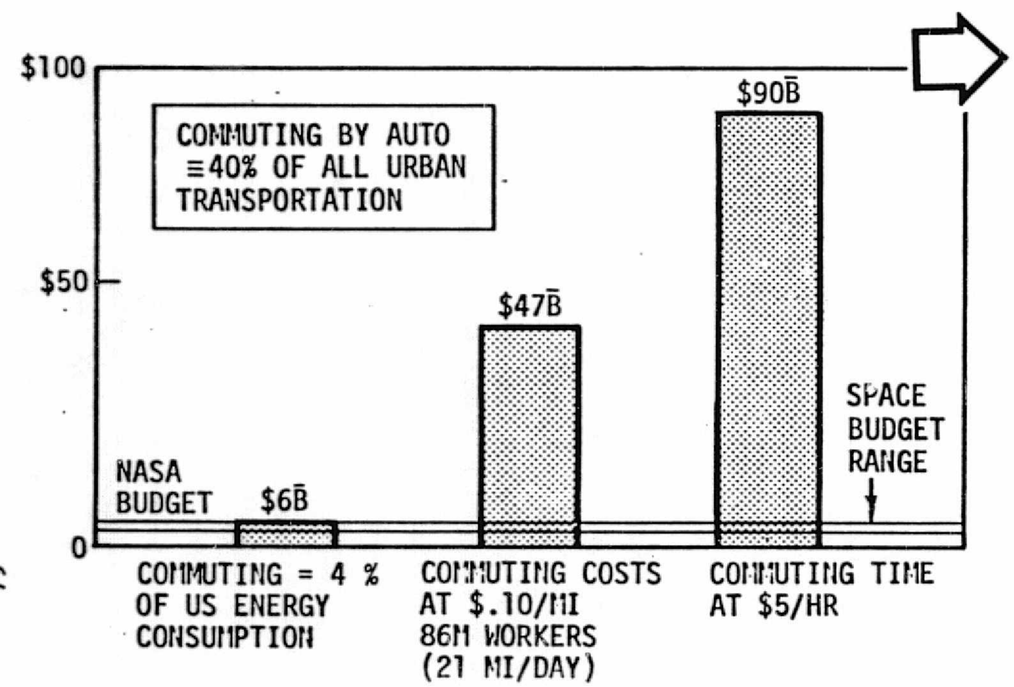
Electronic Telecommuting

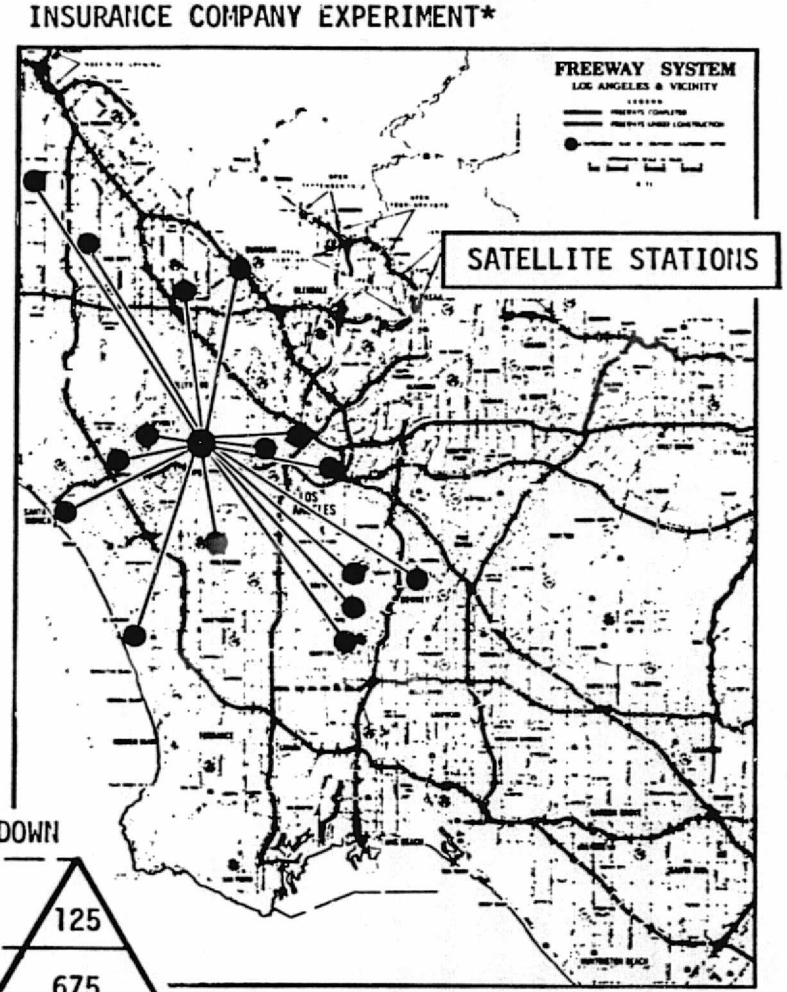
Electronic telecommuting is a concept in which workers would be linked to their offices electronically. Hence, rather than having to drive to work each day the worker operates from his home or from a small satellite office where he can interact electronically with machinery located at a central location. The fundamental advantage of such a system is that it reduces commuting to a minimum level. This saves fuel, transportation costs, and commuting time.

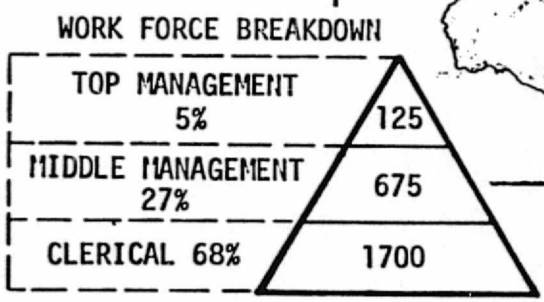
Commuting to work by automobile makes up about forty percent of all the urban transportation in the United States. This commuting consumes about four percent of all the U.S. energy — or about $6 billion per year in fuel costs alone. If commuting costs are calculated at $0.10 per mile, it costs American's 86 million workers about $47 billion per year just to get to work. Moreover, if commuting time is figured at $5 per hour, there is an additional cost of about $90 billion in lost time. Of course, this lost time could otherwise have been used to make a contribution to our productive capacity.

A recent electronic telecommuting experiment was conducted by a Los Angeles insurance company. Some of the details are summarized in Figure 16. Although this experiment did not utilize satellite relay links, it did provide some important incidental information on the practicality of a satellite system and on its economic viability.

The company, which was located in downtown Los Angeles, employed 2500 workers, 1700 of whom did routine clerical work that did not require face-to-face contact. The primary job of these workers consisted of entering data into computer







*TELECOMMUTING - A POSSIBLE TRANSPORT SUBSTITUTE, JACK M. NILLES AND PAUL GRAY. THE LOGISTICS AND TRANSPORTATION REVIEW, VOL II, NO. 2

Figure 16. Electronic Telecommuting

terminals. Because of high rental costs, the company officials decided to open two smaller offices in the San Fernando Valley. Then, rather than have all the workers report to the downtown headquarters, some of them (those who lived in the local area) were permitted to drive to the San Fernando Valley locations and operate electronic terminals whose impulses were transmitted to the downtown location. Because of the success of this operation, the company now plans to open two additional remote sites in the Los Angeles area. Using this practical experience as a guide, they have employed special computer simulations to determine the savings that would be achieved if they opened as many as 18 similar remote sites.

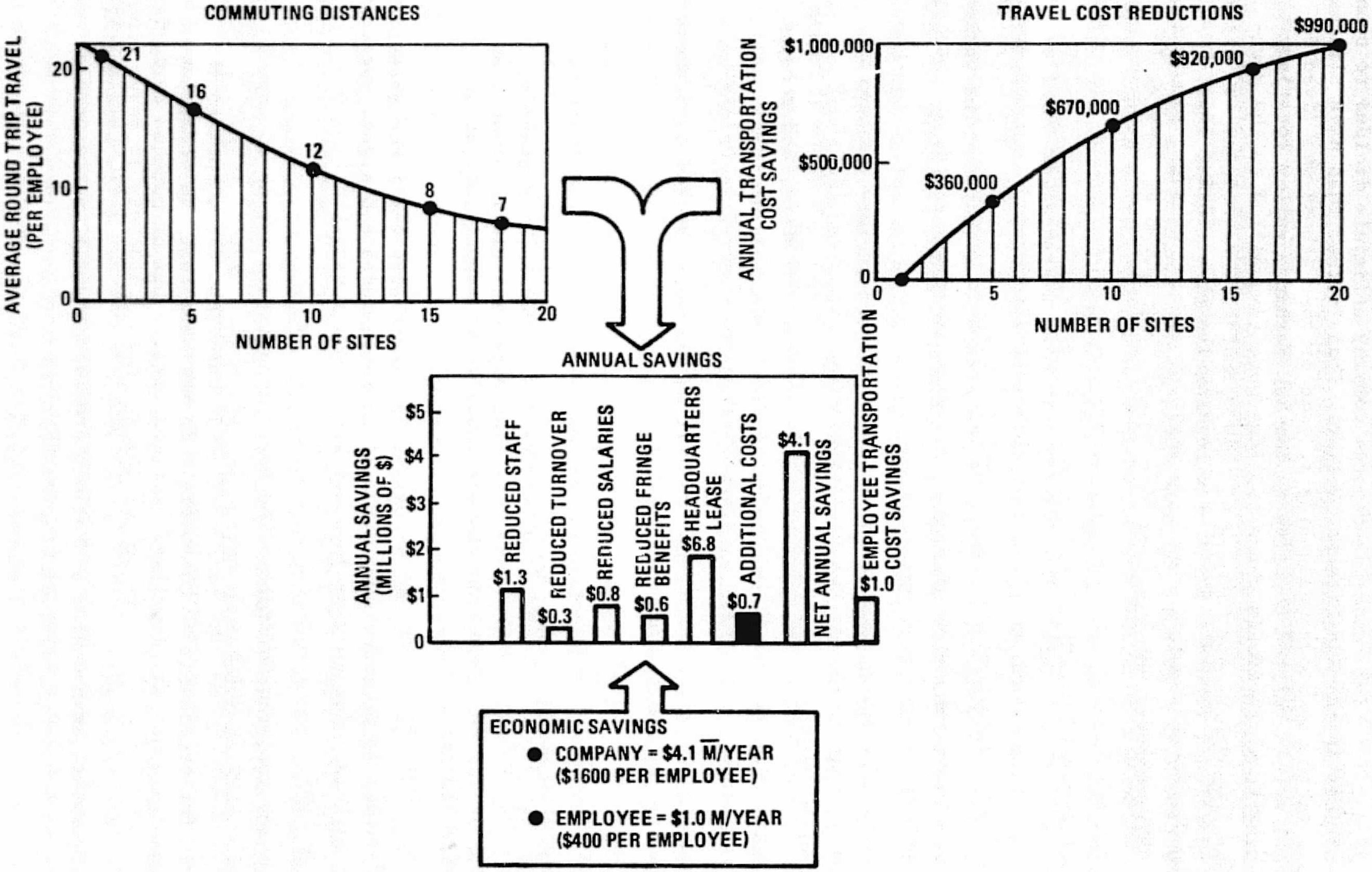
Figure 17 presents a plot of the number of sites versus the round-trip travel distance of the workers. The average commuting distance was 21 miles in the original system (when they had only the centrally-located headquarters). If they opened 18 remote offices, the average driving distance would be reduced to about seven miles per worker. A plot of the economic savings for the workers is shown on the right-hand side of Figure 17. With 18 remote sites, the savings would be almost $1 million per year.

The bar chart at the bottom of the figure shows the various component economic savings that resulted from this experiment. The most important savings for the company consisted in reduced headquarters lease costs (because the satellite terminals were located in the lower-rent districts, and reduced salaries (premium salary rates were not necessary in the more desirable San Fernando Valley area). In addition, the employees saved about $1 million in reduced transportation costs, so that the net total savings for this telecommuting experiment amounted to about $5 million per year, spread over about 2500 employees — or about $2000 per employee.

If such a system, using satellite relay links, could be installed, the geography could be completely removed from commuting to work. In essence, workers could live anywhere they chose. Operations of this type could easily be conducted within the continental United States. Workers, for example, could live in rural areas and perform jobs that were essentially urban. An alternate use of the telecommuting concept would be to export jobs across international borders.

Production jobs have often been exported to areas with low labor rates. For example, vinyl jackets are mass-produced in South Korea and alpaca sweaters are made in Bolivia. But service jobs are not normally exported from one country to another.

A few years ago, the California Teachers' Association set up an export system of this type in which they routinely flew their computer source documents to Taiwan for keypunching. The completed cards were than flown back to the United States for processing by computers. It may seem that the economics of such a system would not be favorable. But, in fact, a box of punched cards is worth between $40 and $140. This box of cards, which weighs six or seven pounds, can be flown from Los Angeles to Taiwan for about $6. Thus, it is economically reasonable to export keypunching operations provided there is a reasonable differential in the labor rates of the two countries.



*"TELECOMMUTING - A POSSIBLE TRANSPORT SUBSTITUTE", JACK M NILLES AND PAUL GRAY THE LOGISTICS AND TRANSPORTATION REVIEW, VOLUME II, NUMBER 2.

Figure 17. Electronic Telecommuting: A Practical Experiment*

Rockwell International
Space Division

However, despite the cost savings, the time delays were somewhat inconvenient and the California Teachers' Association now has its cards keypunched domestically. However, with an electronic system using satellite relay links the keypunching operations could be accomplished instantaneously. In such a system the source documents would be transmitted via facsimile machines to the distant country; the keypunching operations would then automatically transmit pulses at electronic speeds back to the location of the computer. Such a system might be called an *electronic cottage industry.* A very small amount of equipment could be located in a distant village where labor rates are low, and it would allow the export of the services jobs without bringing in immigrants from other countries.

In a sense, electronic teleconferencing is a variation of electronic telecommuting. In electronic teleconferencing, busy executives would utilize electronic means to transport visual images of themselves to distant locations rather than making the trip in person. But, is there enough money now being spent in the United States for commuting by airlines to distant locations to justify such an elaborate system? In 1975, the total revenues for all the airlines in the United States amounted to about $15 billion. Of this, $12 billion was for passenger transportation; 46 percent of this $12 billion figure — or over $5 billion — was spent on business travel. So it is clear that there is a large potential for electronic teleconferencing, assuming that the system could be made to work in an economical way. In addition to the travel cost savings and the labor and fuel savings of moving these people to distant locations, there are significant time savings.

Dr. Jack M. Nilles, at UCLA, has conducted detailed studies* of electronic teleconferencing. He concludes that television images are not necessary for effective teleconferencing. In fact, according to Dr. Nilles, only two things are needed for an effective teleconferencing system: strong leadership to control participation at both ends of the conference and a sterophonic sound system.

It has been estimated that 20 percent of the jobs in America could be decentralized through the use of the high-quality communication facilities that could be developed in the era of *space industrialization.*

Some of the overall savings that could be achieved through a widespread use of electronic telecommuting are shown in Figure 18. The curve in the upper left-hand corner of the figure shows the number of cars that are expected to be on our highways over the next few decades. The curve in the upper right-hand corner represents the cumulative number of miles per year that would be driven by these automobiles.

Because of the increases in the efficiency of automobiles, a welcome plateau in fuel consumption eventually will be achieved. However, such efficiency increases will not likely be sustained forever and the curve eventually levels off. If telecommuting becomes a major factor in this same time period (and we think it can), the number of miles driven will begin to level off as shown in the upper right-hand corner. The corresponding fuel

*Nilles, J. M. and P. Gray, *Telecommuting - A Possible Transport Substitute*, Logistics and Transport Review, Vol. II, No. 2 (1975).

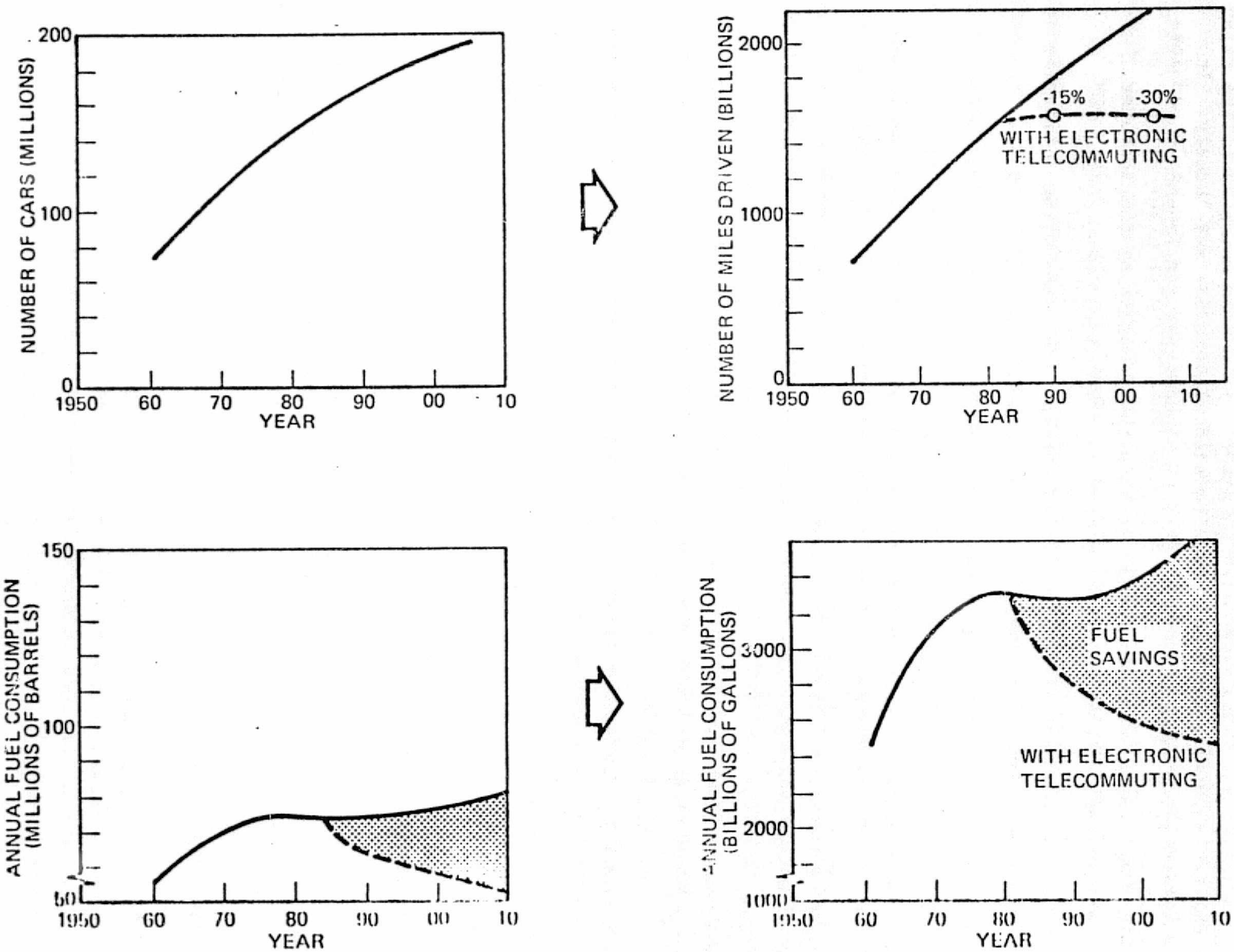


Figure 18. Savings Through Improved Communications

ORIGINAL PAGE IS OF POOR QUALITY

Rockwell International
Space Division

savings, starting at this point, show up in the strongly modified consumption curve in the lower right-hand corner of the figure. Assuming that oil costs $15 per barrel, these savings could amount to approximately $60 billion in 1990 and $120 billion a decade later.

The direct implications of these savings to our national economy are obvious. Additional fringe benefits include time savings for commuters, reduced pollution, reduced traffic jams, reduced accident rates, and reduced maintenance costs for the automobile owners. This system, if it can be implemented, may be less expensive than the rapid transit systems which are now being envisioned, and it accomplishes similar objectives with less fuel consumption. Moreover, this approach would keep Americans in their cars rather than forcing them into public transportation, thereby retaining the job-related advantages of the automobile industry and its large infrastructure.

Electronic Telecommuting

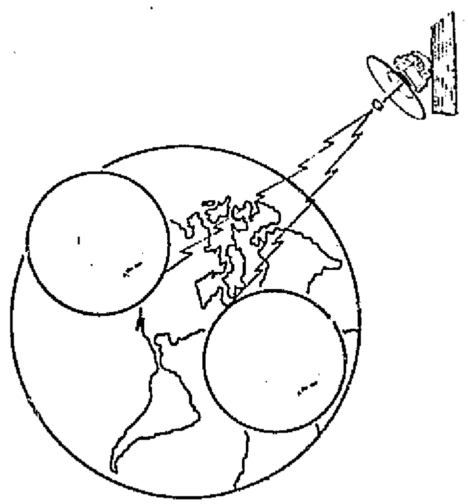


Figure 19. Electronic Telecommuting

General Objective

About 20 percent of our present workers perform office jobs at some central location. Their duties include handling records, thinking, writing — none of which require the use of specific machines. Many of these jobs could be carried out anywhere, since it is individual, not group, effort. Application of todays technology could, and soon will, implement an *office-at-home* or at least near the home.

Product to Earth

Conservation of resources (gasoline); improvement in office work productivity; reduced environmental pollution; reduced congestion in cities and freeways.

Key Objectives

Using communications, *intelligent terminals*, and a CCTV approach, the usual office job could be accomplished by allocating one room at home to be an office. Even today, it is less costly to use a geosynchronous communications relay link than conventional landlines for long-distance telephone calls for distances as short as 600 miles. The combined recurring and non-recurring costs for implementing the *office-at-home* would be more than offset by the reduction in automobiles, gasoline and highway maintenance. An additional fringe benefit is a gain of one or two hours per day not spent in purposeless travel.

Principal Contributions

Application of this concept would reduce our dependence on imported oil, reduce urban pollution (smog) and congestion; eliminate roughly 10 hours per week per person of non-productive, irritating travel time (commuting). It would also eliminate large amounts of duplicated paper products (reports, slides, etc.).

Level of Contribution

Every individual in urban and suburban areas would benefit: the *white-collar* workers by not commuting, the construction and manufacturing workers by easier access to roads, streets, parking; significantly cleaner air; easing of balance of payments (because of reduced gasoline consumption).

Uniqueness of Contribution

Very few office work activities require eyeball contact; where necessary, the CCTV provides an admirable, and even advantageous alternative. It is easier to concentrate on one small screen than trying to watch a whole roomful of displays. Attention can be directed to the major points of emphasis; even hard copies can be transmitted if necessary. Moreover, the worker is not limited to a home in the suburbs; he could just as well live in Bali — communication time is the same, and just as clean and convenient. And there is an additional advantage of such a system: office workers differ in the time of day they are most productive — some in the morning, some at night. With this concept, the worker's time need not be synchronized with the clock; they can do their work when they were most productive.

Time Factor

Initial dispersion (United States Government services) by 1990; extend to the United States commercial by 2000.

Principal Installations

Space - One or more high-power communication relays

Ground - Many small remote *intelligent* terminals and low-power transmitters. Preferably at EHF (10- to 900-GHz); several thousand audio band channels for multiple random access

Principal Functional Units

Space - The space element would be useful only for long distance communication. Regional linkages by fibre optic cables similar to present telephone or CTV installations. Where needed, the space element would be analogous to the Satellite Business System Satellite. No new government-funded satellites are needed.

Ground - Extension of CTV and/or telephone networks to individual terminals in small, neighborhood centers (10 to 100 workers); later to individual homes. Neighborhood centers include roof-top antennas for satellite linkages.

Principal Technologies

All existing except high-power transmitter at K-band or higher.

Impact Spectrum

Technology - Very small additional requirements

Economy - Billions of dollars saved by reducing reliance on automobile transportation, less gasoline consumption, etc. Millions of dollars added to the economy by increased productivity, relaxation of tension, etc.

Environment - Reduce pollution significantly; reduce centralized congestion; improve housing problem

Social - Significant improvement in life style for many; should show immediate public acceptance

Political - No immediate impact; long range may have effect of wide-scale decentralization

Scientific - No impact

Front-End Capital

Space terminal about $50,000,000; ground terminals for $3,000 each (10 million terminals).

(

Personal Communications (Pocket Telephones)

A personal communication system can be regarded as a portable telephone which you carry in your pocket or strap to your wrist. The technical problems associated with such a system are quite intriguing. However, before we discuss the mechanization of the personal communication system, let's look at some background material on personal communication activities in the United States.

In recent years, the United States has experienced an explosion of interest in personal communication activities. As Figure 20 shows, approximately 2 billion long-distance calls were placed in the continental United States in 1955. By 1975, the number of calls had grown to 11 billion. In the same 20 years, the number of telephones in the Bell System increased from 45 million to 120 million. The total number of phones in the United States (including those outside the Bell System) is about 144 million. Thus, we have almost one telephone for each American citizen.

In 1975, there were only about one million citizen band radios in operation in the United States. Within 18 months, this number had grown to six million, and sales are still continuing at a high level. The Federal Communication Commission recently estimated that the number of citizen band radios in the United States will peak out at about 40 million, or approximately one citizen band radio for each American family.

Viewed as a whole, personal communications activities are quite profitable. In 1973, the revenues collected by Bell Telephone totaled $28 billion. In that same year, total revenues for all forms of personal communications amounted to about $40 billion.

As has been mentioned, a personal communication system can be regarded as a portable telephone. However, it is much more than that; it has some rather intriguing characteristics. For one thing, it is a telephone on which you can reach the desired party without knowing his exact location. Moreover, the time charges for the use of such a system are independent of distance, and, hence, it removes the geography from long-distance communication. Once such a system is operational, it will be just as cheap to call coast-to-coast as it will be to call your next-door neighbor. At this point, certain services which now penetrate only local markets will become national or international in scope. For example, rather than calling your local reference librarian, you will be able to call the reference librarian at the Library of Congress at the same cost. Stock market quotes, sports statistics, and other services of this type also will be available on a national basis. And once they become national, they can rapidly expand in quality and quantity. When the Library of Congress begins to receive tens of thousands of inquiries daily, it can justify the use of computer search procedures, high-paid academic experts, 24-hour-a-day services, etc.

Additional communication links can be established in conjunction with the personal communicator system. For example, the units can be linked into nationwide paging services, telephone hookups, time-synchronization services, and possibly other services of this type. The devices also will have increased versatility. In the long run, the units will incorporate electronic calculators, electronic wristwatches and, perhaps, devices which provide navigation services.

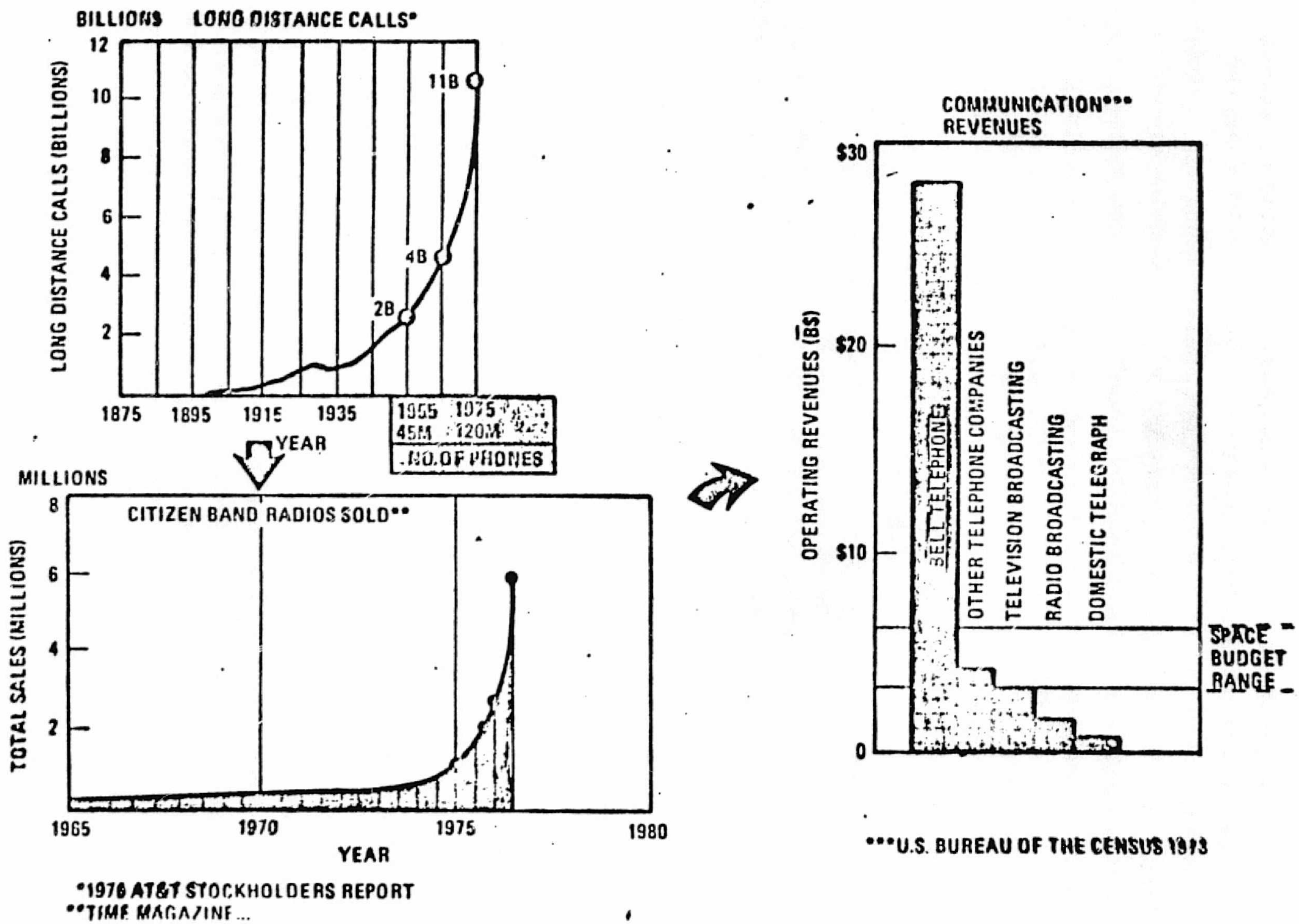


Figure 20. Current Personal Communications Activity

Personal Communications (Pocket Telephone)

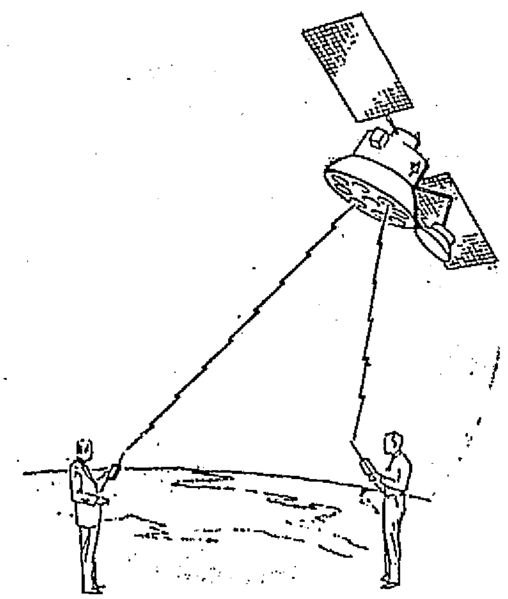


Figure 21. Personal Communications Systems

General Objective

To provide personal communications capabilities to all interested Americans or at least a significant fraction of the general public.

Product to Earth

Communication capabilities of unprecedented power and flexibility.

Key Objectives

To allow any user to communicate with his colleagues on a nearly instantaneous basis, even if their exact locations are unknown. Also to open up nationwide services such as library information to a broad segment of the general public.

Principal Contribution

Nearly instantaneous communications with friends and colleagues even under relatively adverse conditions.

Level of Contribution

Initial system would serve approximately 2.5 million users at an average usage rate of 5 percent. Later, this system could serve the entire American population provided sufficient bandwidth can be obtained.

Uniqueness of Contribution

Terrestrial communication links could provide some of the envisioned services, however, it does not seem possible to install a nationwide system at a reasonable cost without satellite relay links.

Time Factor

Initial system could be available in the 1985 time frame. Full, nationwide system could be operational by 1990.

Principal Installations

Large array of multi-beam antennas (approximately 200 feet in diameter) located in a geosynchronous orbit. Initial system would require 3 to 5 antennas; the nationwide system may require as many as 30 antennas of similar size. Raw power is defined as approximately 3 watts per user. This, in turn, necessitates a solar collector of approximately 65,000 ft^2 per antenna.

The earth installations include the communicator units (hand-held or wrist models), the billing system, and central control station which maintains the operational integrity of the system.

Principal Functional Units

Principal space units consist of one or more large multibeam antennas which relay messages to various points within the continental United States. The antennas will likely be rigidly attached to facilitate mutual message exchanges. However, they could, instead, be electronically crosslinked.

Principal Technologies

The principal technologies necessary to make the system operate include complicated switching electronics, large multibeam antennas, accurate figure control methodology, and advanced thermal control techniques.

Impact Spectrum

Spectrum availability will constitute one of the major socio-economic problems associated with the personal communications system. The full-service system would require a bandwidth of 500 MHz or more. Theoretically, this much of the spectrum could be used for the envisioned purposes, but this would require delicate international negotiations. Political conflicts with existing communications carriers, such as AT&T, also seem likely to many observers.

Front-End Capital to First Prototype

The investment necessary before the system can bec. ne operational is on the order of $450M. However, this expenditure would also enable the implementation of the National Information Service opportunity in as much as they both require identical space hardware. The annual operating cost for the space segment is estimated to be $12.3M in 1977 dollars.

Implanted Sensor Data Collector

General Objective

To provide the service of receiving data from any earth source and returning appropriate information to the customer.

Product to Earth

Timely accurate, processed information. Examples are:

a. Read-out of water level sensors for control of dam gates
b. Emergency help to people in distress
c. Sensors in cows to tell when they are in-heat for artificial insemination
d. Environmental data from remote or ocean locations
e. Fire warnings from heat or smoke sensors
f. Burglar or vandalism warnings from entry or noise sensors
g. Sensors throughout a huge strip mining machine (operating on a winter night in Montana) sending up data to be processed on a large computer to warn of an impending failure
h. Etc., etc., etc.

Key Objectives

To open up a profitable service whereby we could use one satellite system and get paid by a multiplicity of users. It would also open up a wide variety of small business opportunities and new jobs on earth as more and more ideas for products and services could be keyed to this capability.

Principal Contributions

The service of receiving almost any kind of data from anywhere within the covered region (like the continental United States) and either relaying it on to its user and/or providing time share computer power to convert the data to information directly to the user.

Level of Contribution

This depends on the economics of sharing the cost of the service across a large number of users. Each user could presumably handle his own communications with dedicated radio transmissions or wire links, their own computers, etc. However, if the space service were offered, there is a strong probability that ingenious uses would multiply rapidly. In such a case, this could become a multi-million dollar service industry.

Uniqueness of Contribution

It is difficult to interconnect moving things electronically with hills, buildings, and other barriers in the way. Hard wire systems are out of the question for devices like combines, earth movers, etc. For stationary devices, time-shared systems wired to earth computers are formidable competitors, particularly in urban areas. Outside the cities, there may be economies in a space link, but we could nearly always, with sufficient investments, put in hard wired connectors.

Time Factor

Mid-1980's.

Principal Installation

The space portion is basically a large antenna, perhaps including a large orbiting computer. The ground portion is a multiplicity of users, each with a transmitter and a small antenna. (Note: these transceivers need not be as small as the two-way wrist telephones envisioned for personal communications.)

Principal Functional Units

Antenna-like large structure in space, probably unmanned.

Principal Technologies

Large structures, computers, and coding/decoding devices to make maximum use of scarce bandwidth. Minimum-cost ground transmitters.

Impact Spectrum

No significant impact.

Front-End Capital

To be determined.

National Information Services

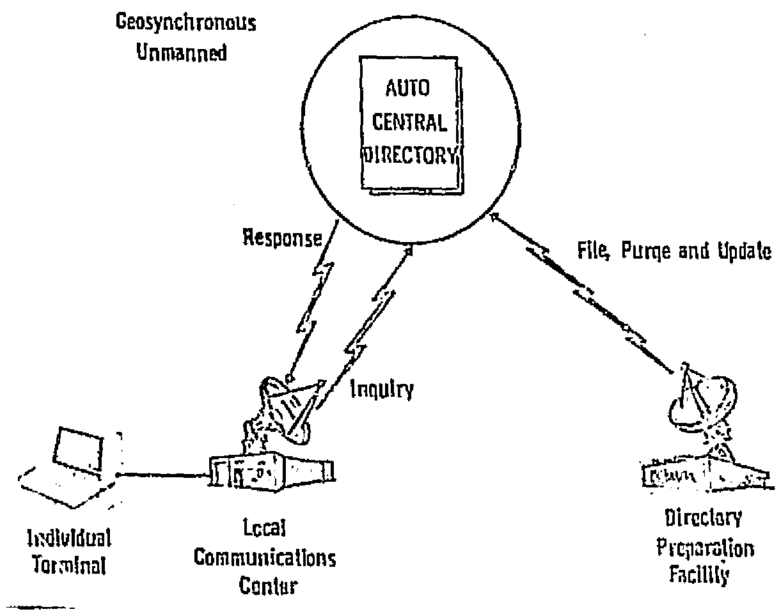


Figure 22. National Information Services

General Objective

The percentage of human time wasted in re-inventing wheels is incalculable; this is due primarily to lack of knowledge of *where* to find information about these previous solutions. All manner of ground information banks exist, and continue to proliferate. What is needed is a directory keyed to the user's problem description.

Such a directory could be implemented on the ground, using a geosynchronous satellite relay; however, each inquiry would then require four channels, two up and two down. If the directory were installed in the satellite, only one half-duplex channel per user is needed. To serve the public, several hundred simultaneous channels would be required. Each channel would have its own microprocessor to access one common mass memory. Updating, file maintenance, purging, etc., could be uplinked, perhaps once a day.

Product to Earth

Rapid access to sources of data relevant to all levels of technical, social, environmental and other concerns. Data banks exist at numerous governmental agencies, universities, and commercial operations that can be made available, for a nominal fee, to those individuals who are attempting to evaluate a problem and formulate a feasible solution.

Key Objective

Provide a common, easily available directory similar to the Federal Information Center (Los Angeles); a telephone call will receive information on where to find the desired service, what agency, telephone numbers, mail addresses, application forms, etc. Expand this concept to include civilian and commercial data banks, and include sufficient automatic data processing for file search and retrieval (analogous to a library's card catalog or periodical indexes).

Principal Contribution

Provides a single reference source wherein available knowledge can be readily accessed by any individual.

Level of Contribution

Usable by anyone with access to an *intelligent terminal* connected to local ground communications terminals.

Uniqueness of Contribution

Combines in one address many data sources that exist, but are not generally known. Example: Few potential users of earth observation data are aware that there is a National Earth Observation data bank in South Dakota from which copies of LANDSAT-type data (false color photographs) can be obtained. The potential economic benefit of these photographs is enormous, but will not be realized until the concerned users know about it, and how to get it.

Time Factor

Ground-based central directory about five years; transfer to a geosynchronous facility by 1990; expansion to full commercialization by 2000.

Principal Installation

Centralized directory file preparation.

Principal Functional Units

Space geosynchronous automatic directory; ground, directory update facility.

Principal Technology

Information management; develop universal file search and retrieval syntax.

Impact Spectrum

Technology - Within present state-of-the-art

Economy	-	Increased productivity by avoiding redundant work. Potential commercial (non-Government) operation utilizing DOMSAT-relay in initial stages. Employment of large numbers of personnel to collect, abstract and develop the directory.
Environment	-	No impact
Social	-	No impact
Political	-	Would improve visibility of Government services, and relate use of public tax funds to individual benefits

Front-End Capital

Directory data base about $500M; Geosynchronous Directory about twice that of a DOMSAT relay.

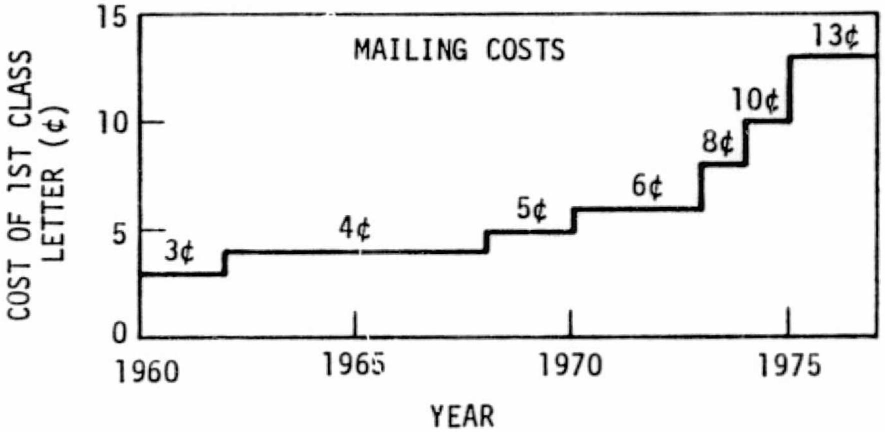
Electronic Mail

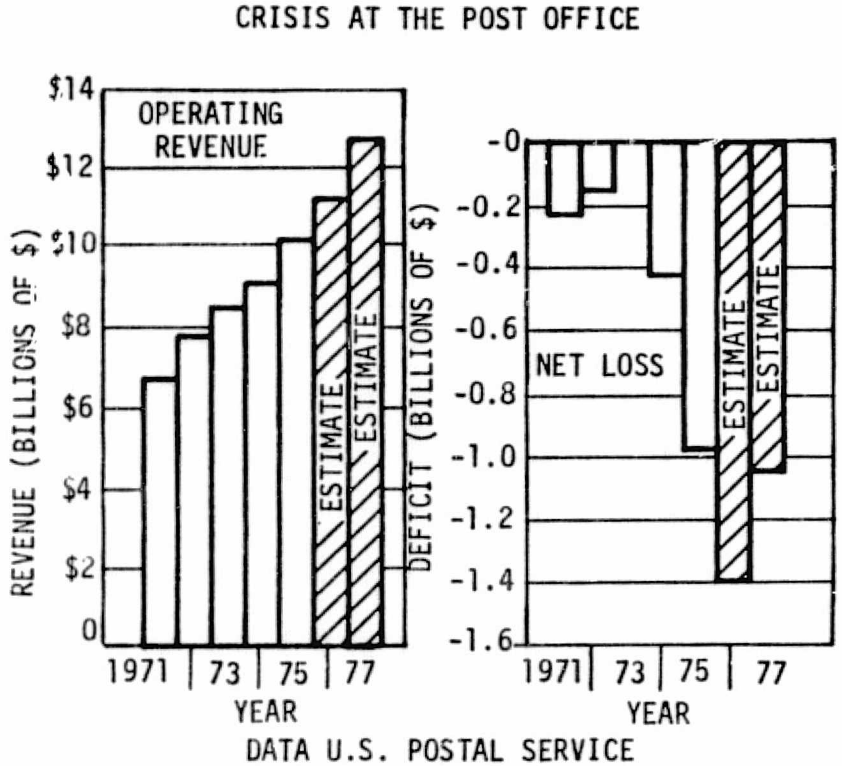
Despite increasingly large expenditures, the American Postal System has become a large, complicated bureaucracy, barely able to carry out its functions. At present there are about 31,000 Post Offices in the American Postal System, supplemented by 10,000 branch offices and substations. These Post Offices handle approximately 89 billion pieces of mail, or about 2,000 pieces for each American family. In addition, they handle 16 billion packages in an average year; most of them associated with business transactions.

Between 1960 and 1977, the cost for a first class letter was increased from 3 cents to 13 cents (see Figure 23). It will probably reach 16 cents next year and long-term projections indicate that in the early 1980's it will cost approximately 34 cents to mail a first class letter.

When the Post Office became a private corporation a few years ago, deficit spending was to be eliminated within a short time. However, in the interim deficits have actually increased. Recently they have exceeded $1 billion per year. Because of these enormous deficits, rumors of service cuts are widely circulated. Specifically, Saturday delivery may soon be eliminated. third class mail may be delivered only on alternate days, certain business deliveries may be curtailed, and curb-side mail stations may be installed in new suburbs. Unfortunately, these service cuts typically involve savings of only about $100 million or so each, less than 10 percent of the current deficit.

Thus, it would seem that the Post Office is in desperate need of new techniques for streamlining its costly operations. One concept calls for the electronic delivery of mail. In the simplest version of the electronic mail concept (see Figure 24), the mail would be picked up and delivered to the local Post Office in the conventional way. Once there, it would be transmitted electronically to the destination Post Office via a satellite relay link using facsimile techniques. The reconstructed letter would then be delivered to the proper party by conventional procedures.



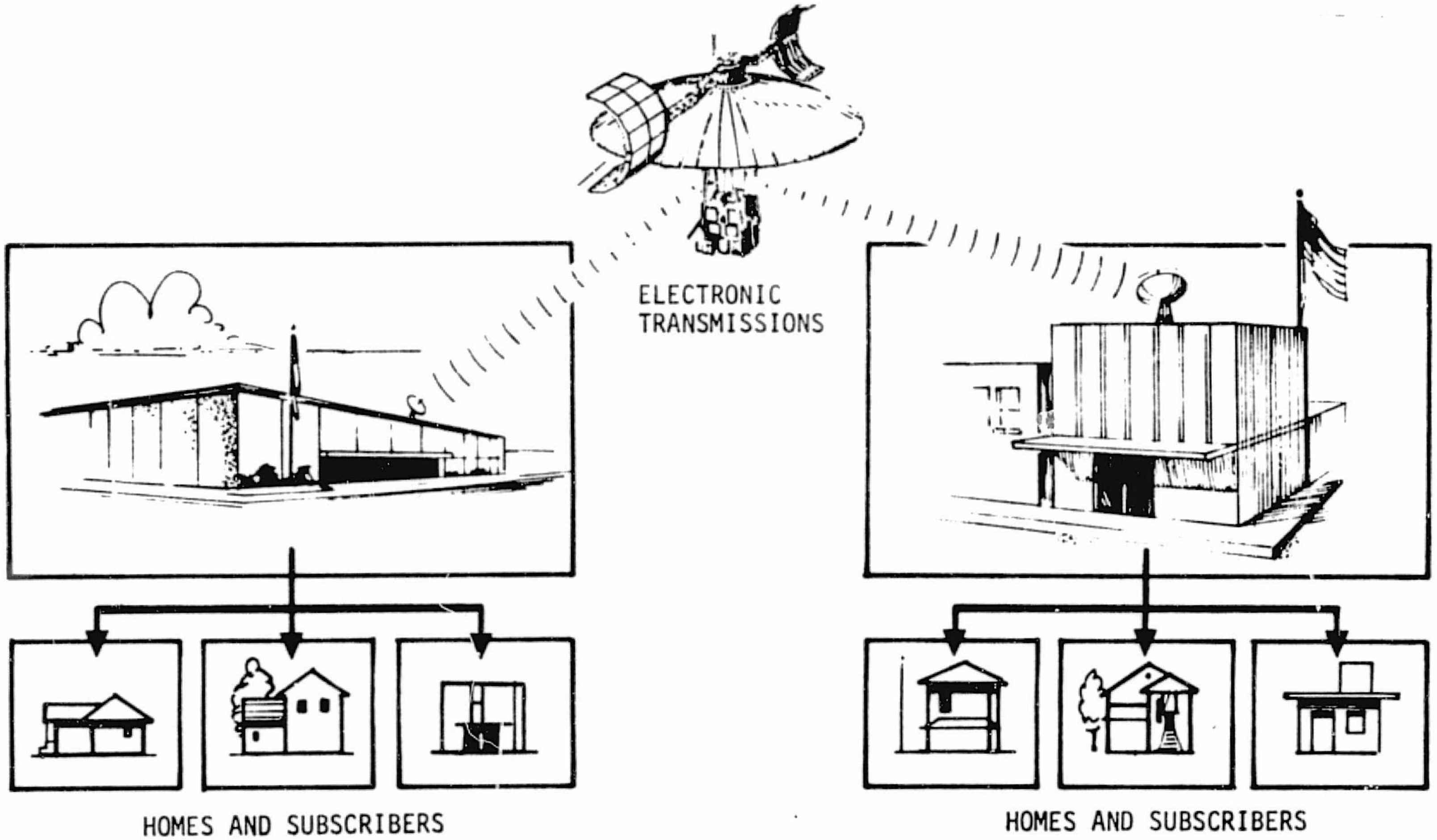


- 31,000 POST OFFICES PLUS 10,000 BRANCHES AND SUBSTATIONS
- HANDLE 89 BILLION PIECES OF MAIL (~2000/FAMILY) (PLUS 16 BILLION PACKAGES)
- 1% OF ENTIRE AMERICAN WORK FORCE WORKS FOR THE POSTAL DEPARTMENT

RUMORS OF SERVICE CUTS

- NO SATURDAY DELIVERY
- ALTERNATE DAY DELIVERY OF 3RD CLASS MAIL
- BUSINESS DELIVERIES ONCE A DAY
- CURBSIDE MAIL STATIONS, ETC., ETC.

Figure 23. Electronic Mail



ALTERNATIVES

- DISTRIBUTED PRINTING SYSTEMS (WALL STREET JOURNAL, U.S. NEWS USING NOW)
- ELECTRONIC FUNDS TRANSFER SYSTEMS (65% OF FIRST CLASS MAIL INVOLVES FINANCIAL TRANSACTIONS)

Figure 24. Mail Delivery Methods

At first thought the major savings associated with electronic mail might seem to be the transportation costs. In fact, however, the potential savings in sorting costs is considerably more important. Last year the operating budget of the Los Angeles Postal Department was broken down as follows: 55 percent for sorting the mail; 38 percent for delivery.* Some of the sorting operations have been mechanized, but at the present time the fastest mechanical devices can sort only about 3200 letters per hour. Moreover, the sorting machines often damage important letters. In an electronic mail system the sorting operation would be performed electronically. That is, the contents of the letter would be transmitted to the proper destination without mechanically moving the letter itself into separate bins. This could significantly speed the sorting operations.

Electronic mail system could take several alternate forms. Distributed printing systems are one promising possibility. In a distributed printing system, the copy to be printed is composed at a central location (e.g., New York or Washington) and the individual pages are electronically transmitted via facsimile to the proper destinations where printing presses duplicate them on a mass scale for subsequent distribution. The Wall Street Journal, U.S. News World Report, and several other national magazines and newspapers are already distributed in this way. Theoretically, such a system could be operated by the Post Office. It could be particularly effective if it were used in conjunction with nationwide advertising circulars. The primary advantage of a distributed printing system is that millions of copies can be transported to distant locations with only a few low-data-rate transmissions.

Electronic funds transfer systems offer another possible alternative to our present antiquated mail system. About 65 percent of all first class mail involves financial transactions, e.g., bills, receipts, invoices, etc. An electronic funds transfer system circumvents the physical delivery of these bills and receipts by transfering funds from one bank account to another electronically. Large banks and financial institutions are already operating electronic funds transfer systems. In theory, the Post Office could also operate such a service. With satellite relay links it could probably be operated nationwide at economically feasible rates.

Electronic Mail Service Discussion

In analyzing space opportunities associated with electronic mail, it became very apparent that the analysis, economic merits, and conclusions were highly sensitive to the assumptions that were made. Dynamic changes are occurring across the entire communication/data transmittal field. For example, the expanding use of word processors, facsimile devices, and electronic funds transfer systems will all diminish the use of postal services as they currently exist. In addition, telephone rates have been decreasing at the same time that mail rates have been increasing. An analysis, which assumed a substantial diversion of data transmission from conventional postal channels to private electronic systems, is discussed in this section. It assumed a dedicated satellite and reached negative conclusions concerning

*Delivery includes essentially all the productive operations except sorting.

the economic viability of electronic mail. However, in order not to overlook a potentially promising area, another analysis was made in which electronic mail was combined with other similar services requiring the transmission of large volumes of information.

In keeping with this new philosophy, the new baseline electronic mail concept assumed that 40 million pages would be transmitted nightly. The letters, which would be written or typed on a standard form, would be delivered to local Post Offices during late afternoon or early-evening hours. The letters would then be physically transported to one of 800 regional Post Offices where the destination of each letter will be identified from its ZIP code, the letters opened by machinery, and a facsimile of the letter transmitted via satellite relay to the regional center servicing the destination area. After facsimile transmission, the original letter would be momentarily held by the automated machinery pending receipt of a *received satisfactorily* signal. Upon signal receipt, the letter would be automatically shredded. If the letter was not satisfactorily received, it would be remerged into the basic letter flow for another try.

At the receiving regional center, the letter facsimile would be automatically folded, sealed, and sorted by ZIP code. The letters would then be physically transported to the local Post Office for delivery that day.

Each regional center was assumed to have an 8-foot antenna for transmitting to the relay satellite on a frequency of 30 GHz. The satellite would have six pairs of antennas (8-foot diameter to receive, and 12-foot to transmit) and would require 13,000 watts of primary power. It would analyze the ZIP code and route the data block to the appropriate transmitting antenna. Each of the six transmitting antenna beams would contain 50 spot beams at a frequency of 20 GHz. In addition to the 8-foot transmitting antenna, each regional center would also have a 12-foot receiving antenna.

The Postal Service is endeavoring to speed up conventional mail delivery, especially among major population centers. For a fee of about $5.00, the Postal Service and Federal Air Express will guarantee overnight delivery of small packages to most major cities. Advances in competing communications systems (such as private facsimile units and word processors) and the limitations of electronic mail as envisioned (i.e., one page per letter), create substantial uncertainty regarding the public acceptability and economic practicality of this approach. Correspondence in some form will certainly travel electronically, but careful planning and foresight will be required if the U.S. Postal Service is to be heavily involved in this enterprise.

Evaluation of Electronic Mail as a Potential Space Initiative

During the process of evaluating the various space opportunities, electronic mail has always been one to bring out an emotional response from most participants. We are all familiar with the mail service and are concerned about the trends that indicate a future of continually paying more, but getting poorer service. The term *electronic mail* seems well defined in each person's mind, but certainly not uniformly defined across the group. In order to conduct our evaluation and its space versus terrestrial aspects, it was necessary to postulate a specific meaning of the term to plan a specific means of implementation and to determine the viability of the concept. In particular, we looked at the credibility of electronic mail as a major aid to the problems of the U.S. Postal Service. As the following discussion indicates, the concept of electronic mail that incorporates a single large dedicated satellite which interconnects all postal centers for facsimile transmission of personal and business mail does not appear economically viable. However, there are concepts that do have merit. One promising possibility is to combine electronic mail services with other useful high-data-rate services to form a *geosynchronous platform* which can perform several services in an economically practical way.

Problem. The United States Postal Service faces a future of increasing deficits. In spite of a $5 million surplus from the end of March 1976 through March 25, 1977, Postmaster General Benjamin F. Bailar declared that another rate increase will be needed in the spring of 1978 to cover higher costs and wage boosts.[1] In another article, Bailar was quoted as saying, "...*It is clear from recent experience that there is a lot of price elasticity in our business. As rates go up our volume declines. If we continue what we are doing, we would destroy the Postal Service...*"[2] The same article states that mail volume peaked in 1974 and began what is envisioned as a steady decline. James T. Ellington, Jr., Senior Assistant Postmaster stated, "... *We see a steady erosion of as much as 4 percent per year ...* "[2] A fiscally degenerating spiral appears in effect. As rates increase, volume decreases—causing revenues to decrease which, in turn, require further rate increases or major service curtailment to reduce the deficits, thus resulting in further volume decreases. To reverse this trend, the U.S. Postal Service is investigating alternative technological approaches, especially electronic mail systems. In the summer of 1976, the U.S. Postal Service awarded a two-year $2.2 million contract to RCA's Government Communications Division in Camden, New Jersey, to determine the technical and economic aspects of an electronic message system (electronic mail).

To avoid semantic ambiguity, the term *electronic mail* in this discussion will be confined to those concepts that transform text or the equivalent, received at a post office, into electronic signals that are transmitted to another post office and there reconstituted into text for delivery to the U.S. Postal Service. Specifically excluded from this definition are such concepts as electronic funds transfer, inter- and intra-company facsimile systems, as well as terminal-to-terminal world processing concepts. These may require dedicated satellites with unique antenna arrays.

---

[1]*Postal Chief See Need For Rate Rise Despite Surpluses*, Wall Street Journal (April 20, 1977).
[2]*Why The Post Office Can't Break Even*, Business Week (March 29, 1976).

Space Concept. Mail suitable for electronic transmission would be collected by the participating Post Offices and transported to one of the 1300 electronic transmission/reception centers. There, the letters would be coded to the proper receiving center, opened, and an image of the envelope and letter contents transmitted to a relay satellite in geosynchronous orbit. The satellite would analyze the receiving station code and relay the images to the appropriate receiving center, where a facsimile of the envelope and letter would be produced, collated, and the letters compiled for transport to the Post Office nearest to the addressee.

The 1300 electronic mail centers would be highly automated. However, personnel would be needed to code the destination of letters without ZIP codes or with ZIP codes that could not be accurately read by the optical readers. Personnel would also be required to screen and handle any letters with merchandise or non-transmissible material. The machinery would recognize letters with text on both sides of a page and would automatically transmit both sides. Multi-page letters would be also handled automatically. After transmission, the letter would be stored momentarily until a signal acknowledging its successful receipt was received from the receiving center. The letter paper would then go into hoppers for compaction prior to waste paper reclamation. Recent technological advances in facsimile transmission by the 3M Company have reduced transmission time to less than 30 seconds per page.[1] IBM is reported to have developed a prototype facsimile system that can send a page in two to five seconds.[1] The average letter contains two pages (actually 1.95).[2] If each page takes 3.5 seconds, plus 2 seconds for the envelope, then the average letter will require a total of 9 seconds for transmission. The data will be sent via a 1 meter dish antenna on the center roof to the electronic mail satellite in geosynchronous orbit.

The satellite (as conceived after three conceptual design iterations) will consist of a matrix of nine, 5-meter (16 ft) diameter antennas, so the 3 x 3 array will be 15 meters by 15 meters (50 ft x 50 ft) in size. It will require approximately 700 kW of solar array output. Assuming that GaAs solar cell technology results in 10 W/sq ft by 1985, the 700 kW power requirement (actually 770 kW to allow for cell degradation during the 10 year system life) will require an 85 m x 85 m (280 ft x 280 ft) solar array. The weight of the 78,400 sq ft array is estimated to be:

Solar Cells (9.36 lb/sq ft)	28,200 lb
Deployment & Supporting Structure (0.20 lb/sq ft)	15,700
Gimbals, Orientation Mechanism, Slip Rings	4,000
Cable Harness	2,500
	50,400 lb

[1]*Set For The Shift To 'Electronic Mail,'* Business Week (April 25, 1977).
[2]*Electronic Mail,* Science (March 18, 1977).

The weight of the satellite is estimated to be:

Structure and Thermal Control	5,000 lb
Electric Power	50,400
TT&C	500
Message Switching Computer & Related Electronics	500
Attitude Control/Stationkeeping (±100 km; 300 I_{sp}; 10 yrs)	14,000
	70,400 lb [1]

It was assumed that the satellite would have an on-orbit life of 10 years (limited by solar cell degradation and electronics reliability).

Terrestrial Alternatives. Several competitive technological developments are occurring that could strongly impact electronic mail. The feasibility of electronic mail is not driven by technology as much as it is by economic considerations. Diversion of mail volume into competitive systems could reduce the potential market for electronic mail below its break-even point. The competitive systems include facsimile transmission systems, electronic funds transfer systems and word processing systems. These electronic alternatives to mail are rapidly expanding, thus, further decreasing the volume base of first class mail. There are now over 130,000 facsimile machines in use in the United States,[2] more than 50,000 of these were added within the past three years.[3] Wiltek Inc., Xerox Corporation, and IBM all have word processors that connect typewriters to computerized systems that can edit, format, compress and transmit typed material over telephone lines. By using compression techniques and data storage devices, a full page of text can be transmitted in approximately 2-1/2 seconds.[4]

All of these systems will tend to reduce the potential market for electronic mail. This market can be estimated as follows.

According to estimates prepared by the GAO, the total annual mail volume is expected to decrease to 85.1 billion pieces in 1984.[5] First class mail has consistently represented 60 percent of the total mail volume.[6] If this percentage continued, then in 1984/85, the total potential volume of first class mail would amount to 51 billion pieces. According to a report titled: *Telecommunications Policy*, prepared by A. D. Little, Inc., for the White House

[1] A 5 May '77 Concept: Space Construction Electronic Mail Satellite (One Beam Machine Concept), Drawing 77015-31 was also estimated to weigh approximately 70,000 lb even though it was a substantially different design.

[2] *Set For The Shift To 'Electronic Mail,'* Business Week (April 25, 1977).

[3] *The Fax Of The Matter*, New Scientist (July 1, 1976).

[4] *Electronic Mail*, Science (March 18, 1977).

[5] *Future Shock 1984: Postal Rates Seen at 34 Cents an Ounce*, The Wall Street Journal (April 1, 1976).

[6] *Why The Post Office Can't Break Even*, Business Week (March 29, 1976).

Office of Telecommunications Policy, *"... About two-thirds of all first class mail ... is devoted to messages concerned with transactions-orders, invoices, bills and payments."* This would amount to a potential 34 billion pieces in 1984/85. More than half of that volume consists of bills and invoices going out and checks coming back,[1] so that 17 billion pieces would contain checks and, thus, would not be candidates for electronic mail. This would leave (51-17 =) 34 billion pieces of first class non-check mail. Studies made by the National Bureau of Standards showed that only 35 percent of mail was non-local (greater than 100 miles).[2] This means that only about 12 billion pieces of first class mail are non-checks and non-local, and so potential candidates for electronic mail. Included in this amount are an estimated 5-6 billion pieces of inter-office communications that are now sent annually by big companies.[3] If the existing 130,000 fax machines double in number by 1984, and if each machine sends only 50 messages per day - the fax machine at the Seal Beach facility sends more than 100 messages on some days - than 3.2 billion pieces of facsimile will be sent annually. Word processors will make additional inroads into interoffice mail. *"...A growing number of companies now are convinced that the way to move their growing volume of interoffice memos and letters is by a sophisticated system of electronic communications ... a corporation can now get away from depending on the U.S. mail for its interoffice needs ... IBM already has hooked the new printer to its own text-editing typewriters to provide electronic mail service among five divisional offices."*[3] If only half of the interoffice mail of major corporations is diverted away from the U. S. Postal Service, than 9 million pieces of first class mail remain as potential electronic mail. However, included in this amount are Christmas cards, post cards, birthday cards, letters containing photographs, securities, legal documents, over-sized items, highly personal letters, over-seas mail, and other items that preclude their transmission via electronic mail as envisioned. If this non-eligible mail constituted 1/3 of the remaining mail, then the amount of mail that would constitute the electronic mail market in 1984/5 would amount to 6 billion pieces.

The first class mail rate is expected to increase to between 22 cents and 28 cents by 1985 (1977 dollars).[4] If saturday mail delivery is elminated, and the ceiling on Government subsidies of the Postal Service are removed, then the 22 cent rate may prevail. Without these measures, the rate will need to be increased to 28 cents. Since the average first class letter contains 1.95 (2) pages,[5] the cost would be 11 cents per page. It is possible today to send a page of text at prices lower than mail cost. To send the page of text (by word processors) 1000 miles via telephone lines would cost only 5 cents and delivery takes place in a few minutes.[6] The advances being made in facsimile machines and in word processors will enable the transmission of messages between units virtually instantaneously a: a cost cheaper than U. S. Postal Service first class rate. Only a relatively small fraction of total first class mail would be sent through the electronic mail system as conceived.

---

[1] *Why The Post Office Can't Break Even,* Business Week (March 29, 1976).
[2] Roth, L. H. and L. A. Wolter, The Domestic Communications Services Market, North American Rockwell (Rockwell International), Space Division (Sept. 1972).
[3] *When The Interoffice Mail Goes Electronic,* Business Week (Sept. 13, 1976).
[4] *No Saturday Delivery - 22 Cents For Mail Termed Possible,* Los Angeles Times (March 30, 1977).
[5] *The Fax Of The Matter,* New Scientist (July 1, 1976).
[6] *Postal Service Going Out Of Business?* Machine Design (March 24, 1977).

Comparative Economic Evaluation.

Operational Description.

Postal Centers - Equipment. Assuming that 6 billion letters are to be sent via electronic mail annually, and that the average letter contains two pages of text, then for each letter, three facsimile transmissions would be required: one for each page plus one for the addressed envelope. The new envelope page would be folded to form a container for the two pages of reproduced text. Consequently, on the order of 18 billion facsimile transmissions would be made annually by the network of 1300 postal centers. If the centers operate 250 days each year, then each center will need to transmit an average of 55,400 facsimiles each day. During the past two years, facsimile transmission technology has advanced from a transmission rate of four minutes per page to slightly less than 30 seconds per page.[1] By 1984/5, it is expected that the technology will enable transmission of a page in two to five seconds, depending on the quantity of material on it. If the average page requires three seconds to send, then 166,200 seconds would be required to transmit the 55,400 facsimiles. Since there are 86,400 seconds in a day, at least two units would be required to transmit the average work load. However, since most of the mail arrives towards the close of the normal working day (between 4:00 p.m. and 6:00 p.m.), and the sender expects that his letters will be delivered on the following working day, then three parallel transmitters and receivers, working two shifts would be required to transmit the 55,400 facsimilies per day. (In order to prevent machine interference and efficiency-diminishing queuing, more receivers would be required than transmitters.) Of course, some postal centers might require four or five parallel units while others would require only two.

Postal Centers - Personnel. The personnel to operate the centers would consist of the following:

		Total Center
1.	ZIP coder, 1 per shift. These persons would code the ZIP code on uncoded mail, or on mail whose code the automatic ZIP code reader could not decipher	2
2.	Operator, transmitter, 1 per transmitting unit per shift. These employees would monitor the mail for oversized items (after unfolding), letters with non-transmittable items enclosed, monitor removal of processed letters (after confirmatory signal from receiving station indicated successful receipt of the complete letter), etc.	6
3.	Operator, receiver, 1 per receiving unit per shift. These operators would monitor the printing operation, making certain rolls of paper are available (changed), *ink* supplies are adequate, legible copies are being produced, etc.	6

[1] *Set For The Shift To 'Electronic Mail'*, Business Week (April 25, 1977).

4.	Equipment mechanic (mechanical and electronic), 1 per shift	2
5.	Relief personnel, 2 per shift	4
6.	Supervisor, 1 per shift	2
		22

<u>System Cost</u>. Non-recurring (Acquisition) cost:

1. Postal Centers - It is assumed that each of the 1300 postal centers will cost \$1.0M. This includes the facility (or its modification) for housing the equipment, key spare parts and supplies, three transmitting units, three receiving units, automatic equipment for opening, extracting, unfolding and orienting the contents, translating the ZIP code, assembling and folding the received facsimile, the roof antenna, micro processors, etc.,

   \$1.0 million x 1300 centers — 1.3 B

2. Satellite - The 70,000 lb satellite consists primarily of solar cells, antennas and electronics and is analogous to current communications satellites. Because of its many unique features, the development cost is estimated to be on the order of \$100M. Because of its size, it may be considered to be 1.3 times as complex as a *conventional* communications satellite which weighs 2000 lbs and costs \$16.0M, or \$8000 per lb (3rd or 4th generation with learning curve). On this basis, the satellite (with a cost scaling exponent of 1.0) would cost:

   70,000 x 8000 x 1.3 — 0.728[1]

3. Transporting the satellite to geosynchronous orbit would require the Shuttle plus an advanced tug. If it assumed that the Shuttle/Tug can emplace 8000 lbs into geosynchronous orbit per flight, then nine flights at a cost of \$25.0M each would be required. If a SEPS were available, then approximately five Shuttle flights would be required (\$100M). If a 425 kw SEPS were assumed with a 350 day round-trip time, then the SEPS cost would be \$27M (\$77,500/day) for a total transportation cost of: — (0.225) 0.127

TOTAL NON-RECURRING COST — \$2.255B

[1]A recent detailed cost estimate of an electronic mail satellite concept with a design weight of 53,000 lbs was \$1.34B - without transportation costs.

System Cost. Recurring Operating Cost (Annual):

1.	Personnel - Each center was assumed to require 22 employees. In 1976, the average postal service salary (non-management) was $14,086 plus approximately $3,000 fringe benefits for a total of $17,086.[1] In 1984/85, it can be assumed that the average annual salary (including fringe) will be on the order of $25,000[2]	
	$25,000 x 22 x 1300	$0.715B
2.	Equipment Maintenance - 5 percent per year x $1.3B	0.065
3.	Paper, *Ink*, Utilities, Etc. - Paper cost $.003 per page plus 10 percent	0.060
	ANNUAL RECURRING COST	$0.840B

Economic Analysis of the Electronic Mail Concept. As has been mentioned, the expected rate for first class mail in 1984/85 is expected to be 22 cents. Conversations with postal authorities revealed that 52 percent of mail cost is attributable to sorting and final delivery, 38 percent is attributable to transportation between receiving and delivering Post Offices, with the balance attributable to overhead operations. With electronic mail, the 52 percent of costs will still be incurred; only the 38 percent will be affected. At a rate of 22 cents, the apportioned charge for transportation (38 percent) is 8.36 cents. The annual revenue thus available for electronic mail would be $502M. The annual recurring cost of the electronic mail concept was estimated to be $840M, without including amortization of the capital costs (non-recurring - $2.255B). At an 8 percent discounting (interest) rate for 10 years, the capital recovery factor times the $2.255B yields an annual amortization cost of $0.336B.[3] Thus, the total annualized cost of the electronic mail system as conceived is $840M plus $336M or $1.176B. In order to break even, the electronic mail rate would need to be increased to 52 cents. Just to cover the annual operating costs, the rate would need to be increased to 36 cents. The increase in cost would further reduce the volume by making competitive systems more attractive. If the regular first class mail rate was 22 cents, then it is unlikely that electronic mail would be commercially successful with a 52 cent rate.

Conceptual Variations. Although the evaluation of the basic conventional electronic mail concept was found not to be economically viable, it does not follow that some variation might not be. Consequently, several variations to the basic concept were examined and evaluated. These included expansion of the concept to include direct linkage of all 30,000 Post Offices, the expansion of the U. S. Postal Service to printing and addressing of bulk second and third class mail, and expansion of the current Mailgram system.

[1] The Budget Of The United States Government, Fiscal Year 1978, Appendix.
[2] Assumes an annual increase of 4.5 percent.
[3] If the equipment was amortized over 30 years, the annual charge would be $0.200B.

Expansion of the Basic Concept to Include Every Post Office. The costs of this concept would be similar to those of the basic concept, except that approximately 28,700 additional installations would be required. The additional Post Offices would need to have either a *conventional* three-second machine, or a slower (less expensive) machine plus a buffer storage unit into which the data could be stored for release to the satellite at the standard three-second rate. A 20-30 second machine, such as the 3M 601AA, costs $14,500 or approximately $20,000 with the buffered storage. Added to this would be the cost of transmission equipment, antenna, etc., so that even a minimal installation would cost on the order of $25,000. If the capacity of each of the 1300 basic centers was assumed to be reduced by one-third, then this would amount to a cost reduction on the order of $130M. However, the addition of 28,700 new installations at $25,000 each would add $718M, for a new addition of $588M in non-recurring costs over the cost of the basic concept. Thus making it even less attractive economically.

Expansion of the U. S. Postal Service Into Printing. The initial thought was that the facsimile equipment could be used for printing (copying) bulk material. The basic weakness in this variation stems from the difference in cost of conventional printing - one side, black and white, $0.0125/copy in large quantities - versus $0.047/copy (*Xerox*, 2 minute facsimile) to $0.058/copy (601AA - 20 to 30 seconds per copy). A three second facsimile machine would be even more expensive per copy because of the greater sensitivity and faster reactivity of the paper/chemicals required.

Expansion of the Mailgram System. Western Union Telegraph Co., in conjunction with the U. S. Postal Service, has instituted electronic mail in the form of Mailgrams. Following are some of the key points of their system:

- *Electronic Mail* is a registered trademark of Mailgram.
- Eighteen tool-free telephone centers have been established in the U.S. to accept Mailgram messages.
- The messages are relayed (via Westar) to a computer in Middletown Virginia, where they are automatically sorted by ZIP code, verified for authenticity, and relayed by ZIP code to one of the 2200 terminals in 142 Post Offices. (Los Angeles has four Post Offices with Mailgram terminals.) The messages are received in a closed-off area (privacy) automatically bursted, folded, stuffed into envelopes and sealed. All of this is accomplished by 2:00 a.m., so that the Mailgrams can be delivered in ZIP coded lots to the appropriate Post Offices and be in the mailman's hands by 6:00 a.m. for delivery that day.
- Volume is expanding. Last year, 350,000 Mailgrams were delivered per week; this year's average is expected to be over 500,000 per week. Some weeks it has been as high as 800,000.
- Western Union Electronic Mail is a word processing subsidiary at McLean, Virginia. Computer outputs can be fed directly into the Mailgram system. Standard messages can be sent automatically to computer-stored mailing lists. The cost can be as low as 95 cents per Mailgram.

- The system is being expanded as the economics justify.
- Customers can dictate letters into the nearest pay phone and have the charges billed to their home phone or company phone, and be assured that the Mailgram will be delivered the following day.
- The above strongly indicates that the Mailgram system is evolving into an *electronic mail* system as rapidly as economically feasible.

Conclusions. The discussions above suggest that electronic mail is probably not the major remedy for U. S. Postal Service ills. In a broad sense, however, electronic mail is happening and will expand ... most likely to the detriment of the U.S. Postal Service rather than to its benefit. Fundamentally, the ritual of a person visiting each mail box or door once a day is not likely to be abolished, even though many of these trips are never fully paid for by stamp revenues (while others are quite profitable). For example, in the suburban areas outside of Los Angeles, most major magazines and local business flyers are delivered by private carriers (often using child labor). That is not likely to ever be the case in rural areas. Thus, the U.S. Postal Service, whose price structure is geared for a franchise-type of charter and averages out its costs, tends to lose the easy (profitable) business and must retain the rest. Another area of volume loss for the Postal Service is business mail, financial transactions, etc. Mailgrams can now be dictated over the phone and delivered by the Postal Service although facsimiles of the original letters are not transmitted. It, nevertheless, is electronic mail in a very real sense. At the current time, the Mailgram system is expanding rapidly and computers are helping to bring down the cost, especially to major users with mailing lists already stored in the computer memory.

In summary, *electronic mail* does not appear to be a single major initiative which remedies the major problems of the U.S. Postal Service. However, it is believed that *electronic mail* will be realized — if only by expansion of the Mailgram system. Therefore, it is being retained in our list of *anchor opportunities* and it is being included as one of the five electronic services to be provided by our geosynchronous platform.

Electronic Mail Service

General Objective

The purpose of space-based electronic mail services is to transfer the mail with increased speed and efficiency so as to permit overnight delivery of standardized letters anywhere in the United States.

Product To Earth

The product to earth would be electronic facsimiles of the source letters.

Key Objective

The key objective is to interconnect America's Post Offices electronically so that a large number of facsimile messages can be processed daily. The cost of the service must be low so as to attract mail from conventional channels. Therefore, the system must be highly efficient.

Principal Contributions

By instituting a fast, economical mail transfer system, national commerce can be expedited while simultaneously cutting Postal Service costs.

Level of Contribution

Benefits currently enjoyed by commercial enterprises in rapidly exchanging facsimile documents will be made available to the general public through the use of new Postal Service equipment.

Uniqueness of Contribution

Electronic mail would assure that rapid and economical delivery of information would be available to the general public.

Time Factor

Because of the increasing volume of information that must be exchanged annually by commercial enterprises, various systems are being devised and implemented to alleviate the problems experienced. The economic success of electronic mail depends on a large volume of use (for amortization of the necessary equipment). Consequently, if electronic mail is to serve the general population, it must be implemented at an early date (i.e., 1985 to 1990), otherwise alternative, non-public channels will arise that may reduce the mail volume below that level which is necessary for economic viability.

Principal Installations

The principal installations in this electronic mail concept are ground stations at each of the 800 regional postal centers, automated, high-speed facsimile transmitting and producing equipment, and a data relay satellite to direct the in-coming data to the appropriate regional centers.

Principal Functional Units

Each of the regional centers will contain equipment for automatically reading the ZIP codes on the standard letters, opening the letters and transmitting a facsimile to the relay satellite via a transmitting antenna. Conversely, each center will contain a receiving antenna and equipment for producing the facsimile copy, folding and sealing it, and sorting it by ZIP code.

The relay satellite will include receiving and transmitting antennas along with a computerized switching system which will direct the electronic facsimiles to the appropriate ground station on the basis of the ZIP code.

Principal Technologies

The technologies required include higher speed facsimile units than are currently available and expanded capacity data relay satellites.

Impact Spectrum

Technology	-	Within capability of current laboratory prototypes
Economy	-	Large number of jobs for facsimile equipment manufacturers. More efficient social and economic activities because of timely receipt of information. Less energy (petroleum) required by elimination of requirement to physically transport mail. Reduction of postal deficits.
Environment	-	Reduced pollution arising from reduced energy (petroleum) use
Social	-	Improved planning of social activities because of more timely availability of correspondence.
Political	-	Revenue sufficient to cover costs would reduce need for governmental subsidies. (Deficit amounted to $687M in the year ending September 30, 1977.)
Scientific	-	No impact.

Capital to Initial Operating Capability

Capital required would be on the order of $2.5B in 1977 dollars.

World Medical Care Center

In a world medical care system, the communication capabilities of space satellites will be used to supplement present medical treatment facilities in a variety of important ways. In 1950, medical care in the United States cost our citizens about $13 billion. In the intervening years, these expenditures have increased dramatically and they now exceed $150 billion per year (see Figure 25). Unfortunately, there is scant evidence that these enormous expenditures have resulted in a more healthy population. Between 1950 and 1970, our longevity rates have increased only about 1.3 years. The other measures of national health — maternal death rates and infant mortality rates — have fared a little better but, in comparison with the other industrialized countries of the world, we are not doing very well in these areas. At the present time, approximately 20 countries in the world have lower infant death rates than does the United States. Various cases have been cited for the relative lack of progress in improving the health of our countrymen despite our enormous expenditures on medical care. Our life style clearly has an important impact. In particular, drinking, smoking, and obesity are known to impact our longevity rates in a significant way.

It does not appear that space technology can do much to alter our life styles or our habits to improve our health. However, the delivery of traumatic treatment and preventive medicine could be fostered by recent advances in space. In particular, a space system utilizing paramedics linked to a centrally-located

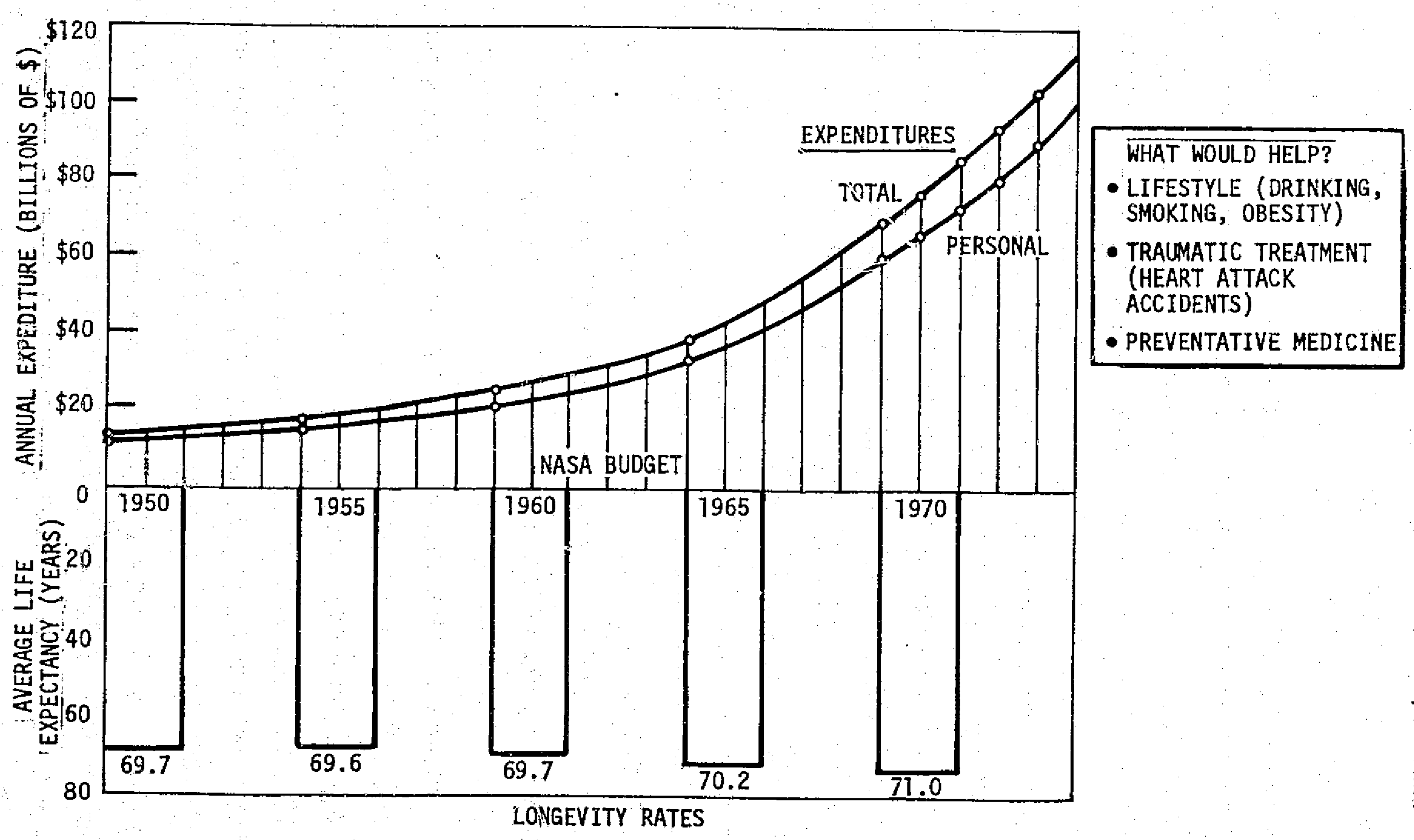


Figure 25. American Health Care Statistics Annual Expenditures

medical center could provide quality traumatic treatment for the advanced countries. Similar facilities also could improve preventive medicine and even provide primary care, particularly in the underdeveloped countries of the world.

Traumatic care — that is, care immediately following a serious attack or injury — could have an important impact on the longevity rates of our American citizens. In particular, heart disease, strokes, accidents, and respiratory diseases often respond favorably to traumatic treatment if it can be delivered with dispatch. Moreover, if the victim survives the first few hours he often has several years of productive life ahead of him. The shaded bars in Figure 26 represent health care problems which frequently respond favorably to quality traumatic treatment. As can be seen, these specific diseases trigger an important fraction of all our current deaths.

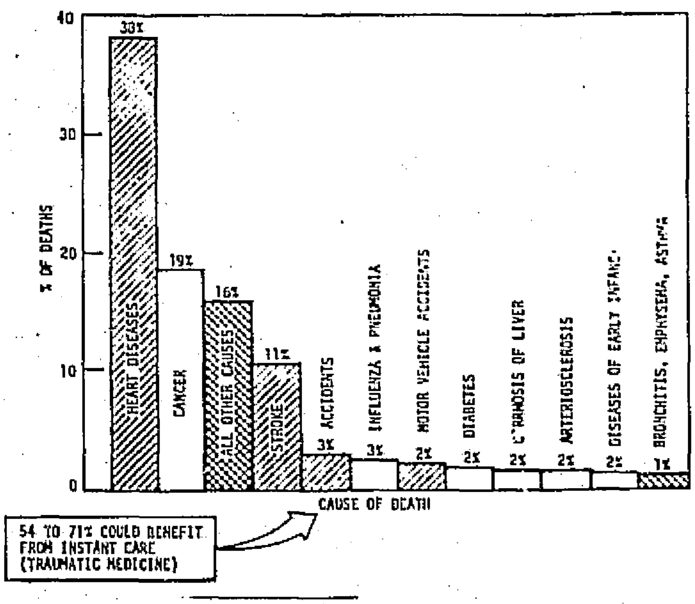


Figure 26. The Causes of Death

A typical health care delivery system utilizing satellite relay links is sketched in Figure 27. In such a system, paramedics, who are located in emergency vehicles or at permanent locations, would perform emergency treatment under the direction of skilled medical personnel at the central medical facility. The medical advice, prescriptions, consulting, and medical records they could provide would likely have a significant impact on the health care of the world population. Paramedical experience of this type was accumulated in Alaska in conjunction with the recent experiments with the ATS-6 Satellite.

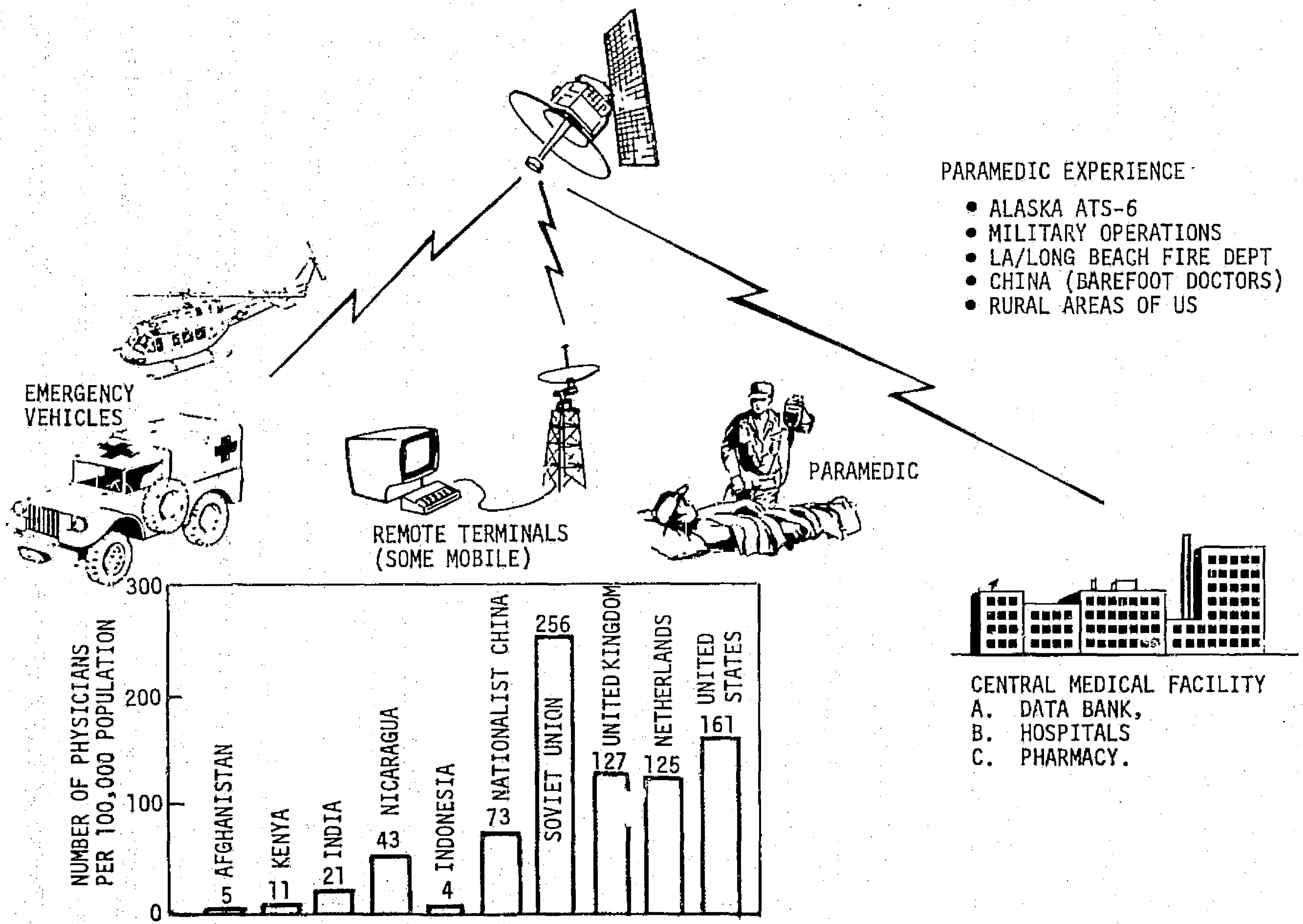


Figure 27. Public Health Care Delivery

Contacts at the Long Beach Paramedical Corps, which is attached to the local fire department, recently revealed that is requires only five months to train a practicing paramedic. These paramedics operate in two-member teams. Their vehicles (vans, boats, and helicopters) are each equipped with about $10,000 worth of medical equipment. Experience indicates that such paramedics are almost as efficient in treating injuries and traumatic medical problems as highly trained medical doctors who have received many years of medical training.

A satellite-based paramedical system could have an important impact on the traumatic medical care within the continental United States. Paramedics also could be served by a satellite information relay system in the primitive countries. These primitive countries often have surprisingly few doctors. In Afghanistan, for example, there is only one doctor for every 20,000 persons. Indonesia has even fewer doctors per capita: one for every 25,000 citizens. In such countries, the paramedics could perform important life-saving functions. Additional applications of the proposed satellite would include the relay of electrocardiogram readings and other body-functions as well as national medical records and health care statistics.

World Medical Care Delivery Discussion

Public health is limited, in this discussion, to those aspects that would preserve the functional utility of individuals. The medical aid can be defined as therapeutic intervention directed towards helping individuals who are sick or injured. Generally speaking, a seriously ill person cannot successfully diagnose and treat his own affliction unaided; it is the purpose of the health care delivery system to provide such aid whenever and wherever it is needed. Therefore, some method of observing the individual must be provided.

The observer need not be a highly-skilled medical practioner; experience in China, in our military services, and civilian paramedic crews clearly show that the ability to observe, to communicate, and to perform simple actions are the essential requirement — plus, of course, the capability to be with the victim. It is the co-location requirement that precludes having a large cadre of medical doctors dispersed throughout the global population: training large numbers of doctors is prohibitively expensive. Fortunately, the observer can be guided by remote advice if a communications link can be established between the (remote) observer/victim and a (central) advisory source.

The advisory source may be a doctor or a computer data bank, at least for the initial analysis. Analysis begins with observation of a few basic physical parameters, such as temperature, blood pressure, etc., together with verification of the victim's condition. These parameters, in the initial analysis, may suggest specific questions, either verbally or by test, which would progressively narrow the field of possibilities to a small number. Eventually the analyzer reaches a diagnosis and from experience issues a prescription.

All of these procedures, with the exception of authorization to begin treatment, could be provided by a computerized, interactive information system. Such systems are being developed initially in hospitals and clinics to support the attending physician. The fact that the computer data bank can be more extensive than any one doctor's memory leads to more accurate identification of obscure maladies. The same data bank provides more complete data and, perhaps, a greater probability of success than an unaided physician.

There is, however, one problem that must be considered if such a system is to be implemented on a global basis: medical practioners in different parts of the world have widely-varying approaches to the treatment of similar maladies. In the United States, a headache is treated with aspirin; in China with acupuncture; in Zambia by drilling a hole in the skull to let the demon out. The difference in technology is less important than the victim's acceptance of that technology. A global system must not only accommodate these preferences, but allow and stimulate an interchange of technology.

Most western medication is in the form of vaccines or prescription drugs; the same data bank could be an inventory record of where, and how much of rarer medicines are available, and trigger emergency manufacture. Delivery would need to be via conventional transport. However, one potential in-space contribution could be the manufacture of vaccines; experiments on Skylab demonstrated that a zero-gravity environment is conductive to more rapid production.

The personnel required to provide a global health care delivery system would not require a large increase in formally-trained medical doctors if the present cadre were to be supplemented by a much-larger number of paramedic personnel linked electronically to the data bank, and to regional medical centers. The paramedics need not be full-time practioners, provided they are widely dispersed in local communities.

The in-space contribution relates to the need for widespread multiple-access communications link between the many remote paramedics and the data bank, and to the regional medical centers. The local terminal would be very similar to conventional intelligent terminals for computers, supplemented by a low power (1 watt EIRP) communications set. Low power transmitters and small antennas are essential to minimize capital costs, but this, in turn, dictates a high-power, ultra-sensitive relay as the space terminal, considerably larger than the existing INTELSAT relays. Thus, a space-station-size vehicle is indicated.

It is less clear how the data bank(s) should be implemented. In order to reduce the number of channels, it would seem desirable to locate the data bank in the space station. However, while there may be hundreds of half-duplex low-rate channels to the remote terminals, there need be only a few full-duplex high-rate channels from the station to the data bank and the medical centers. Therefore, these facilities could be ground-based.

The feasibility of widespread dissemination of public health information from space was demonstrated in India during the past year. Relatively inexpensive television receivers with a moderate-sized antenna were set up in a number of remote villages. Broadcasts originating in Delhi were relayed by a synchronous satellite. Evaluation of the permanent benefits achieved by this experiment are not yet available, but the feasibility of information dissemination via space systems was clearly shown.

The India experiment did not provide capabilities for information collection since, for the satellite used, the many ground transmitters required to provide feedback would be expensive and unmanageable. To meet the needs of the users, the ground terminals must be of very low cost and this is possible only if the space terminal is extremely large.

An important part of the system suggested is communications traffic control. The requirement on the space terminal to provide random-access multiplexing of thousands of remote ground terminals to a hundred or more ground-based central facilities implies an exotic space switchboard technology. Crowding so many users into a narrow RF spectrum space would require that both FDMA and TDMA techniques be exploited; unfortunately, this would increase the ground terminal cost unless certain technical improvements are forthcomming. Even with an economical ground transceiver, the communications switching network is complex and would require on-board supervision and maintenance if not direct human control. For this aspect of public health, it would appear that the major analysis and advisory capability be on-board.

Public Health Care Delivery

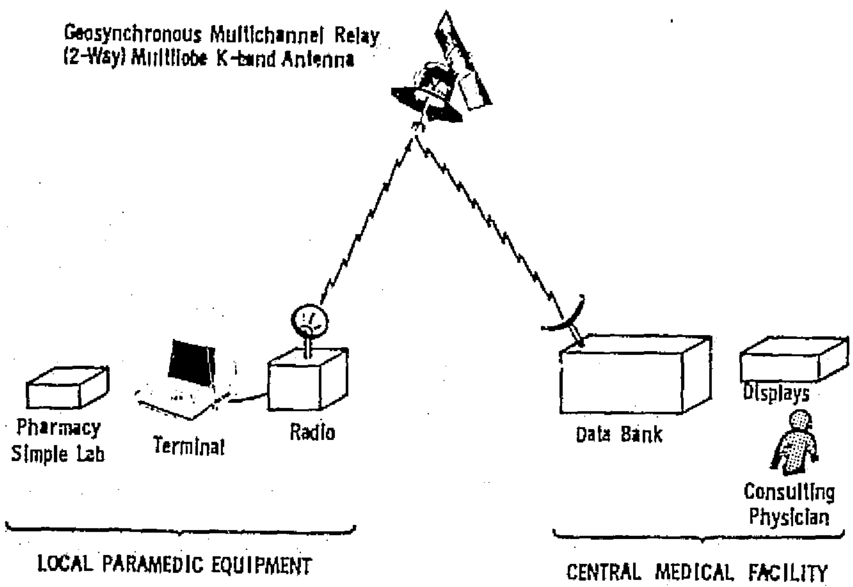


Figure 28. Public Health Care Delivery

General Objective

The primary purpose of the proposed system is to provide primary health care services to remote areas without access to hospital facilities or in-residence medical doctors. A recent survey indicates that over 100 of the 3,300 counties in the United States have no resident physician.

ORIGINAL PAGE IS
OF POOR QUALITY

Product to Earth

A maxim of medicine is that recovery is greatly enhanced by initiating treatment as early as possible to *stabilize* the patient; a complete diagnosis and recovery can then be made. A major part of this primary diagnosis and treatment can be delivered by parametic personnel on-site with advice and guidance from centrally-located medical experts. By utilizing widely-distributed paramedics, or *physician assistants*, health care can be brought to the victim rather than requiring the victim to come to a distant medical facility.

Key Objective

Provide an accessible communication link (relay satellite) between widely-dispersed paramedical personnel and the limited number of professional medical specialists located in centralized hospitals. Provide training for many additional physician assistants for assignment to remote areas.

Principal Contributions

Provision of primary medical observation and treatment to areas where none now exists. Present paramedic teams provide good service to densely populated urban/suburban areas; extension to thinly-populated areas is limited by transportation and communication obstacles. Availability of communications unlimited by wire or line-of-sight capabilities allows distribution of personnel to remote areas.

Level of Contribution

Direct delivery of help and treatment to the patient or victim. Present system requires delivery of patient to a distant treatment center; patients who are seriously ill, or accident victims, may not survive the transportation and delay.

Uniqueness of Contribution

Improvement of the present system is possible if a communications link unrestricted by geography or surface facilities is provided. A satellite relay does overcome geographical limitations. EHF radio is limited by both line-of-sight and atmospheric attenuation. But it is more than adequate to reach a synchronous satellite.

Time Factor

The space element could be in place by 1985; the dispersed paramedics could also be trained and in place by this time. Extension to other nations (using additional satellites) would be governed by the demand for similar capabilities.

Principal Installation

Space relay satellite with multi-lobe *spot-beam* antenna. Two-way linkage at high frequencies reduces size of antenna and total power needed.

Antenna Diameter	–	15 feet
Number of beams	–	100
Number of Channels/Beam	–	10
Bandwidth/Channel	–	15 kHz
Power-Gain/Channel	–	30 db
Prime Power	–	5 kW
Orbit	–	Synchronous, equatorial
Ground	–	The ground transmitter at the paramedic site must be light and battery-powered. Voice, narrow-band data capability is required. The base station equipment would be similar, but multiplexed to serve several paramedics simultaneously.
Antenna Diameter	–	1 foot
Band Width	–	15 kHz
Power-Gain/Channel	–	30 db
Prime Power	–	10 watts

Principal Functional Units

Space	–	1 to 10 satellites
Ground	–	50,000 paramedics (one per 5000 population) tied to 100 regional hospitals (most already exist, but need to add the emergency-response capability)

Principal Technologies

RF system design, multi-beam antenna development; ground terminal design.

Impact Spectrum

Technology	–	Existing
Economy	–	Employment for 50,000 paramedics, manufacturing jobs to build terminals, greater utilization of medical supplies
Environment	–	No impact

Social	-	Improvement in patient survival and rate of recovery; provide health service to large segments of population that have none at present.
Political	-	Greater benefit to taxpayer than National Health Insurance; should be welcomed by the American Medical Association to avoid nationalization of doctors' services. International services would enhance relationships with developing countries.
Scientific	-	Interchange of medical treatment methods between cultures would spread scientific knowledge rapidly.

Capital to Initial Operational Capability

Space Element	-	1 = $500M
Paramedic Terminals	-	50 @ $10K = $500M
Base Terminals	-	100 @ $50K = $5M
Paramedic Training	-	50,000 @ $20K = $1,000M

Navigation and Tracking Opportunities

This group of services is separated from the others to emphasize that relatively unsophisticated space elements, when operated in conjunction with a dedicated ground center, and utilizing other space elements for communication, can provide a number of very real, immediate applications. The primary distinction between these services and those discussed previously is that these satellites are also dedicated, and not shared, as in the case for many of the data acquisition opportunities.

Off-Shore Limit Monitoring

General Objective

Since the failure of the latest conference on the *Law of the Sea*, several nations have unilaterally extended their offshore boundaries to 200 miles, to cover fishing, mining and navigation rights. This will certainly lead to poaching and trespass, and a desire to police their new territory. At present, no economical enforcement approach is available. Those countries that attempt to enforce their limits rely upon aircraft and patrol boats.

Product to Earth

High-definition image information to discover and identify surface ships, thereby enabling apprehension by surface forces with documentary proof for enforcement.

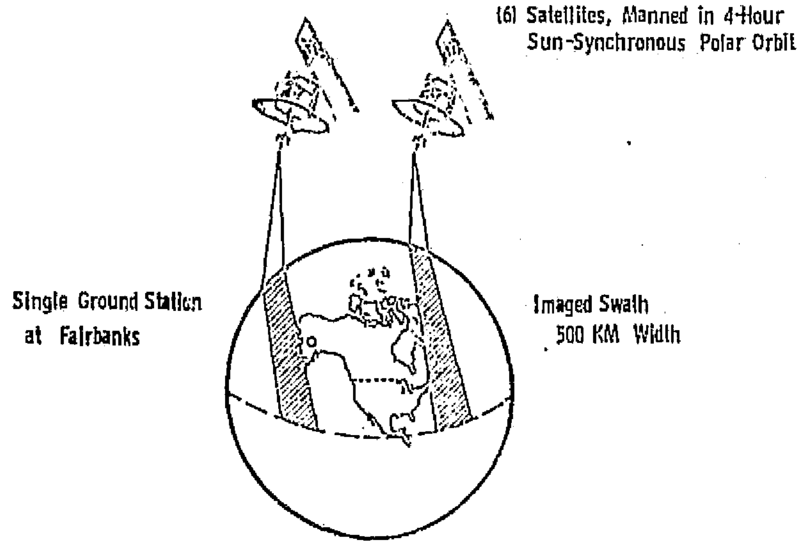


Figure 29. Offshore Limit Monitor

Key Objective

Timely delivery of images surveying the coastline and beyond, for delivery to participating national coast guard services.

Principal Contribution

Availability of real-time images with sufficient detail to identify position and nationality of surface ships (trawlers, drilling platforms) will: (a) detect undesired intrusions, (b) enable enforcement in judicial proceedings, (c) provide a deterrent to poachers, and (d) contribute to international cooperation.

Level of Contribution

Near-global coverage would provide a service which could be sold, or traded for concessions to all participating nations.

Uniqueness of Contribution

Provides an economical solution to what would otherwise be a tremendously expensive surveillance operation.

Time Factor

Capability is needed now; first initial operational capability should be possible by 1985. Only a few LEO satellites would be needed, and one ground center.

Principal Installation

Space. Six unmanned satellites in four-hour polar orbit, equally spaced equatorially would provide adequate response time for all coastline surveillance. Each would report the results of its survey as it crossed the polar area. A single ground terminal, possibly at Fairbanks, Alaska, would collect and analyze the images, retransmitting via INTELSAT to the affected nation.

Principal Functional Units

High resolution optical, IR and radar sensors, covering a swath about 500 km wide; desired resolutions are on the order of 1.0 meter. Scan rate can be quite slow, since multiple scans per pass are unnecessary; data rates to ground are not excessive since a high degree of on-board data compaction is possible.

Principal Technology

Large aperture optics and/or antennas; on-board data processing; similar to existing NIMBUS with extended resolution.

Impact Spectrum

Technology	-	Within present state-of-the-art
Economy	-	Potential to sell service, or trade it to other countries for concessions to explore or exploit their areas
Environment	-	Could be very beneficial in protecting endangered species (whale, porpoise, tuna); may also be used to detect oil spills
Social	-	No apparent impact except on those poachers who violate international fishing agreements.
Political	-	Provides a usable lever to maintain cordial relations with cooperating nations such as Peru and Japan

Front-End Capital

About the same as the NIMBUS system.

DATA ACQUISITION OPPORTUNITIES

The following opportunities are classified as *data acquisition*, i.e., a sensor system onboard an orbiting platform transmits data to several ground centers, each dedicated to a specific application. In most examples, these are extrapolations of the LANDSAT technology, and could be satisfied with very few vehicles, since the sensor technology is highly common. The application is determined by how the data is reduced and interpreted. Figure 30 lists the opportunities that have been identified, and emphasizes (boxes) the *anchor opportunities*.

Data Acquisition Discussion

By far, the majority of recommendations of the National Space Council and many in the Aerospace study are concerned with observation of earth-surface phenomena. A listing is given in Figure 30 of those extracted from, or inspired by these reports. A number of these are presently not feasible due to a lack of appropriate sensors, or technological limits. Many others, however, are within the reach of present technology and could be implemented with a variety of unmanned satellites, and a corresponding number of ground terminals and data processing centers.

This approach, while conventional, would be extremely costly not only in terms of funding, but also in terms of congestion of the electromagnetic spectrum, the duplication of skilled manpower, and the long response time between a request for data and actual receipt by the ultimate user. Even combining several applications into one satellite would complicate the situation by increasing the down-link data rate. Some of the proposed sensors have data rates (3×10^8 bps is typical) that exceed our present technical capabilities.

Therein lies both the problem and a possible solution. The unmanned sensor produces data and admits no judgement as to the quality or redundancy of the data; it is spewed out regardless of worth. On the other hand, the user has no desire for a long string of *bits*; his desire is for a map, a chart, or an image in a form that can be interpreted immediately.

At least two processing steps are required to transform the raw *bits* into significant images: (1) a mechanized process, usually a computer, to separate the *bits* and reform them into an image, and (2) an editing (human) process to select those which are significant. Existing earth observation systems apply these two processes in the order given; as a result, there are millions of reels of computer tape storing redundant and non-significant data that was never reduced to image form — and never will be.

The potential solution is to transpose the two processing steps and perform the editing process first. But this requires installing a judgement mechanism at the sensor location; a manned observation facility. It also implies a change in the sensor form so that the man may judge the data in his own terms — that is, as an image.

A. LAND DATA

1. AGRICULTURAL MEASUREMENTS
   - SOIL TYPE CLASSIFICATION
   - CROP MEASUREMENT
   - CROP DAMAGE ASSESSMENT
   - GLOBAL WHEAT SURVEY
   - CROP IDENTIFICATION/SURVEY
   - AGRICULTURAL LAND USE PATTERNS
   - CROP HARVEST MONITOR
   - RANGELAND EVALUATION
   - CROP STRESS DETECTION
   - SOIL EROSION MEASUREMENT
   - AGRICULTURAL ACREAGE SURVEY
   - SOIL MOISTURE MEASUREMENT
   - SOIL TEMPERATURE MONITOR
2. FOREST MANAGEMENT
   - TIMBER SITE MONITORING
   - LOGGING RESIDU INVENTORY
   - FOREST STRESS DETECTION
   - FOREST FIRE DETECTION
   - RURAL/FOREST ENVIRONMENT HAZARDS
   - LIGHTNING CONTACT PREDICTION/DETECTION
3. HYDROLOGICAL INFORMATION SYSTEM
   - SNOW MOISTURE DATA COLLECTOR
   - WETLANDS MONITOR
   - TIDAL PATTERNS/FLUSHING
   - WATER MANAGEMENT SURVEILLANCE
   - IRRIGATION FLOW RETURN
   - RUN-OFF FORECASTING
   - INLAND WATER/ICE COVER
   - SUBSURFACE WATER MONITOR
   - WATER RESOURCE MAPPING
   - SOIL MOISTURE DATA COLLECTOR
   - IRRIGATION ACREAGE MEASUREMENT
   - ACQUATIC VEGETATION MONITORING
   - SALINE INTRUSION

3. HYDROLOGICAL INFORMATION SYSTEM (CONT)
   - UNDERWATER VEGETATION SURVEY
   - LAKE/RIVER SUSPENDED SOLIDS
   - SEDIMENT MEASUREMENTS (RIVERS)
   - FLOODED AREA MONITORING
4. LAND MANAGEMENT
   - LAND CAPABILITY INVENTORY
   - LAND USE MAPPING
   - WILD LAND CLASSIFICATION
   - RANGE VEGETATION MAPPING
   - RANGELAND UTILIZATION/POPULATION
   - FLOOD DAMAGE ASSESSMENT
   - BEACH EROSION
5. POLLUTION DATA
   - ADVANCED RESOURCES/POLLUTION OBSERVATORY
   - SALT ACCUMULATIONS (IRRIGATION)
   - AGRICULTURAL POLLUTANT MONITORING
   - LAKE EUTROPHICATION MONITOR
   - GREAT LAKES THERMAL MAPPING
   - EFFLUENT DISCHARGE PATTERNS
   - TOXIC SPILL DETECTOR
   - AIR QUALIFY PROFILOMETER
   - AIR POLLUTANT CHEMISTRY (FREON)
   - POLLUTION DETECTION AND DISTRIBUTION
   - MOSQUITO CONTROL (WETLANDS FLOODING)
6. RESOURCE MEASUREMENTS
   - OIL/MINERAL LOCATION
   - DRILLING/MINING OPERATIONS MONITOR
7. GEOGRAPHIC MAPPING
   - URBAN/SUBURBAN DENSITY
   - RECREATION SITE PLANNING
   - HIGH RESOLUTION EARTH MAPPING RADAR
   - WILDLAND VEGETATION MAPPING
   - OFFSHORE STRUCTURE MAPPING

B. WEATHER DATA

- ATMOSPHERIC TEMPERATURE PROFILE SOUNDER
- RAIN MONITOR

C. OCEAN DATA

- OCEAN RESOURCES AND DYNAMICS SYSTEM
- MARINE ENVIRONMENT MONITOR
- OIL SPILL
- SHORELINE OCEAN CURRENT MONITOR
- ALGAE BLOOM MEASUREMENT

D. GLOBAL ENVIRONMENT

- GLACIER MOVEMENT
- OZONE LAYER REPLENISHMENT/PROTECTION
- HIGHWAY/ROADWAY ENVIRONMENT IMPACT
- RADIATION BUDGET OBSERVATIONS
- ATMOSPHERIC COMPOSITION
- ENERGY MONITOR: SOLAR TERRESTRIAL OBSERVATORY
- TECTONIC PLATE OBSERVATION

Figure 30. Data Acquisition

It is needed, here, to identify what is meant by *significant data*. A meter connected across two voltage levels produces a reading; the first such reading is, indeed, significant in that it provides information (an knowledge) not available previously. A second reading would have far less significance in that it merely confirms the validity of the first reading. Further samples, if the value is unchanged, become redundant, and have significance (meaning) only to the sense that the situation is static. If, however, the value of the reading deviates, then some new, unsuspected factor is at work, and requires an explanation. Thus, it is the *change* in readings that is significant.

Redundancy, too, can be significant in the sense that *no change* is just as meaningful as *changed*; however, *no change* can be defined as a normal status and does not require a total retransmission of the entire measurement: it can be represented by a *ditto*. Thus, significance is almost wholly determined by a change in a previously defined status.

For example, the appearance of a ship within the 200-mile offshore limit, where no ship was detected previously, is a change in status and requires an explanation — it is significant. A repetition of an empty ocean lane is only confirmation of the *status quo*.

Note, especially, in this example, the difference in system complexity between an unmanned, unedited sensor data system, and one which includes the man-editor. The unmanned system would probably rely on a radar or IR-scanner; it can only measure, and transmit what it views, without judgement as to significance. The manned observation past would utilize an optical telescope or an expanded version of the *snooperscope*; no data would be transmitted unless a target were detected, and then only the map coordinates, not the entire image area.

The foregoing example (Off-Shore Limit Monitoring) was selected at random; almost any of the feasible earth observation applications would have shown the same, or analogous, difference between a pre-editing (manned) and a post-editing (unmanned) system approach. But there is another advantage in manned systems [illegible] is even more advantageous and related to the speed of response.

Unmanned sensors are invariably serial in nature, for this is the only practical means of transmitting digital data. The manned sensor utilizes optical techniques, which are parallel in nature — the whole image is processed in one pass. Further, the human visual sense is a very sensitive discriminator of minute (as well as gross) variations, whereas a mechanical scanner always has a lesser threshold, both in discrimination and in resolution. All sensor data must, eventually, be reduced to visual form; it is recommended that the visual form be evaluated prior to conversation to serial form for transmission.

Of all the feasible sensors, the multispectral scanner (such as utilized in LANDSAT) is, perhaps, the most useful for earth observations. Can this multispectral approach, where radiation from low-IR to high UV is divided into 10 to 22 bands, be converted to manned visual observation? The answer is certainly positive. One example has been mentioned — the *snooperscope* — where IR radiation is converted to an active image using a unique IR-sensitive cathode to stimulate a visible phosphor screen. Other examples can be found in the field of astronomy, where special photographic dye-couplers have been employed to produce visual images of radiation spectra far beyond the human visual range. Utilizing special phosphors and dichroic filters it should be possible to provide image sensors in any variety of wavebands desired. Such image converters, coupled to relatively small telescopes, could provide the same measure of data resolution to the human eye as the present multispectral scanner equipment.

Assuming ten or more waveband images converted to black/white monochrome visual images, can we produce the equivalent of the present LANDSAT *false color* images? The answer is positive, where commercial color TV has provided the prototype. Here the active spectrum is divided (by optical filters) into three contiguous bands, each of which is imaged on a separate vidicon cathode. The result is three monochrome images, each corresponding to a specific waveband. The three vidicons are scanned, synchronously, and their outputs combined in certain ratios to provide, eventually, a full-color image on your home receiver. Extension to ten or more bands is simple engineering.

Having shown that a human-sensor system can, feasibly, replace multispectral scanner systems, we have not yet exploited the full potential of a manned system. That is, for the man to exert his full editing potential. Up to this point, we have only utilized his functional capabilities to delete unwanted data — he can observe when the ocean is empty of boats. To more fully utilize his judgement requires adding a data base for reference of the *status quo* of less discernible changes, such as the referenced LANDSAT photographs. Again, we would rely upon optics in the form of a color camera, *Polaroid*-type, to establish and maintain a data base. These *hard-copy* images would be produced, retained and retrieved by the space observation platform.

When requested to repeat a selected observation, the man would configure his sensor as previous records define (not all wavebands are used for every observation, nor in the same ratio) and retrieve the previous image from the file. When the area to be observed appears, he would record it both on magnetic tape (for later transmission, if warranted) and on film. Using the new film and the reference film in a blink comparator device, any changes are readily detected; if judged significant, the recorded image data would be transmitted; if not, discarded and a voice message substituted.

The advantages of implementing a manned observation platform, with pre-transmission editing capability, are far superior to many dedicated unmanned systems in cost, complexity and in adaptability. Note that the on-board editor does not interpret the meaning of the acquired data — he only decides whether it has changed. Therefore, the observing platform objectives can be modified at any time without making the in-space machinery obsolete. New programs can be instituted by defining different instrument settings and pointing directions.

Ocean Resources and Dynamics

General Objective

The world's oceans, comprising almost 70 percent of the surface, represent a vast source of food, minerals and chemicals virtually untapped today, but essential in the future. Knowledge of fish feeding grounds, migratory habits, ocean currents, is sparse. Sensing ocean surface conditions (temperature, emissivity, etc., in varying wavebands from IR to visible) can locate schools of fish, plankton, currents, trace migratory heards, etc. A near-earth space observation platform (see Figure 31) would provide this exploratory data.

Product to Earth

Increase in production of protein by location and (potential) management of sea life; knowledge of sea currents, both vertical upwells and horizontal movement; identification of kelp and seaweed areas for harvesting.

Key Objectives

Provide an observation platform to survey and map ocean areas, currents and resource areas. This would improve world food production by identifying fish feeding areas, time of year when they are present, establish resource management and conservation procedures to avoid over-fishing certain species and areas.

Principal Contributions

Increased knowledge of this vast, largely unknown resource will permit greater (and better) exploitation for increasing human needs.

Level of Contribution

Guidance to all sea-harvesting nations to the most productive local areas; present fish harvesting technology as *hunt until found*, relying upon past experience (seldom shared) of individual fishermen.

Uniqueness of Contribution

Exploration and monitoring via satellite provides data in near-real time (for fishing) and understanding of ocean dynamics and resources unobtainable by surface, or air observation. One satellite could cover all ocean areas every 12 hours.

Time Factor

Unmanned satellite could be in place by 1980; the present SEASAT is a prototype. Downlink data would require a synchronous relay satellite (such as TDRS) at the same time.

Principal Installation

Space only. One satellite in 300-mile polar orbit with IR and multiband sensors; 24 to 30 MHz downlink data rate, 100-foot surface resolution with

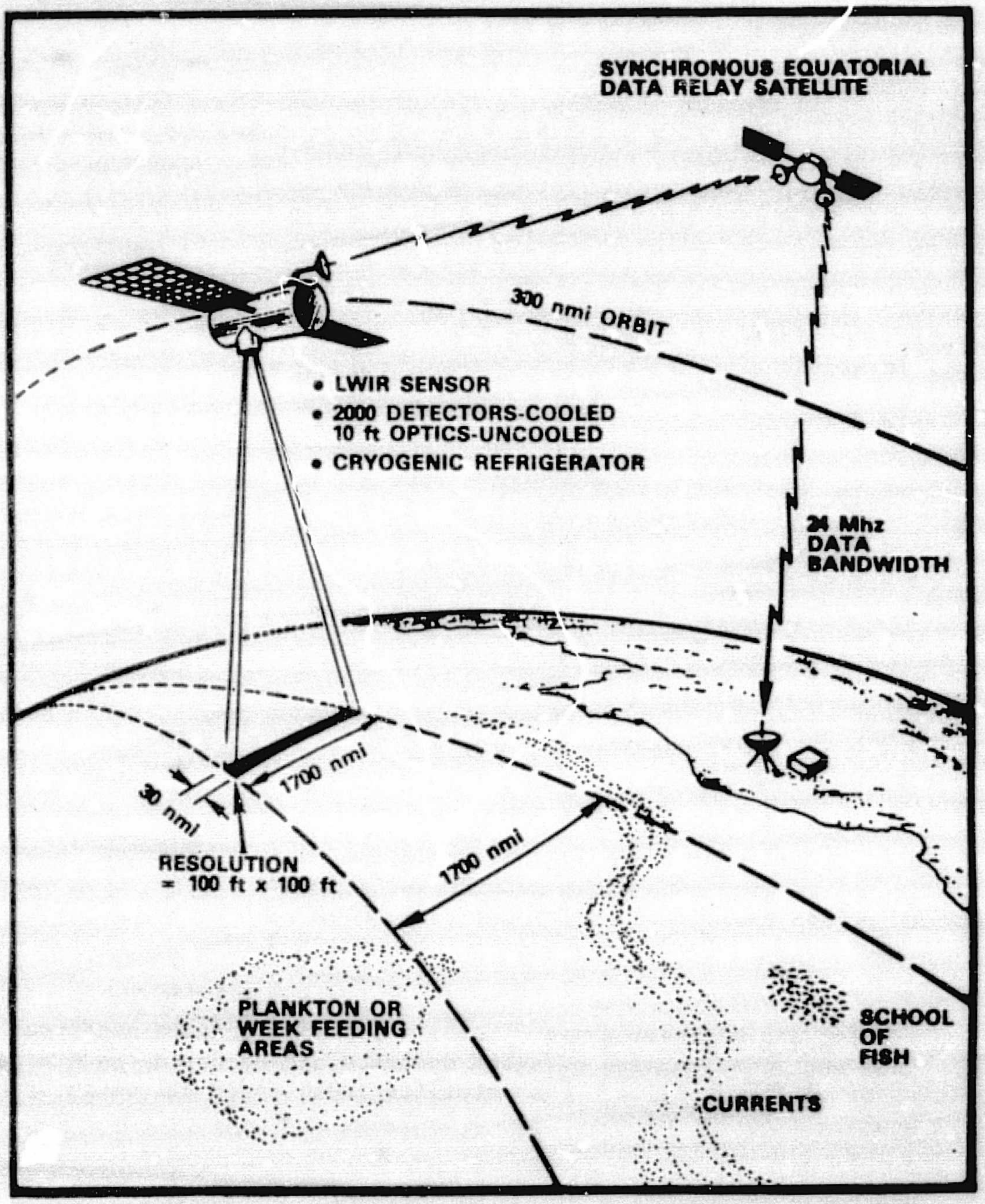


Figure 31. Ocean Resources and Dynamics System (CO-4)

.002 degrees at sensitivity:

Weight	–	15,000 pounds
Size	–	10 x 60 feet (erected)
Raw Power	–	25 kW

Principal Functional Units

Space	–	One satellite plus TDRS (two)
Ground	–	One control, tracking and data handling center linked by voice/facsimile to all major and minor fishing centers and fleets

Principal Technologies

Multispectral data reduction, including unique *signature* analysis and identification. Long-term cryogenic cooling of long-wave IR sensors.

Impact Spectrum

Technology	–	Extension of present development
Economy	–	Would generate a worldwide market for information on the location of schools of fish
Environment	–	No impact; sensors may also be used to detect effluents; information would stimulate conservation and prudent harvesting procedures
Social	–	By increasing availability of protein (fish) to developing nations, their living standards, health and productivity would be improved.
Political	–	No impact nationally; international relations would be improved
Scientific	–	Much increased knowledge of ocean dynamics would help us understand the climatic aspects of the earth.

Capital to Initial Operating Capability

Space only: about $300 M.

<u>Water Resource Mapping</u>

General Objectives

The availability of water is of paramount importance for *third and fourth world countries* that are seeking to expand their agricultural, as well as industrial base. Water quality, quantity and seasonal variation all bear heavily on developmental decisions. Synoptic mapping via ground or aerial surveys can require years for completion and, in the meantime, it consumes scarce resources.

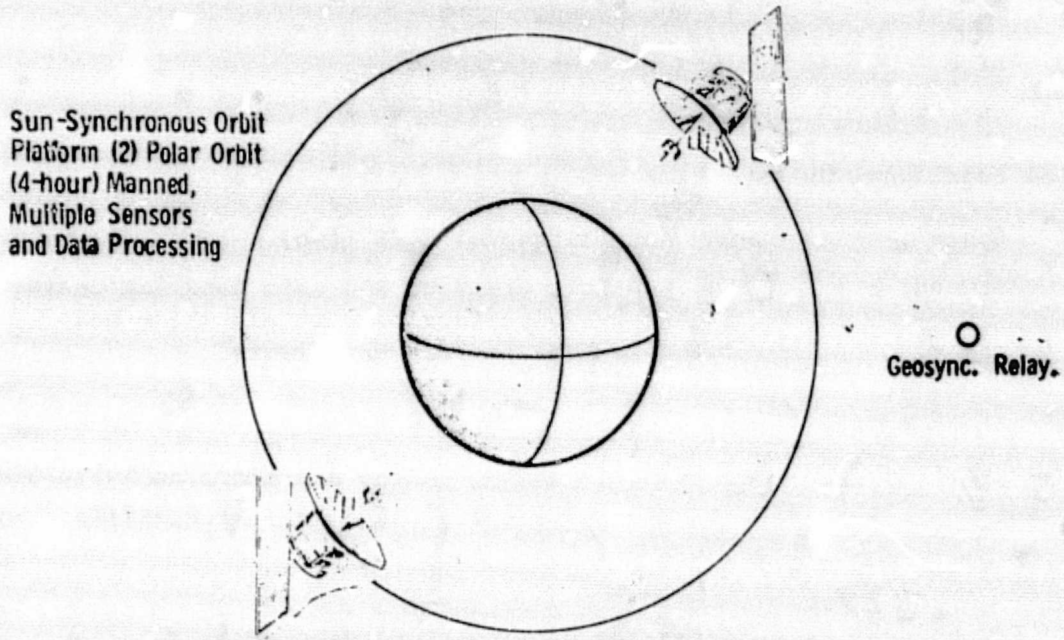


Figure 32. Earth Observations Complexity Inversion

Product to Earth

Photography from earth orbit at appropriate frequencies can provide the required data. This data can be in either video or film. Large areas can be covered at satisfactory resolution.

Key Objectives

An examination of the current development plans for *third and fourth world countries* reveals that the conduct of water resource surveys is an almost universal objective.

Principal Contributions

Water resource mapping from earth orbit would be more economical and faster (once the system is operative). Synoptic changes with the season could be readily observed.

Level of Contribution

Conventional aerial surveys cost $200 to $300 per square mile. If a water resource mapping satellite cost $100 M, it would break even in mapping 400,000 square miles, or less than the land area of 6 of the 13 *fourth world countries*.

Uniqueness of Contribution

Conventional aerial or land surveys provide data valid for the time (i.e., season) of the survey. Four-season coverage would quadruple cost. By contrast, seasonal or repetitive coverage from earth orbit would result in only marginal cost increases.

Time Factor

Near term; 1980 to 1985.

Principal Installation

One satellite in sun-synchronous polar orbit could cover the entire earth every 14 to 18 days, depending on altitude and view angle. Because of the possibility of cloud cover, several passes may be required to obtain the required measurements. Local people could be trained to do photo-interpretation and gather ground truth data.

Principal Functional Units

Constellation size	–	One
Orbit	–	Sun-synchronous
Spacecraft weight	–	2000 lbs
Power	–	1000 watts
Size	–	10 Ft Dia. x 15 Ft Len.

Principal Technologies

Water-sensitive sensors with high resolution.

Impact Spectrum

Technical	–	System is minor advance over existing technology. Applicable to other water-related missions (i.e., snow pack measurement)
Economic	–	Need to devise plan for financial reimbursement from user nations. Marked cost-benefit advantage over current approaches.
Environmental	–	No detrimental effects other than launch vehicle exhaust
Social	–	Conductive to accelerated rate of development of *third and fourth world countries* through more efficient development planning

Political	–	Possibly increased international goodwill towards the United States
Scientific	–	Serendipitous discoveries likely

Front-End Capital

Acquisiton Cost	–	$80M (LANDSAT evolution)
Launch Cost	–	$24M
Annual Operating Cost	–	$10M to $100M, depending on number of ground stations and data processing support required

Runoff Forecasting

General Objective

Snowpack melting is one of the primary causes of floods in the United States. In the spring of 1973, 35,000 persons were driven from their homes and over 20,000 square miles were innundated by flooding in the Missouri-Mississippi River valleys. The property damage incurred was in the millions of dollars. The extent of flooding could have been reduced by better water management in the dams along the Missouri River. (Fort Peck, Fort Randall, Garrison, Oahe, Tuttle Creek and Yellowtail.) However, better management would have required more accurate knowledge of the snowpack and forecasting of the runnoff. Snowpack measurement from space would provide essential data for improved water management.

Product to Earth

Snowpack measurement data and water level in tributaries of major rivers.

Key Objectives

Reduce flood damage by drawing down dams in anticipation of runoff. Maximize water storage for irrigation and power generation in keeping with the needs to minimize flooding.

Principal Contributions

Reduce property damage, reduce crop losses, reduced loss of life. More accurate and timely data than obtainable by surface surveys.

Level of Contribution

Aerial surveys cost $200 to $300 per square mile. Several 100,000 square mile areas would need to be surveyed each year to manage the runoff on the Missouri-Mississippi Rivers.

Uniqueness of Contribution

Snowpack measurement from orbit has been tested with LANDSAT data and proven feasible. Runoff forecasting and water management would require additional unique-temperature data and stream water level data.

Time Factor

Near term; 1980 to 1985.

Principal Installation

Two satellites, in sun-synchronous polar orbits, could provide complete earth coverage every seven to nine days, depending on sensor view angle and satellite altitude. Data would be relayed to ground stations where it would be computer processed and analyzed by computer comparison with topographic data. Results would be provided to appropriate government agencies.

Principal Functional Units

Constellation Size	-	Two
Orbit	-	500 nmi circular polar; sun-synchronous
Spacecraft Weight	-	2000 lb
Power	-	1000 watts
Size	-	10 ft dia. x 15 ft len.

Principal Technologies

Temperature sensors; water and snow sensors.

Impact Spectrum

Technical	-	System is minor advance over existing technology
Economic	-	Flood damage reduction by half likely. Market service to foreign countries
Environmental	-	Highly beneficial in alleviating potential flood damage
Social	-	Reduction of crop and pasture land losses. Improved irrigation and energy production by improved water management
Political	-	Would provide runoff forecasts to foreign nations. Would also provide disaster assessment of monsoon-flooded regions.
Scientific	-	Serendipitous discoveries of water sources likely

Front-End Capital

Acquisition Cost	–	$120M (LANDSAT Evolution)
Launch Cost	–	$24M
Annual Operating Cost	–	$5M to $20M, depending on extent of service provided

Oil and Mineral Exploration

General Objective

As oil and other mineral resources become scarce, it is imperative that new techniques be found to increase our capability to locate these minerals. The proposed system would greatly enhance our capability to locate these ever dwindling resources.

Product to Earth

Image negatives at a wide variety of wavelengths.

Key Objectives

To provide multispectral analysis of the earth to determine the location of geologic formations, structures, and lineaments in order to locate possible reservoirs of oil, gas, as well as zones of mineralization.

Principal Contributions

This system will provide a quick, efficient, and less expensive means of locating resources.

Level of Contributions

There is a definite need to increase land-surface coverage and the detail of this coverage in order to increase our mineral exploration capability. The needs can be met quite easily using resource-evaluation satellites.

Uniqueness of Contribution

The trend in resource exploration is in a direction which will rely more and more heavily upon satellite reconnaissance. Satellite observation, using photographs as well as multispectral scanners, provides data which are of such quality that they can be obtained by no present alternative. However, the Thematic Mapper, to be launched in the mid-1980's, may be a viable alternative.

Time Factor

The proposed system is required as soon as possible. Our country's ever-dwindling energy supply necessitates an increase in our capability to locate these resources.

Principal Installations

The primary installations will be space-based monitors. Data acquisition will be from space-based observatories. However, earth-based sensors can be utilized in conjunction with the space-based monitors.

Principal Functional Units

Space-based functional units may be manned or unmanned observation platforms. The earth-based sensors may be useful in accumulating certain data which can then be transmitted via satellite to a central ground station.

Principal Technologies

Technological advances are required to expand the capability to differentiate rock types, soil composition and geologic structures.

Impact Spectrum

The spin-offs of this system could be numerous. The detectability of a large variety of phenomena could result from the technological advances required for this proposal.

This proposal could significantly enhance the United States energy reserve and will have a positive impact on environmental concerns.

Front-End Capital

Satellite Development and Production	–	$200M
Launch from Vandenberg Air Force Base	–	$24M
Ground Service	–	$10 to $50M
Transportation (Shuttle Flights to Retrieve Film)	–	$100M
Processing of Data	–	$50M

Oil and Mineral Exploration Discussion

The results of our oil and mineral exploration activities will be of increasing importance to mankind in the next few decades. As the three graphs in Figure 33 indicate, we are beginning to deplete some of our country's important reserves of oil, natural gas, metals and minerals. In the decades between 1850 and 1950, a foot of exploratory drilling produced, on the average, approximately 200 barrels of oil. In recent years, however, large domestic oil deposits became increasingly difficult to locate. Today, a foot of exploratory drilling produces an average of only about 35 barrels of oil. Most experts believe that this downward trend will continue within the continental United States, although results may be considerably better in other parts of the world.

As the second graph in Figure 33 shows, domestic production of natural gas peaked out in about 1972 and has experienced a steady decline in the intervening

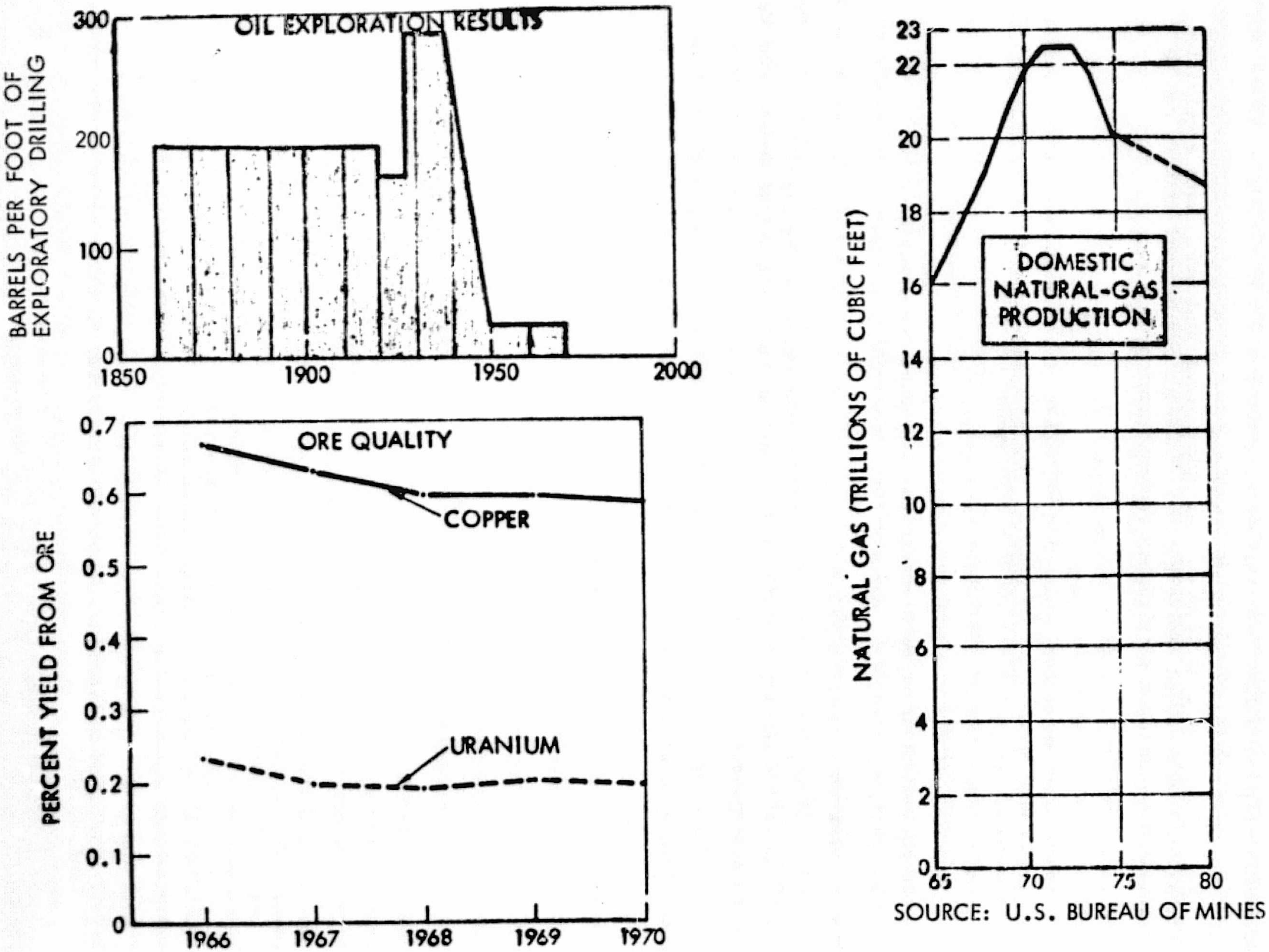


Figure 33. Resource Depletion

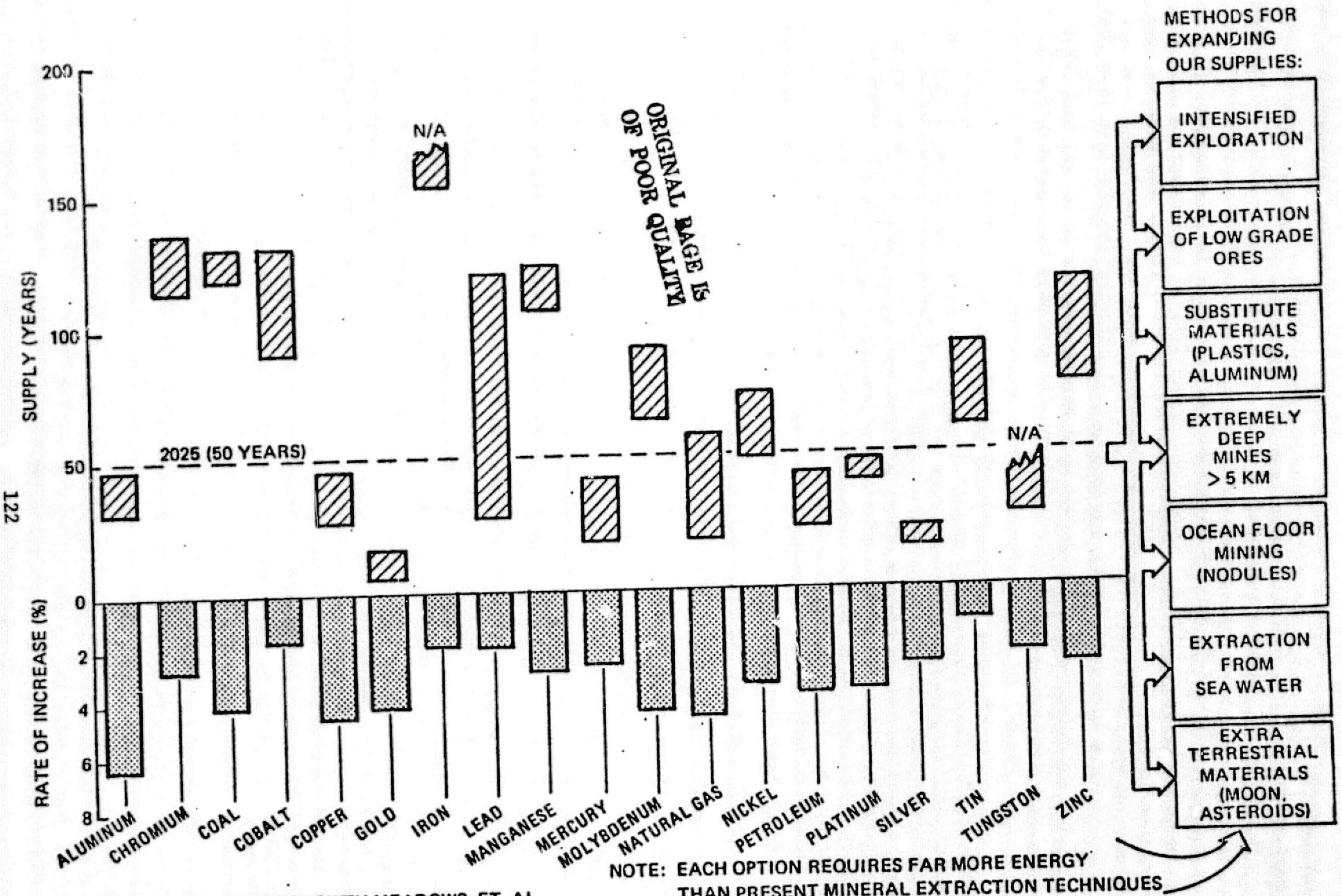
years. Projections indicate production will decline much further unless significant price increases are allowed.

In the case of metals and minerals, the situation is considerably more complicated. In some cases the average ore quality is declining; in others it is actually increasing. Two important domestic ores: copper and uranium have declined in quality over the last few decades. However, this decline has not been particularly abrupt. It is the belief of the Rockwell analysis team that most key mineral resources are adequate for the needs of mankind for many decades. More energy will be required to obtain some of these minerals, and costs may increase, but adequate supplies will probably be available for the foreseeable future.

Figure 34 provides additional insight into the future of the world's mineral supplies. This chart, which was extracted from *The Limits To Growth*, shows that the known reserves of eight crucial minerals will be exhausted within the next fifty years at the present rate of increase in usage. We do not believe that these minerals will actually be exhausted in the indicated time frames. Instead, mankind will expend whatever energy and exploration efforts are required to locate needed minerals. Substitutions will also occur. Nevertheless, Figure highlights a crucial problem: *Our known mineral reserves are not infinite*; consequently, large new supplies will be needed by future generations.

Fortunately, as the right-hand column of the chart illustrates, many techniques can be used to expand our supplies. These include intensified exploitation, the extraction of minerals from sea water, and the exploitation of ocean-floor reserves. If they were fully exploited, these techniques could expand our mineral supplies to an essentially unlimited extent; however, a careful study of the list will reveal that each technique requires larger inputs of energy than we are now expending. Of the methods listed, intensified exploration is probably the least energy-intensive. It is our belief that this intensified exploration can be greatly aided by well-equipped space platforms.

Some of the geological clues which can be observed from space are listed in Figure 35. The skylab experiments and other recent tests indicate that promising geological structures, oil seeps, lineations and arcurate structures can all be spotted from space. Fault lines, which sometimes stretch over hundreds of miles of the earth's surface, are particularly apparent from the vantage point of space, whereas at close range they are often obscured by interrupting structures such as rivers and mountain ranges. Arcurate structures occur when a large bubble is formed under the ground. When the bubble collapses it leaves behind concentric rings which reveal its past existence. Of course, even with all the clues listed in Figure 35, space observations cannot provide definitive proof of the presence of economically recoverable oil and mineral resources. Ground truth data must supplement the satellite-based observations before the resources can be accurately accessed.



*SOURCE = THE LIMITS TO GROWTH MEADOWS, ET. AL.

Figure 34. Potential Exhaustion of Selected Minerals*

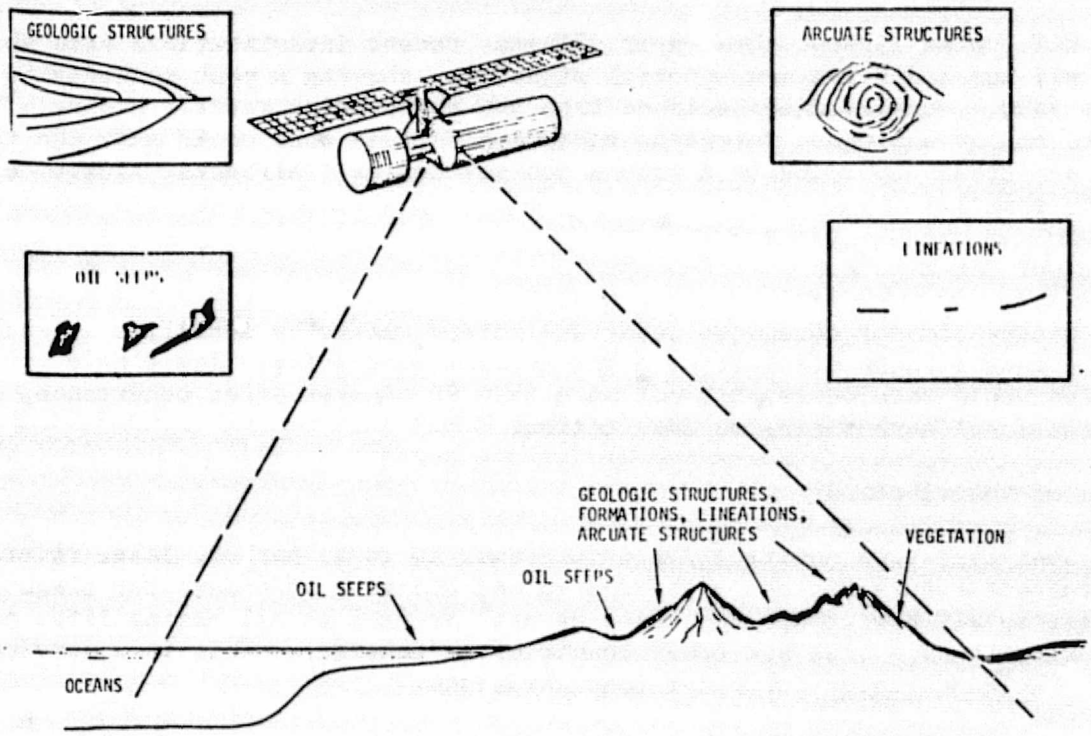


Figure 35. Geologic Clues to Mineral Location

Oil Spill Detection

General Objective

Ocean and fresh water pollution from tanker and drilling platforms is easily detectable by existing means. Oil spills, caused by vessels cleaning the bilges and similar overboard dumping, are virtually unnoticed, are common practice, and in the aggregate are much greater than the major events. What is needed is a system to detect and identify those minor events so that corrective action may be instituted and charged to the offenders.

Product to Earth

Timely identification of location and magnitude of covert or accidental contamination of navigable waters by oil, fuel, or other petroleum products. If the offender could be made to pay the costs of cleanup, or instituting procedures and mechanisms to prevent spills, this would achieve multiple benefits to people, shellfish, water fowls and commercial agencies that share the water resources.

Key Objectives

Oil, being lighter than water, floats; recent investigations have shown that oil has a distinctive spectral signature, showing a peak reflectance at about 4500 Å, easily distinguished from the surrounding water. A single photometer, at low altitude, detecting radiation in this band would mark the time this occurred, reporting to a ground control center (Fairbanks, Alaska) every orbit (polar).

Principal Contribution

Observation of extensive ocean and inland waters by satellite is much more cost-effective than aircraft or surface-craft monitoring. The single ground station would receive reports not more than 90 minutes after occurrence, notifying the local authorities to take action.

Level of Contribution

Near-real time notification of offenses to local harbor, lake, river and coastal water authorities, apprehending and charging offenders for cleanup costs. Benefit to all people who use these waters, as well as all marine life, etc. Extension to high seas and other countries is inherent. This is a service that may be sold or traded for other considerations.

Uniqueness of Contribution

No other affordable monitor system can detect the minor offenders and police these waters.

Time Factor

Design and construction of oil spill monitor satellites (initial system of ten to twelve) to be accomplished by Shuttle polar orbit operational capability.

Principal Installation

Space only. Small battery-powered cold-gas stabilized satellites containing a single photometer restricted to 4500 Å waveband. Limited lifetime (one year), low-altitude (approximately 100 miles).

Ground. Single ground control station to track satellites and collect reports (similar to satellite control facility, for DOD satellites).

Principal Functional Units

Approximately ten satellites injected by one Shuttle flight. Ninety-minute, high inclination orbit; may be recovered and refurbished, recharge batteries and gas system by later Shuttle flights (about once per year).

Principal Technologies

All needed technology already exists.

Impact Spectrum

Technology	–	Design and build
Economy	–	Save millions of dollars by reducing oil spill damage. Few new jobs created, but existing enforcement practices greatly improved (productivity); exportable service to other nations
Environmental	–	Reduce one significant cause of water pollution
Social	–	Improve the survivability of water life-forms; positive reaction by environmental protection agencies
Political	–	No additional national impacts; internationally, the service can be exported for *good will*, money or consideration
Scientific	–	None foreseen

Capital to Initial Operational Capability

Space Elements	–	About \$50M to design and build ten to twelve satellites
Ground Element	–	About \$25M to install; \$5M per year to operate

Pollution Detection Discussion

Oil spills are one serious form of pollution, but there are many others — several of which could be detected and monitored from space. Pollution is an ambiguous term; for this discussion, it is constrained to those actions by individuals that degrade some characteristic of the environment outside the boundaries of that individual's property. Pollution can be found in air, water and ground, sometimes visible, sometimes dangerous, but (conversely) sometimes acceptable if alternatives are less beneficial.

What is considered to be polluting varies widely on a global basis. In Los Angeles, automobile exhaust is a pollutant; in rural areas of America it is disregarded. Discharge of sewage into lakes, rivers, and oceans can be detrimental to fish and human beings; sulfur dioxide from coal or gas furnaces have a tendency to develop into carcinogens; the hot water discharged by nuclear power stations is thought to be harmful to shoreline shellfish. According to environmentalists, the list is endless. Only those processes in which everything can be recycled, on-site, to its original state can be considered to be non-polluting.

Our discussion is limited to those types of pollution that affect relatively large areas or groups of people and only those types that are detectable by long-range sensors. Detection is further limited to sensors using the electromagnetic spectrum, from microwaves through ultraviolet light. The human eyeball is, of course, a sensor of this type.

Observation is, by necessity, a scanning process registering the intensity of various spectral components; analysis consists of correlating the observed *signature* to actual physical components; detection is then a comparative process to identify observed signatures with known pollutants. Having detected an undesirable signature, the detector must also locate the offending substance and, specifically, the emitting source in a geographical reference.

Whether these signatures can be detected from geosynchronous orbits is questionable; that they can be detected from low-orbit platforms has been demonstrated by LANDSAT, and some of the Gemini photographs, although neither mission had this as a prime objective. Both the LANDSAT and the photographic techniques are too slow in response to be effective as a pollution control enforcement mechanism.

But consider the human eye, coupled to its brain, as an in-orbit sensor detector. Although limited to the visible spectrum, a great deal of data can be processed very rapidly, all with a resolution far better than any multispectral scanner yet conceived. Many pollutants do, indeed, have a discernible color and, specifically, a color different from their surroundings. Thus, one man, with a medium-power telescope in orbit, could be an effective pollutant detection/location system. And space can provide a habitable observation platform.

Prediction and warning functions imply the capability for detecting and extrapolating trends which, in turn, require some form of archival data system to compare present and past conditions. Earth orbit photographs, in natural color (for a human observer) and false color (such as the LANDSAT data), are the best candidates for dense data storage, easy retrieval and rapid comparisons. The optimum location for the archives would be the orbiting space station. Comparison may be made by direct vision or automated. Indeed, automated techniques, using image dissectors and digital computation, may be the only way to detect small differences.

Locating the processing units in the space element reduces the space-to-ground communications requirement to nominal voice-grade channels for transmission of results, avoiding the wide-band requirement to transmit real-time image data.

The on-board observer/analyst would transmit his conclusions to some local control center, perhaps supplemented by facsimile transmission of selected image frames, to pinpoint the location of the offender. Armed with hard, documented evidence, the enforcement agency would quickly apply whatever remedies were authorized.

A low-earth orbit space platform devoted to manned observation is envisioned; fortunately, there are many other objectives such as a manned platform fulfill, nearly all based upon human vision and analytical capability. Of course, the more objectives that are integrated into one station, the larger will be the on-board crew; however, there are few implementations that can return such immediate benefits to all of mankind.

Crop Measurement

General Objective

To evaluate the physical extent, maturity, and health of various crops.

Product to Earth

Photographic negatives and multispectral prints in a variety of different frequencies to allow for crop analyses.

Key Objective

The proposed system will provide a quick, efficient, and accurate means of monitoring the stage of development of crops as well as the detection of crop diseases.

Principal Contributions

The proposed system will contribute significantly to man's ability to control, regulate, and monitor the development of crops.

Level of Contributions

Millions of dollars are lost every year due to the late detection of disease, insect infestation, as well as the unexpected surplus of crops. The proposed system would greatly enhance man's capability to reduce these loses.

Uniqueness of Contributions

Outer space provides a unique opportunity to observe and analyze vast areas of crops using a variety of sensors. This capability is available on a limited basis from LANDSAT data. The Thematic Mapper, to be launched in the mid-1980's, will increase these capabilities.

Time Factor

This system should be implemented as soon as possible; the necessary payloads are light and compact.

Principal Installations

The principal installations would be space-based and consist of orbiting observatories that would transmit multispectral data. The photographic negatives would be retrieved by Shuttle flights.

Principal Functional Units

No supporting units required. However, ground truth data will be required to enhance evaluation.

Principal Technologies

Critical technologies will be required in the area of remote sensing in order to better differentiate crops and evaluate their maturity and health.

Impact Spectrum

Technologically and scientifically this system would require advancement of the state-of-the-art of remote sensing which would positively impact the area of mineral exploration.

Socially, politically and economically the proposed system would have substantial benefits. In general it would allow better crop utilization and, therefore, maintain a more stable price system for agricultural goods.

Front-End Capital

Satellite Development and Production	- $200M
Launch (from Vandenberg Air Force Base)	- $24M
Ground Service	- $10 to $50M
Transportation (Shuttle Flights to Retrieve Film)	- $100M
Processing of Data	- $50M

Earthquake Fault Monitoring

General Objectives

To reduce the number of lives lost and the damage costs due to earthquakes and fault movement; to allow close monitoring of potentially hazardous situations (i.e., fault motion near an off-shore oil platform); to increase our understanding of the mechanisms responsible for fault movement.

Product to Earth

Continuous detailed monitoring of ground movement as well as earthquake location along faults and associated features providing a complete history of movement in a given region.

Key Objectives

At present, fault-movement and in-situ conditions are monitored only at a few locations which are easily accessible to land vehicles. The instruments are monitored on a monthly basis by on-site inspection. Data is, therefore, accumulated slowly from a few stations leaving large gaps in coverage. Also, two-thirds of the earth's surface (that covered by the oceans) is not monitored in any meaningful way. The proposed fault monitoring efforts would include instruments implanted in the ocean floor and along continental faults to monitor their movements.

Principal Contributions

The proposed system will give scientists a clear picture of movement on the continents and along the ocean floor. This data could eventually help us to learn to predict such movements as well as increase our understanding of the mechanisms within the earth which create these movements.

Level of Contributions

At present there is no way to obtain a detailed picture of motion of the earth's crust. The communications network envisioned requires satellites as an integral part of the data-link. Technology is presently available to develop and construct the instruments needed to perform the desired observations, but a satellite system is required to monitor this data on a continuous basis and to transmit it to a central ground station.

Uniqueness of Contributions

At present, less than 10 percent of the earth's surface is being actively monitored for earthquake activity and fault displacement. The proposed space-based approach would allow scientists to observe a much larger region providing a unique look at the dynamic processes of the earth.

Time Factor

The technology for the proposed system is presently available and could be utilized with ease in the 1980 to 1985 time period.

Principal Installations

Principal installations will be required both in space and on earth. The instruments which will gather data on physical properties and those that will transmit this data to the satellites will be ground-based.

A satellite system is required to gather this vast amount of data from a broad area of the earth and transmit it, on a regular basis, to a central base station for processing and analysis.

Principal Functional Units

The functional units can be broken into two categories: *land-based* and *ocean-bottom*. *Land-based* units will be composed of seismometer, tiltmeters, frequency analyzers, stressmeters, argon/ground-water detectors, gravimeters, and magnetometers. *Ocean-bottom* instruments will be equipped with seismometers, tiltmeters, frequency analyzers, stressmeters, gravimeters, magnetometers, current meters, and instruments to analyze chemical elements in the oceans.

The ground-based instruments will transmit their data directly to satellite relays. The *ocean-bottom* instruments will be attached to bouys which, in turn, will relay their data to the satellite.

Principal Technologies

The necessary technologies exist today and this project requires only the implementation of these technologies. A 1980 to 1985 implementation is well within our capabilities.

Impact Spectrum

The proposed space-based system will reduce loss of lives and property damage in the event of an earthquake and allow continuous measurement of fault creep and stress. The proposed system would greatly increase our knowledge of the earth and its dynamic processes. It would also increase our ability to predict and monitor the possibility of off-shore oil drilling hazards.

Politically and environmentally, the proposed system will have important positive spin-offs. The ability to reduce environmental disasters is an important consideration.

Front-End Capital

Ocean Floor Equipment	-	$1M per unit
Satellite	-	$100M
Launch (from Vandenberg Air Force Base)	-	$24M
Operation	-	$10 to $15M per year
Land-Based Equipment	-	$0.1M per unit

Disaster Detection Discussion

Natural disasters, including earthquake, floods, volcanic eruptions, etc., usually occur without much warning and in isolated areas where communication is sparse. Observation from near-earth orbit would be highly advantageous for early detection and location.

Earthquakes can be detected seismographically by existing ground facilities; unfortunately, these techniques can locate the epicenter, but cannot locate and assess damage. Flooding damage, such as the Mississippi overflow, is difficult to assess even using high-altitude aircraft. Volcanic eruptions, hurricanes, tornados, tsunami, fire — all are potentially disasterous and difficult to assess with existing methods.

In many cases, we know that a disaster has occurred, but cannot communicate with the area to assess the extent; in at least one instance (Guatamala), relief was delayed because normal transportation facilities (roads, bridges, airport) were destroyed by an earthquake and alternate paths were not known.

High-altitude photography, as from an orbiting platform, could have alleviated this situation within hours; this form of observation could be combined or integrated with many other earth-observation services utilizing existing optical technology. The benefit is enhanced if the processing and analysis is performed by on-board operators. A series of surveying photographs would be reduced to a topographic map for transmission to appropriate relief agencies.

Using similar technology, the mapping of flooded areas, tracking of hurricanes or even individual icebergs in the north Atlantic can be beneficial on a global basis at a very small incremental cost. While not in the same category, downed aircraft and surface ships would be easily located by an orbiting, manned observation facility. Ocean shipping could be protected by guiding ships away from storm centers. Present methods for locating lost aircraft or boats usually involve search aircraft which, themselves, may become additional casualties. An orbiting observation platform would avoid the need for such hazardous operations.

High Resolution Earth Mapping

General Objective

The borders of many *third* and *fourth world countries* are ill-defined. These borders must be mutually established prior to intensive, detailed mineral resource mapping. The mapping should be of sufficient quality (e.g., 1: 62,500 or 1 mile to the inch) to allow accurate topographical mapping. Topographical maps are required for rational planning of roads, dams, irrigation canals, airfields, etc. It would be possible to map *fourth world countries*, like Chad (495,000 square miles), Ethiopia (395,000 square miles), Mali (465,000 square miles), Niger (458,000 square miles), or Mauritania (398,000 square miles), by aerial photography. However, approximately 7000 photographs taken from an aircraft, flying at 60,000 feet, would be required to map each country. By contrast, less than 150 satellite photographs would be necessary to do the same job. As of August 1976, the only complete coverage of the United States is at a scale of 1:250,000 (four miles per inch) which is not sufficiently accurate for many purposes. Computer processing would enable the automatic production of topographic maps from satellite data.

Product to Earth

Stereophoto data (60 percent overlap) at high resolution.

Key Objectives

High resolution earth mapping via satellite will enable the construction of detailed topographic maps necessary to national developmental planning. The topographic profiles will facilitate geological surveys in search of water supplies or mineral deposits.

Principal Contributions

Topographic maps are essential to effective planning of transportation, water and energy systems. Because of the long time required and high cost of gathering the necessary data by conventional means, developmental decisions in the above areas will be made on the basis of fragmentary or erroneous data.

Generation of topographic data by satellites can provide the required measurements economically and quickly; because of the wide area covered by each frame, ground processing of the data is reduced.

Level of Contributions

Conventional aerial surveys cost on the order of $200 to $300 per square mile. By spreading the cost of the satellite system over the many potential users, the cost of obtaining the needed data should be reduced by an order of magnitude. With computer processing, the desired maps could be produced at a reasonable cost.

Uniqueness of Contribution

No current space or ground system can be used to generate the data needed at a reasonable cost.

Time Factor

Near-term; 1980 to 1990.

Principal Installations

A satellite in a high inclination or sun-synchronous orbit would be required. Depending on technological advances, either high resolution film — to be recovered by the Shuttle — or a high-resolution video system (with either a very large data storage and high-speed dump capacity or possibly data relay via satellite) would be required. Because of the specialized nature of the computer processing and personal skills required, a single centrally located facility is envisioned.

Principal Functional Units

Constellation Size	-	1
Orbit	-	Sun-synchronous
Spacecraft Weight	-	3000 lbs
Power	-	2000 watts
Size	-	14 ft dia. x 20 ft len.
Payload	-	Self-loading camera and film reels or video scanner with data storage

Principal Technologies

High-resolution video, large-capacity data storage or replaceable film storage and protection module with automatic film loading. The video approach is preferred because it would eliminate the need for periodic Shuttle support missions.

Impact Spectrum

Technical	–	System is largely an application of military technology with modest improvements.
Economic	–	Plan for amortizing cost would have to be developed
Environmental	–	No detrimental effects other than launch vehicle exhaust
Social	–	Conductive to more efficient development of *third* and *fourth world countries* through improved development planning.
Political	–	Possible need to establish international consortium to acquire and process nationally sensitive data
Scientific	–	Serendipitous applications to geology, mineral and water surveys

Front-End Capital

Acquisition Cost	–	Video \$150M; Film \$80M
Launch Cost	–	Video \$24M; Film \$24M
Annual	–	Video \$10 to \$50M; Film \$105 to \$150M (service 90 days)

Global Effects Monitoring

General Objectives

To develop an understanding leading to prediction and, perhaps, eventually modification and control of our weather and climate patterns. The orbiting satellites would measure the long-term dynamics of earth surface, atmosphere, and the magnetosphere.

Product to Earth

Initially, science only. Eventually the ability to make accurate long-range forecasts of major weather and climatic conditions on a global basis. Also, a deeper understanding of the disruption of RF communications caused by solar storms.

Key Objectives

The principal hardware element in this initiative is the Solar Terrestrial Observatory, which would be assigned to investigate the coupling of the solar activity to the variability and dynamics of the earth's magnetosphere and atmosphere.

Principal Contributions

Longer-range weather forecasting, climate change predictions, possibly clues as to how to minimize the effects of natural, catastrophes caused by changes in our weather and climate. In addition, this initiative could result in more reliable RF communications.

Level of Contributions

Difficult to predict at this time. It depends on the accuracy to which the predictions could be made and the effectiveness of weather modification efforts. Could have a significant impact on the *Gross World Product.*

Uniqueness of Contribution

Space is the only vantage point for unfiltered viewing of the sun and is a unique vantage point for observing and measuring earth-based weather and climate phenomena.

Time Factor

1990's for major understanding (science) advancements. Modification and control: well into the twenty-first century.

Principal Installations

The Solar Terrestrial Observatory is comprised of four basic space elements:

1. A manned module (space station) in a high inclination, low earth orbit
2. A magnetospheric satellite located near the manned module and used to investigate the magnetospheric conditions at a point away from the disturbing influences of the space station, and as an experiment link in the active magnetospheric investigations
3. A solar weather satellite placed outside the magnetosphere whose purpose will be to study variations on the surface of the sun and to make direct particle and field measurements of the solar wind and its variability.
4. A manned space station module in geosynchronous orbit equipped with instruments similar to those used by the low altitude earth orbit module

Principal Functional Units

The space station module contains: optical instrumentation for studies of the sun and solar activity; optical instruments, lidar, and radiometry instruments for studies of the earth's atmosphere; active instruments and particle measuring devices for studies of the magnetosphere. A large enough crew is needed to conduct investigations throughout the 24-hour day. The manned station at the geosynchronous altitude would probably be a four- to six-man station.

Principal Technologies

The new technologies are reasonable extrapolations of present state-of-the-art, particularly in lidar, laser radars and data processing of doppler effects, elastic scattering, electromagnetic spectrum and absorption signatures. Other system requirements for the space station module are:

Power	–	5 kW average; 20 kW peak
Pointing	–	A few arc seconds for optical instruments
Orientation	–	Earth pointing for atmospheric instruments; sun pointing for solar instruments
Cooling	–	Cryogenics for IR and other instruments
Data	–	1 Mbps peak (on-board recording and analysis equipment required)
Telemetry	–	Downlink-voice, real time TV, periodic data transmittal; Uplink is same as above
Payload Weight	–	Unpressurized – 10,000 kgm; Pressurized – 3,000 kgm
Crew Size	–	two-plus-two (12 hour shifts)

Impact Spectrum

Weather is a paramount driver in the daily lives of most of the people of the earth. Certainly many losses of crops, structures, etc., could be saved with better short-range weather prediction. Long-range climate change prediction could avert, or at least mitigate, major multi-year catastrophes. However, in such an interrelated system as global weather and climate, there will surely be legal and political implications.

Front-End Capital

To be determined (multi-millions to billions).

TERRESTRIAL ALTERNATIVES

All of the human needs, which were the sources of *anchor opportunities*, were reviewed for economically attractive terrestrial solutions. Because the problems associated with the selected *anchor opportunities* were, indeed, substantial, the literature compiled in Task 1 generally contained data on planned terrestrial solutions or activities. These data were reviewed and embellished. In several instances new terrestrial options were then generated. The economic merits of the terrestrial options were then cursorily assessed against the merits of the respective anchor opportunity — generally on an *order of magnitude*, largely qualitative basis. This analysis revealed those *anchor opportunities* for which comparatively strong terrestrial options existed. A more rigorous analysis was then made of each case thus identified.

Of the many analyses made, the results of the following three resulted in the elimination on the economic merits of the respective *anchor opportunities*. These *anchor opportunities* are being held in abeyance pending possible integration with other *anchor opportunities*, thereby enhancing their economic merits.

Oil Spill Detection

Problem

Oil spills generally stem from three sources. The first source is tank ruptures due to accidental grounding, collisions or from structural failures. According to the American Hull Syndicate, as insurance group, approximately ten accidents occur daily among the world's 4500 tankers. Very few of these result in significant oil spills. In 1976, at least 19 tankers, totalling over 1,100,000 deadweight tons, were lost. Oil spills totalled 67,000 tons in 1974; 188,000 tons in 1975; over 200,000 tons in 1976. These oil spills, because of their obvious nature, present no initial detection problems.

The second source of oil spills stems from leakage from off-shore drilling operations. Here too, detection of the spill and tracing it to its source generally presents no major problems.

The third source of oil spills is caused by the discharge of oily sea water from tanks where it had been used as ballast. Cargo ships and tankers use sea water in their tanks as ballast when running empty or off-loaded. Upon nearing their destination, they pump out the oily sea water before entering port. United States regulations require that this be done at least 50 miles offshore.* The quality of oil released in this manner during the past 12 years is estimated to be four to five times the quantity released by accidental oil spills. The oil spill detection problem focuses on detecting violations of this regulation.

Major oil companies adamantly claim their tankers follow the following procedure:

> When ready to depart port (empty), they take on just enough sea water into their tanks - in a checkerboard pattern - to assure control while navigating out of port. Once at sea, they add additional ballast. The empty tanks in the checkerboard pattern are spray cleaned (Butterworthing) and the oily residue is all pumped into one holding tank. Then sea water ballast is pumped into clean tanks and the dirty tanks are spray cleaned. Again, the oily residue is pumped into the holding tank. The sea water

*Reference 33, Code of Federal Regulations (CFR), Part 151, *Oil Pollution Regulations*.

settles to the bottom (along with clumps of tar) and is pumped out, leaving the oily sludge in the holding tank. Upon loading, fresh crude is pumped on top of the sludge and the mixture transported to the refinery where it is all pumped out. (Per Mr. Sheehan, Union Oil Company (213) 486-7019.)

Most major oil company terminals have *ballast receiving facilities* which can accept relatively small quantities of oily sea water and separate the oil from the sea water.

Illicit oil discharges would most likely come from leased, independently owned, tankers. According to 33 Code, Federal Regulations, "... *ships are prohibited from discharging oily wastes within 50 miles of the west coast of the United States (100 miles in the case of Canada). Ships are required to keep an Oil Record Book into which the times of ballasting, tank washing, dumping, etc., are entered. The penalty for dumping oily waste within the prohibited zone is a fine of $500 minimum, $1000 maximum plus up to 6 months in jail.*" All major ports have ballast and bilge unloading barges (slop barges). The nominal charge for this service in the Port of Los Angeles is 17-1/2 cents per barrel, with a minimum charge of $950. Consequently, it would cost more to unload sea water ballast in a port than the fine would be if caught dumping if off the coast.

Space Concept

A constellation of satellites equipped with sensors for detecting sunlight reflected off oil would be placed in a low polar orbit. Upon detection of oil slicks, the data would be transmitted to a ground station at a polar latitude (such as Fairbanks, Alaska) where computer analysis of the data would reveal the location, direction and extent of the oil slick. These data would be used to alert responsible authorities (i.e., Coast Guard) to intercept and identify the offending ship so that action could be taken against the ship owner. About ten or twelve satellites would be required to provide the necessary ground coverage.

Terrestrial Alternative/Space Concept Impediment

Although current regulations prohibit dumping of oily wastes within 50 miles of the United States coast, it appears to be standard practice for many tankers, particularly those those courses parallel the coast.

More aggressive enforcement of existing laws; U. S. ratification of an international convention requiring separate tanks for oil and ballast water on all new tankers over 70,000 tons; funding 50 additional Coast Guard tanker inspectors; the closing of U. S. ports to violating ships are all steps currently being taken or actively considered to reduce coastal pollution from tankers.

Because of the possible penalties imposed, violators would take steps to minimize the likelihood of detection via the satellite system (as they apparently do today). If pollutants are to be dumped overboard, this could be done in the early evening (after sunset). Without sunlight, the satellite sensors would be unable to detect the revealing oil slick. The number of hours of darkness would depend on the time of year and latitude. However, if 8 hours are assumed, plus an additional hour for the detecting satellite to complete its orbit to the data receiving station and an additional hour for data analysis, 9 to 10 hours could have elapsed since the dumping. If the offending ship were traveling at 15 knots, it would be 155 to 170 miles away, making ship identification and subsequent proof of guilt highly unlikely. Furthermore, clouds and/or coastal fog would also preclude sensor operation. On an average day, 14 ships enter and deport Los Angeles Harbor. At any given time, there are approximately 20 ships within a 100-mile radius of Los Angeles, which would compound the problem of identifying the offending ship. Those ship captains, who would be willing to falsify the Oil Record Book, would likely not be deterred or significantly intimidated by a slick-detecting satellite which required sunlight for detection.

Economic Evaluation

The minimal cost of acquiring the satellite system is estimated as follows:

Non-Recurring Cost

Space Segment:	
DDT&D	$ 20.0M
Acquisition of 10 Satellites @ $10M each	100.0M
Launch Costs - 2 Launches @ $20M each	40.0M
	$160.0M
Ground Segment:	
Acquisition	$ 10.0M
TOTAL	$170.0M

Recurring Cost

Annual Operating Cost $10M/Year x 10 Years	$100.0M
10 YEAR PROGRAM COST	$270.0M

The strict enforcement of existing laws, imposition of more severe penalties, construction (where lacking) and compulsary use of on-shore (or barges) ballast receiving facilities in all major ports would appear to be more prudent actions than reliance on an oil spill detection satellite that could readily be thwarted by a few simple precautions taken by an offending ship captain.

Border Surveillance

Problem

Surreptitious border crossings by illegal immigrants into the United States are considered to constitute a serious threat to order and economic stability. In 1977, it is anticipated that 800,000 illegal immigrants from

South America, Central America and Mexico will enter the United States across the Mexican border. Approximately 200,000 of these will settle in the Los Angeles area, where they will compound the unemployment problem and, according to the Los Angeles Police Department, contribute substantially to the crime rate. Based on crime records, illegal immigrants commit 20 to 25 percent of all burglaries, 30 percent of all hit-and-run accidents, and 20 percent of all auto thefts. Furthermore, a Los Angeles Police Department study revealed that illegal aliens constituted 36.6 percent of all felony arrests.* With a current population growth rate of 3.5 percent, the 60 million population of Mexico is expected to double in 20 years, thus maintaining the immigration pressure. In order to reduce the influx of illegal immigrants, illegal border crossings need to be detected and the immigrants apprehended and returned.

Space Concept

Approximately a million small sensors (intrusion detectors) would be deployed along the border. Upon detecting an intrusion, the sensors would broadcast an identifying signal to a satellite in geosynchronous orbit. The signal would be relayed from the satellite to a ground control station which, in turn, would alert the Border Patrol Office nearest to the intrusion to take appropriate action.

Terrestrial Alternative/Space Concept Impediments

A variety of point defense intrusion detectors have been developed and used extensively by the military over the past 10 years. Many types found use in Viet Nam. The Border Patrol currently uses seismic sensors that detect the footfalls of illegal border crossers. The data from these sensors are currently transmitted to the adjacent Border Patrol Station.

Under either the Space Concept or Terrestrial Approach, ground sensors would be used that would transmit an identifying signal upon triggering by an intrusion. In the Space Concept, the signal would be relayed via a geosynchronous orbit satellite. The problems of antenna size, power, sensor identification and system saturation by simultaneous receipt of signals would add substantial complexity to the Space Concept. The current intrusion detectors, which transmit to the adjacent station, function adequately. They transmit on a long wave length (about 1 to 3 meters) which restricts their signal to line-of-sight. A station with a 100-foot high antenna can receive signals from sensors up to 14 miles away so that it can cover 28 miles of border. Additional range could be obtained by mounting the antenna at a topographically elevated site or using relay stations. The key problem is not so much that of detection as it is staffing.

Economic Evaluation

More than half of the illegal immigrants crossing the Mexican border enter into California or Arizona. In 1976, the 801 Border Patrol officers stationed in California and Arizona, and operating with a budget of $31.9M, apprehended 438,320 illegal aliens. The apprehensions during the first two months of 1977 were running 10 percent higher in the Chula Vista sector than in 1976, when more than 270,000 persons were apprehended.

*Los Angeles Times (January 30, 1977).

A dedicated border surveillance relay satellite (25-foot antenna minimal) would cost an estimated $150M to develop, produce and emplace. Assuming a 10 percent interest rate, the interest on this investment would amount to $15M annually. For this amount, the Border Patrol force could be expanded by 300 men (37 percent), plus 20 helicopters and, in addition, the entire border between the Pacific Ocean and El Paso could be arrayed with sensors; the helicopters and sensors replaced every three years.

In the opinion of the Los Angeles Police Department committee looking into the problem of illegal aliens, the current resources of the Immigration and Naturalization Service and Border Patrol are grossly inadequate to stop illegal immigration.* Consequently, it is deemed that the satellite funds could be more effectively spent on expanding staffing of personnel who would act on currently received intrusion signals, or signals from an expanded intrusion system to apprehend illegal aliens.

Off-Shore Control Limit Monitoring

Problem

On March 1, 1977, the Fishery Conservation and Management Act went into effect. It extended the U.S. fishing (not territorial) jurisdiction to 200 miles off-shore and established quotas for foreign and U.S. commercial fishermen. Foreign fishermen may fish only if they have a permit - which costs $5000 - and agree to U.S. regulations. Each nation is assigned a limited number of permits. These include where, when, what kind, how, and how much fish may be taken within the 200 mile zone. The U.S. Coast Guard has the responsibility for patrolling the added territory. To police the area, it will use 39 cutters, including two 270-foot high-speed helicopter-carrying vessels; 41 new, medium-range jet aircraft; 21 long-range C-130 Hercules; 5 new HH-52A Sikorsky helicopters, plus 75 other helicopters. Policing will focus on the commercially productive fishing areas. In 1975, 2700 foreign vessels fished these waters The number varied from 240 in December to 970 in June. A number of other countries have, or are about to extend their fishing (and mineral) jurisdictions to 200 miles. The policing of this zone can impose substantial economic burdens on the respective countries.

Space Concept

A constallation of satellites equipped with radar antennas would be placed into polar orbit. As they circled the earth, they would be continually sweeping ocean areas and recording the locations of all ships. The radar would be capable of penetrating fog and clouds. Upon passing over a data receiving station, located at polar latitudes, the satellites would transmit stored data on all ship sightings. The off-shore coastal limit monitoring satellites are proposed to be placed in a 4000 mile, 4-hour polar orbit. The orbital trace would repeat itself every six orbits. Only four satellites would be required to provide 4-hour global coverage. If the satellite radar would scan 30 degrees to each side of the orbital path, then every spot on the globe would be covered twice each day by three satellites, for a total of six observations, or an

*Los Angeles Times (January 30, 1977).

observation each 4 hours on the average. This is the worst-case (equatorial) coverage. Because of scan-paths overlap at higher latitudes, most areas would be covered more frequently. The satellites would be scheduled to dump their data at 40 minute intervals. A computer would process the data. By masking out all irrelevant (or non-paying) zones, a running record would be kept of all ships in the areas of concern. Ships travelling through an area (at 10 to 18 knots) could interject uncertainty into their tracking. However, the primary concern is on ships that would be loitering within a 200 mile coastal area. Occurrences of loitering would be detected by the computer and reported to authorities responsible for policing the area.

Terrestrial Alternative/Space Concept Impediments

Foreign ships licensed to fish within the U.S. jurisdictional waters are being equipped with transponders. Coast Guard aircraft flying their daily patrols will transmit an interrogatory signal and receive a response from the transponders on the licensed vessels. If no return signal is received (or an inappropriate one), then the aircraft will alert the nearest Coast Guard cutter to investigate. The severe penalties for violations (ship seizure or $500,000 fine) make the possible benefits from illegal fishing insufficiently attractive. Furthermore, publication of lists of licensed ships will enable U.S. fishing vessels to spot and report violators.

A more subtle problem is that associated with enforcing the tonnage and species limitations. The satellite would not be able to contribute in this area. To monitor compliance with the take limitations, 20 agents of the National Marine Fisheries Service are being placed aboard foreign trawlers · factory ships to observe fishing practices and hauls. The foreign nations on whose ships the observers are placed will bear the costs associated with the observers. Thus large, potential violators will be closely monitored.

Foreign nations, which do not have a large enforcement fleet, might appear to be candidates for the surveillance service. However, both fishing and sea-bed mineral recovery are time-consuming operations. To be profitable, the ships need to be on-station for substantial periods of time. Location of fishing grounds are well known, as are areas containing mineral modules. Consequently, the <u>entire</u> coastal area does not have to be monitored. Ships exploiting either resource would be conspicuous by their design and long-time presence and so would be prime candidates for investigation by patrol vessels. Foreign nations would need to have patrol vessels for apprehending violators. These vessels would perform policing duties as well. Each apprehension, with a $500,000 fine or sale of confiscated trawler, would be sufficient to buy another patrol boat. Native fishermen could be given a small percentage of the fine as an inducement to report illegal fishing vessels.

The contribution of satellite data to monitoring of fishing vessels in, say, the Geoges Bank would be of questionable merit. During the peak fishing months, hundreds of vessels are located at the fishing grounds. United States trawlers would normally stay five to eleven days, with some arriving and others departing on any one day. To rely on the satellite data on number of ships and their location to detect one or even a dozen <u>illegal</u> ships among the hundreds of legal ships milling over the area does not appear practical.

Finally, a determined violator could paint his trawler with a radar absorbtive paint or coating. A 200-foot ship could easily be made to return the signal of a less than 100-foot vessel (HIDE material). Consequently, sole reliance for detection of violators could not be placed on the satellite system.

Economic Evaluation

The estimated cost of the space based concept is:

Non-Recurring Cost

Satellite RDT&E	$40.0M
Satellite Procurement - 4 @ $20M	80.0M
Computer System	20.0M
Computer Software	20.0M
Launch Costs - 2 Launches @ $30.0M each	60.0M
TOTAL	$220.0M

Recurring Cost

Ground Station - 4 Shift $10.0M/Year x 10 Years	$100.0M
10 YEAR PROGRAM COST	$320.0M

For this expenditure, the system would report the presence of every ship longer than 100 feet within the 200 miles of the United States coast, and the coasts of subscribers.

The primary purpose of the data would be to detect violators of fishing or mining restrictions. Since the U.S. Coast Guard is responsible for search and rescue operations, detection (and apprehension) of smugglers, detection of oil pollution, etc., the extension of its responsibilities to the policing of fishing within the 200 mile limit was an incremental extension of its existing duties. The additional cutters and manpower acquired were needed for possible apprehension as well as detection of violators. Patrol craft already fly missions associated with smuggling, oil pollution, and ice patrol. An incremental analysis reveals that two new 270-foot, helicopter-carrying cutters are being acquired and four reconditioned cutters demothballed. These, however, would be required for apprehending violators. The 41 new medium-range Falcon jets will be replacing 23 HU-16 Albatross aircraft that are 20-years old. Five new HH-52A Sikorsky *Flying Lifeboats* are to be taken out of reserve, and 800 men are to be added to the service. The patrol aircraft policing fishing areas will be equipped with transponder interrogators. Every licensed foreign fishing vessel will be provided a transponder which could be designed to report the license number of the fishing vessel upon interrogation. This *lock box* would be similar to the altitude-reporter transponders on aircraft, which report aircraft altitude to the Air Traffic Control radar. These units cost about $600 to $700. This cost could be covered by the $5000 license fee. The patrol planes flying routine patrol could be interrogating the fishing ships as they fly.

Foreign nations such as Peru and Ecuador do not seem to have significant difficulty in detecting or apprehending our tuna fishing boats. Any nation with fish or mineral resources worth exploiting would have their own ships in the area. It would be in the self interest of the native fleets to report foreign violators to the enforcing authorities.

Finally, the high probability of detection by conventional terrestrial means, when weighed against the cost of fishing vessels subject to confiscation, coupled with the severity of the possible fines assessed, appear to serve as strong deterrents to potential violators. Thus, the expenditure of $320M to detect possible violators does not appear economically justifiable.

Global Effects Monitoring

Problem

Weather exerts an influence on all human activities. It significantly impacts major problem areas such as the utilization of energy resources, food production, and transportation. In spite of its potential importance, weather prediction beyond four or five days remains a highly inaccurate art rather than a precise science.* Climatologists cannot even agree on gross trends, such as whether the climate in the north temperate zone is undergoing a long-term warming or cooling cycle. Attempts at modeling weather have proven unsuccessful, largely because of the number of variables involved, the difficulty of acquiring synoptically accurate values for the variables, and processing the data to produce a meaningful model. RFP's are being issued for the next generation of large computers (termed *Phoenix*). The specifications of the computer call for a capability two orders of magnitude greater than the currently largest computer (Illiac IV). The *Phoenix* is expected to be capable of processing 10 billion instructions per second — sufficient, hopefully, for weather modeling if we understood the dynamics and relationships among the variables. The global effects monitoring space opportunity is designed to provide data on which to base models of global weather in the expectation that if the interrelationship among variables can be understood and modelled, then accurate forecasts can be generated.

Of course, the earth is not a closed system. Solar phenomena directly influences the weather. If the earth's weather is to be predicted, then greater capability towards predicting solar activity must be acquired.

System Description

The concept envisioned for acquiring the necessary data consists of four basic space elements. These are:

*_How Good is Weather Forecasting?_ The Christian Science Monitor (Mar. 2, 1977).

1. A manned module in high inclination, low earth orbit (space station-type)

2. A magnetospheric satellite located near the manned module and used to investigate the magnetospheric conditions — at a point away from the disturbing influences of the space station

3. A solar weather satellite placed outside the magnetosphere, whose purpose will be to study solar variations on the surface of the sun and to make direct particle and field measurements of the solar wind and its variability

4. A manned space station module in geosynchronous orbit equipped with instruments similar to those found on the low earth orbit module.

Because of the level of sophistication of some of these items (particularly Items 1 and 4, it is not likely that the system will become operational before 1990.

Estimated Cost of Global Effects Monitoring System

The pacing item in this *anchor opportunity* is the manned space station module in geosynchronous orbit. Before a manned space station is placed in geosynchronous orbit, a low earth orbit space station would have been developed and qualified. This station would have absorbed most of the developmental and test costs. The geosynchronous version would be largely a copy of its predecessor. Inasmuch as the low earth orbit space station would have borne the development and test cost, the production cost of the geosynchronous station was assumed to be 1/3 of the acquisition (development, test, and production) cost of the initial space station.

The manned station in the high inclination, low earth orbit was assumed to be less elaborate and so cost slightly less than the geosynchronous station. The magnetospheric satellite, co-orbital with the high inclination manned station was estimated to cost $200 million to procure and launch. Because of its greater complexity and higher orbit, the solar weather satellite was assumed to cost $300 million.

The low earth orbit station, which is the forerunner of the geosynchronous station, consists of six modules — each weighing approximately 40,000 pounds. Consequently, six Shuttle launches will be required to deliver this station to low earth orbit. It is assumed that the geosynchronous station will likewise be delivered by six Shuttle launches to a low earth orbit. Two modules will be mated together and transported to geosynchronous orbit via a solar electric propulsion stage (SEPS). SEPS missions of 360 days are envisioned at approximately $30M each. Crew rotation will be accomplished with a crew module containing appropriate life support for a complement of six to ten persons on a seven-day mission (14 days in emergency) of this recoverable and refurbishable module acquisition of the crew module is assumed to cost $300M. An advanced technical tug will be required to transport the crew module between low earth orbit and geosynchronous orbit. The acquisition cost of this vehicle — which is a scaled-up version of the chemical tug — is estimated to be $250 million. Consequently, the cost of implementing this *anchor opportunity* is estimated to be:

Non-Recurring Cost

High Inclination Manned Module		$1.0 B	(1977 $)
Magnetospheric Satellite		0.2 B	" "
Solar Weather Satellite		0.4 B	" "
Manned Geosynchronous Space Station		2.0 B	" "
Space Station	$1.20B		
Shuttle Launches (6)	.15		
SEPS Trips	.09		
Crew Module	.30		
Chemical Tug	.25		
TOTAL NON-RECURRING COST		$3.6 B	" "

Recurring Cost - Annual

Crew Changes - 3 per year			
6 Shuttle launches - 2 per Crew Change	$150M		
TEN YEAR RECURRING COST		$5.0 B	" "

Description and Economic Evaluation of Benefits

The ability to generate accurate long-range weather forecasts would produce a variety of diverse beneficial results. If the severity of the winter of 1976-77 had been predicted, then adequate fuel supplies could have been stockpiled, thereby making fuel rationing and plant closings, with their economic hardships, unnecessary. At one point, 1,800,000 Americans were kept from their jobs by the weather.* Forecasts of adverse weather, such as late rains, early freezes, unusually wet or dry summers, would all influence farmer's decisions and result in greater crop production through the incorporation of the information into planting decisions. Foreknowledge of weather disasters, such as hurricanes and their severity, paths, and times of arrival, would result in the saving of lives. Property could be boarded up, areas subject to flooding could be sandbagged, and crops harvested before storms struck. Dams could be drawn down for energy production if their replenishment was assured by accurate weather forecasts.

**Coping with Nature's Forces,* The Christian Science Monitor (June 23, 1977).

An estimate of just one of the myriad possible economic benefits resulting from accurate long-range weather forecasts will be made, namely, of the possible economic impact of improved weather forecasting on wheat production. The National Research Council, in a recent report on climate and food, emphasized that *"...long term trends in climate are not as important to the U.S. food production as are fluctuations or increased variability in climate over a season a year, or several years."*[1] Strains of wheat have been and are continuing to be developed for special or regional weather conditions. For example, Vona, a new strain of wheat, is much more drought resistant than standard varieties. It has the potential to increase wheat production by as much as 10 percent in areas such as Colorado.[2] This wheat would not be suitable for use in the weather or altitude conditions of Nebraska or the northern areas of Minnesota and the Dakotas. The point here is that varieties of grains are being developed which will optimize yield for specific weather conditions. If wheat farmers knew the weather conditions of the coming season, they could plant appropriate strains, thereby increasing the yield. The 1976 wheat crop in the United States was 2.147 billion bushels.[3] If by planting strains that had been developed for the anticipated weather conditions, crop yields could be increased by 10 percent, then based on 1976 production, an additional 215 million bushels would be produced in the United States at $2.50 per bushel; this would amount to $538 million annually for just the United States wheat crop. Over ten years, the benefits would amount to $5.38B. The planting of weather-compatible strains would not be limited to wheat, but would apply to most major crops.

The 10 year program costs appear to about equal the benefits expected to be derived from increased wheat production alone. All other benefits accruing from the ability to forecast weather could be viewed as *profit*. Among these benefits would be:

- Optimal fuel storage
- Dam impoundment water management
- Advanced storm warnings
- Water resource management
- Crop planting
- Crop harvesting
- Ship scheduling/routing
- Etc.

Once accurate forecasting models were generated, the next step would be to try to control the weather to prevent detrimental extreme conditions. The use of weather control as a military weapon was outlawed under terms of a convention signed on May 18, 1977 by the United States, U.S.S.R, and approximately 18 other countries.[4] Modern attempts at controlling weather have centered primarily on cloud seeding. To date, man appears capable of making only very minor

---

[1]*Weather: A New Kind of Challenge*, The Christian Science Monitor (Feb. 25, 1977).
[2]*New Strain of Wheat Could Up Yield 10%*, The Christian Science Monitor (Feb. 8, 1977).
[3]*Farmers Paid Less for More Wheat and Corn*, Los Angeles Times (Jan. 23, 1977).
[4]*Outlawing Weather as a Weapon*, The Christian Science Monitor (May 18, 1977).

modifications. However, legal problems associated with weather modifications need to be resolved. Fifteen lawsuits have been filed against weather modification projects.* However, to date, none of the plaintiffs have recovered any money for damages because of the inability to establish casual relationships between attempts at weather modification and the alleged damages. Once reliable predictive models are established, then lawsuits could proliferate unless somehow precluded by new laws.

Funding Schedule

The development of a space station for low earth orbit was assumed to precede. Current space station planning is aimed at having the low earth orbit station fully operational about 1989 to 1990. Consequently, the development of the geosynchronous orbit station, which is the pacing item here, was assumed to commence in 1988 and require 5 years. This period would allow for operational qualification of the initial station and the incorporation of any required changes into the geosynchronous orbit station designs. The six elements of the station are assumed to be transported in pairs (one pair per year as they are completed) from low earth orbit to geosynchronous orbit by a SEPS. The trip was assumed to require 360 days.

Table 2 shows the schedule and arrival funding level by elements. Under the assumptions made, an IOC date of 1996 is indicated. The peak funding (in

Table 2. Global Effects Monitoring Funding Schedule

ELEMENT DESCRIPTION	COST ($M)	ACQ. TIME	1988	1989	1990	1991	1992	1993	1994	1995	1996 (IOC)	1997
HIGH-INCL MAN MOD	1000	5				41.5	202.2	328.3	304.5	123.5		
MAGNETOSPHERIC SAT	200	3						31.5	105.5	63.0		
SOLAR WEATHER SAT	300	4					22.6	97.4	123.6	56.4		
					16.6	80.9	131.3	121.8	49.4			
				16.6	80.9	131.3	121.8	49.4				
			16.6	80.9	131.3	121.8	49.4					
MANNED GEO ORB SAT	1200	5/3										
SHUTTLE LAUNCHES								50.0 2	50.0 2	300.0 2+4+6	150.0	150.0
SEPS TRIPS								25.0 1	25.0 1	25.0 1		
MANNED OTV	300	5			12.4	60.7	98.5	91.4	37.0	3		
CHEM OTV	250	4				18.8	81.2	103.0	47.0	3		
ANNUAL FUNDING			16.6	97.5	241.2	455.0	707.0	897.8	742.0	567.9	150.0	150+
SPREAD: 40:60			TOTAL THROUGH 1995: $3725M									

Why Not Alter Weather? Answer is Easy, Los Angeles Times (Feb. 23, 1977).

1977 dollars) would be on the order of $900 million. This amount could be reduced by starting development of the manned and chemical OTV's earlier. A 10-year operational life should enable the acquisition of sufficient solar and terrestrial data for weather model building and verification. A solar sun spot maximum should occur about 2002, which would enable the observation of solar phenomena both preceding and following the solar maximum.

Crop Measurement

Problem

Accurate foreknowledge of crop production is essential to efficient crop management and marketing. Historically, county agricultural agents have reported on plantings in their areas. This information, coupled with yield data and weather data, have constituted the basis for the Department of Agriculture crop estimates. As the growing and harvesting seasons progress, estimates of crop production are updated. Current methods are ponderous, slow and insufficiently accurate. The need for crop forecasts is so urgent that private forecasters provide early estimates to farmers and major grain dealers, who either cannot wait for the official U.S. Department of Agriculture forecast or who believe the private forecasters are more accurate.* Better methods of crop measurement are required for a variety of reasons. Based on recent trends, world wheat production is expected to expand at almost 2 percent per year for the next decade. This means that in the United States alone, wheat storage capacity would need to increase at a rate of over 30 million bushels per year. If an excellent growing season is experienced, then transportation and storage capacity must be available throughout the *pipeline* if losses are to be avoided. Knowledge of the additional storage capacity required and its location is vital to prevent losses.

If farmers had accurate and timely data on crop production between the northern and southern hemisphere, they could make decisions on crop plantings so as to optimize their profits as reflected by the economics of the crop demands.

System Description

The space portion of this *anchor opportunity* would consist of an operational version of LANDSAT D (thematic mapper). This satellite and the ground based data processing computers, would be under the jurisdiction of the Department of Agriculture. Crop measurement requires first of all, knowledge of the acreage planted and, secondly, an estimation of the yield per acre. The current Large Area Crop Inventory Experiment (LACIE) uses LANDSAT-derived data to identify crop acreage. Data on temperature and precipitation, obtained from the NOAA satellites (or from the Global Effects Monitoring Program), will enable estimation of the yield. These data can then be processed to provide estimates of crop tonnage.

**Wheat Harvest in U.S. Seen Off 5% From 1976 By Private Forecaster*, The Wall Street Journal (July 11, 1977).

In order to fully utilize the operational LANDSAT D capability, data will need to be relayed via the TDRS to the ground station(s) because the LANDSAT will be out of range of the ground stations and will not have sufficient storage capacity to store all of the data acquired.

Estimated Cost of Crop Measurement System

The crop measurement satellite is envisioned as being a long-life, uprated version of LANDSAT D (thematic mapper). Because of the prior LANDSAT programs, the satellite cost reflects a legacy from these programs. The costs (1977 dollars) are estimated as follows:

<u>Non-Recurring Cost</u>

Satellite Acquisition	$150M
Launch Cost	$ 20M
Ground Station/Data Center Acquisition (including Computer and Software)	$ 50M
TOTAL NON-RECURRING COST	$220M

<u>Recurring Cost (Annual)</u>

Ground Station/Data Center Operations	$ 15M
10 YEAR PROGRAM COST	$235M

The crop measurement center is assumed to be staffed by 150 to 200 employees who, with the aid of computers, analyze satellite data from all major food producing countries. Data will be compiled on all major crops, and released simultaneously to all countries concerned. In addition, special analyses will be conducted to monitor for, detect, and determine the extent and impact of drought, freezes, storms, blights, locusts or insect infestations, or other crop-reducing phenomena.

Proposals have been advanced for the establishment of international grain reserves. The data acquired from the crop measurement satellite and compiled by the Crop Measurement Center would be essential for the orderly (and economic) administration of such reserves.[1,2]

Description and Economic Evaluation of Benefits

While there are a large number of economically beneficial aspects associated with advanced knowledge of crop data, most are difficult to pin down with credibility. This analyses will focus only on the economic implications

[1] *Restrictions on Winter Wheat Plantings are Studied Due to Glut and Low Prices,* <u>The Wall Street Journal</u> (June 27, 1977).
[2] *Bergland's Grain Plan,* The Christian Science Monitor (July 1, 1977).

of Government policymaking regarding wheat. In 1977, because of the large wheat harvest in 1976, the U.S. had a wheat surplus of 1.1 billion bushels. This is the largest stockpile since 1963, and is certain to grow with the 1977 crop. As of the end of June, the Department of Agriculture did not have a final figure on the 1976-77 plantings, let alone the yield.[1] By August, the Government will have to decide whether or not to impose planting restrictions on wheat and, if so, to what extent because planting of winter wheat starts in August. However, in August the harvesting of spring wheat is still in progress and with present technology, the size of the crop cannot be estimated with confidence until after harvesting is completed. Thus, decisions involving tens of millions of dollars have to be made before essential data are available. If the wheat crops in other parts of the world are poor, then the surplus would be reduced. However, if the wheat crops are large, then our wheat exports would decrease and our surplus would grow substantially and would have to be stored. At the present time, the Department of Agriculture, under the Uniform Grain Storage Agreement, pays farmers 1-1/2 cents per bushel per month to store surplus wheat. At this rate, a 1.1 billion bushel surplus cost $198 million to store for one year. The 1-1/2 cent rate is expected to be increased to 1-3/4 cents or 2 cents, further increasing the storage costs. On the one hand, farmers need to make a *reasonable* profit so that a large quantity of grain must be produced and sold at a reasonable price; on the other hand, it is expensive to store excess surplus wheat. In view of the current uncertainties within which agricultural decisions are made, it is likely that the *excess* surpluses could be safely reduced about 30 percent if accurate crop estimates could be available sooner than at present. If it is assumed that the excess wheat surplus could be reduced by 30 percent, then the annual saving would be on the order of $60 million per year. This would amount to a $600 million saving based on wheat storage costs alone over a 10-year program life. The total program cost (including system acquisition and 10 year operation) is estimated to be $370 million. The benefits of the crop measurement satellite would extend to other crops and enable a smoothing of the cyclical and wasteful nature of agricultural policy due to the lack of accurate and timely information.

Funding Schedule

Because the operational crop measurement satellite is an evolutionary offshoot of the experimental LANDSAT D, its acquisition is assumed to commence after the launch of LANDSAT D in 1981, and require 4 years to initial operational capability. Consequently, it is assumed to become operational in 1985. The funding is assumed to be incurred on a 40:60 ogive and so would appear as shown in Table 3 .

The peak funding would occur in 1984 and require approximately $82.4 million. This would amount to less than 15 percent of the Agriculture Department's research and development budget for 1978.[2]

[1] *Restrictions on Winter Wheat Plantings are Studied Due to Glut and Low Prices*, The Wall Street Journal (June 27, 1977)
[2] Special Analyzes, Budget of the United States Government, Fiscal Year 1978, p. 296.

Table 3. Crop Measurement Program Funding
(M 1977 Dollars)

	1982	1983	1984	1985	TOTAL
Satellite Acquisition	11.3	48.7	61.8	28.2	150.0
Ground Center Acqui.	3.8	16.2	20.6	9.4	50.0
Launch Cost				20.0	20.0
	15.1	64.9	82.4	57.6	220.0

Electronic Telecommuting

Problem

A major portion of our unfavorable balance-of-trade arises from the need to import oil. Studies have determined that automobile commuting accounts for 3.9 percent of our total energy consumption, or almost 3 quads.* This converts to 510 million barrels of oil. At an average price of $13 per barrel, this amounts to $6.6B of oil (gasoline) consumed annually in commuting by automobile. In addition, city cores are congested and deficient in parking facilities. It has been proposed that *white-collar* jobs be decentralized from city core areas into outlying offices - all linked to a computer-centered electronic network. Instead of producing paper output, the office workers could be processing the data directly into a computer. By instituting outlying offices in suburban areas, the paperwork could be moved (processed) electronically, thus eliminating the need for the employees to commute into the city core, thus resulting in a variety of savings. The study, referenced in the below footnote, contains an economic evaluation of this concept as developed for an insurance company in Los Angeles. It produced net savings of more than $4.0 million annually.

System Concept

To expand the concept nationally, it is proposed that data relay satellites be used to relay processed data from the remote processing centers to the central corporate computer. Several satellites (in geosynchronous orbit) could be required, depending on the amount of traffic generated. The employee at an outlying office would receive original, basic documents, such as purchase orders or various transaction notifications. The employee operating a CRT terminal could enter data into or request data from the computer, make revisions, or instruct the computer to initiate various actions. The outlying offices would be linked via a data relay satellite to the central computer installation.

System Cost

In the document referenced in the below footnote, the costs of implement- such a system were generated and analyzed in detail. However, that concept used conventional land lines — phone — for linking the outlying offices. Because

*Nilles, J. M., et al. The Telecommunications-Transportation Tradeoff, John Wiley & Sons (1976).

of the current near-saturation of land lines and limited capacity, it appears that a relay satellite would be required for extensive implementation of the concept. The first data relay satellite is estimated to cost approximately $500 million plus an additional $125M for launch and replacement. Additional relay satellites would cost an estimated $200M plus the $125M to emplace. The satellite would be designed for a ten-year life. This cost would need to be amortized over hundreds of users. The annual charge for capital recovery (assuming 8 percent and 10 years) would be $93M. Assuming 500 subscribers, this would amount to less than $200,000 annually per subscriber. Each subscriber could have many outlying data handling centers. In the case of the insurance company discussed in the previous footnoted reference, five outlying offices were located in the San Fernando Valley. Assuming an annual charge of $200,000 for the relay satellite, the savings would still be on the order of $4M annually.

Determination and Evaluation of Benefits

There are an estimated 90 million workers in the United States. Approximately 50 percent are in *white-collar* jobs.* Of course, only a small portion of these would be candidates for telecommuting. The likely candidates would be from finance, insurance, government, and from corporate sales and purchasing departments. If only 5 percent of the *white-collar* workers were telecommuting, then this would amount to 2.25M workers. If it is assumed that, as in Los Angeles, 1.1 commuters ride in each car, on an average commute of 10 miles one way, and the cars cover 20 miles per gallon, then the annual gasoline savings would be:

$$\frac{2,250,000}{1.1} \times \frac{20}{20} = 2,050\overline{M} \text{ gallons of gasoline per day,}$$

or, in 240 working days per year, 492,000,000 gallons annually. At 60-cents per gallon, this would be a saving of $295M annually for the telecommuting workers. If the 492M gallons of gasoline were considered to be crude oil at $13 per barrel, the annual savings would amount to $152M.

Funding Schedule

It is anticipated that the development of telecommuting would gradually evolve as the economic benefits become more pronounced. At some point, the development and use of the data relay satellite would make economic sense. Because the awareness of the potential merits of telecommuting are just being uncovered, it is anticipated that the development of the data relay satellite would not begin until 1985, and require six years for acquisition. The funding schedule, based on a 40:60 ogive would appear as follows:

	1985	1986	1987	1988	1989	1990
Date Relay Satellite	12.6	66.0	121.4	142.4	114.2	43.4
Launch						125.0
	12.6	66.0	121.4	142.4	114.2	168.4

*Statistical Abstract of the United States, U. S. Dept. of Commerce (1976).

The data relay satellite would likely be built by a domestic satellite communication consortium, as an expansion of their current (planned) market.

Medical Aid and Information - United States

Problem

Three areas of dificiencies in health care provided the focus for this analysis. The first of these consists of the need by paramedics of essential data in emergency situations. Currently, first aid in case of serious accidents generally centers on keeping the patient alive until he can be transported to a hospital. If breathing has stopped, the patient must receive immediate attention. If the patient is bleeding, it must be stopped. In many instances, the patient may be unconscious, breathing and not bleeding, and quick emergency action might still be required to save his life. However, to take proper action would require knowledge of the patient's medical status. Quick access to his medical history might be required to save his life. For example, the patient had lost considerable blood, an immediate transfusion might be essential to save his life. Rapid access to his medical data would be required to determine his blood type. Emergency vehicles could carry supplies of the more common blood types, thus enabling initiation of treatment prior to formal hospital admission. Furnishing paramedics with key items of information on the patient or furnishing professional guidance for specialized treatment, could result in the saving of lives that would otherwise be lost. STARPAHC — a NASA sponsored telemedicine system operating on the Papago Indian Reservation in Arizona, is currently testing some of these system elements.[1]

The second area of medical deficiency centers on the art of medical diagnostics. Doctors are expected to be knowledgeable about literally thousands of symptoms/illnesses. Where there is doubt, expensive medical tests are performed to aid in diagnosis, thus, increasing medical costs. For over 20 years, research has been conducted on the development of diagnostic computers. The state-of-the-art has advanced to the point at which computer diagnostic programs can guide a doctor or even a non-physician to the correct diagnosis. Even in cases in which the patient is suffering simultaneously from two or three ills.[2] Basically, the diagnostic programs consist of computerized versions of The Merck Manual and Symptoms: The Complete Home Medical Encyclopedia. Dr. Norman Jensen, Director of Adult Medicine at the University of Wisconsin Hospitals, and Larry Van Cura, computer specialists, have developed a computer program which takes data on patient height, weight, blood pressure and serum cholesteral, and answers to some 70 multiple choice questions, to provide a computerized version of an annual checkup (for $10) as an alternative to costly annual physicals.[3] In Israel, general physicians are using a computer-aided diagnostic system, developed in conjunction with IBM, to perform advanced diagnosis of female endocrine disorders which otherwise would require detailed examinations by specialists.[4]

[1] *Coming: The Era of Telemedicine*, by R. Allan, IEEE Spectram (December 1976).
[2] Sherman, H., Reiffen, B., and A. L. Komaroff. *Aids To The Delivery Of Ambulatory Medical Care*, IEEE Transactions on Biomedical Engineering, Vol. BME-20, No. 3 (May 1973).
[3] *Medicine: Instant Checkup*, Time (Jan. 10, 1977).
[4] *Terminal Case for the Doctor's Surgery*, New Scientist (Dec. 23/30, 1976).

With the aid of a sequential questionnaire and an interactive computer, medical disorders can be rapidly narrowed down to several discrete possibilities from which the final diagnostic decision(s) can be made. Initially, access to the diagnostic computers would be through terminals in hospitals. Eventually, however, as the cost of the system was spread over a broader base, many doctors in private practice would avail themselves of the service. Because of the need to keep the diagnostic program current with data from the Index Medicus, it is anticipated that one central computer and diagnostic data bank would be established.

The third area of dificiency involves the 100 countries in the United States that do not have a resident physician. In numerous instances, the population base is insufficient to attract and support a doctor. In those countries, a registered nurse or a paramedic, trained to use the diagnostic computer and, perhaps having access to an automated clinical analyzer, could diagnose and treat a majority of disorders. The paramedic could be licensed to dispense *routine* medication. In complicated cases, he could consult electronically with a doctor, who would render the final diagnoses and prescribe the appropriate treatment. The nurse/paramedic would also be trained to treat traumas.

System Description

In all three instances, the medical practioner would need to have rapid, reliable access to medical data. Data would often be required in areas without telephone service. In the first instance, the data would be in the nature of the patient's medical history and professional consultation, whereas in the second and third cases, the data would be primarily computer diagnostics. The ground portion of the emergency system would consist of a mobile transmitter housed in the emergency vehicle, and in fixed installations in the two diagnostic examples. The ground station would transmit to a medical data relay satellite in geosynchronous orbit. In the first case, the satellite would relay the medical data requests to regional medical data banks (approximately 10) in which medical histories would be stored. At the same time, the medical relay satellite could be relaying thousands of quiries to the diagnostic computer which would process the symptomatic data, identify the likely disorders, along with recommended treatment and transmit these back via the medical satellite to the respective ground terminals. Ground personnel would be required at each of the medical history data banks for updating the personal histories, as well as at the central diagnostic computer for maintaining the diagnostic scheme in accord with current medical knowledge. With the patient's approval, a copy of the doctor's record of each office call would be sent to the regional medical data center for updating of the patients medical file.

Estimated Cost of the Medical Aid System

The non-recurring and recurring costs associated with the medical data retrieval and diagnostic computer system are estimated as follows:

ORIGINAL PAGE IS
OF POOR QUALITY

Non-Recurring Cost

Ground		
Medical History Data Bank		$ 155M
Ground Terminals (10,000 @ $5000 each)	$ 50M	
Computers/Data Bank (10 Required @ $10M)	100M	
Software (Common)	5M	
Diagnostic System		$ 75M
Ground Terminals (7000 Hospitals @ $5000 each)	$ 35M	
Central Computer	20M	
Software (Basic)	20M	
Space		
Satellite		$ 500M
Launch and GSO Insertion Cost		125M
TOTAL NON-RECURRING COST		$ 855M

Recurring Cost - Annual

Operations	
Medical Data Banks - 10 (250 personnel each)	$ 100M
Diagnostic System (Maintenance & Expansion)	20M
ANNUAL RECURRING COST	$ 120M
10 YEAR RECURRING COST	$1200M
TOTAL PROGRAM COST - 10 YEARS OPERATIONS	$2055M

It was assumed that paramedics and existing hospital staff personnel would be trained to use the interactive computers so that special high paid operating personnel would not be required.

Description and Economic Evaluation of Benefits

The estimated total cost of acquisition plus 10 years of operation of the Medical Aid System is $2055M. This amounts to less than $10 per capita, or less than $1.00 per capita per year. Of course, not all individuals would wish to be included in the medical data bank. However, in most instances, inclusion would be viewed as a form of insurance of securing better, quicker, and more specific emergency treatment in the event of an accident or other emergency.

The following analysis focuses on the diagnostic computer system which could be totally decoupled from the historic medical data aspect. There are currently almost 7000 hospitals in the United States and more than 200,000 doctors in office-based practice. It is likely that most hospitals would avail themselves of the diagnostic service. In addition, doctors in private clinics as well as those practicing in remote areas would subscribe to the service. Figure 36 shows the relationship between the annual cost of the amortized system and the number of installations over which the fixed costs could be spread. For example, if 33,000 installations were sold, then in addition to paying a fixed charge of $5000 for the terminal and related transmitting and viewing electronics, each user would pay $5000 annually for the service. This annual charge would cover the computer installation costs plus amortization of the fixed costs at an interest rate of 8 percent. If a local medical clinic staffed by three doctors used the system on 10 percent of their ambulatory patients, then the per patient cost would be less than $5. While doctors might readily diagnose single illnesses, patients suffering from two or more afflictions simultaneously could present confusing symptoms. Tests of computer diagnostic programs have shown that the computer programs have been successful in properly diagnosing patients with multiple chronic diseases.* The system could more than pay for itself by reducing the number of diagnostic laboratory tests currently required to aid in the diagnoses.

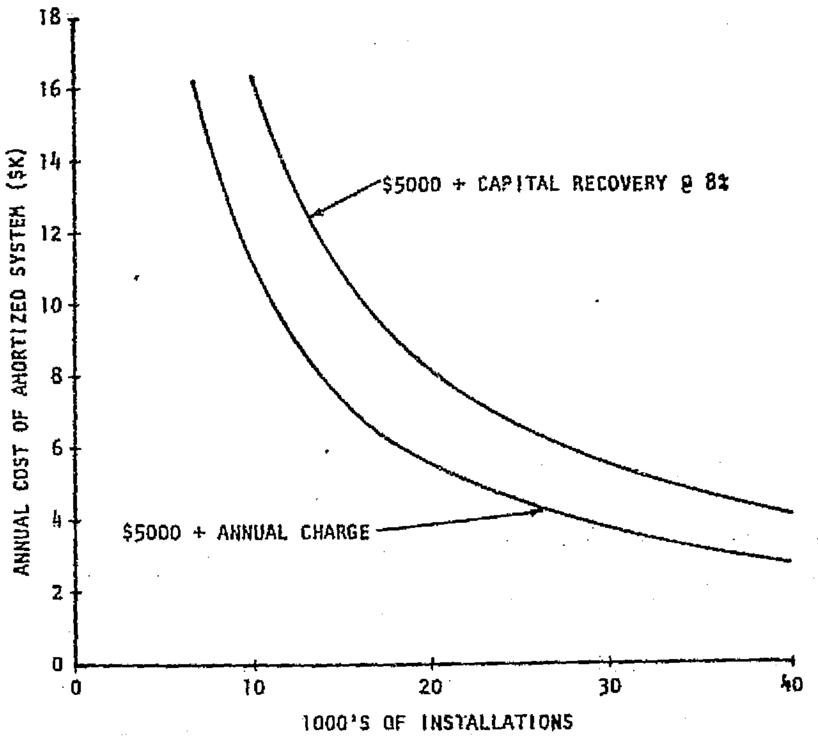


Figure 36. Sensitivity of Diagnostic Computer System Annual Unit Cost to Number of Installations

*Sherman, H., Reiffin, B., and A. L. Komaroff, *Aids To The Delivery Of Ambulatory Medical Care*, IEEE Transactions on Biomedical Engineering, Vol. BME-20, No. 3 (May 1973).

Funding Schedule

The pacing item in the Medical Aid System would be the data relay satellite. It was estimated that the development and acquisition of the satellite would require approximately seven years. The other non-recurring elements are estimated to require five years for their acquisition. A 40:60 ogive was assumed. Since no plan to implement or finance such a system have been formulated to date — and this would require about two years — a 1980 start date was assumed. Following is the annual funding required in millions of 1977 dollars for the acquisition of the system:

	1980	1981	1982	1983	1984	1985	1986
Data Relay Satellite ($500M)	8.2	45.1	89.5	118.4	118.8	87.8	32.2
Launch							125.0
Ground Facilities							
Computer and Software ($145M)			6.0	29.3	47.6	44.2	17.9
Terminals ($85M - 3 Years)							
Annual Funding Required	8.2	45.1	95.5	147.7	179.8	176.8	201.9

The system could be developed using Government funding (Department of Health, Education and Welfare). However, it also appears feasible with private financing. In 1976, four pharmaceutical companies — Johnson & Johnson, Eli Lilly, Merck, and American Home Products — had a total net income of $938M. The peak funding ($179.8M) would be less than 20 percent of their combined annual net income. In reality, a consortium of these four could provide the initial and majority backing and raise the necessary funds through other sources than earnings *per se*.

ORIGINAL PAGE IS
OF POOR QUALITY

BIBLIOGRAPHY

1. Shamaskin, R. B., Communication Satellites and Medicine. Public Service Satellite Consortuim Conference, Washington D.C. (Dec. 8, 1976).

2. Edelson, B. I., *Global Satellite Communications*, Scientific American (February 1977), pp. 58-73.

3. Smith, D. D. *Educational Satellite Telecommunication: The Challenge of a New Technology*, Bulletin Of The Atomic Scientists (April 1971), pp. 14-18.

4. Feiner, A., *Health Care and Education: On The Threshold Of Space*, Science, Vol. 186 (December 27, 1974), pp. 1178-1186.

5. *TV Education Role Gains World Interest*, Aviation Week and Space Technology, (August 23, 1971), pp. 70-74.

6. Paul, G., The Satellite Spin-Off: The Achievements Of Space Flight. Robert B. Luce, Washington-New York (1975).

7. *Advanced In The Astronautical Sciences*, Vol. 30, International Congress of Space Benefits, American Astronautical Society, Tarzana, Calif. (1974).

8. Ehricke, K., *Space Station — Symbols and Tools of New Growth in an Open World*, keynote address, International Space Hall of Fame Dedication Conference, Alamagordo, New Mexico (October 3, 1976).

9. The CBS News Almanac: 1977, S. Westerman, Editorial Director, Hammond Almanac, Inc. Maplewood, New Jersey (1977).

10. Ehricke, K., Space Industrialization Mid-Term Briefing, Rockwell International, SD77-SP-0012, presented at Marshall Space Flight Center, Huntsville, Alabama (February 15, 1977).

11. Stine, G. H., The Third Industrial Revolution, G. P. Putnam's Sons, New York, Library of Congress Catalog Card No. 75-21783 (1975).

12. Space Industrialization Proceedings, AIAA/MSFC Symposium held at NASA MSFC (May 26-27, 1976).

13. Ehricke, K. A., *The Extraterrestrial Imperative*, Bulletin of the American Scientists (November 1971).

14. Ehricke, K. A., Extraterrestrial Imperative, Space for Mankind's Benefit, J. von Puttkamer and T. J. McCollough, editors. Proceedings of a Space Congress at NASA George C. Marshall Space Flight Center (November 1971); Scientific & Technical Information Office, NASA SP-313, Washington, D.C. (1972).

15. Ehricke, K. A., and E. Miller, The Extraterrestrial Imperative (In Publication).

16. Ehricke, K. A., A Strategic Approach to the Development of Geolunar Space, Rockwell International SD 69-710, presented at the IAA Orbiting International Laboratory and Space Sciences Conference, Cloudcroft, New Mexico (May 1967).

17. Ehricke, K. A., *Toward a Three-Dimensional Civilization*, Space World (December 1970).

18. Ehricke, K. A., *Philosophy and Outline of Long-Range Space Planning for the Needs of this Nation and Mankind,* present tion by K. Ehricke before NASA Deputy Assoc. Administrator (Planning), Dr. W. von Braun. North American Rockwell (now Rockwell International), Space Division PD 71-16 (July 1971).

19. Ehricke, K. A., Statements during Hearings before the Subcommittee on Manned Space Flight of the Committee on Science and Astronautics, U. S. House of Representatives, 92nd Congress (1973), NASA Authorization, Second Session on H.R. 12824, No. 15, Part 2 (March 8, 1972), pp. 375-428.

20. Ehricke, K. A., *Extraterrestrial Industry, A Challenge to Growth Limitations,* The Essential Resources Conference, The Conference Board, Washington D.C. (April 1973).

21. Ehricke, K. A., *Space Industrial Productivity, New Options for the Future,* presentation before the Subcommittee on Space Sciences and Applications of the Committee on Science and Technology, U.S. House of Representatives, 94th Contress, Serial M, Vol. II (September 1975).

22. Bono, P., and K. W. Gatland. The Commercial Space Station, Frontiers of Space. The MacMillian Company, New York (1970).

23. von Puttkamer, J., and T. G. McCollough (ed.), Space for Mankind's Benefit, National Aeronautics and Space Administration, Washington, D.C. NASA SP-313 (1972).

24. von Puttkamer, J., On Man's Role in Space -- A Review of Potential Utilitarian and Humanistic Benefits of Manned Space Flight. NASA, Office of Manned Space Flight Monograph (December 1974).

25. Ehricke, K. A., Beyond the First Space Stations, AIAA Meeting, NASA George C. Marshall Space Flight Center, Huntsville, Alabama (January 1971).

26. Ehricke, K. A., Space Stations, Tools of New Growth in an Ope World. Fifth Invited Lecture of the International Astronauti al Federation, 25th International Astronautical Congress, Amsterdam, The Netherlands (October 1974).

27. Ehricke, K. A., Use of the Shuttle in Establishing Large Space Installations. Annual meeting of the American Astronautical Society, Washington D.C. (Dec. 1972) North American Rockwell (now Rockwell International) Space Division SD73-SA-0015 (December 1972).

28. Ehricke, K. A., Hearing before the Committee on Aeronautical and Space Sciences, U. S. Senate, First Session, Candidate Missions for the Space Shuttle, Part 2, U.S. Government Printing Office, Washington D.C. (1973).

29. Burton, A., and Weisbrod, Economics of Public Health. University of Pennsylvania Press, Philadelphia, Pa. (1961).

30. Gould, C. L., Study Plan for Space Industrialization. Rockwell International, Space Division SD76-SA-0079-3B (September 24, 1976).

31. Gould, C. L., Space Industrialization, Education, Productivity and Employment Seminar, Pomona, California (December 10, 1976).

32. Potter, J. G., A Satellite Communication Network for Public Service Users? Public Service Satellite Consortuim Conference, Washington D.C. (Dec. 8, 1976).

33. Nilles, J. M., and P. Gray, *Telecommuting — A Possible Transport Substitute*, The Logistics and Transport Review, Vol. 11, No. 2 (1975).

SPACE OPPORTUNITIES — PRODUCTS

1. Introduction
2. Space Processing of Organic Materials
3. Space Processing of Inorganic Materials

SPACE OPPORTUNITIES - PRODUCTS

INTRODUCTION

Many imaginative ideas have been advanced in the last few years for the manufacture of consumer products in space for the use of the people on earth. Most of these products would capitalize on the zero-g conditions that can be achieved, but others would utilize some of the other beneficial properties of the space flight environment. In particular, high-density electronic devices may be possible because of the virtual absence of vibration, and sodium coatings of extreme reflectivity may be possible because of the absence of a corrosive atmosphere.

The Spacelab, ASTP flights, and various sounding rocket programs have provided strong indications that it will be practical to process many different commercial substances and products in space. However, these preliminary tests have been too sketchy to provide definitive clues as to which substances will turn out to be the most viable and competitive in the commercial marketplace. For this reason, a broad-ranging coverage of all the proposed possibilities will not be attempted in the discussions to follow. Instead, the material will focus on two specific commercial possibilities: a biological substance called urokinase and space-manufactured crystals of extreme regularity and purity. These two examples are representative of the two non-overlapping categories of materials that can benefit from space processing: organic and inorganic substances.

SPACE PROCESSING OF ORGANIC MATERIALS

Biomedical substances and pharmaceuticals are an important subclass of organic substances of both societal and economic importance. The biomedical and pharmaceutical industry concentrates a large fraction of its research and development expenditures on improving the production of products through purification and separation processes. These processes include zero-g separation of cells and proteins in order to generate new and better vaccines, hormones, enzymes, organic/inorganic materials, etc. Similar separation technologies could also benefit the agricultural and animal husbandry industries. For example, beef and milk production could be enhanced if x-y chromosome separations could be performed on livestock sperm in low-g environments. This would allow farmers to breed cattle and other animals of the desired sex.

Based on what has been learned so far from space experimentation, it appears that component-oriented companies in the fields of electronics and drug-oriented markets will take the lead in space-manufacturing investments. The benefits and social value of some of the potential biomedical space products are emphasized in the sections to follow.

As a result of successful electrophoresis experiments, carried out during the Apollo-Soyuz Test Project (complementing similar experiments during Apollo Missions 14 and 16), it appears that it may be possible to enhance the production and development of drugs and other biologicals used in medical treatment. Electrophoresis involves the separation of materials such as dyes, cells (living or dead), proteins and other biological materials. Urokinase, the only naturally occurring human enzyme that dissolves hazardous blood clots, is one useful substance that could be produced in quantity by electrophoresis.

Production of large quantities of urokinase outside the human body (for use in treating heart attacks, strokes and phlebitis) is difficult in the terrestrial environment. Roughly one ton of human urine must be processed to obtain a single dose. The cells separated on board the Apollo spacecraft produced *about seven times* more urokinase than would have been possible on earth, according to the Abbott Laboratory in New York. Scientists believe that with experimentation and research, it may be possible to increase the throughput of such products to over a *factor of 100 times* the rate of earth processes.

A high degree of sterility is required for this process. The ASTP and Apollo 14 and 16 Missions clearly demonstrated superior *clean room* conditions in space. However, the major advantage is that the absence of gravity prevents the settlement of biological materials involved in the separations.

The following discussion identifies specific biological products under consideration for space processing.

Kidney Cells

The importance of these cells stems from the ability of some of them to produce the enzyme urokinase which can be used therapeutically to dissolve blood clots. As was previously mentioned, the isolation of these cells for subsequent culturing, to obtain their valuable product, is severely retarded under ground-based conditions. Separation in space offers a potential solution to this problem.

T- and B-Lymphocytes

These two species of white blood cells are high-value medical products. They have been identified as our body's primary cell-mediated immune defense mechanism. These cells could either be milked of their products (B-cells produce immunoglobulins) after space separation, or perhaps in the future, after careful isolation and characterization, they could be transplanted into the body where they would combat specific diseases (possibly including cancer).

Bone Marrow Cells

Bone marrow cells are believed to have considerable economic potential for separation in space. It is within the bone marrow that many blood constituents are produced by the body. These include the red blood cells and some white blood cells species (i.e., B-cell lymphocytes). The making of blood is one of the most basic body functions and affects almost all other functions. Thus, this potential is unparalleled in its diversity. Much research, directed at discovering the blood formation mechanisms, is needed with isolation of some of those different cells as an initial requirement.

Hormones

Highly purified hormones, derived from the human anterior pituitary, are in extremely short supply. This shortage is due both to scarcity of starting materials and to inadequate separation techniques. Separation of these hormones could provide preparations useful as highly purified antigens (for the production of specific antiserums for immunoassay), assay standards, research materials, and therapeutic agents. These hormones include growth hormone, follicle-stimulating hormone, leutenizing hormone, prelactin, thyrotropin, ACTH, and a number of poorly-defined materials. Again, space processing could be potentially beneficial.

Isoenzymes/Proteins

With recent advances in protein isolation techniques, it has become apparent that enzymes catalyzing specific cellular chemical reactions can exist in different molecular forms. These alternate forms of an enzyme, which differ slightly in physiochemical properties, are called isoenzymes. Enzymes and, hence, isoenzymes play such important and specific roles in the complex metabolic processes that they are vital to the maintenance of life. It has become apparent that any isolation method which could readily provide high yields of high purity isoenzymes would have a large impact on the early clinical diagnosis of various diseases and also go far in providing tools for further insights into the basic cell process. Many feel space processing can help in this vital area of research.

Interferon

Interferon is a product of virally-injected cells which successfully destroy any other intruding viral species. Therapeutic application of this species, if large enough quantities can be obtained, could conceiveably provide cures for such diverse diseases as cancer and the common cold.

Antibiotics

Antibiotics inhibit or destroy microorganisms. It is believed that performing experiments in space could potentially improve the production of antibiotics and vaccines. Indeed, Biosatellite II experiments strongly indicate that biological changes occur under conditions of weightlessness. These changes include the production of dense and fast growing populations. Thus, the potential is there for space processing of antibiotic substances.

Lipoproteins

These species are present in rather large quantities among the serum proteins. While their function as a transport mechanism for fats, lipids, cholesterol, hormones, and the like, is clearly evident, many feel further investigation of these species would prove fruitful. Pure samples could be obtained using space processing. These samples could help researchers gain added insights into any promising therapeutic applications.

Immunoglobulins

These species of protein represent a primary candidate supported by most researchers as one of immediate therapeutic application. It does, however, have much potential beyond its present utilization. Indeed, these antibody species, as potentially separated, characterized, and isolated in good-sized pure quantities in space, may well represent a highly effective vaccine with many promising future uses.

Chalones

Chalones are substances which have been extracted from a number of tissues and which, in the presence of traces of the hormone adrenaline, inhibit mitosis. Their action is tissue-specific, but not species-specific because these are believed to be involved in the actual mechanism whereby cell division is controlled. One potential application of purified quantities of these substances might lie in the treatment of cancer. For, if a chalone specific against some various cancers is isolated, control of these rapidly proliferating cells might be possible.

Hypothalmic Factors

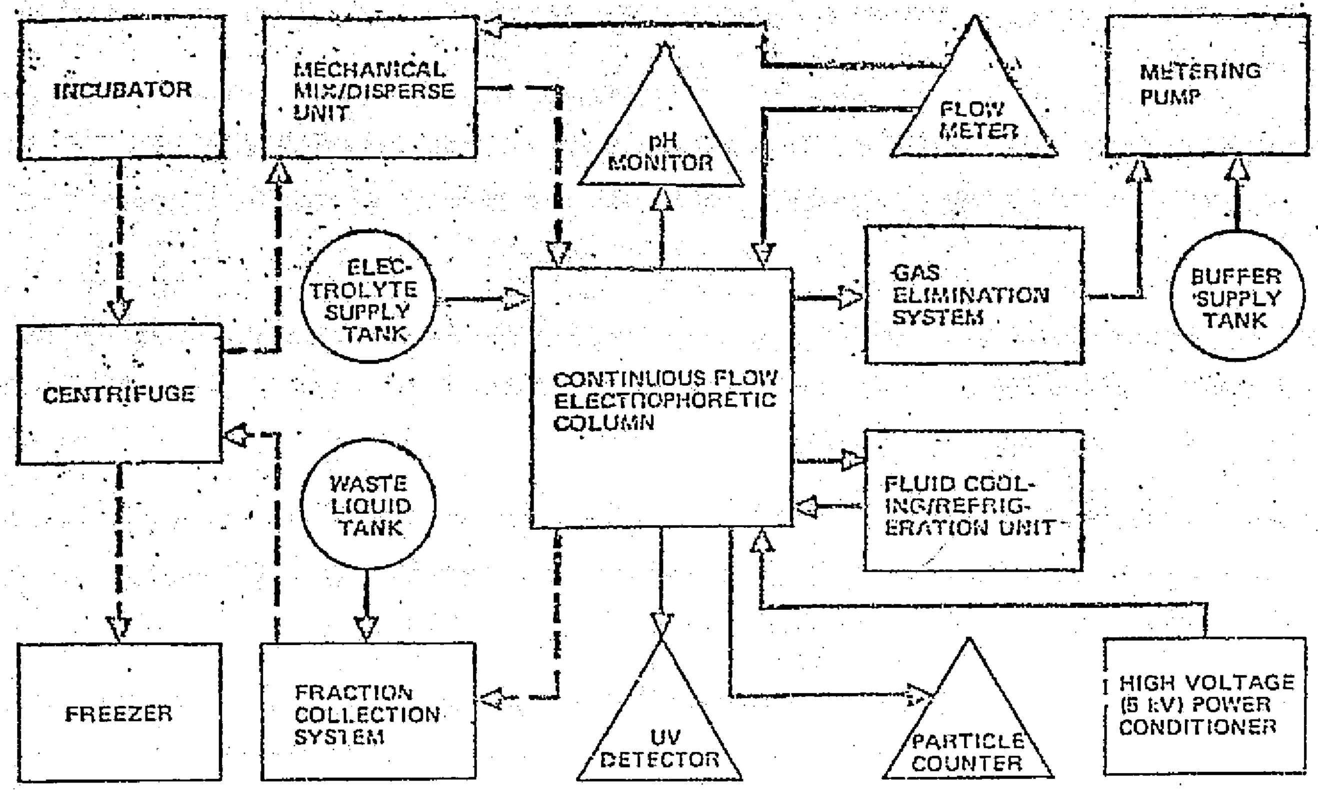
Hypothalmic factors which control pituitary function are also of value in research and potentially in therapeutics. Peptides in other sections of the brain appear to function as memory storage agents. Nerve growth factors could possibly, if separated, aid where presently permanent paralysis persists. Separations of these and others, such as proinsulins, glucagon and kinins, are incomplete and only small quantities of those agents that have been purified are available for research.

Other areas for possible application include capillary buds (transplanted to replace hardening or cut blood vessels), clotting factor (hemophilia victims would be prime candidates for such a substance), and anti-antibody (as in the case of anti-Rhesus antibody). These and several possibilities deserve careful consideration as NASA formulates its plans in the coming years.

Figures 37 and 38 represent probable operational methodology that may be employed to achieve some of these product ends. The particular method shown in these figures is used for producing urokinase.

Urokinase - Discussion

Cardiovascular diseases, which include failure of the heart, stroke, and arteriosclerosis, account for half of all deaths in the United States each year. These one-million deaths are generally proceeded by the formation of blood clots. It has been known for many years that a biological substance called urokinase can dissolve these clots, but the treatment is very expensive ($1200 per dose); therefore, it is only used clinically rather than therapeutically. Urokinase



NOTE: DASHED LINE INDICATES PROCEDURE OF SAMPLE

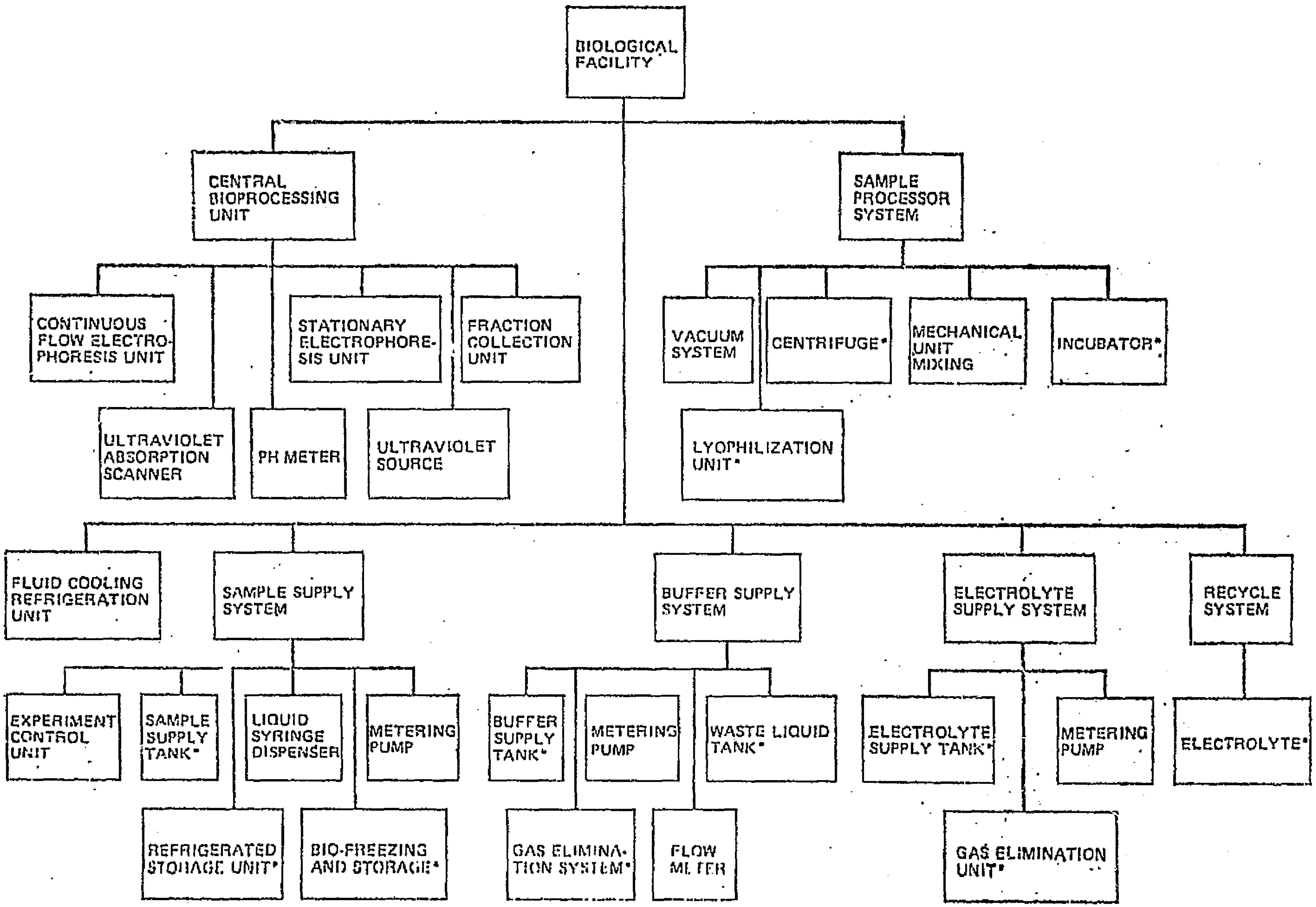
Experimental Procedure

1. Remove culture media from incubator and put into centrifuge.
2. Centrifuge and wash culture.
3. Place specimen No. 1 into mechanical mix/disperse unit and mix with buffer.
4. Insert specimen No. 1 into continuous flow electrophoretic column and electrophorese.
5. Collect fractions from specimen No. 1 with fraction collection system.
6. Centrifuge fractions
7. Purge electrophoresis unit and fraction collection system with buffer.
8. Suspend fractions in culture media.
9. Place culture media into freezer for stowage.

Figure 37. Electrophoretic Separation of Urokinase-Producing Kidney Cells

---

*Study For Identification Of Beneficial Uses Of Space, Phase I, II, and III. General Electric Report No. 75SDS4281 (November 30, 1975).



*MAJOR SCALE-UP OR ADDITION FOR SPACE STATION

Figure 38. Biological Processes Facility Equipment Organization

is produced via a costly process of separation from urine. Although the body produces the needed enzyme (urokinase) in the kidney (see Figure 39), it cannot be produced in sufficient quantity and low enough cost to make it available to the general public.

The potential of rapid processing and separation in space may make human urokinase available at low cost, on the order of $100 per treatment. A joint effort is envisioned involving the NASA and Abbott Laboratories, who specialize in the development of methods to culture the specific cells that produce urokinase. The growth in space product of urokinase is anticipated to meet half the market demand by the late 1980's.

A space-based electrophoretic separator, for the separation of urokinase-producing cells from a culture of ground-prepared kidney tissue, will provide a means to manufacture, economically, an important blood anticoagulant. Space processing will expand the availability of this life-saving drug to those patients who require treatment for diseases such as cardio- and pulminary-thrombosis, atheriosclerosis, and phlebitis, as well as post-operative conditions of blood vessel damage and stasis (bed-ridden) which contribute to the formation of blood clots.

The utilization of zero-g should foster the rapid production of urokinase. The lack of gravitationally induced convection and sedimentation in the zero-g environment of space will enable the separation of urokinase cells from progenetors and waste with higher throughput and resolution (purity) than possible in a ground-based production facility. This achievement has been demonstrated in manned space flight missions (Apollo 14, 16, ASTP) and is planned for further evaluation in a rocket probe shot. If the experiment works properly, the cell cultures will be brought back to earth for production of urokinase in large quantities.

There is a need for an estimated 600,000 treatments with urokinase per year. The cost of ground-based production is $1200 per dose and requires the processing of 1500 liters of urine. The production of urokinase with specific kidney cells will decrease the volume of substance to be processed and simplify the logistics of obtaining source material. Flight Experimentation has demonstrated that the throughput achieved is many times that experienced on earth. It is anticipated that ten- to one-hundred-fold improvements will be obtained over that which presently appears possible on earth.

Minimal FDA approval needs will make urokinase available to patients by 1985. The time for availability of space-processed urokinase enzyme to patients will not be appreciably extended as a result of required FDA approval procedures. Since this enzyme has already been through the approval route for clinical use, it will be only necessary to identify the space product and determine its purity. These procedures should take no more than one to two years. It is anticipated that by 1985, the drug should be available to patients.

The initial installation for processing urokinase producing cells will presumably be in the Spacelab facility. The processed cells will be brought back to earth for the production of urokinase enzyme. The space-borne supply of excised renal tissue must be transfered from the Orbiter biological storage

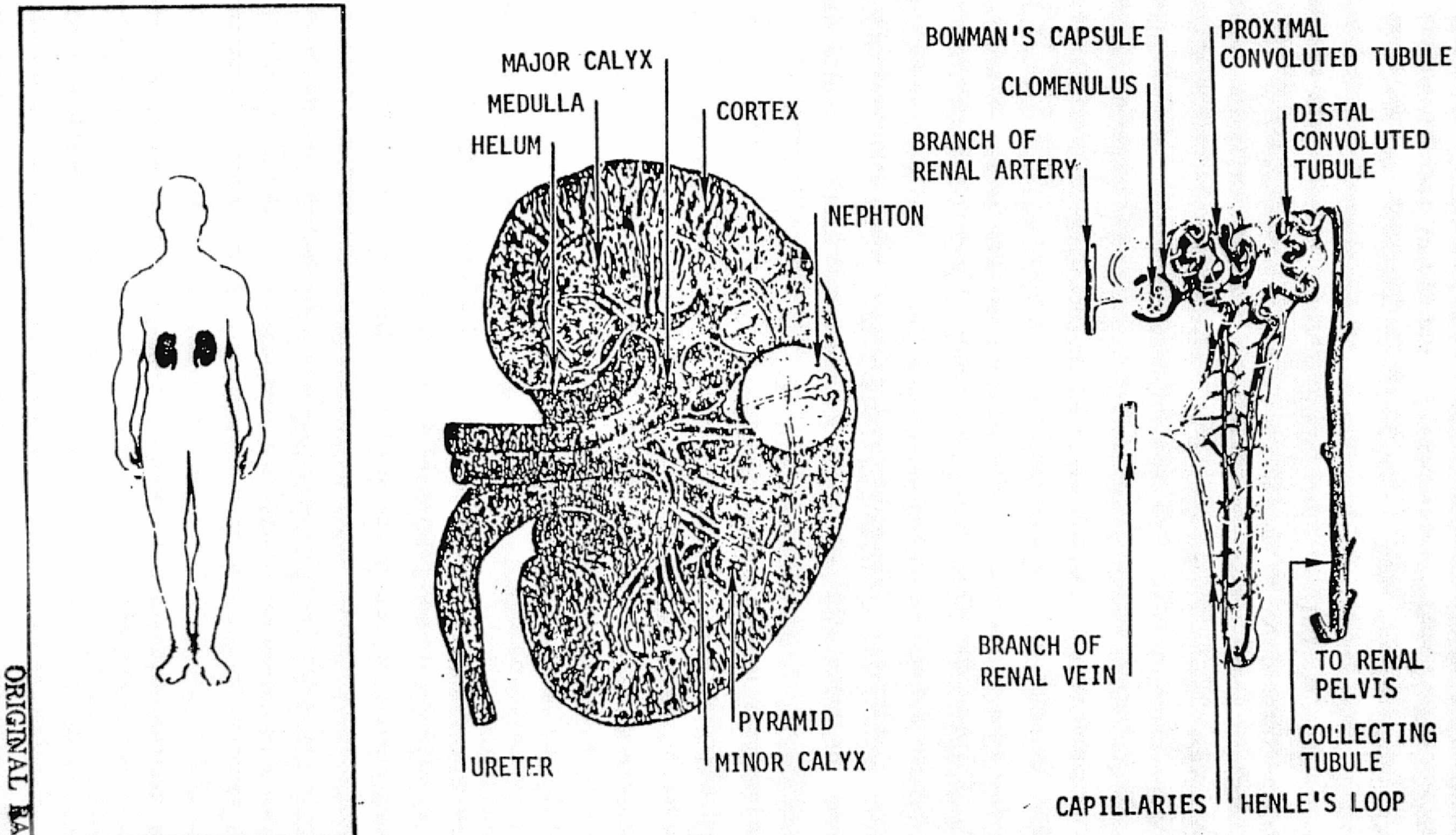


Figure 39. Anatomy of the Renal System

to Spacelab storage, to the sterile work station, and then to the electrophoretic processor station. Also, certain aseptic procedures will be carried out periodically to ensure that harmful bacteria do not accumulate in the process area or that the process itself does not generate pyrogens, which are subsequently transmitted to the patient as a fever-producing agent.

The electrophoretic process is likely to be fully automated. Although it will be complicated, all together it can contain up to thirty subsystems involving electrical, fluid, and process control.

There are two important parameters in any electrophoretic process: the throughput rate and the resolution. The throughput is the process rate, whereas the resolution is the degree of separation or purity with which the desired substance is produced. As is shown in Figure 40, the relationship is inverse. In other words, good resolution can be achieved on the ground, but at a correspondingly reduced throughput. The relationship in space is in the region above the curve. Thus, the same resolution may be achieved, but at orders of magnitude higher levels.

Further increases in throughput are expected to result if we extend the flow into a laminar pattern. Experiments on this mode of operation have already shown promising results. Laminar flow electrophoresis is expected to be preferred for space processing in production quantity.

Urokinase

General Objective

Space manufacturing of the substance, urokinase.

Product To Earth

Delivery of large quantities (equivalent to 10 kg/yr) of the organic catalyst enzyme urokinase, for medical and pharmaceutical industries.

Key Objectives

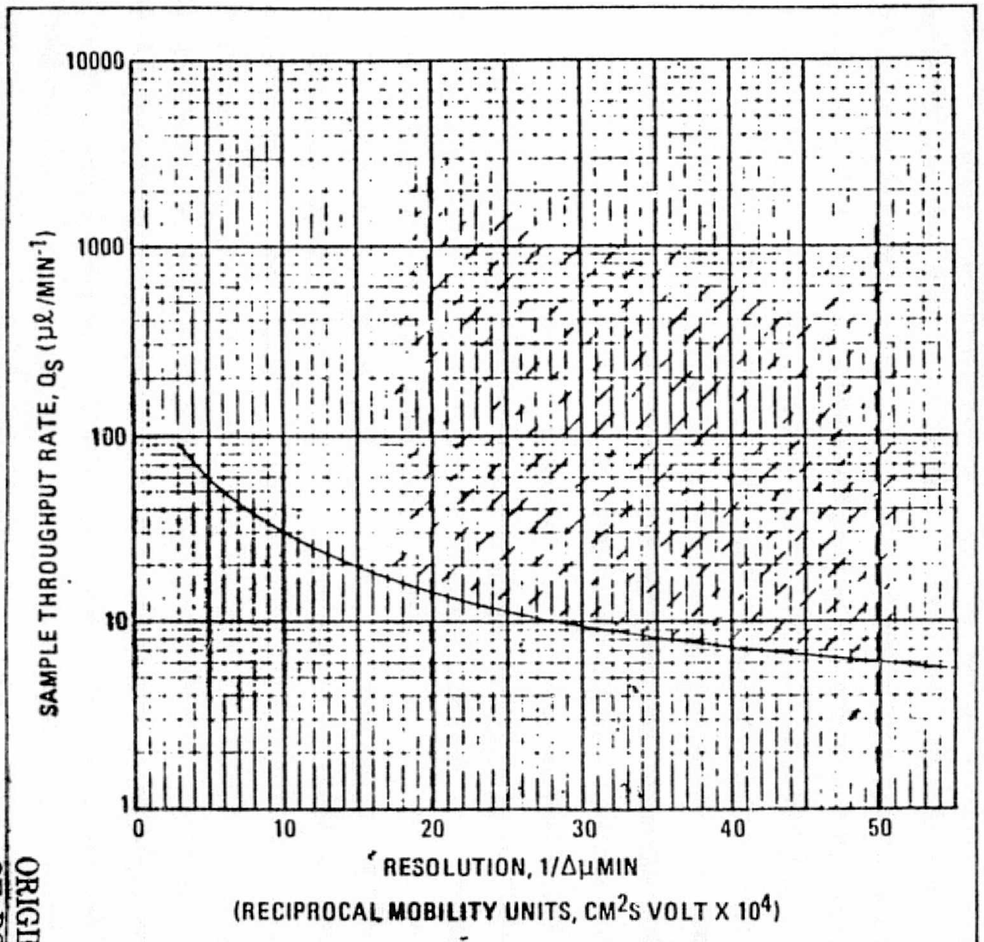
Save lives. Dissolves blood clots after they have formed, to save victims of strokes or other situations where a blood clot within the body is blocking the flow of blood.

Principal Contribution

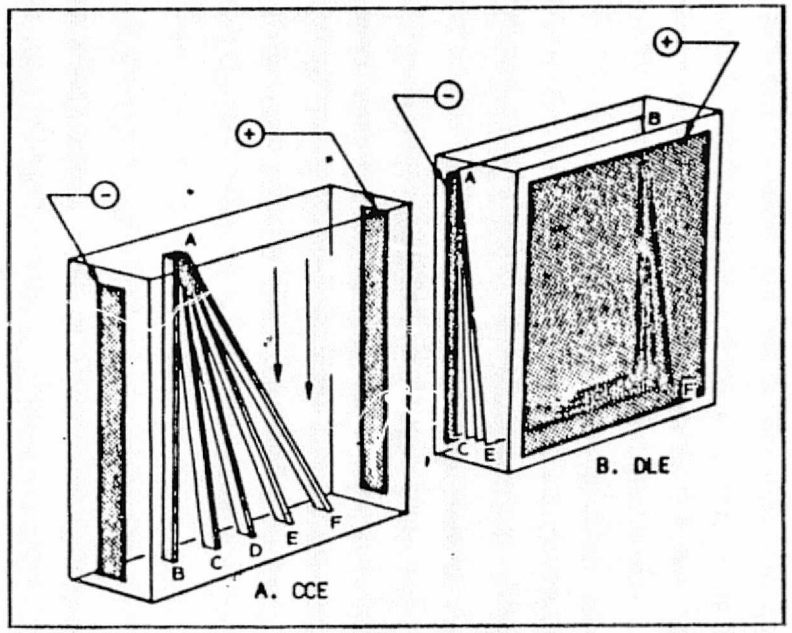
Will provide medicine with a unique product to combat *blood clot* related diseases.

Level of Contribution

Production of large amounts of *urokinase* will benefit victims of heart attacks, strokes, phlebitis ... 7 to 100 times more of the product will be possible in orbit.



PERFORMANCE RELATIONSHIPS IN CONTINUOUS FLOW ELECTROPHORESIS



CONFIGURATIONS OF CONVENTIONAL CONTINUOUS ELECTROPHORESIS AND DEFLECTED LAMINA ELECTROPHORESIS

Figure 40. Electrophoresis Concepts and Parameters

Uniqueness of Contribution

Should reduce the cost several fold so that it is practical for each emergency kit to have a supply.

Time Factor

Early 1980's.

Principal Installation

LEO manufacturing facilities: free flyers, portions of a space station, or portions of a spacelab.

Principal Functional Units

Electrophoretic separators.

Principal Technology

Electrophoresis separation of cells.

Impact Spectrum

Pharmaceutical industry will benefit financially. Perhaps, one percent of the United States population will benefit. The economic effects of a healthy work force is difficult to quantize, but could not help but improve the economic condition of the country.

Front-End Capital

To be determined - combined with other products in facility.

Isoenzymes

General Objective

Manufacturing of isoenzyme diagnostic kits for early, effective diagnosis of disease.

Product to Earth

Extremely high efficiency diagnostic kits for medical doctors to diagnose patients. Should be much more effective in early detection/warning of contagious or catastrophic diseases.

Key Objectives

To provide more effective ways of combating vectors of disease and the saving of lives.

Principal Contribution

Unique biochemistry enabling medical science to improve its efficiency in diagnosing and curing patients.

Level of Contribution

Each doctor in the field or in city hospitals will have access to these inexpensive kits.

Uniqueness of Contribution

No way to produce such a product on earth. Its amplification of effectiveness must be determined empirically.

Time Factor

Early 1980's.

Principal Installation

LEO manufacturing facilities: free flyers, portions of a space station, or portions of a spacelab.

Principal Functional Units

Isoenzyme (antibody-type) vaccine to be injected in patient.

Principal Technologies

Separation of proteins (enzymes) via electrophoresis.

Impact Spectrum

To be determined.

Front-End Capital

To be determined (will be combined with many other items).

Hybrid Animals/Plants Agriculture

General Objective

To improve food production capability of agricultural, cattle, and dairy products.

Product to Earth

New hybrid types of plants and new types of animal husbandry (beef) and livestock products.

Key Objectives

To provide the cattle and produce industry with new products — dairy, cattle, and new agricultural goods, e.g., by controlling XX-/XY-chromosome separations to produce more female milk-producing cows.

Principal Contribution

New types of food in more abundant quantities for terrestrial consumers.

Level of Contribution

The Department of Agriculture would regulate control of products generated by space process methodology.

Uniqueness of Contribution

This type of genetic engineering is not possible or desirable on earth. The environment of space offers isolation from earth's fragile closed system biosphere.

Time Factor

Approximately 1985.

Principal Installation

LEO manufacturing facilities such as free flyers, space stations, or spacelab.

Principal Functional Units

Space - One satellite

Ground - Several control, tracking and data handling centers

Principal Technology

Existing separation of biological methods include electrophoretic, magnetic (mass spectrometer), high-vacuum refinement, and velocity condensation.

Impact Spectrum

To be determined.

Front-End Capital

To be determined.

SPACE PROCESSING OF INORGANIC MATERIALS

Many inorganic substances can also benefit from space processing. These include high-strength permanent magnets, large dc crystals, new optical glasses, higher-temperature turbine blades, and LSI circuit chips. Most, but not all, of these materials will benefit from the fact that extremely pure crystals can be grown in space from a liquid mix, which is suspended without contact with a supporting crucible. Because of the crutial importance of crystal growth in space, a discussion of the possibilities and the merits of space-produced crystals is presented in the next few pages. Much of this material was obtained from the General Electric *Beneficial Utilization Of Space (BUS)* study. Dr. Charles Cheeseman, of General Electric, was a consultant on our study.

The Case for Space-Manufactured Crystals

Crystal Growing Methods

Single-crystal silicon can be prepared in several ways. These include: (1) growth from solution, (2) growth from the vapor phase, and (3) growth from the melt. Growth from solution (silicon in tin solution at 900°C) limits the size and quality of the crystals obtained and is seldom used for silicon. Growth from the vapor is widely used as a processing method for preparing expitaxial layers on single-crystal silicon wafers. Unfortunately, this method is inherently unsuitable for growing single-crystal silicon because the crystal perfection degrades for layers thicker than about 4 mils. Consequently, most of the available single-crystal silicon is grown from a melt at the melting point of silicon — approximately 1412°C.

Czochralski Method (Growth From a Melt). The Czochralski Method, the technique of crystal pulling from the melt, is the most widely used commercial technique for growing silicon. The silicon melt is contained in a suitable-purified quartz crucible which is heated by an energy source, usually either a graphite resistance heater or a radio frequency induction heater. The seed is a single crystal section which is dipped into the melt and then raised at a controlled rate and simultaneously rotated, in most cases. As the seed is lifted, molten silicon from the melt solidifies onto the seed following the crystalline orientation of the seed. This process continues and the silicon grows on the seed as a large single crystal until the melt is depleted or the growth is interrupted.

Excellent crystals have been grown using this technique and the approach can be used in growing crystals with large diameters. Diameters of up to four inches (10 cm), which are useful in making microelectronic circuits, are currently commercially available with good resistivity, homogeneity across the diameter, high carrier lifetime and low dislocation densities. The major disadvantage of this technique stems from the requirement for a crucible to contain the melt during growth. The high chemical reactivity of the molten silicon causes residual impurities from the crucible, principally boron and oxygen, to be included in the silicon. While the amounts included are of little significance for most microelectronic circuit applications, such silicon is not sufficiently pure for the fabricating of high-performance detectors for sensing infrared radiation.

Floating Zone Method (Growth From a Melt). The disadvantages of the Czochralski Method are overcome in the floating zone crystal growth process which avoids the requirement for a containing crucible. In this technique, the coil is moved along the entire length of the rod. By repeated zone passages through the rod, zone refining (in which impurities are swept up to one end of the rod) can be achieved. Single crystal growth is achieved by initiating a zone between the single crystal seed and the polycrystalline rod, sweeping the zone through the poly rod, recrystallizing the silicon to a single crystal in the orientation of the seed. (See Figure 41.)

The primary advantage of the floating zone technique lies in the absence of many of the sources of contamination which are present in other crystal growing processes. Since the silicon surface in effect serves as a crucible for its own melt, crucible contamination is avoided. Moreover, since the heating is performed by a radio frequency induction coil, the only part of the crystal growing apparatus that is heated to a high temperature is the silicon itself. The placement of the melt in a vacuum or in an inert gas isolates the silicon from atmospheric contamination and permits selective impurity outgassing.

All of the important electrically active impurities which are commonly found in silicon can be removed by the floating zone refiner, with the exception of boron. This is because these impurities have distribution coefficients of less than one, while boron has a distribution coefficient which is nearly unity. The distribution coefficient is a measure of the preference of an impurity for the molten or solid phase. For boron, there is nil preference so that zone refining is ineffective. Although various esoteric methods for the selective removal of the boron have been proposed in the literature, the practical limitation on the purity of the single-crystal silicon is determined by the boron content of the polycrystalline rod.

The basic zone refining process follows this equation:

$$C_g = K C_o(1 - g)$$

C_o = Initial impurity concentration in the liquid zone

where

g = Fraction solidified

K = Distribution coefficient (the ratio of the concentration in the solid to that in the liquid in equilibrium)

C_g = Impurity concentration in fraction most recently solidified

For those impurities having K of 1, as does boron, zone refining is relatively ineffective. For impurities having K << 1, zone refining can be extremely effective in sweeping the impurities to one end of the silicon rod. This same effect is highly valuable in zone leveling, in which a desired impurity is doped uniformly throughout the crystal as it grows. Suppose that

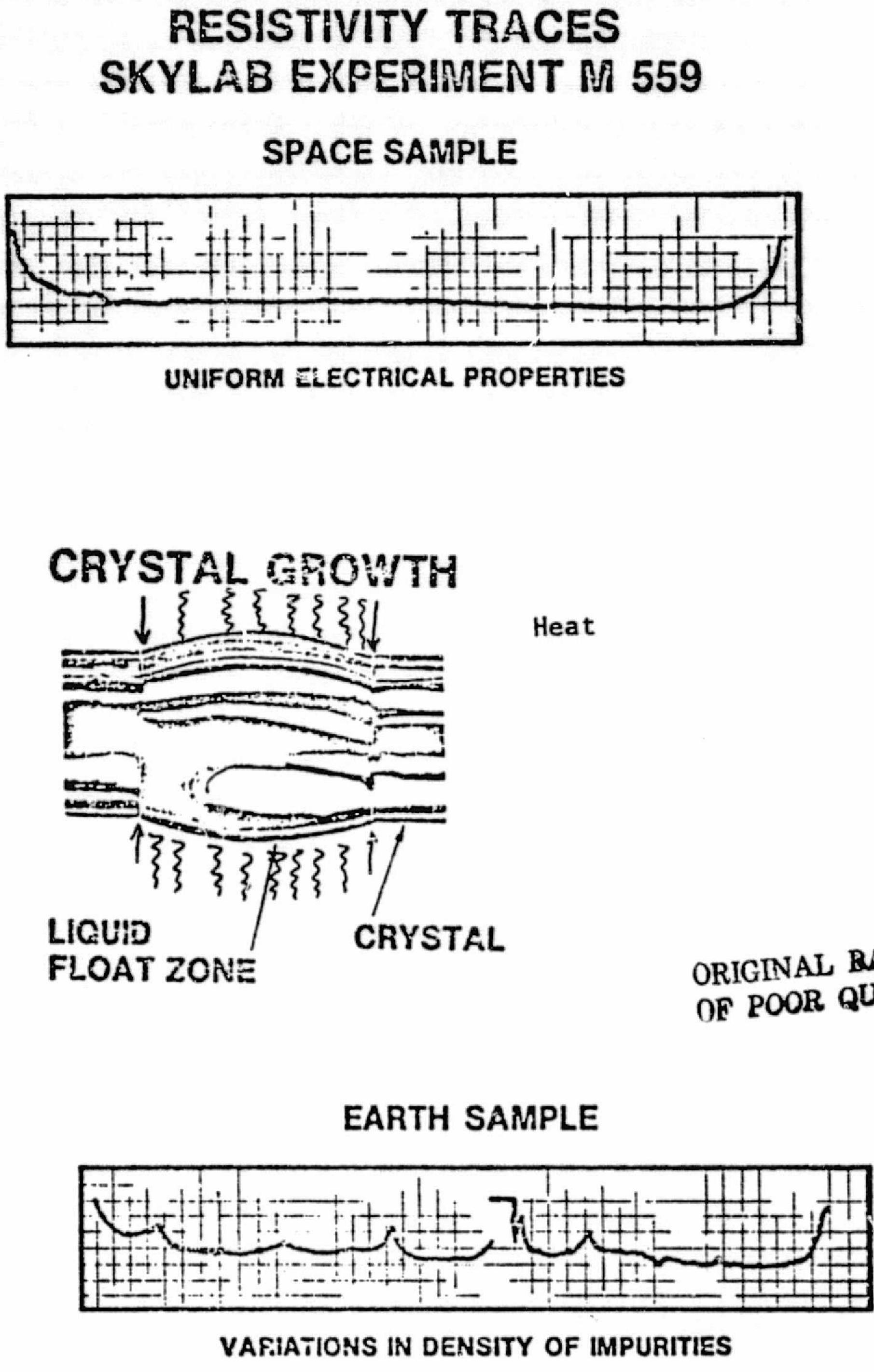


Figure 41. Polycrystalline Rod Being Transformed (by Localized RF Heating) into Single Crystal (Floating Zone Method)

the silicon material is sufficiently purified by zone refining and is now ready for final crystal growth. The desired doping impurity is introduced into the region of initial melting. For an impurity with very low K (for example, indium with $K = 4 \times 10^{-4}$), the crystal volume grown, as the zone moves, will retain only a miniscule part of the impurity and the impurity concentration will remain essentially constant during the entire crystal growth pass. The impurity incorporated into the crystal will be correspondingly uniform. Thus, the low value of K is highly advantageous to uniform doping of the crystal.

Purification Of Intrinsic Silicon

Silicon Polycrystal Fabrication. The polycrystalline silicon is the starting material for the single crystal produced by the Czochralski and floating zone techniques. Rods are fabricated by a chemical reaction to form a gaseous silicon compound, which is purified by fractional distillation and then decomposed to form the polysilicon. The major goal in the process is to reduce the boron content to the minimum. The gasses: monosilane ($Si{:}H_4$) and trichlorosilance ($Si{:}Cl_3H$) have been used in this process. Achievable reduced boron contents of about 0.02 ppb (parts per billion) are possible using this method.

High quality polycrystalline silicon can be purchased from Dow Corning, or other qualified supplier, with an impurity content of minimal 0.4 ppb donors and 0.02 ppb acceptors (mainly boron). This boron content represents a concentration of 1×10^{12} atoms/cm^3. This production test crystal undergoes seven vacuum passes in a float-zoner at the Dow Corning Test Laboratory to determine the boron level measured as resistivity, by two- or four-point probe. Heavy ions are investigated by mass spectroscopy, Dow Corning will provide this data with every batch of material accepted, including information about oxygen and carbon content.

At the Rockwell International facility, further purification of the just mentioned raw silicon is attained by multiple vacuum float zoning. Impurity removal is achieved by a combination of zone refining and evaporation. The theoretical consideration of this purification process, when evaporation and segregation occur, is expressed as:

$$\left(\frac{C_f}{C_o}\right) = \left[k - \left(\frac{k}{u}\right)\right] \exp - \frac{ux}{\ell} + \left(\frac{k}{u}\right) \qquad (1)$$

where

C_f = Impurity concentration in solid (ppb or atoms/cm^3)

C_o = Impurity concentration initially solid (ppb or atoms/cm^3)

k = Segregation coefficient (#)

x = Distance solidified (cm)

ℓ = Zone length (cm)

u = Modified distribution coefficient (#)

$$u = k + \alpha \frac{\ell}{v} \quad (2)$$

where

v = Growth rate

α = Measured evaporation rate

The evaporation rate, α, depends on the geometrical condition and the pressure. Equation (1) is justified, assuming a cylindrical zone, no diffusion in the solid, uniform concentration in the liquid, and constant segregation coefficient. Equations (1) and (2) give a maximum purification in one pass of $(\frac{k}{u})$, and for n passes $(\frac{k}{n})^n$ at constant coil speed.

The values of k and u for a certain impurity (or certain known impurities in the silicon) permit calculation of the purification needed to reach a desired resistivity. This procedure is often used when partial purification is planned, where residual donors in the raw material are used for the boron compensation. The reduction rate of these donors impurities chosen will reduce them to the concentration level of 100 percent and x-percent, of n-type impurities needed for the zone pass in the gas zoner during doping. This additional x-percent of donor impurity is the calculated reduction caused in the gas zoner during one pass at a determined inert gas pressure. Using raw silicon material with a donor concentration of 0.2 ppb and an acceptor concentration of 0.03 ppb, one purification pass in vacuum and one doping pass in the gas zoner achieved detector grade doped silicon material with compensated boron and a minimal amount of residual donors.

Purified Single Crystal Used For Applications In Manufacturing Of Crystal Detector Material. Using the multiple vacuum float zoning method, purified single crystals will be grown. The boule geometry will be two-inch diameter (minimum) and a minimum length of five inches.

The multiple passes needed for background impurity reduction provides the operator with the ability to develop optimum conditions for the single crystals. The application of those experiments incorporated into the final crystal pass (while doping in the gas zoner) should then produce high quality single crystal detector material. The following parameters influence the zone passing process and will be investigated and optimized.

1. Coil Design
2. Melt Shape
3. Shape of Freezing Interface
4. Effect of Cooling Thermal Geometry on Resultant Thermal Stresses

As the diameter of a crystal grown by the float zone method becomes larger, the difficulty of maintaining physical control of the molten zone also becomes greater. In general, the main forces acting on the molten zone are gravity and the liquid surface tension. If the molten zone is not properly controlled, it can spill out one side and interrupt the growth process.

Therefore, various techniques have been developed for maintaining control on the liquid zone in spite of the larger size. These techniques include electromagnetic levitation of the molten zone, special shaping of the molten zone by off-set centerlines of seed and feed bodies, and large diameter crystal coupled with small diameter feed rod. It is intended to provide for these manipulative features in the new equipment being investigated, and to use them, as appripriate, to grow large diameter crystals.

Structural Quality. In addition to the presence of residual or doped impurities, the spatial distribution must be considered. Resulting from detailed growth processes, these impurities can be distributed in striation patterns that are strongly dependent on impurity identity, and conditions of growth and rotation rates, thermal gradient in the crystal, etc. The presence of a supersaturation of lattice vacancies, resulting from the growth process, also will further add to the point defect population. To some extent, the defect concentration and distribution in striae can be modified by annealing processes.

It is not yet know to what extent these defects will interfere with performance of IR detection by devices fabricated from material with these defects. Therefore, investigations will be directed toward evaluating device performance correlation with point defect distribution, and to determine optimum annealing treatment of silicon in boule or wafer form to obtain maximum device performance.

The melt shape is a function of the coil design and so of the coupling between the coil and the silicon rod. When coil and silicon rods are coupled too close, small deviations in centricity of the rod and the coil cause uneven heating in the zone and interface. In general, growth conditions (like high growth rate, small segregation coefficient and small temperature gradients) create the possibility of *super cooling* resulting in polycrystalline growth, stresses and purity gradients in the solidified crystal. This problem can be explained as follows.

In the zone passing process, a narrow zone is melted and moves with the motion of the coil. The advancing of the molten zone causes the following changes in the surrounding silicon rod. A layer, with thickness, dx, melts from the upper part of the rod. At the same time, a layer, dx, freezes onto the lower part of the crystal rod. The freezing layer, dx, removes $k\ N_e\ dx$ impurities (k = segregation coefficient, N_e = impurity concentration in the liquid). The value of k is smaller than unity for most impurities. The rejected impurities are added to the melt above the new frozen layer, dx. Diffusion and stirring of the melt (rotation of the lower crystal part) cannot always transport these additional impurities and a stagnant layer of impurity-rich melt collects near the interface. This condition reduces the freezing point of the mixture, demanding that the temperature at the melt, crystal

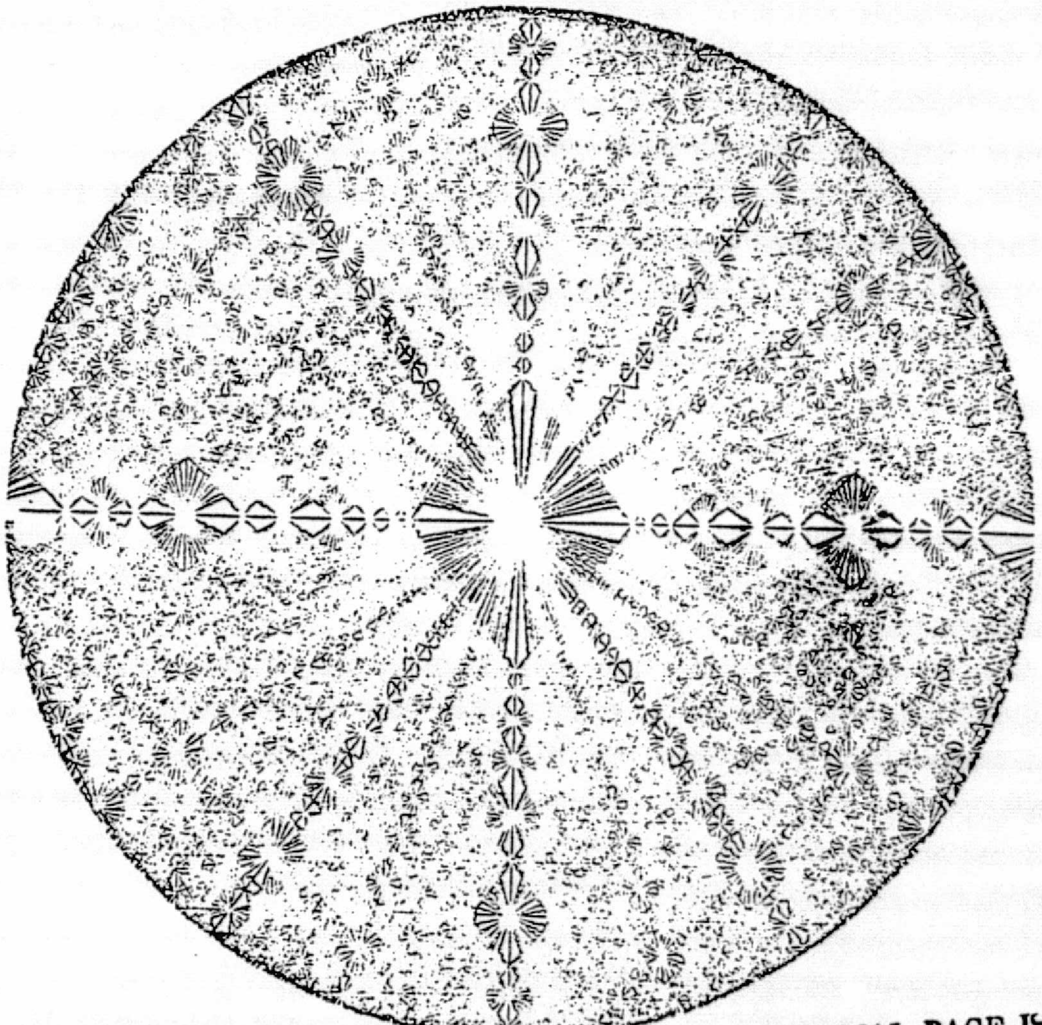


Figure 42. Sensor/Computer Trace of Silicon Crystal Doped with Boron (N-Type Semiconductor). This is a Cross Sectional View (Point Blank View) of the Passage of Positively Charged Ions Through the Single Silicon Crystal

interface, must be reduced below the point required for the pure melt. At low concentrations (as we consider this growth process after purification), the temperature decreases will be proportional to the concentration increase. This often causes polygrowth and stresses in the solidified crystal and must be avoided by proper coupling between coil and silicon rod.

The solubility limit for indium in silicon is not known to a certain value. However, it has been reported to be approximately $4 \times 10^{17}/cm^3$, and concentrations of this amount have been reported. In prior Rockwell experience, one-inch diameter float zone silicon has been doped with indium to levels of approximately $10^{17}/cm^3$, and this material has been used to make very successfully operating detectors. Since no attempt was made to maximize the indium content, we believe that a concentration higher than $10^{17}/cm^2$ can be achieved.

The indium will be introduced at the final stage of crystal growth, following material purification. The indium will be distributed uniformly by the *zone leveling* method. By this method, a small calculated amount of indium will be placed in the feed stock at the location of the initial molten zone. Since the distribution coefficient is so very small (approximately 4×10^{-4}), virtually all the indium will remain in the molten zone as it passes along the entire work piece, and this will result in a correspondingly uniform doping of the crystal as it is formed.

Dislocations and Crystal Growth

Dislocations can be detrimental to the operation of the CCD's, although they apparently affect IR detection only a small amount. Thus, the crystal growth process must be conducted in a manner that will minimize dislocation generation.

One mode of dislocation formation has been proposed to be the condensation of vacancies. During the growth of dislocation-free material, a supersaturation of vacancies is formed in the crystal lattice. Under proper thermal conditions, these can condense to form vacancy loops. As the loops become large enough, the loops will begin to operate as dislocation sources and the dislocation concentration will increase.

A more likely source of dislocations, especially in the larger diameter crystals, is by propagation of resident dislocations from the initial seed stock, and arising from stresses between the rotating crystal and the molten zone.

A further likely source of dislocation generation would be vibration of the molten zone from a vibrating structural environment. To reduce this potential source of dislocation generation, it is important to use an equipment design that will avoid internal vibration as far as possible, then take special care to isolate the system from vibration arriving through the ground or the building structure.

For the purpose of this program, it will be necessary to determine the effects of these structural flaws on device performance and to optimize growth conditions so as to minimize those flaws that are found to degrade device performance.

It has been shown by several researchers that in some cases the presence of dislocations may be the controlling factor in crystal growth. When crystals are grown in conditions of low supersaturation, of the order of one percent, it has been observed that the growth rate is enormously faster than that calculated for an ideal crystal. The actual growth rate is explained by Frank in terms of the effect of dislocations on growth.

The theory of growth of ideal crystals predicts that in crystal growth from vapor, a supersaturation (pressure/equilibrium vapor pressure) of the order of 10 is required to nucleate new crystals of the order of 5 to form liquid drops and of 1.5 to form a two-dimensional monolayer of molecule, on the face of a perfect crystal. Volmer and Schultze observed growth of iodine crystals at vapor supersaturations down to less than one percent, where the growth rate should have been down by the factor e^{-3000} from the rate defined as the minimum observable growth. This is a substantial disagreement between observation and theory.

The large disagreement expressed the difficulty of nucleating a new monolayer on a completed surface of an ideal crystal. But if a screw dislocation is present (Figure 43), it is never necessary to nucleate a new layer: the crystal will grow in spiral fashion at the edge of the discontinuity shown. (An atom can be bound to a step more strongly than to a plane.) The calculated growth rates for this mechanism are in good agreement with observation. We expect that nearly all crystals in nature, grown at low supersaturation, will contain dislocations that otherwise they could not have grown.

Spiral growth patterns have been observed on a large number of crystals. A beautiful example of the growth pattern from a single screw dislocation is given in Figure 44.

If the growth rate is independent of direction of the edge in the plane of the surface, the growth pattern is an Archimedes spiral,

$$r = a\theta$$

where a is a constant. The limiting minimum radius of curvature near the dislocation is determined by the supersaturation. If the radius of curvature is too small, atoms on the curved edge evaporate until the equilibrium curvature is attained. Away from the origin, each part of the step acquires new atoms at a constant rate, so that

$$dr/dt = \text{constant}$$

There are several basic types of dislocations. We first describe an edge dislocation. Figure 45 shows a simple cubic crystal in which a slip of one atom distance has occurred over the left half of the slip plane, but not over the right half. The boundary between the slipped and unslipped regions is called the dislocation. Its position is marked by the termination of an extra vertical half-plane of atoms crowded into the upper half of the crystal, as shown in Figure 46. Near the dislocation the crystal is highly strained. The simple edge dislocation extends indefinitely in the slip plane in a direction normal to the slip direction. In Figure 47, we show a photograph of a dislocation in a two-dimensional soap-bubble raft, obtained by the method of Bragg and Nye.

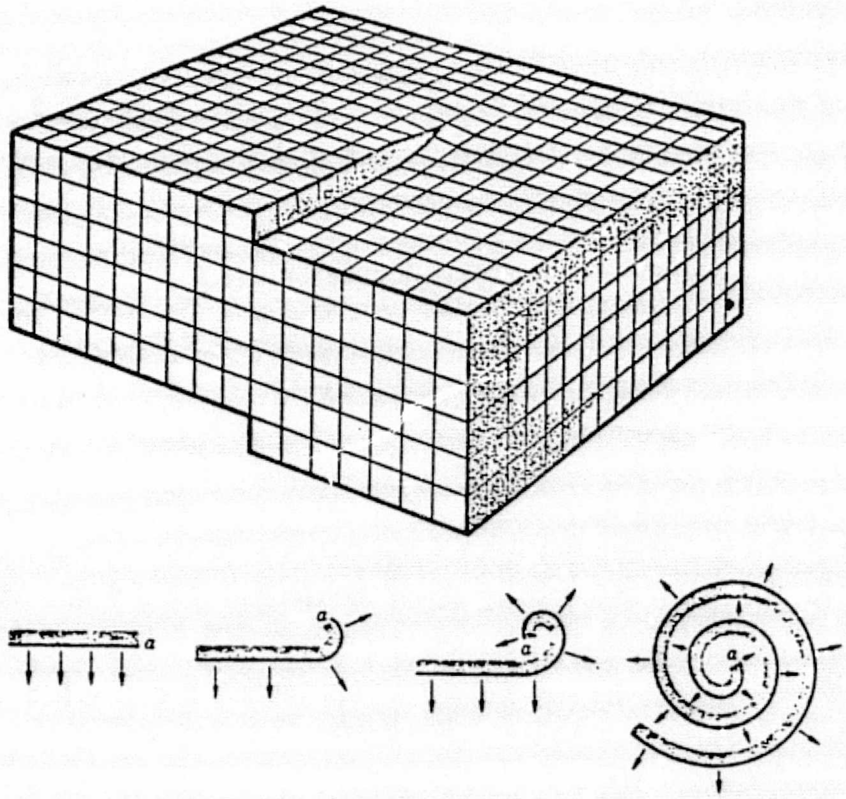


Figure 43. Development of a Spiral Step Produced by Intersection of a Screw Dislocation with the Surface of a Crystal. Each Cube Represents a Molecule. (After F. C. Frank.)

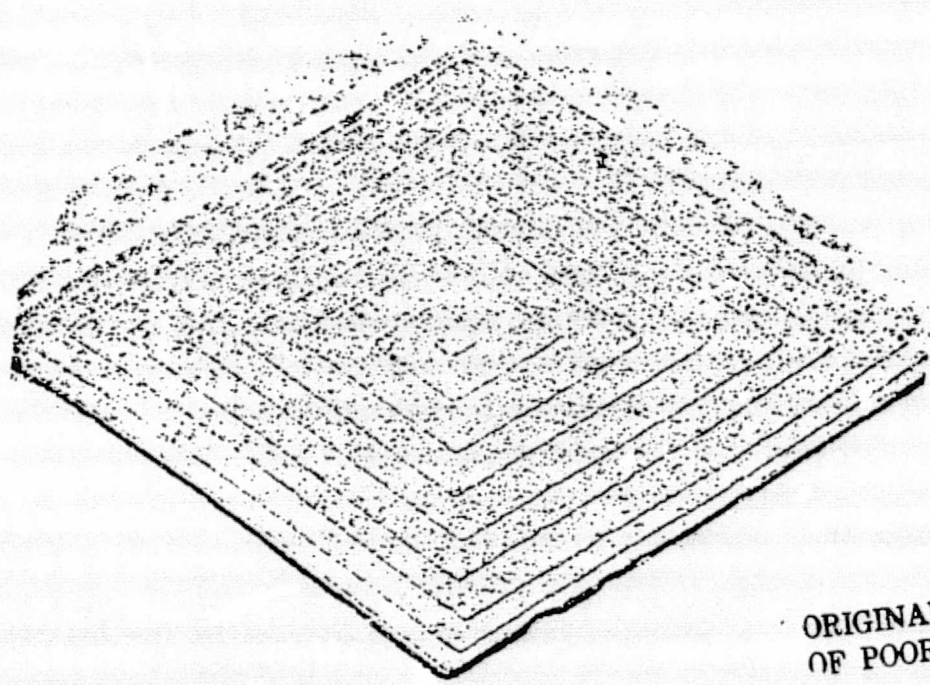


Figure 44. Growth Pattern from Single Dislocation on Single Crysta. of Paraffin n-$C_{36}H_{74}$. [Electron Micrograph Courtesy of H. F. Kay and B. J. Appelbe, After Dawson and Vand, Proc. Roy. Soc. (London) A2C6,555 (1951).]

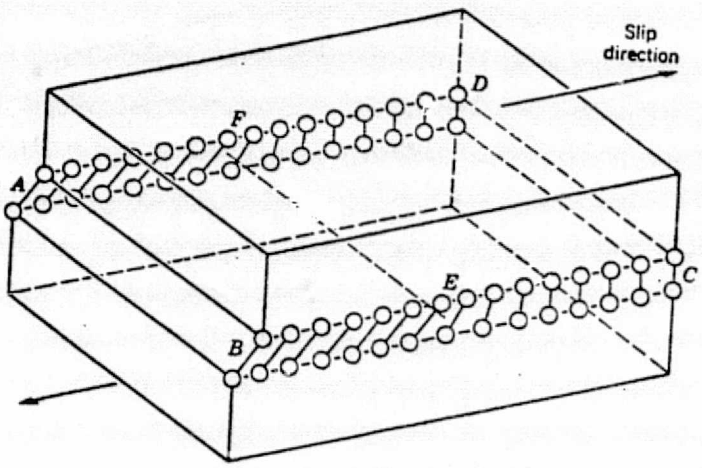


Figure 45. An Edge Dislocation EF in the Glide Plane ABCD. The Figure Shows the Slipped Region ABEF in which the Atoms have been Displaced by more than half a Lattice Constant and the Unslipped Region FECD with Displacement Less than half a Lattice Constant.

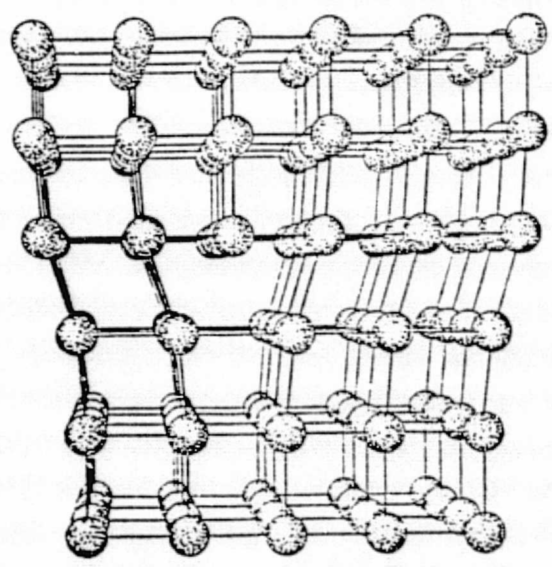


Figure 46. Structure of an Edge Dislocation. The Deformation may be Thought of as caused by Inserting an Extra Plane of Atoms on the Upper Half of the Y-Axis. Atoms in the Upper Half-Crystal are Compressed by the Insertion; Those in the Lower Half are Extended.

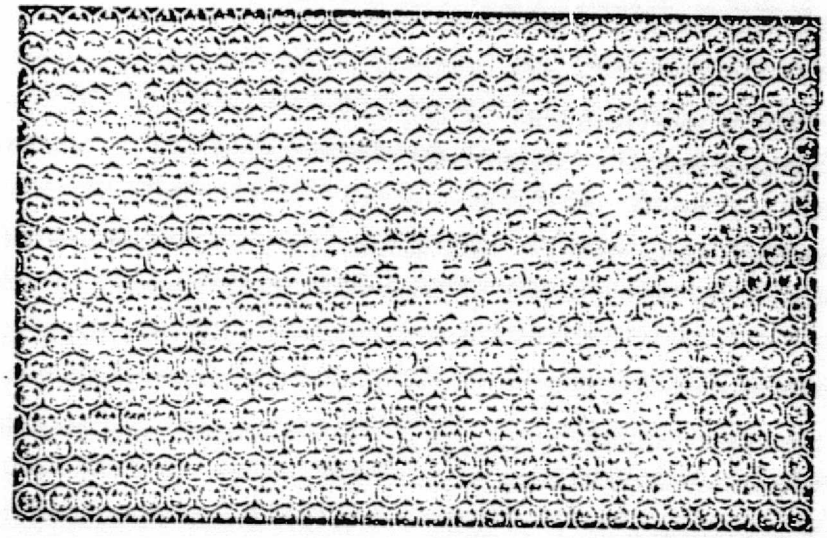


Figure 47. A Dislocation in a Two-Dimensional Bubble Raft. The Dislocation is most easily seen by Turning the Page by 30° in its Plane and Sighting at a Low Angle. (Courtesy of W. M. Lomer, After Bragg and Nye.)

C-3

Silicon Crystal Growth for Power Applications

The use of large silicon crystals for the transmission of dc power could bring substantial benefits to the electrical power industry. These include load sharing across time zones and different geographical areas.

The goals and objectives of such a program are two-fold:

1. To manufacture silicon crystals having improved resolution and signal to noise discrimination capability. To be accomplished by growing crystals of more uniform composition by avoiding saturation anomalies caused by convection in the melt.

2. To manufacture large-diameter, superior performance silicon wafers for large-scale electrical power rectification. To be accomplished by growing larger crystals in absence of gravity loading.

The present dc crystals are limited due to non-uniformity in the electrical field within the crystal, attributed to uneven distribution of dopants and impurities.

Electrical Power Application

Silicon crystals, as large as 150 mm in diameter, are highly desirable for electrical power distribution systems. These large crystals, with appropriate electrical characteristics, are not feasible with current processing techniques in the earth's gravitational environment. The following paragraphs discuss these limitations and the way in which space manufacturing may solve the problem.

The technique used to refine silicon boules used in large-scale power distribution application is float zone refining. A molten zone in a silicon rod is held in place by its own surface tension. The heat for melting the zone is provided by a ring-shaped resistive heater or induction coil. As the float zone is moved along the axis of the rod, the impurities are displaced and a homogeneous monocrystalline structure is formed. Pfann* shows the fundamental equation for determining the shape of the surface of a liquid under the influence of surface tension:

ORIGINAL PAGE IS OF POOR QUALITY

$$P = \gamma \frac{1}{R_1} + \frac{1}{R_2} \qquad (6)$$

where P denotes the inward pressure exerted by the surface of the liquid, γ denotes the surface tension, and R_1 and R_2 denote the principal radii of curvature.

Applying appropriate boundary conditions to this relationship, the maximum height of the melt zone (lm) may be determined as follows:

$$lm \cong 2.8 \, (\gamma/\rho g)^{1/2} \qquad (7)$$

*Pfann, W. G., Zone Melting, Second Edition. John W. Cez & Sons (1966), p. 109.

where γ denotes the surface tension, ρ denotes the density, and g is the gravitational constant. For a given set of material properties, the limit in the height of the melt zone is a function of the square root of the inverse of the local gravity vector. This places a practical limit upon the diameter that can be attained in a 1-g environment because melting the entire cross-section of a large diameter boule requires a correspondingly large height. In space, there appears to be no limit to the diameter that could be float-zone refined because surface tension would maintain the integrity of the melt zone.

One of the primary impediments to using silicon wafers larger than 40 mm to 50 mm in diameter has been the proportionally larger density of dislocations obtained in the larger diameter crystals. It cannot be predicted whether dislocation densities in larger crystals, obtained by using the float zone technique, will still be sufficiently low to meet the power density requirements in electrical power applications. A technique that should be considered in the proposed program for this application is Czochralski pulling in a weightless environment. For the same reasons described in the discussion concerning crystal growth for medical applications, the Czochralski method in space may result in the lowest dislocation density that is attainable. This will be made possible by permitting the removal of the liquid-solid interface away from the crucible. The effect of low dislocation-density would be a more uniform distribution of electrical characteristics in the crystal, thus, enabling the larger diameter of the semiconductor to be used effectively in carrying larger voltage and current loads.

The use of semiconductor rectifiers for electrical power distribution systems is gaining momentum with the trend toward high voltage direct current (HVDC) energy transmission. HVDC has distinct advantages in reducing reactive power transmission losses and in making large-scale underground power transmission feasible. The silicon wafers are currently obtained commercially in sizes of 40- and 50-mm diameter. The power industry would like to have the flexibility to choose from wafers up to 100- to 150-mm in diameters, depending on the particular design situation at hand. A large number of applications require the smaller diameters; a 40-mm wafer, for instance, can handle up to 700 amperes. Large installations require the rectification of megawatts of power. A GE-built rectifier-inverter installation now under construction* will use 9600 forty-mm silicon wafers to handle up to 360 megawatts of power. The advantage of larger silicon wafers in such major installations is significant in terms of simplified peripheral equipment. Each semiconductor device requires peripheral equipment for heat dissipation, load balancing, controls, and electrical protection. Therefore, a reduction in the number of semiconductors, required to handle the same power load, affords the design advantage of requiring less peripheral equipment.

The result of a successful space process to produce large, low-dislocation silicon crystals would be the establishment of a new market for large silicon wafers that offer the power industry the aforementioned design advantage. In order to estimate benefits, the total market for silicon wafers was examined, and an estimate was made of the portion of the market that would deal with the large wafers.

*HVDC Facility, New Brunswick, Canada.

By the early 1990's, it is estimated that 350 new generating plants will be needed to supply a million megawatts of additional power in the United States. The transmission lines for this energy will double the current acreage required to accommodate the right-of-way for the overhead cables. When current developments in cryogenic transmission and superconductor technology come to fruition, underground cables will likely be used to reduce the land usage problems. Underground transmission will very likely utilize high voltage direct current, which in turn will make large demands on the production of silicon crystals for power control and distribution equipment. Half of the new power distribution network is constructed underground. All of the silicon wafers will not require the large size and ultra-low dislocation density produced in space; thus, we assume 50 percent utilization of the space manufactured silicon.

Czochralski Pulling Method

The method proposed to attain the desired uniformity of crystal characteristics would utilize Czochralski Pulling, in a weightless environment.* The material is completely melted in a crucible and a seed crystal is introduced in the liquid. The temperature of the melt is adjusted in such a way that solidification at the seed promotes gradual growth of the crystal. The seed crystal is slowly raised at a rate which, together with the temperature of the melt, determines the diameter of the crystal. In a weightless environment, the length of the liquid column extending beyond the surface of the melt can be extended considerably, and the melt/solid interface is removed from the portion of the melt contained by the crucible. Isolation of the melt/liquid interface to a considerable distance from the crucible wall will decrease crucible emitted impurities and thermal gradients. Absence of thermal convection, settling, and buoyancy in zero-g, coupled with controlled stirring (e.g., through externally induced electromagnetic fields) is likely to promote homogeneous distribution of dopants and other trace elements in the melt and, thus, prevent uneven distribution of these traces in the crystal.

Crystal Makers

The growth of silicon crystals on earth is limited to boules of 3- to 4-inches in diameter. Large diameter, more uniform, 100- to 150-mm silicon crystals grown in space would likely have applications in medicine and for electrical power rectification. It is estimated that 90.7 to 181.4 x 10^3 kg (100 to 200 short tons) of silicon crystals will be required each year by 1990 for electrical power uses alone. These crystals would have an estimated value of $50 to $100 million.

Power Equipment and Instrument Makers

The instrumentation and power equipment industries would utilize the silicon crystals to make avalanche detectors for radiological medicine uses, and to make silicon diode rectifiers for the electrical power equipment makers.

*Frost, R. T., et al., Free Suspension Processing Systems for Space Manufacturing, Final Report. General Electric Company, Valley Forge, Pa., DCN-1-0-64-27017.

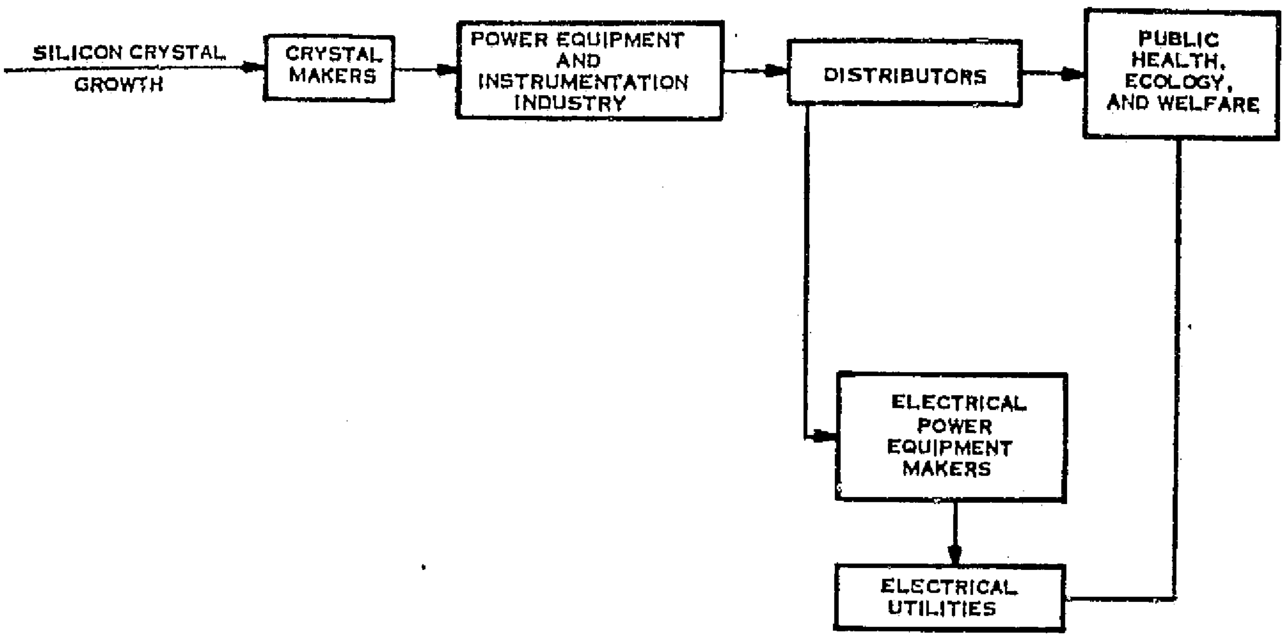


Figure 48. Potential Beneficiaries from Space Production of Silicon Crystals for Medical and Electric Power Applications

Based on the above estimate that most of these crystals would be used by the electrical power industry, the $50 to $100 million inventory of crystals each year might have an average value added of approximately 25 percent* when incorporated in diodes for power rectification uses. To the instrument maker then, his total sales of diodes would be approximately $62.5 to $125 million per year.

Electrical Utilities

Electrical utility company profits are Government regulated to a certain percentage of return on investment, but the capital investment required by these companies is a function of the efficiency with which they provide the public with electrical power. The benefits to these companies from use of silicon crystals lies in the reduction of capital investment required. Large silicon diodes, which could facilitate the transmission of large amounts of power to cities from electrical conversion stations.

The following are typical semiconductor requirements for many of the applications discussed:

Silicon Wafer Target Specifications (Typical Commercial Requirements).

1. Orientation - the wafer face shall be along the 100 direction with a rotational error of less than 1.5 degrees.
2. Size - wafers will be 50.8 mm (2.0 inches) or larger (preferable 2.25 inches [57.2 mm] in diameter). All wafers to have the same diameter within ± 2 percent.

*Statistical Abstract of the United States (1971), U. S. Government, Department of Commerce, p. 731.

3. Thickness - wafer thickness shall be .58 mm ± .008 mm (.020 inch). All wafers to have the same thickness.

4. Parallelism or Taper - the wafers shall have both sides parallel.

5. Dopant - the dopant shall be indium to the level of 2 x 10^{17} atoms/cm^3. Individual wafers are to be within ± 10 percent of this value.

6. Dopant Uniformity - The resistivity shall vary less than ± 7.5 percent over the surface of the wafer, measured at center, and at 1/2 radius from edge of four quadrant positions.

7. Boron - wafers shall be boron free ($B < 10^{12}$ atoms/cm^3). Residual boron should be compensated by a phosphorus doping of $\lessgtr 10^{13}$ atoms/cm^3.

8. Oxygen Content - less than 50 ppb ($O_2 < 10^{14}$ atoms/cm^3).

9. Dislocation Density - shall be as small as possible, in any case, no larger than 500 dislocations/cm^2.

10. Polish - both sides of wafer shall be electrochemically polished.

11. Surface Roughness - average surface roughness shall be less than 0.25 μm (1 microinch) rms on each side. Maximum surface roughness shall be less than .50 μm (2 microinches).

12. Surface Cracks - there shall be none within 10 mils from the wafer perimeter.

13. Slip and Lineage - shall not exist within 10 mils of the wafer perimeter.

14. Wafer Curvature - shall be less than 1.5 mils (departure from flatness) over the entire surface to within 10 mils of wafer periphery. The periphery of the wafers (both sides) shall have a convex radius so as to avoid projections. There shall be no dimples more than 16 μm from planarity.

15. Stress - the wafer shall be stress free. Wafers should not change flatness after anneal at 1000°C for 1 hour lying flat.

16. Flat - the wafer shall have an alignment flat on the 110 edge with an orientation tolerance of ± 1.0 degrees.

17. Lifetime - the room temperature minority carrier lifetime shall exceed 1 microsecond, and should be as high as possible.

18. Twinning - none shall be present.

19. Contamination - there shall be no evidence of adherent contamination when wafers are viewed under 100-times magnification.

20. Scratches - at 5-times magnification, 90 percent of the wafers shall have no scratches. The remaining 10 percent of the wafers shall not have more than three barely visible scratches per wafer with a total cumulative scratch length not to exceed .5 inches.

LSI Circuit Chips

General Objective

Manufacture of defect-free substrate wafers for LSI circuit chips and computer storage applications.

Product to Earth

Large-scale integrated circuit chips. Bubble memory devices.

Key Objectives

To provide the microelectronic industry with ultrahigh resolution photolithography for imprinting circuits with line spacings measuring in the millionths of an inch. Seismic motions of the earth presently inhibit such small separations of circuit lines.

Principal Contribution

Use the vibration-free environment of space to perform these delicate operations. Will benefit the microelectronic industry.

Level of Contribution

Annual market assessment of the communications products (such as ATC radar, collision-avoidance systems for aircraft) alone are estimated at $100M per year.

Uniqueness of Contribution

Benefit communication needs (military and civilian) improves yield factor. Produce LSI circuit chips with $\gamma/4 \rightarrow \gamma/2$ spacing for high frequency applications. Only way to isolate process from terrestrial and eusmic and acoustic coupling vibrations.

Time Factor

1985 to 1990.

Principal Installation

LEO manufacturing facility.

Principal Functional Units

To be determined.

Principal Technologies

The principal technologies are: crystal growth from a melt and LSI circuit chips photolithography techniques.

Impact Spectrum

To be determined.

Front-End Capital

To be determined.

Large Silicon Crystals For The Rectification Of DC Power

General Objective

Manufacturing of flawless silicon wafers for large-scale electrical power rectification.

Product to Earth

Silicon control rectifiers for public utilities companies.

Key Objective

To provide power equipment builders with large (15 cm diameter) and dislocation-free silicon semiconductor components for control rectifier devices used in ac/dc/ac power converter facility stations.

Principal Contributions

For this specific application of single-crystal silicon, there is an urgent need for flawless, large diameter (~15 cm) wafers for use in ac/dc/ac power conversion system, i.e., conversion rectifiers.

Level of Contribution

Will provide the power industry with semiconductor rectifier silicon wafers (10-15 cm) that can handle up to 700 amperes and reduce the number of smaller size SCR's to handle up to 360 megawatts of power.

Uniqueness of Contribution

The float zone refining method is capable of producing high grade wafers (~4-5 cm) diameter SCR's for electrical power applications. However, the primary impediments are the unavailability of large diameter wafers. Space manufacturing can provide this unique semiconductor material.

Time Factor

~ 1985.

Principal Installation

LEO manufacturing facility, i.e., free flyers, space stations, and spacelabs.

Principal Functional Units

Space - one satellite or more (to be determined); one tracking/control and data handling center.

Impact Spectrum

To be determined.

Principal Technology

Crystal growth from a melt zone refining

Front-End Capital

To be determined.

<u>High Temperature Turbine Blades</u>

General Objective

Manufacture of high temperature/high strength metal turbine blades for turbojet and power conversion-type engines.

Product to Earth

Long life/high temperature turbine blades for fuel burning turbojet engines.

Key Objective

To grow single crystal and eutectic turbine buckets without anomalies for less than 1650°C turbine inlet temperature and minimized grain boundaries for increased blade life.

Principal Contribution

Some replacement costs of ~ $4.5M per year. Reduce fuel consumption; reduce air pollution. Some material development costs. Reduce fare of air transportation. Improve public safety.

Level of Contribution

Public safety, national defense, public transportation, balance-of-payments all have some impact.

Uniqueness of Contribution

Space processing metallurigical methods offer new metals with unique temperature and strength properties. By increasing the temperature threshold of present turbine blade engines the efficiency and lifetime of the engine would increase, thus, saving energy and reducing maintenance of the engine.

Time Factor

~ Late 1980's.

Principal Installation

LEO manufacturing facility.

Principal Functional Units

The principal functional units would be: one or more (directional solidification) free flyer satellites (to be determined); one control/tracking center.

Principal Technology

Variation of earth metallurgical process adapted to space.

Impact Spectrum

To be determined.

Front-End Capital

To be determined.

New Optical Glasses

General Objective

Manufacturing of optical glasses for refractive optics and laser windows.

Product to Earth

New glasses with superior characteristics: IR transparency, high strength, pure, thermal shock-resistant glass.

Key Objectives

To obtain containerless melt to minimize convection and contamination and sources of nucleation to prevent devitrification.

Principal Contribution

High index/ABBE number glasses. 5 to 10 μ IR transparency improvement for lasers.

Level of Contribution

Optical instruments and lens market estimation $10 M per year.

Uniqueness of Contribution

No way to do containerless melts in terrestrial industries; therefore, space only way to go.

Time Factor

~ 1985 to 1990.

Principal Installation

LEO manufacturing facility.

Principal Functional Units

The principal functional units are: furnace melt facility (to be determined); one or more acoustic levitation free flying satellites; one control/tracking and data handling center.

Principal Technology

Existing glass manufacturing

Impact Spectrum

To be determined.

Front-End Capital

To be determined.

High Strength Magnets

General Objective

The manufacturing of special terrestrially immissible metals for application to very high strength permanent magnets.

Product to Earth

New and unique alloys, e.g., AgMgAl or combinations of Fe, Al, Ni, Co, and Cu, that when magnitized have high and long lasting properties.

Key Objectives

To produce terrestrial immiscible alloys via solidification (metallurgy) methods in space.

Principal Contribution

Instrumentation industry, e.g., motors (long life) medical science, high strength has favorable affect on healing wounds.

Level of Contribution

Electronic and the medical industry.

Uniqueness of Contribution

Immiscible alloys would be unique to earth.

Time Factor

~ 1985 to 1990.

Principal Installation

LEO manufacturing facility.

Principal Functional Units

Principal functional units would be one or more free flying satellites (to be determined); one control/tracking and data handling station.

Principal Technology

Existing use in space.

Impact Spectrum

To be determined.

Front-End Capital

To be determined.

Silicon Solar Cells

General Objective

Manufacture of cheap, high-efficiency silicon solar cells for terrestrial or other applications.

Product to Earth

Cheap, high efficiency silicon solar cells either from silicon ribbon or vacuum deposition in low-g space.

Key Objective

The key objective of this initiative is to provide the consumer with reliable and cheap electrical power. It should be easier and cheaper to manufacture amorphous semiconductors in high-yield/high-throughput single-crystal cells.

Principal Contribution

This initiative is an intrinsic part of solution to energy shortage. Solar energy may not be the total answer to energy crisis, but it is a key element in the resolution of the problem.

Level of Contribution

Solar cells are presently being used in space systems as well as earth systems. There is an urgent need to improve and increase terrestrial electrical capabilities as soon as possible.

Uniqueness of Contribution

There are many methods of producing solar cells in space: (1) epitaxial growth, (2) vacuum deposition behind a wake shield of amorphous silicon, and (3) silicon ribbon drawing method. It is not clear yet which is the optimum method to use.

Time Factor

1985 to 1990 time period.

Principal Installation

LEO manufacturing facility.

Principal Functional Units

One or more silicon ribbon pulling facility and vacuum-deposition molecular wake-shield free-flying satellite(s); one control, tracking and data handling center.

Principal Technology

Czochralski seed pulling (from a melt). Thin film vacuum deposition in extremely hard vacuum (10^{-15} torr).

Impact Spectrum

To be determined.

Front-End Capital

To be determined.

<u>Fiber-Optics</u>

General Objective

To produce high transmission fiber-optics in space.

Product to Earth

Fiber optics for applications in optics, e.g., communication by wideband light beams.

Key Objective

To obtain containerless melt to minimize convection and contamination and sources of nucleation to prevent devitrification.

Principal Contribution

Very high transmission fiber optics with a minimum of losses.

Level of Contribution

Medical, communication industry will benefit.

Uniqueness of Contribution

No way to do containerless melting in 1-g terrestrial environment — space unique in that industrial sense.

Time Factor

~ 1975 to 1990.

Principal Installation

LEO manufacturing facility.

Principal Functional Units

One or more furnace melt facility fiber drawing apparatus, free flying satellite(s); one control/tracking and data handling center.

Principal Technology

Existing.

Impact Spectrum

To be determined.

Front-End Capital

To be determined.

REFERENCES

1. Study for Identification of Beneficial Uses of Space, Phases I, II, III. General Electric Report No. 75SDS4281 (November 30, 1975).

2. Space Processing Payload Equipment Study, Final Report. TRW Report No. 27818-6020-RU-06 (May 1976).

3. Excerpts from *Materials Processing In Space - New Challenges For Industry*, by Dr. James H. Bredt, Brian O. Montgomery and Hans W. Vencher, NASA Headquarters and MSFC, published in the Astronautics & Aeronautics (May 1975), pp. 22-40.

4. Technical Proposal for a HALO Focal Plane Technology Program, Rockwell International, Space Division SD76-SA-0003 -1 (February 9, 1976).

5. Kittel, C. Introduction to Solid State Physics, 3rd Edition.

6. For a full review of this field, see Neugebauer, Ed., Growth and Perfection of Crystals, Wiley (1959), also Chapter 7 of J. Friedel Dislocations Addison-Wesley (1964).

7. Bragg, W. L. and J. F. Nye. Proceedings of the Royal Society. A190, 474, London (1947); W. L. Bragg and W. M. Lomer. Proceedings of the Royal Society, A 196 171, London (1949).

SPACE OPPORTUNITIES – ENERGY

1. Space Light
2. Lunetta
3. Soletta
4. Space Fusion Power
5. The SPS

SPACE OPPORTUNITIES - ENERGY

Electric energy is the fastest growing form of energy in most countries. Moreover, as industrial utilization shifts its energy base from fossil to the less limited primordial energy base — such as fission, geothermal, solar, solar-derivatives and fusion — the primary form of technically useful energy will be electric, to be used directly or in the form of fuels manufactured by use of electric energy. Indeed, one may say that we move from the era of fossil economy to the era of electric economy.

When discussing space and energy sources, an important question arises at the start: *Why look to space for new energy sources when there is obviously an abundance of primordial energy sources on earth — not to mention the still considerable reserves in fossil energy, many of them still untapped, especially in the U.S.S.R.?* The answer is clearly dominated by economic and social considerations. To begin with, industry is indispensable for creating meaningful jobs and a better standard-of-living. Energy is the basis of both industry and improved living standards. But economic realities demand that the least expensive energy sources are used first, while work progresses (at least in far-sighted societies) to improve the economy of future energy sources in terms of their use. Thus, energy sources in space must be, or must become, competitive in relation to terrestrial sources. Competition with terrestrial sources involves not only cost, but also environmental factors and land use. The land use factor is less important in large, sparcely populated countries such as Canada and the U.S.S.R. In any case, if energy sources in space cannot compete economically with terrestrial alternatives, then they are not likely to be used for earth, as long as the terrestrial sources are available.

SPACE LIGHT

Solar energy is an inexhaustible source of light and energy. With it one can illuminate, produce biomass and generate mechanical energy, electric power and hydrogen or artificial hydrocarbons. The mean annual solar irradiation to earth is about 18,000 times the present energy consumption of mankind. Even in energy-intensive industrialized regions (such as in Central Europe), the annual solar irradiation exceeds energy consumption by a factor of 50 or more. Unfortunately, the energy provided to these regions by the sun is subject to large diurnal and seasonal variations. At high northern and southern latitudes, the sun is particularly unreliable. The general objective of the Space Light Project is to transmit sunlight to selected areas on the earth's night side.

In view of the reflection distances involved, the individual reflector is practially a point source of light. Solar radiation converges on it at an angle equal to the apparent diameter of the sun, as shown in Figure 49. The reflected beam, in turn, diverges at the same angle if the reflector is almost planar. The reflector must be extremely smooth; otherwise, the image diameter is increased due by diffuse reflections. Diameter and, hence, the area of the image increases with distance between reflector and image, independent of the

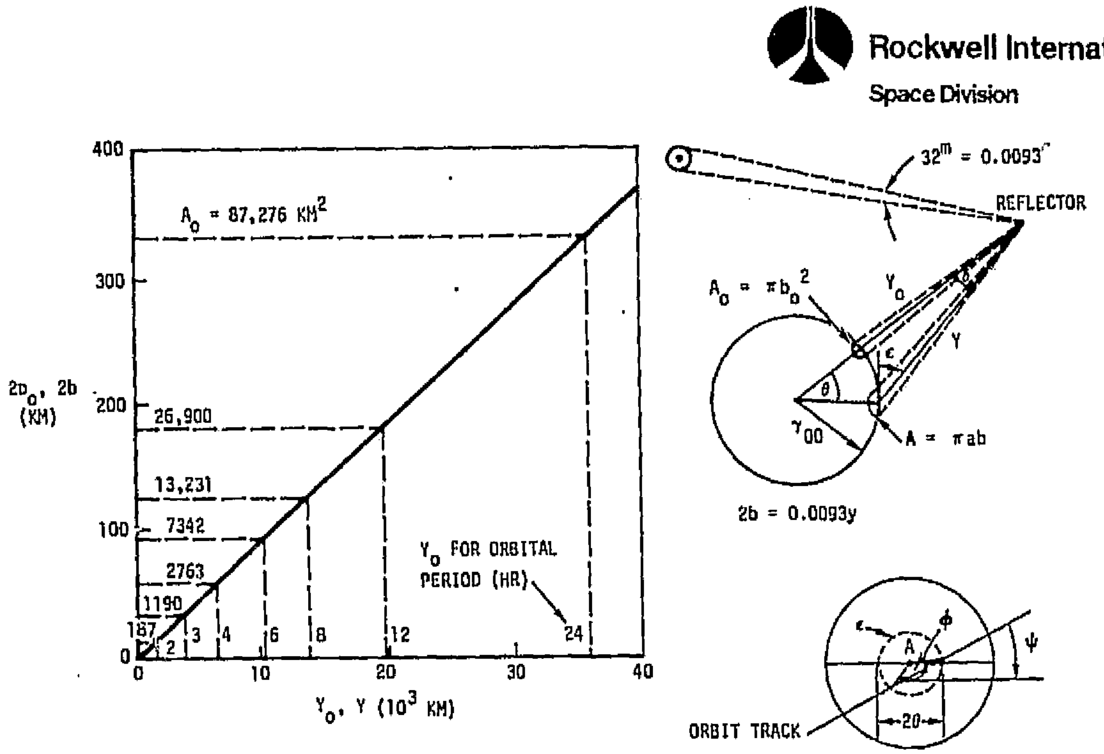


Figure 49. Image Diameter Versus Reflector Distance From Image

reflector area. Vertically beneath the reflector, the image diameter is smallest. When deviating from the sub-satellite point, the circular image becomes elliptical. The minimum radius increases with distance and becomes the semi-minor axis, whereas the semi-major axis increases as a function of the angle of elevation of the reflector above the horizon as seen from an observer in the center of the ellipse.

In the course of a cloudless night, the geosynchronous reflector will illuminate a given image area at ≥71 percent of maximum brightness. For half of the cloudless night, the reflector's brightness will be ≥92 percent. This makes a reflector of given size a far more effective illuminator than the full moon or sun, providing about 23 percent more illumination than either celestial body at equal brightness.

LUNETTA

Lunetta is a Space Light system sized to provide night illumination of the appropriate magnitude. The magnitude is related to the activities to be performed. Figure 50 surveys a wide range of outdoor activities at the desired illumination level. For comparison purposes, the minimum area of the reflector system required to provide the illumination level in the 8- to 24-hour orbit range. It is seen that most of the activities are covered adequately by an illumination level between 100 and 1000 moons. However, the illumination levels given for the particular activities correspond to a high standard. Lighting levels down to half that amount are still acceptable in many cases.

As is shown in Figure 51, the Lunetta is a lighting system of very high efficiency on a clear night (its lighting efficiency is about 64 percent of the original light energy offered to the reflector in space). The average lies around 30 percent, depending somewhat on the region and the season. The minimum is about 9 percent at heavy, unbroken overcast. By comparison, a thermo-electric power plant yields approximately 3 percent of its original fuel energy in the

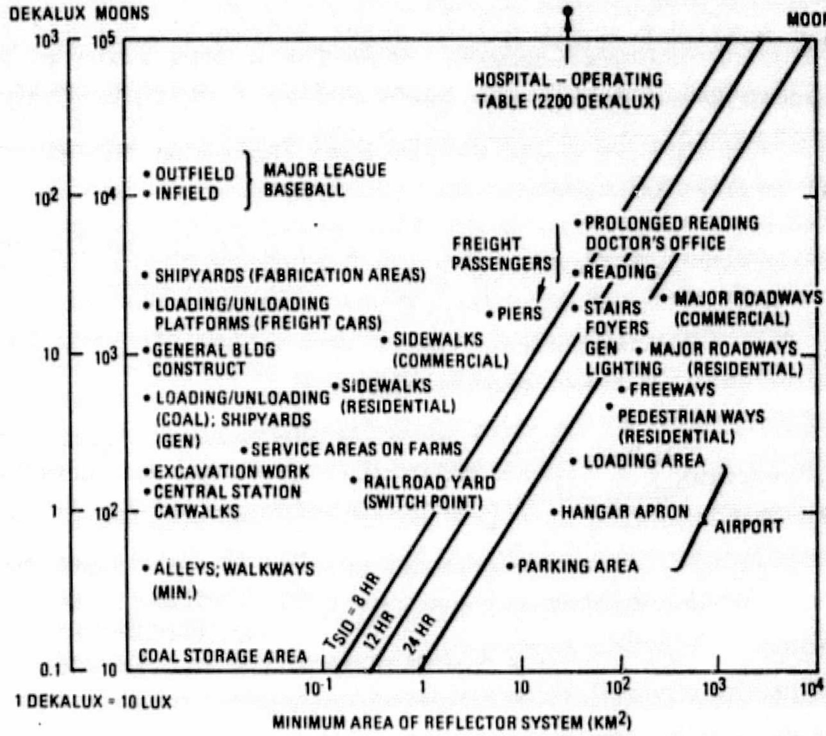


Figure 50. Lighting Levels and Lunetta Sizes

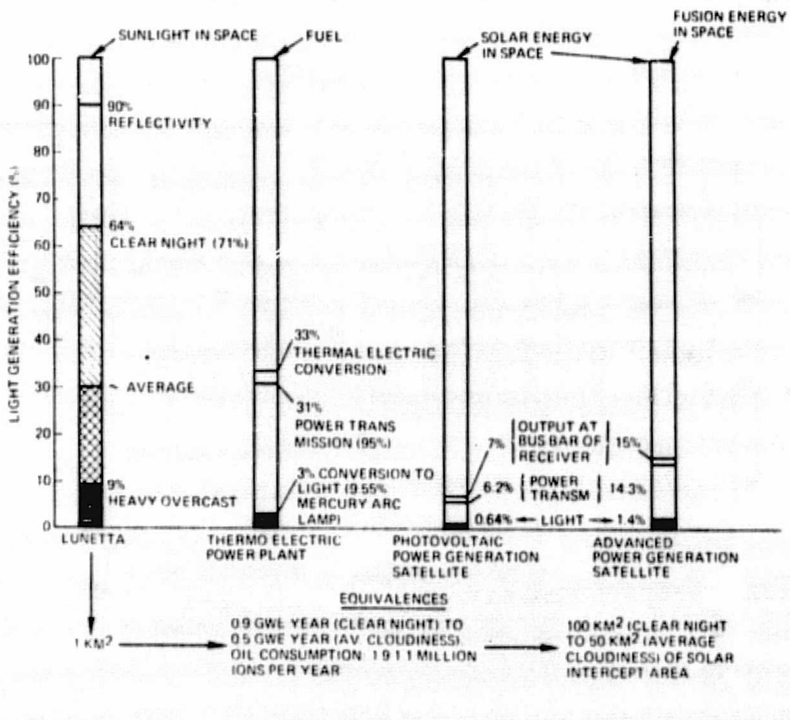


Figure 51. Lunetta Performance in Perspective

form of light. A silicon-photovoltaic power generation satellite has a lighting efficiency of about 0.64 percent. Even for a more advanced power generation satellite based on gallium arsenide solar cells, a Brayton cycle thermodynamic power conversion system or a fusion-MHD system, a lighting efficiency of hardly more than about 1.4 percent would be achieved (based on the given efficiency of the individual conversion steps).

Of course, Lunetta provides area lighting without the intrinsic possibility of spot lighting, as in the case of lamps. The illumination intensity of the entire area is determined by the lighting requirement for the particular working area proper (pier, dock, shipyard, road). Therefore, Lunetta is most suitable for applications which involve a need for area lighting.

Accordingly, there are four broad uses for Lunetta (Figure 52): urban illumination, lighting for remote industrial activities, illumination of rural areas and, as needed, illumination of earthquake and other disaster areas.

Service to large metropolitan areas provides higher quality lighting, reducing the power consumption for conventional lighting. It could also provide backup lighting for brownouts and blackouts. Top illumination of a fog region and light scattering through the fog increases the background brightness in the fog area and improves visibility compared to conventional street lighting.

In cities like Los Angeles, Chicago, New York, the electric consumption for outdoor lighting corresponds to between 5 and 10 watt-years per capita. This probably is true for cities in other industrialized nations. In developing countries the lighting power consumption per city dweller is lower.

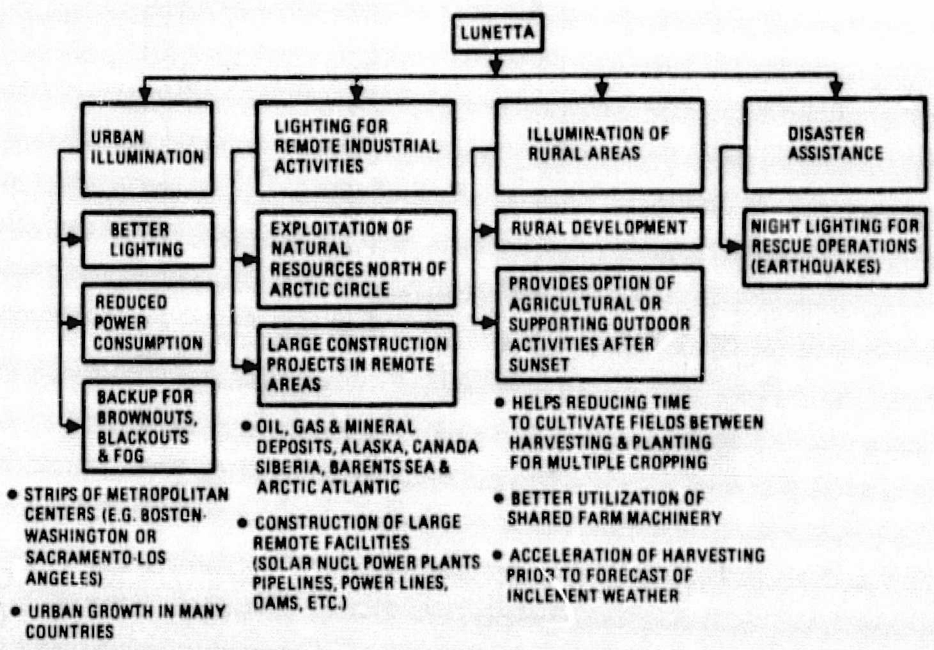


Figure 52. Lunetta Applications

According to estimates by the United Nations, 30 percent of the people in developing countries lived (in 1975) in urban areas of 20,000 habitants or more. The number of urban dwellers by the year 2000 is projected to have risen to 42 percent. If this is correct, this means that the urban population in the developing world will swell by the equivalent of 230 metropolitan areas of 6 million people each. In addition to existing poorly lit urban areas in the world, those additions constitute a large potential market for lighting cities of tomorrow largely with solar power at highest attainable efficiency. The outdoor lighting of these cities by electric means consumes 7 Gwe-years annually even if the per capita allotment is only 5 watt-years. This is equivalent to a mean area illuminance of less than 1 full moon.

Lunetta's light can accelerate large industrial projects in remote areas or during extended polar night — oil, gas and mineral ore extraction above the Arctic Circle, long-distance pipelines, electric transmission lines, distant nuclear power complexes or solar power plants — large projects where cost savings of 10 to 20 percent amount to tens or hundreds of millions of dollars.

In the Spitzbergen region, for example, the sun shines for 134 days alternating with 127 days of darkness, with two periods of 54 and 50 days with diurnal cycle wedged in between. Rich resources of off-shore oil, natural gas and mineral deposits are found or suspected between the Arctic Circle and about 70 degrees. Even larger undersea oil and gas deposits are indicated under the Barents Sea and the Arctic Atlantic between 70° and 80° latitude.

The higher latitudes also tend to be more cloudy. Figure 53 shows a survey of the annual average daytime cloudiness. It will be noted that, at high latitudes, the overcast in ocean areas exceeds that over land areas. The region with an average cloudiness of 50 to 75 percent extends particularly far north over the Eurasian land mass. Importantly, in winter months, the average cloudiness over North America and Eurasia is at its lowest level, except for areas with a maritime climate. Conditions are similarly favorable in spring and summer and comparatively least favorable in fall, especially in northwestern and northeastern North America.

Illumination levels around 100 moons appear adequate for many agricultural activities. The ability to work the fields before sunrise and after sunset, along with better use of roads at night, is part of rural development associated with modernization and intensification of agriculture in the developing world. There are three lines of intensification: better-off farm services; multiple croppings and crop interplanting; improved planting and animal breeding. Off farm services and multiple cropping can clearly benefit from better night lighting.

In the tropics, up to three crops are feasible per year, since seasonal variations are small. This could conceivably triple the annual yield per hectare. Multiple cropping requires more sophisticated irrigation and drainage, more intensive fertilizing and highly effective anti-pest and anti-disease measures. Moreover, the time for planting and harvesting and the time between harvesting one crop and cultivating the land for the next must be reduced below present levels. This, in turn, requires agricultural machinery. The utiliza-

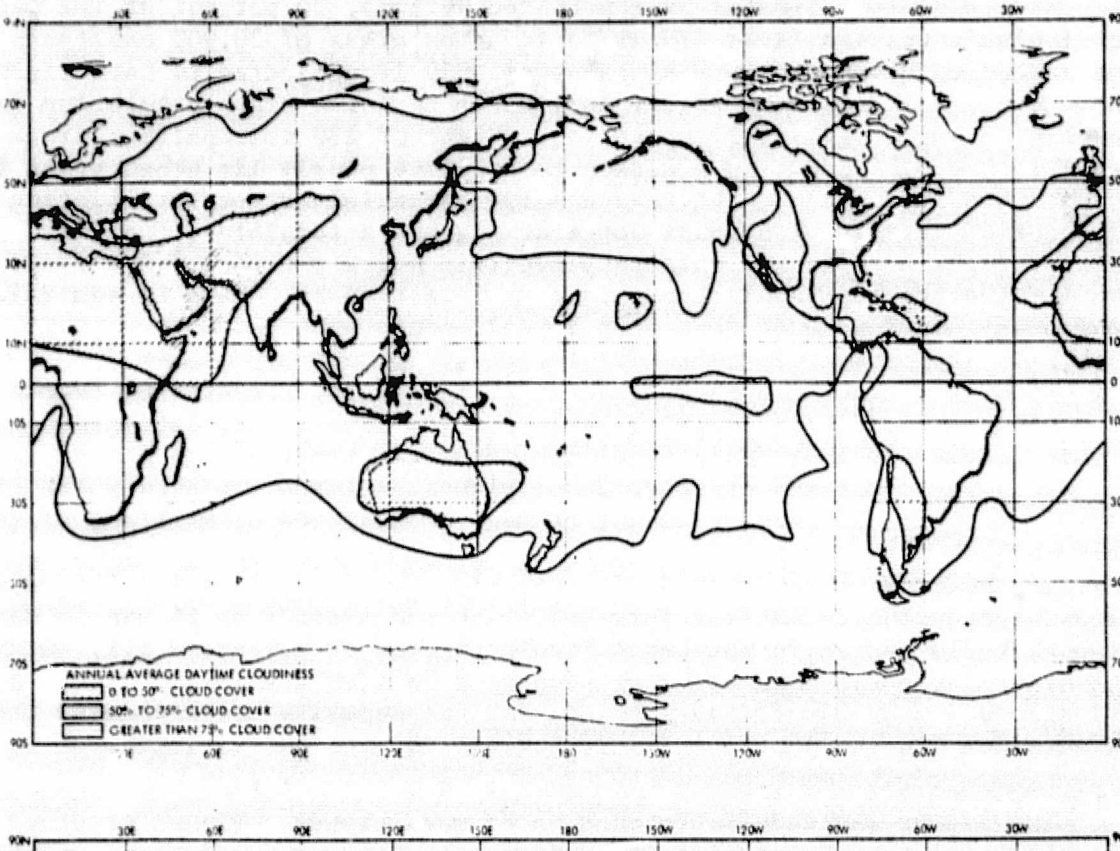


Figure 53. Average Cloudiness

tion of the equipment, shared in most cases by a number of farmers, can be increased and the transition between crops shortened if the equipment can be used beyond the normal daylight hours.

Among several diverse applications, night lighting for disaster areas and rescue operations is the most significant, as least from the human standpoint. As a rule, disasters do not occur in well-lighted areas and those which do occur — primarily earthquakes — wipe out nothing more thoroughly than light and power. Darkness at night compounds chaos, increases the loss of life and makes rescue operations more difficult.

In applying Lunetta to the illumination of urban areas, several factors must be taken into account to provide useful and publicly acceptable lighting. Excessive variations in brightness should be avoided. The light should not generate deep shadows, which is particularly a problem where many high rises or skyscrapers are involved. Thirdly, when being at the limiting elevation below which the reflector is no longer used, the brightness of the larger, elliptically distorted image should be as low as possible to generate minimum disturbance of areas not included in the basic area to be illuminated.

If a single large reflector, or a cluster of closely spaced reflectors, is used to illuminate a certain service area (to be followed by another cluster as it leaves the arc), then the chances are excellent that all these undesirable characteristics will be present. To provide a Lunetta system, whose lighting features avoid as much as possible these features, the cluster needs to be expanded and distributed over the arc. Therewith the gaps between individual clusters disappear .

From the above considerations for optimizing the illumination quality, especially in cities, one can draw the further conclusion that even the distributed reflectors should not necessarily be placed in one orbit, but should instead be distributed over two or three orbits of equal distance and inclination with the ascending nodes at the equator, a few degrees apart. Thereby the light generation is spread along the orbit as well as crosswise. This is shown in Figure 54 . The left side illustrates three successive passes over a city. The right-hand side depicts the conditions if the orbit is *split* into a closely spaced cluster of three orbits.

Under the conditions on the left, the reflectors during Pass 1 illuminate the metropolitan area with a series of beams from southwest, south and east, mostly from the south. During Pass 2, three hours later, the same reflectors illuminate the city from west, north and east. In Pass 3 the illumination is from west, south and southeast.

In the three-track mode, the area is illuminated rather evenly from north, south, east and west during Pass 1. The same is true when the same reflectors pass over the metropolitan area three and six hours later.

Figure 55 presents a three-dimensional view of the conditions during the second pass in the three-track mode. Splitting a single orbit into three does not add to the overall brightness, but rather offers a much milder, better distributed lighting. The overall reflecting area of the orbit is now distri-

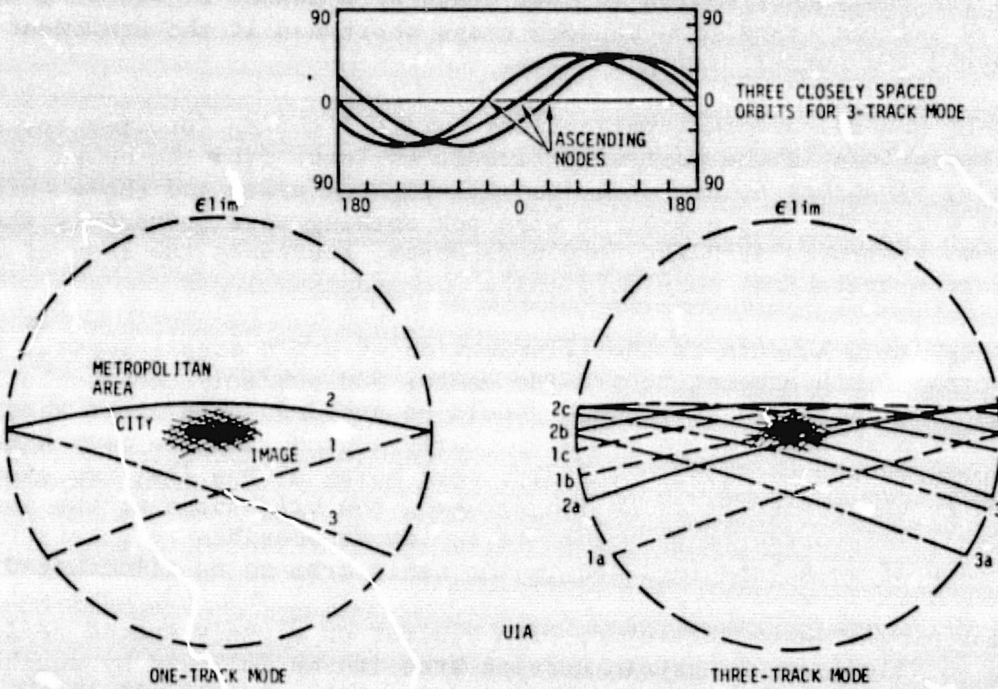


Figure 54. Multi-Track Lunetta Illumination Mode

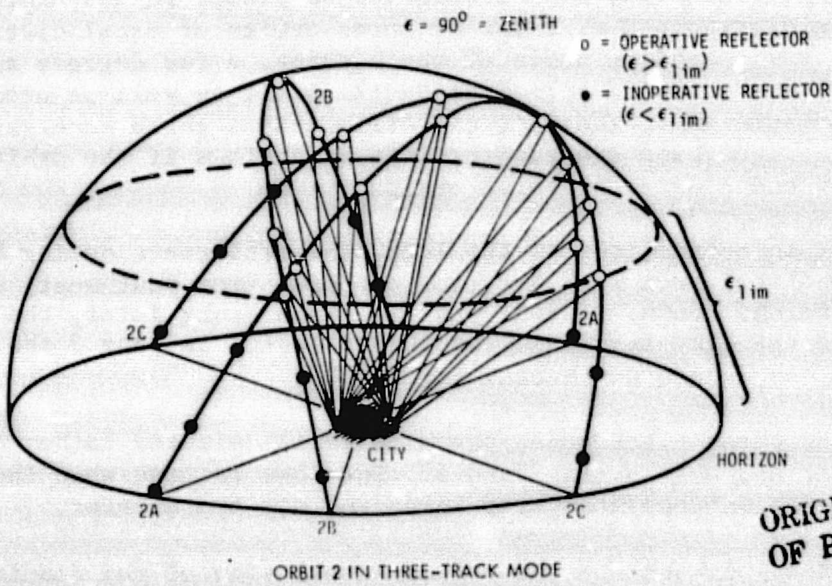


Figure 55. Three-Dimensional View of Three-Track Mode

buted over three orbits. The same is true for a second and third orbit. The repair and maintenance operations, however, become more complex, because a greater number of smaller reflectors is distributed over three to nine orbits rather than one to three orbits. The individual reflector size is reduced further, raising the overall mass. However, quantity production of a small standardized reflector becomes possible with the attendant cost reduction. Failure of a given reflector, or closing it down for repair and maintenance becomes less noticeable in the overall lighting pattern. The system remains highly Shuttle-compatible even to large overall reflecting areas.

The largest megalopolis complex in the United States is the north-east corridor, also labeled the Boswash strip city, encompassing metropolitan centers from Boston to Washington and Richmond. Assuming an average power consumption for outdoor lighting of 7.5 watt-years/capita, Figure 56 shows that the mean area illuminance amounts to only about 1.3 moons. Of course, this light is not uniformly distributed. This particular area would be a highly favorable location for the Lunetta system. Of course, there are several other highly industrialized regions with comparable lighting requirements. These include several sectors of Western Europe and the strip of urban and suburban developments stretching between Los Angeles and San Diego, California.

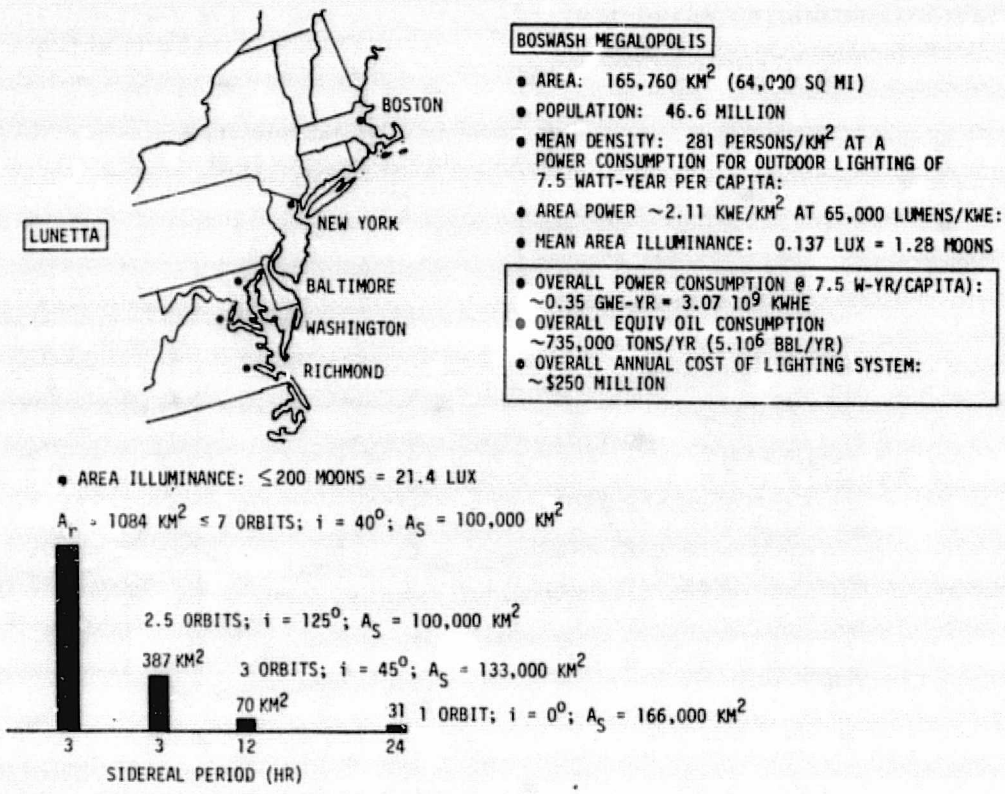


Figure 56. Example: Illumination of Boswash Megalopolis

Lunetta Illumination Geometry

To optimize a Lunetta lighting system — whether it is applied to rural or urban target areas — it is necessary to maximize the quality of lighting and to minimize the cost of establishing and maintaining the system.

The use of co-orbits (see Figure 57) improves the quality of lighting. It also increases the system's flexibility to adjust to the illumination of multiple locations by one system at the minimum of reflector area. The disadvantage of this, in many respects, desirable choice of sub-synchronous orbits is that it tends to lower the utilization factor of the individual reflector. This shortcoming is ameliorated by the fact that sub-synchronous orbiting offers a given Lunetta system the possibility to serve several target areas. Co-orbits offer a measure of flexibility that improve the prospects for taking advantage of this possibility.

Another major variable entering into these trade-offs is the limiting elevation — that is, the lowest elevation above the local horizon of a target area at which a given reflector is still trained at the given target area. The larger the limiting elevation angle ε, the smaller is the circle (subsequently referred to, briefly, as ε-circle); hence, the shorter in the time fraction of one revolution during which the reflector can serve the particular target area; but, on the other hand, the higher is the quality of illumination.

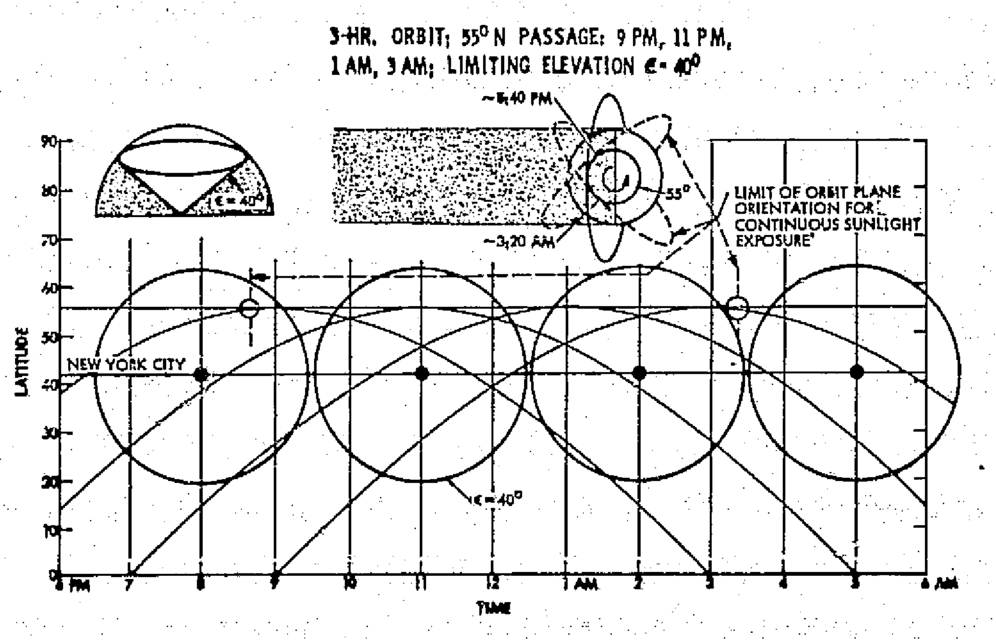


Figure 57. Lunetta Illumination Pattern: New York

Figure 58 illustrates several major variables (using, for the present, only one orbital altitude; or 3-hour sun-synchronous orbit, 4184 km altitude, about 125° inclination with a northermost latitude passage of 55°). The other assumptions used in constructing the figure include:

- The latitude of the target area (in this case, New York
- The limiting elevation (in this case, $\varepsilon = 40°$)
- The distribution of the co-orbits (in this case, latitude 55° N passage at 9 p.m., 11 p.m., 1 a.m., and 3 a.m.)

The ε-circles shown describe the illumination pattern of New York City at 8 p.m., 11 p.m., 2 a.m., and 5 a.m. It is seen that the co-orbits provide multi-directional lighting.

Figure 58 also indicates the limiting orbit plane orientation relative to the earth-sun line for the condition that continuous sunlight exposure of the reflectors is retained in all co-orbits. At the altitude of a 3-hour orbit, the limits correspond to a 55° N passage at 8:40 p.m. and 3:20 a.m. This limit is not absolute, but for the present, it is assumed that the reflectors do not experience periodic shadowing.

The direction of change in the distribution of co-orbits is indicated in Figure 59, in which Houston is replaced by a city at 20 degrees latitude at almost the same longitude as Houston.

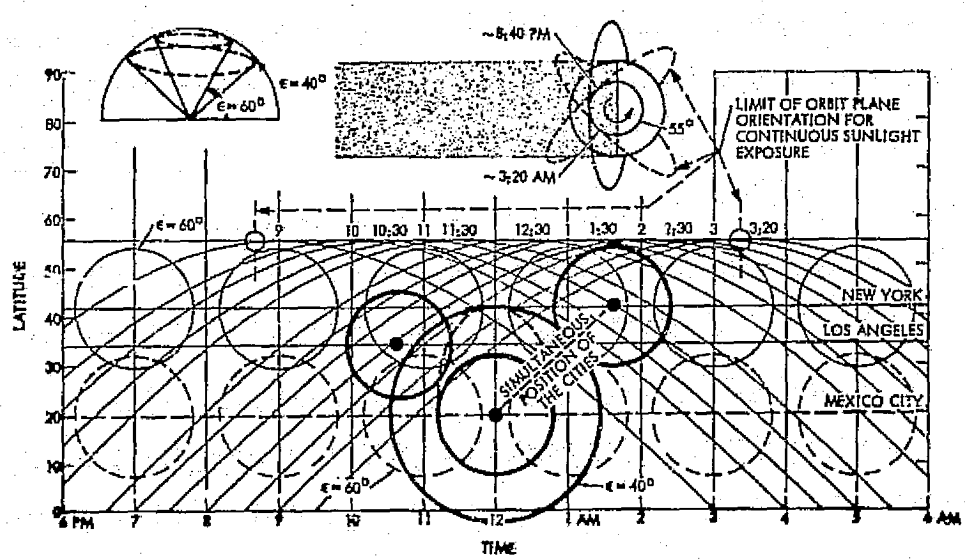


Figure 58. Effect of High Limiting Elevation Angles on Lunetta Illumination Pattern and an Applicability to Multi-City Lighting

ORIGINAL PAGE IS
OF POOR QUALITY

To assure multi-directional lighting at all latitudes, the number of co-orbits must be increased considerably. This figure shows 12 co-orbits. All three cities can be lighted without any mutual interference. However, the southern latitude of Mexico City shows the basic problem involved in lighting cities at low latitudes: they are difficult to illuminate around midnight.

To improve the conditions, it is ncecessary to increase the ε-circle. But since in this case the increased ε-circle would seriously interfere with the illumination of Los Angeles, it is necessary to introduce another innovation — the ε-ellipse (shown by the dashed line). Thereby, reflectors between New York and Los Angeles can be used to light Mexico City. However, it is unavoidable that for a period of about two hours the space light originates only from the northern, north-eastern and north-western sky.

To exemplify the effects of co-orbit distribution and target area latitude, the illumination profiles are shown for three American cities (Figure 59). The nominal clear-night illuminance level of the system is 700 moons. The illumination levels were determined on the basis of $\varepsilon = 40°$ and on the premise that the overall reflector area for 700 moons nominal illuminance is evenly distributed along all four or five co-orbits.

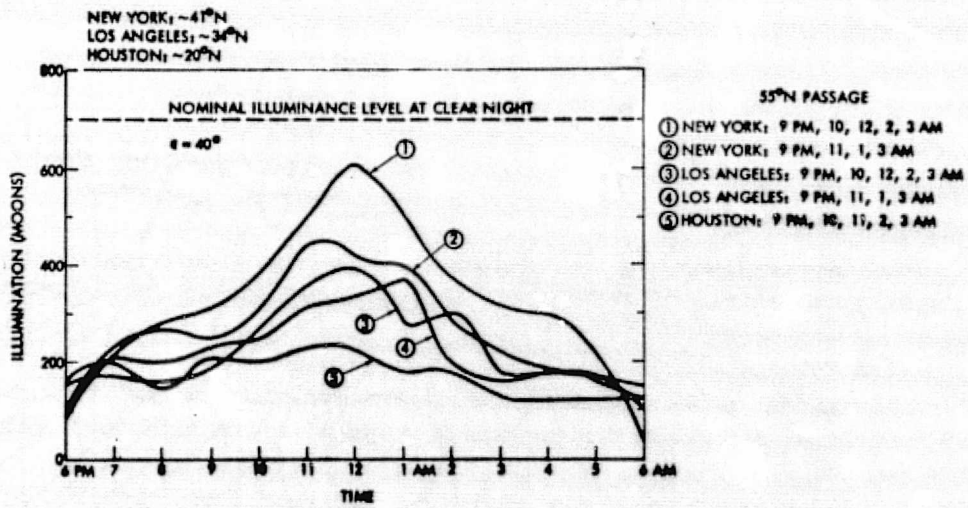


Figure 59. Clear Night Illumination Profiles for Three American Cities

The illuminance level tends to decline for target areas further south of the maximum latitude (55° N). Those locations do not benefit from the prolonged dwell time of the reflectors near the maximum latitude. The distribution of the co-orbits is seen to affect the variation of the illumination intensity in the course of the night.

If the limiting elevation is increased to 60 degrees (see Figure 60), the ε-circle is reduced sufficiently to make it possible for one Lunetta system to serve all three cities with very little overlap. This is an advantage, but to counteract the reduced utilization factor due to the smaller ε-circles around each target area, a more suitable distribution of the co-orbit is required than the one shown in the chart which equals that of the preceding arrangement with ε = 40 degrees.

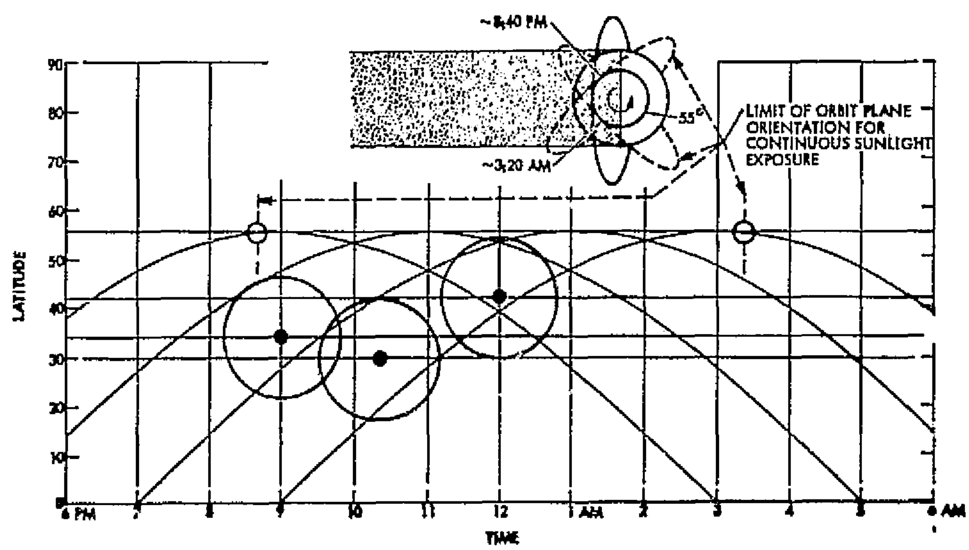


Figure 60. Effect of Limiting Elevation on Lunetta Capacity to Serve Several Cities Within a Longitude Band of 25 to 45 Degrees. Limiting Elevation ε = 60°

<u>Lunetta Economic Aspects</u>

The Lunetta provides light directly. Terrestrial lighting systems require electric energy as an intermediate step from energy source to light. Therefore, the cost per lumen-hour can be computed directly for Lunetta, but needs to be expressed via cost of electricity in terrestrial systems.

For terrestrial systems the cost per lumen-hour is at least in the order 40 to 60 mils/kwhe. The electricity-light conversion efficiency for street lights lies in the range of 40,000 to 65,000 lumens/kwe. Over their rated life (usually 1.8 to 2.7 years), the lamp depreciation usually is taken as percent of the initial light output at 70 percent of rated life. Most depreciations lie between 0.6 and 0.8. Of course, an additional expenditure is incurred by maintaining the lighting system.

For costing purposes, a Lunetta system consisting of seven clusters in a three-hour orbit was assumed. The system is Shuttle compatible. For clear-night illuminance of 200 full moons at the subsatellite point, the nominal reflector area in three-hour orbit, using sodium coating, is 0.24 km^2. This area must be increased by a factor of 2.46 to provide full 200-full moons illuminance at a 40° elevation angle.

Cost comparisons between the Lunetta and terrestrial lighting systems are presented in Figure 61. As can be seen, all Lunetta cost figures lie below the terrestrial value. If only two metropolitan areas are services by this system, the equivalent electric cost incurred by each metropolitan area is 16, 21, and 30.4 mils/kwbe, respectively, compared with 70 mils/kwbe for the terrestrial system.

- MIN ELEVATION FOR ILLUMINATION $\epsilon_{lim} = 40^\circ$
- DIAMETER OF USEFULLY ILLUMINATED AREA $2\theta = 44.9^\circ$
- A_i/A_o AT $\epsilon = 40^\circ$: 2.46 ($A_o \sim 1190$ KM^2)
- NUMBER OF ORBITS: 5 (3-TRACK MODE; $\Delta\Omega = 8^\circ$)
- REFLECTING AREA PER TRACK ORBIT: 1.52 KM^2 (7.6 KM^2 TOTAL)
- NUMBER OF REFLECTORS PER ORBIT: 24 ($\chi = 15^\circ$)
- REFLECTOR: AREA 0.063 KM^2; WEIGHT 150t/KM^2; COST \$8M̄/KM^2
- TRANSPORTATION & ORB OPERATIONS: \$7.10^5/t
- DDT&E COST: \$2.10^9
- RETURN ON INVESTMENT r = 0.15 (30 YEARS)
- ANNUAL MAINTENANCE COST: \$10M̄ (30 YEARS)

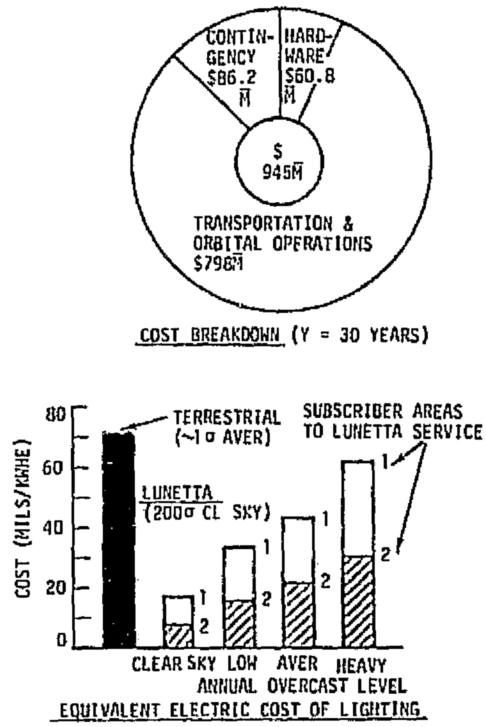


Figure 61. Sample Cost Breakdown of Shuttle-Compatible Lunetta System in Sun-Synchronous 3-Hour Orbit (h ~ 4184 km; i ~ 125°)

The wide geographic distribution of major urban areas permits a high utilization factor with a Lunetta system in orbits of 30° to 60° inclination. If greater numbers of urban or industrial regions are to be serviced, precession is no longer a disadvantage. More orbits would be needed; but all would be used throughout most of their precession year to illuminate a metropolitan, industrial or agricultural area north of the equator. The major *gap* on the Northern Hemisphere is the Pacific Ocean. However, while precessing through that gap, areas in South America and Africa would be serviced from the southern half of the orbit.

A greater number of orbits would increase the initial investment. But lower transportation cost into direct orbits, plus the higher utilization factor would reduce the cost per area served well below the figures given above. Transportation (including the orbital operations) dominate the initial cost which, in turn, represents the bulk of the overall cost. Minimum area weight and low transportation cost, in addition to many *subscriber areas*, are the key to low Lunetta lighting costs. The prospect for beating the cost of terrestrial lighting and high illumination quality appear to be very good.

Focal Area Reduction of Lunetta

In reflecting sunlight directly, the minimum focal image area is invariably tied to the distance between reflector and surface. Thus, the image area may be larger than the service area involved, exposing areas outside the service area to undesired illumination — populated or wilderness territory. In particular, it may be desirable to combine the advantage of geosynchronous positioning with a smaller focal area.

Moreover, in cases of illuminating spots at higher latitudes, it may be desirable to use elliptic orbits. Of particular interest here is the 63.5° inclined elliptic orbit, because it experiences no rotation of the major axis (i.e., the apogee remains over the latitudes of the service areas) and because this orbit covers many potential service areas on the Northern and Southern Hemisphere. A reflector in an elliptic orbit which dwells significantly longer over the hemisphere facing the apogee than over the perigee side, would generate an image of varying size.

Image size, as well as variation of absolute area in elliptic orbits, can be reduced by dual reflection (see Figure 62). In this case, the earth-oriented (secondary) reflector does not *look* at the sun, but at a sun-oriented primary reflector. Therewith the focal image size of the secondary reflector is determined by the angular diameter of the primary reflector as seen from the secondary system. Sizes and distance between the two systems must be arranged so that the angular diameter of the primary reflector is smaller than the sun's.

Either reflector can be primary or secondary. The insert in Figure 62 shows that for obvious optical reasons, the *leading* reflector (in direction of motion) should be the sun-oriented one between dusk and midnight. In the arc between midnight and dawn, the trailing reflector should be primary. The changeover can occur shortly after midnight, in a way that illumination of the service area is not interrupted, but only dimmed for a short time period of a few minutes. Because of this changeover, it appears desirable to make the two reflecting areas roughly equal in this case, the light beam from the primary reflector has a larger diameter than the secondary reflector. The illuminance of the latter, therefore, is reduced. The light bypassing the secondary reflector can be captured by inserting additional reflectors in the primary beam. In this case, the roles between the two systems are not reversable in a simple manner before and after the midnight point.

For a given reflecting area, the image area on the ground can be reduced by increasing the distance between the two reflectors — at simultaneous reduction in illuminance. For constant illumination level, therefore, the reflecting area must increase. The increase in reflecting area is the price that must be paid for reducing the image area.

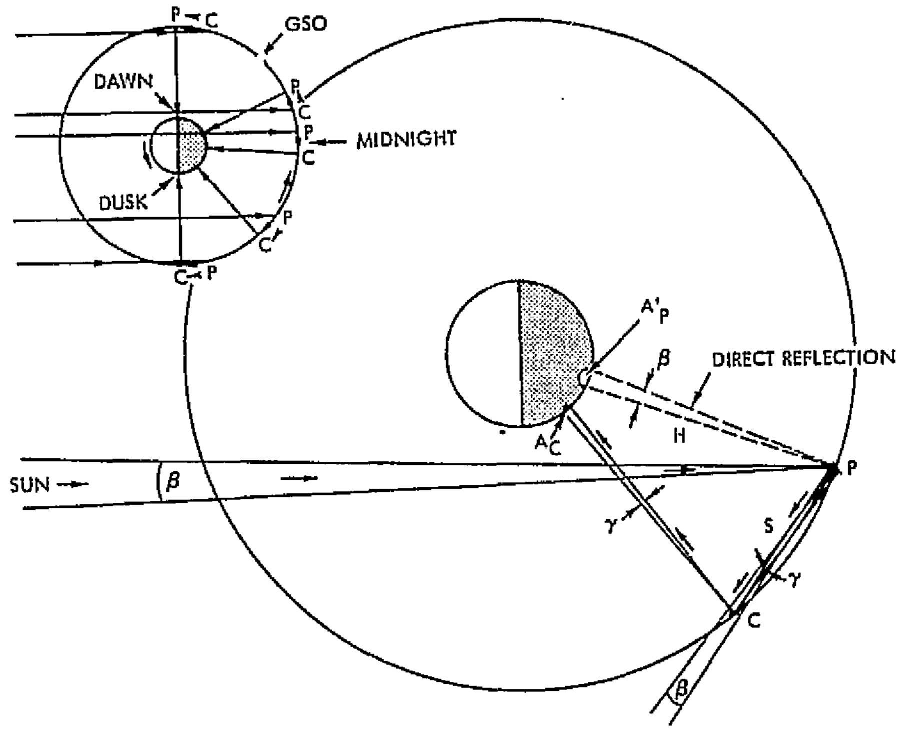


Figure 62. Geometry of Focal Area Reduction of Reflectors in Circular Orbit

SOLETTA

Soletta redirects a high level of solar energy flux into the image area, in the order of 0.25 to 1 — the energy intensity of the sun. The Soletta sizes range from thousands to tens of thousands of square kilometers. They consist of large numbers of reflectors, focused on a common image area on the ground. Their size no longer renders dual reflection feasible. The functions of Soletta are meaningful only if they can be applied to large areas, about as large as that of the Soletta itself. To be effective the Biosoletta should irradiate thousands of square kilometers of land area and ten times that much of ocean area. Therefore, Biosoletta should be in a geosynchronous orbit or higher. Powersoletta irradiates smaller areas (at least initially) in order to keep the ground antennas small and inexpensive. Therefore, a three-hour orbit is a reasonable choice for Powersoletta.

Powersoletta

The purpose of the Powersoletta reflectors is to add to the regular solar energy input to terrestrial solar-electric power stations. Powersoletta replaces the sun at night and can enhance the sun's input during the day. The energy provided at night enables the ground station to operate around the clock as if it were in space, subject only to atmospheric effects. Powersoletta minimizes the effects of local climatic conditions, thus making solar-electric energy practical for countries with less abundant solar insolation.

The higher the reflector orbit, the fewer reflectors are needed, but the longer is the ground image. The image area must match the size of the ground installation otherwise much solar energy would unnecessarily be radiated into the terrestrial environment. Not only would this reduce the system's efficiency, but it would increase the waste heat of the system. On the other hand, if the large image area was essentially occupied by energy processing ground installations, the initial capital investment would be increased substantially. The energy output would amount to hundreds to thousands of Gwe-years and the efficiency of reflector utilization would be high. Unfortunately, the magnitude of the project would not be conducive to its early realization.

The two-hour and three-hour orbits offer more suitable conditions for *introducing* Powersoletta at the expense of reduced efficiency. These relatively low altitude orbits also allow the power output to be better adapted to market needs.

For Powersoletta it is even more important to prevent excessive variations in illumination intensity. The ground equipment is not as flexible as the human eye is with respect to Lunetta. The human eye is capable of logarithmic adaptivity to varying luminance levels (Weber-Fechner law); whereas the efficiency of photovoltaic cells falls off very rapidly if the irradiation level declines too much.

Table 4 summarizes the combined effects of orbital altitude and limiting elevation on the overall reflecting area of a Powersoletta and on the utilization factor of its reflectors. It is seen that a larger ground illumination area saves reflector area in spite of the fact that a larger reflector area is required to compensate for the longer path length through the atmosphere.

Table 4. Powersoletta Characteristic Data for Several Orbits and Limiting Elevations

SIDEREAL PERIOD	2	3			4
DISTANCE, r (KM)	1.26	1.656			2.0
ALTITUDE, Y_o (KM)	1658	4148			6380
SUBSATELLITE IMAGE AREA, A_o (KM^2)	187	1190			2765
IMAGE DIAMETER, d_o (KM^2)	15.4	38.6			59
LIMITING ELEVATION, ϵ_{min} (DEG)	45	30	40	60	60
SPOT AREA AT ϵ_{min} (KM^2)	2.36	3.86	2.46	1.36	1.31
DIAMETER OF USEFULLY ILLUMINATED AREA, 2θ (DEG)	21.7	57	44.3	24.03	33.5
MAXIMUM PASSAGE TIME THROUGH UIA (HR)	0.13	0.54	0.423	0.24	0.744
PASSAGE TIME AT $\varphi = 100^\circ$, $\psi = 25^\circ$ (HR)	0.1	0.41	0.323	0.18	0.553
NUMBER OF CLUSTERS IN ORBIT, N_C	18	6	9	16	11.5
ILLUMINATION INTENSITY (S)	0.8	0.92	0.8	0.6	0.6
CLUSTER AREA (SUBSATELLITE, $\rho = 0.94$)	174	1215	1012	759	3070
REFLECTING AREA FOR ORBIT (KM^2)	3132	7292	9108	12,144	35,302
NUMBER OF TRACKS (AT 3 TRACKS OVER UIA)	9	4	4	6	3
ANGULAR SEPARATION OF TRACK ORBITS, $\Delta\Omega$ (DEG)	5	11	11	7	11
REFLECTING AREA PER TRACK ORBIT (KM^2)	1044	2430	3036	4048	11,767
OVERALL REFLECTING AREA (ALL TRACK ORBITS) (KM^2)	9396	9723	12,144	24,228	35,302
ANGULAR SEPARATION OF REFLECTORS IN ORBIT, X (DEG)	5.538	12	13.85	6	10.9
NUMBER OF REFLECTORS PER TRACK ORBIT	65	30	26	60	33
AREA OF REFLECTOR UNIT (KM^2)	16.1	81	117	67.5	475.5
OVERALL NUMBERS OF REFLECTORS (ALL TRACK ORBITS)	585	128	104	360	99
NUMBER OF REFLECTORS OPERATIVE OVER UIA SIMULTANEOUSLY	~11	~15	9	9	9
REFLECTOR UTILIZATION FACTOR PER UIA (OPERATIVE REFLECTORS/OVERALL REFLECTORS)	0.019	0.117	0.087	0.025	0.091

ORIGINAL PAGE IS OF POOR QUALITY

In the case of Powersoletta, a particular form of chain radiation transfer (referred to as retro-reflection) can be attractive under certain conditions (see Figure 63). In the case of Powersoletta, daylight irradiation is useful since it enhances the energy input into the ground power station. Retro-reflection can appreciably enhance the utilization factor of the reflectors. Whether or not the energy gained is worth the additional navigational complexity depends only on the distance of the reflectors and the losses due to retro-reflected light not one intercepted by the receiving reflectors.

For a small number of widely-separated ground power stations, the three hour sun synchronous orbit seems to be most attractive. If a larger number of ground stations are available, the system is less sensitive to orbital precession and a broader range of orbital choices becomes possible.

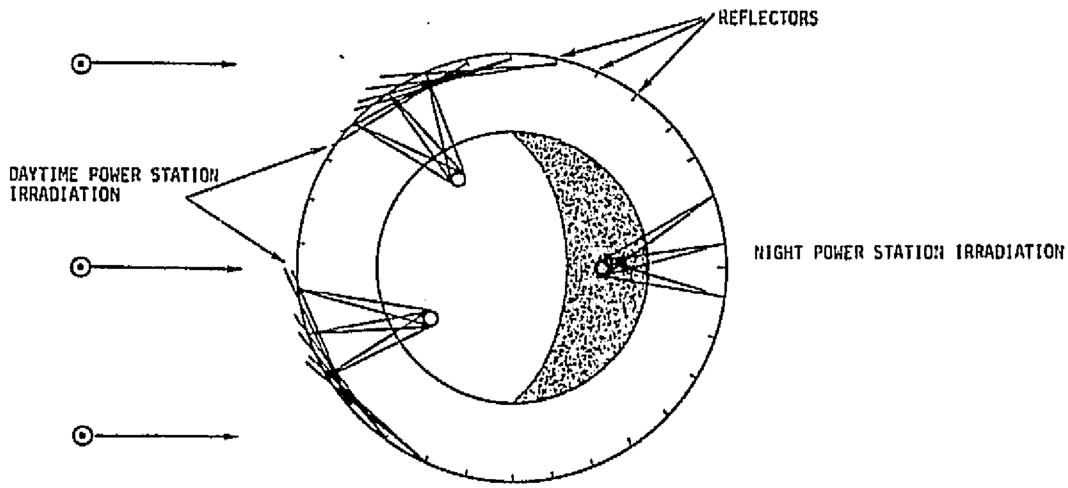


Figure 63. Use of Retro-Reflection for Powersoletta to Enhance Daytime Power Generation

The large number of reflectors involved seems to justify a sun-synchronous service station for assembly at 550 km (sub-radiation belt) altitude. The service orbit should be sun-synchronous also, to keep it in a fixed position relative to the three-hour sun-synchronous orbits. If the reflector unit can be made light enough to permit the use of solar radiation pressure (in addition to electric thrusters) for driving the reflector outward, it must be lifted first to about 1100-km altitude, beyond which the drag is small enough not to offset or overcompensate the radiation pressure effect.

The inclination of the sun-synchronous service orbit at 550 km is 97.6°. This orbital location is more favorable for earth-to-orbit transportation than than the 125° inclined 3-hour orbit. The difference is made up during transfer. Continuous solar exposure provides ample power for an associated material processing facility. This facility would manufacture ultralight structures for reflectors and would coat the reflector surface with sodium which is light, less costly and of higher reflectivity than aluminum, but can be processed on a large scale only in space where its reflectivity is not destroyed by oxidation.

The retrograde three-hour orbit dips into and out of the proton belt. The protons cause sputtering on the reflective surface. This adds to the gradual degradation of reflectivity. The rate of degradation is not known at this time. The reflecting surface may have to be re-coated in intervals of 8 to 15 years because of this degradation. On the other hand, the protons tend to neutralize the negative charges the reflectors pick up outside the proton belt. Thus, less harmful dust may attach itself to their surface.

From a retrograde three-hour orbit, countries or regions lacking abundant solar energy for power generation can establish their own *industrial sun.* Since better coverage can be attained if the service area is located at slightly lower latitude than the maximum latitude of the orbit's ground track, ground stations up to latitudes of about 50° could be serviced. Of course, stations up to at least 65° latitude are within reach of Soletta, which means that Soletta-driven solar power stations could be built in Northern Europe, Northern Siberia or Canada. Of course, the farther north the station, the greater is the fraction of the overall radiation input that is supplied by Soletta. In fact, at high latitude a reverse situation can develop in the sense that the power station operates at maximum level at night when irradiated by Soletta and requires energy storage to sustain a minimum operating level during daylight! To maximize the output of a ground station and take advantage of a high operating level around the clock, the stations should be located in areas with little overcast between 30 and 45 degrees latitude. Figure 64 shows three examples. Locations farther north could also be considered. The increased losses due to cloudiness, however, would have to be balanced by a higher utilization factor per orbit to keep costs down.

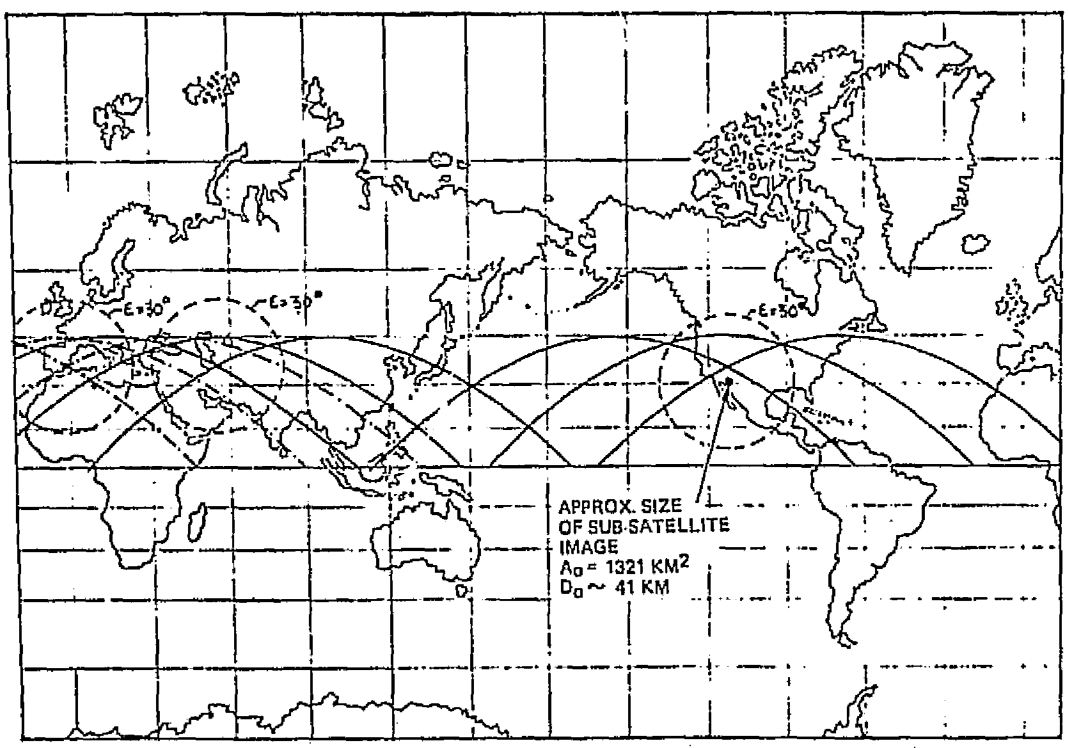


Figure 64. Soletta Power Stations for Western Europe, U.S.S.R. and North America

In the U.S.S.R., one of the most favorable locations would be east of the Caspian Sea in the Turkmen Republic. For electric power transmission to the western U.S.S.R. and eastern Europe, this location is closer and more convenient than western or central Siberian power plants. For western Europe, the eastern half of Spain would offer the most favorable locations, transmitting power via high-power dc trunk lines to the industrial centers to the north and the east. In North America, where the U.S. is the only highly industrialized country in the world to contain high-insolation areas of more than 2 billion kilowatt-hours of radiation energy per square kilometer per year, the most favorable location would straddle the border between Arizona and Sonora, Mexico. From this region, Mexico, the United States, and parts of Canada could be supplied via high-power dc trunk lines.

In Figure 64, an orbit inclination of 45° is shown to accommodate all three locations, although for the U.S. case, 35° would be slightly more effective. The reason is that the western European orbits, the U.S.S.R. orbits, and the U.S. orbits support each other in transmitting energy to their respective power stations. In other words, the U.S. and western European power stations could use the same Powersoletta system.

Figure 65 summarizes the conditions at the three locations. The three groups at the left depict the variation of solar energy received by a horizontal surface in the course of a year (solid lines) and the radiation energy received by Powersatellite. The U.S.S.R. location shows the highest amplitude of solar radiation change during the year. The overcast level appears to increase during the winter months to a larger extent than at the other sites. Allowance was made for this fact in determining the radiative energy input from Powersoletta.

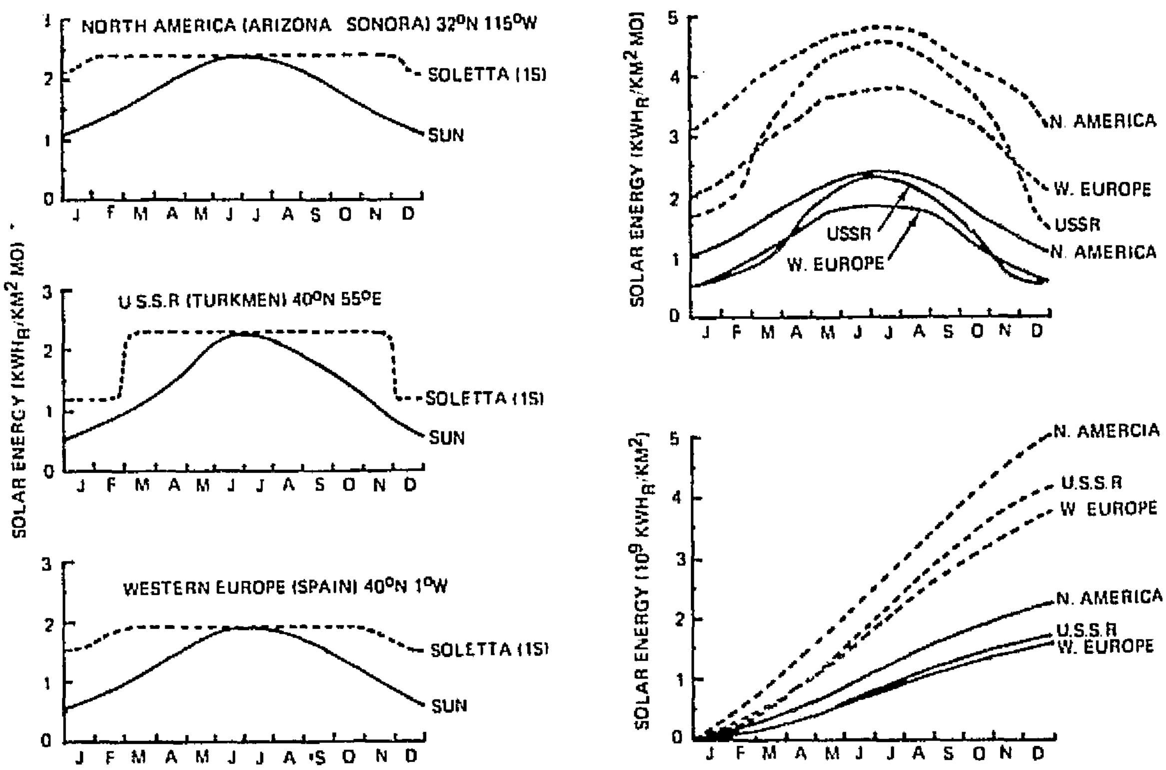


Figure 65. Solar and Powersoletta Overall Energy Input at Three Locations

The increase in the diffuse radiation component would reduce the efficiency of solar-thermal power stations using concentrations. A photovoltaic array system, as chosen here, is capable of deriving energy from diffuse radiation. Therefore, the estimate of energy input decline may be conservative.

For the North American and Western European locations, Powersoletta provides the main energy input between November and February. The same is true for the Russian location, if a less conservative estimate of winter overcast is justified. The graph on the upper right of Figure 65 compares the resulting mean monthly radiation inputs for the sun alone (solid lines) and for sun and Powersoletta. As can be seen, the Powersoletta more than doubles the radiation energy offered to the sites. Even for the North American site (which receives the largest direct solar input), Powersoletta offers a 30 percent higher input. For the Russian and Western European locations, Powersoletta contributes 1.45 and 1.43 energy units for each energy unit supplied by the sun directly. Moreover, the construction cost per electric kilowatt of the solar power station is significantly reduced because the system can operate day and night, thus eliminating the largest single driver for energy storage.

The radiation coming from the Powersoletta is identical to ordinary sunlight and, hence, is benign in every important respect. Only about 8 percent of the incoming energy is absorbed by dry air molecules. Dust and water vapor may absorb as much as an additional 5 percent and 10 percent, respectively. This absorbed energy could be a factor in reducing overcast over the service area, thereby increasing the available radiation energy at the power complex. Most thermal air motion is caused by the heating and thermal radiation of the ground. However, where the energy is absorbed for power generation, the heating effect is greatly reduced.

From the standpoint of minimizing local disturbances as well as maximizing the utilization of the radiative energy, the energy-processing area should cover as large a fraction of the overall image area as possible. High-temperature concentrating systems, using many heliostats to focus energy on a heater atop a tower, have a poorer area utilization than *carpets* of solar cells which also are less sensitive to light dispersing influences in the atmosphere.

Figure 66 lists the electric energy production of a 1000 square kilometer photovoltaic collector system at the three defined locations, based on the cumulative radiation energy input shown in the lower right of Figure 66. The large photovoltaic system can be a major fraction of the initial cost. The cost of solar panels decreases with efficiency. Trade-off considerations suggest that the economically optimum efficiency in the mid-1990's may lie around 15 percent. For conventional solar power station concepts, low efficiency usually is unattractive, because the land area for a given power output is increased accordingly.

Even at a 15 percent conversion efficiency, a significant contribution is made by each area to the overall electric energy supply of each of the three economic regions even by the consumption levels expected by the end of the century. The contribution of Powersoletta alone is equivalent to a consumption of 80 to 100 million tons of oil annually per ground station.

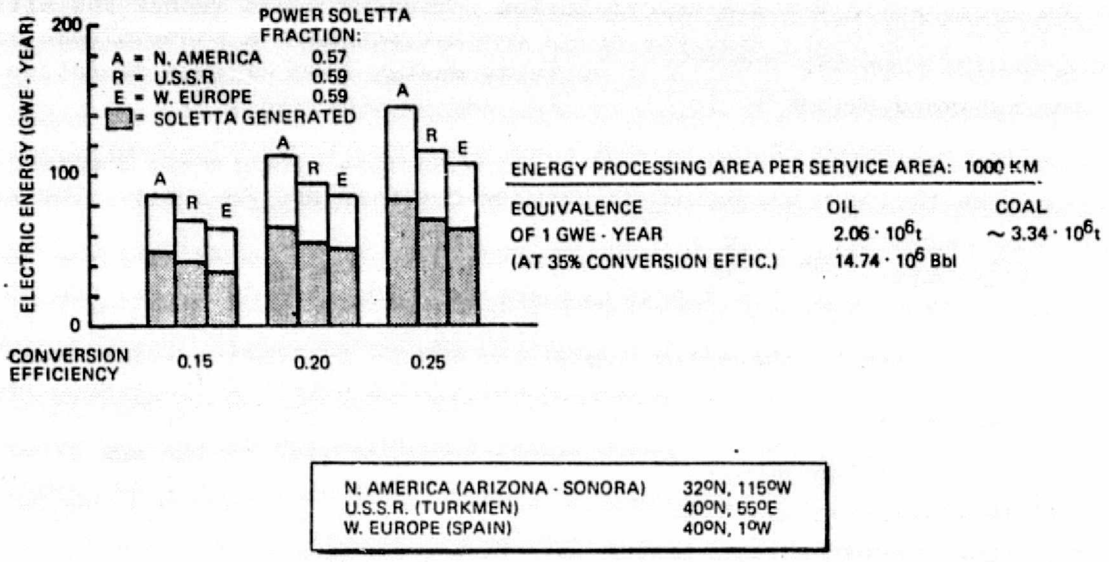


Figure 66. Characteristic Data of Three-Hour Orbit Powersoletta System

Photosynthetic Production Enhancement By Biosoletta

An important potential benefit of Biosoletta is the enhancement of organic growth by stimulating carbon assimilation of agricultural plants and sea plankton to increase the production of commercial seafood as a source of protein for mankind. This can be accomplished by two methods. One is dusk and/or dawn illumination — that is, daylight extension. The other is night stimulation by periodic illumination for one or more hours at night.

For land plants, the light factor is one of several abiotic factors affecting growth. It provides the energy; the carbon dioxide, water and soil minerals provide the materials for this bio-industrial process. At otherwise favorable factors, the efficiency of photosynthesis depends on the light intensity. Increase in light intensity is the more effective in raising the rate of carbon assimilation in those cases in which the existing light intensity is marginal. Thus, Biosoletta is comparatively most effective over regions that are cloudy, shaded, or at high latitudes. Above a certain intensity level, photosynthesis is not further enhanced. For plants thriving in the shade, this level is reached at about 15 percent of maximum sunlight. For sunshine plants, the maximum photosynthesis rate is twice as high and is reached at about 50 percent of full sunlight.

Aside from carbon assimilation, light affects plant growth and the rate of ripening. With longer daylight intervals, the same plants tend to be taller and better developed than at shorter daylight time, except for certain mountain plants whose growth is inhibited by higher UV light intensity.

In addition to the amount of light, its periodic distribution is of ecological importance because the ability to synthesize hydrocarbons is predicated on alternating periods of light and darkness. Long-periodic plants require about 12 hours of light or more to flourish or blossom. These include wheat. Short-periodic plants (which include corn) blossom at less than 12 hours of daylight. A third group (mostly weeds) is photoperiodically indifferent. The daylight period can, without effect, be interrupted by short sunless periods (e.g., by clouds). Conversely, brief periods of light — in some experiments less than 1 second in duration — can have a strong effect. By night stimulation, long-periodic plants at less than 12 hours of daylight can be made to blossom as if growing in a 12-hour daylight environment. Therefore, in largely wheat growing areas, with marginal supply of light, Biosoletta can be effective either by daylight extension or by night stimulation.

Over the oceans, photosynthetic production enhancement can be effectively applied in upwelling regions where nutrient-rich deeper waters are flushed to the surface. Given sufficient sunlight, carbon production during period of active upwelling can approach one gram of carbon per square meter per day. The largest areas where upwelling occurs and light intensity is the limiting factor are — roughly in the order of decreasing magnitude — various stretches around Antarctica, the western North Atlantic (between Newfoundland and Greenland) and the eastern North Atlantic between Iceland and Norway (see Figure 67).

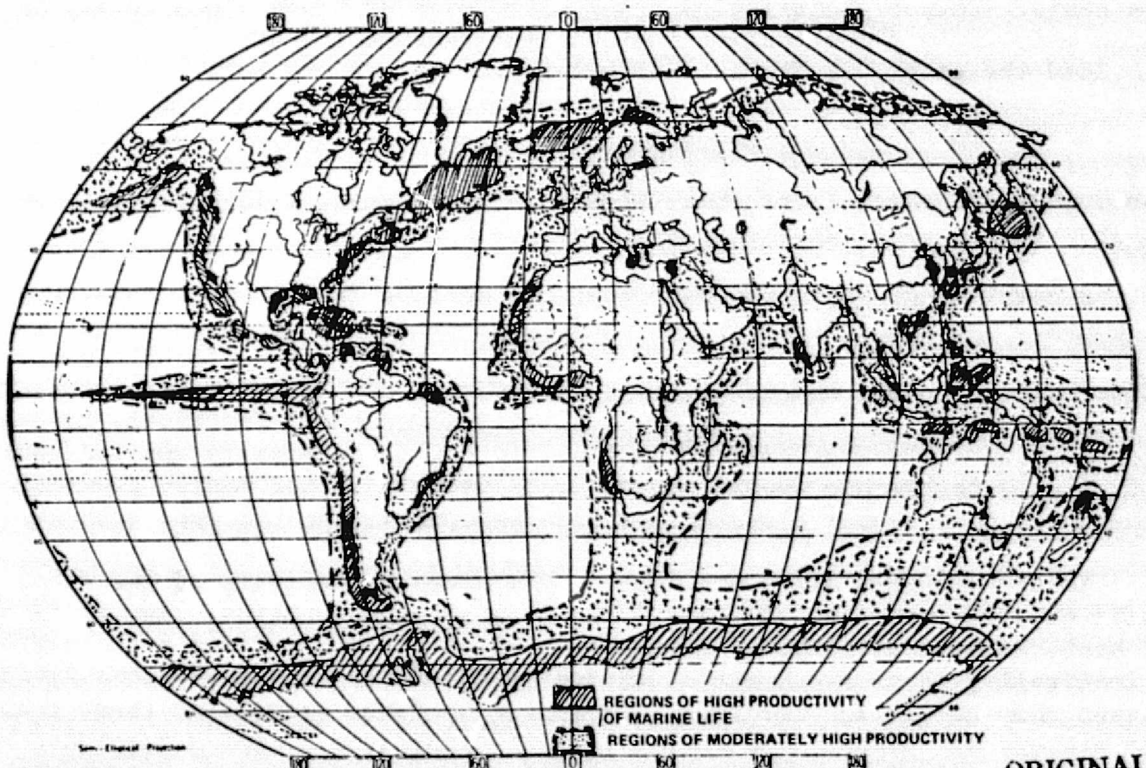


Figure 67. Marine Life Productivity Areas

In the upwelling areas, the food chain from plankton to commercial fish is usually short. Hence, the effectiveness of the Biosoletta deployment is highest. The reason for this is that most abundant species of phytoplanktons in upwelling areas are above average in size so that they can be consumed directly by some commercial fish equipped with specialized grill rakers (anchovies, sardines, etc.); or the phytoplanktons form large colonies of gelatinous masses and long filamentous chains on which even large commercial fishes can feed without special provisions.

The above is a highly simplified presentation of the opportunities available for increasing world food production on land and in the oceans by means of Biosoletta. The light-related physiology of photosynthesis is complex. Many factors enter into the picture. To derive specific production figures, it is necessary to analyze the application of biosoletta in the framework of specific illumination scenarios. These scenarios must take into account annual solar irradiation, cloud coverage, temperatures, soil and water conditions and other influence factors for the areas irradiated by the satellite. However, the significance of light in food production is fundamental. Space industry offers for the first time the means of controlling the amount of photosynthetically effective light influx into important agricultural and productive oceanic areas. This unique capability can be of fundamental importance for mankind's future on earth.

The radiation intensity of Biosoletta must suffice to stimulate photosynthesis. Carbon assimilation takes place even at heavy cloud cover, in which only 20 to 30 percent of the sunlight reaches the earth's surface, provided the other requirements necessary for growth are met.

A Soletta of 0.4 suns in a geosynchronous orbit has a total reflecting area of almost 40,000 km^2. Since its irradiation is most effective at high latitudes, and since large areas should be irradiated, a 12-hour orbit or a geosynchronous orbit are most effective.

A complete *Figure-8* movement over the surface is traced by Soletta in 24 hours. Consequently, only one hemisphere is covered at night, the other at daylight. Both hemispheres can be irradiated, substituting for the sun on the night hemisphere and enhancing solar radiation over the daylight hemisphere. In regions above one of the polar circles, Soletta adds effectively to the midnight sun during the summer. During winter, Biosoletta is applied most effectively to oceanic upwell areas, since Soletta is not nearly powerful enough to alter winter climate over land and permit another crop season.

Multi-cropping, as is possible in the more even climate of the tropics, would greatly increase food production in northern countries. But there are, at best, only a few selected areas where Soletta could produce such an effect. Climatically, these areas are located at moderate latitudes — probably no higher than 40° to 45° latitude. Depending on local factors at these locations, the winters are almost mild enough to render multiple cropping feasible. However, the pacing factor for carbon assimilation enhancement in cold water upwell areas is illumination rather than warming of the upper water layers.

In highly inclined orbits, the Soletta will rise at dusk from a point at the southern (northern in Antarctic regions) horizon to highest elevation and brightness at midnight and set again at dusk on the southern (northern) horizon. In equatorial orbit, Soletta can also be directed at the Northern or Southern Hemisphere; and it is essentially fixed in the sky, but it cannot effectively service the areas above 45° to 50° latitude.

There is not necessarily a single *best orbit* for Biosoletta. Best orbits are characterized by an optimum compromise of inclination and even attitude with respect to their primary function.

In agricultural food production, Biosoletta should illuminate smaller areas than for seafood production, since contiguous cultivated land areas are more limited and the intense illumination of interspersed towns, cities or wilderness areas at night is undesirable. For this reason, the three-hour orbit or perhaps the two-hour orbit (depending on orbit decay rate and the resulting expenditures to maintain orbit) appear more suitable for a *dedicated* land Biosoletta. For occasional land duties, such as night frost prevention, the orbital altitude is less important.

For seafood production, larger areas can be irradiated and the overall efficiency of the system increased. This places the ocean Biosoletta into high orbits; in fact, within reason, the higher the better.

An important factor in the choice of Biosoletta orbits in the potential interference with communication between earth and satellites at the geosynchronous altitude because of the large, highly microwave-reflective areas involved. Presently it is assumed that the presence of reflector systems in three-hour orbit for Biosoletta and Powersoletta purposes can be accommodated; for example, by means of adjustable communications paths via relay satellites, since the orbital position of the reflector units is known and does not change. Nevertheless, this assumption requires further examination.

An ocean Biosoletta in a high sub-synchronous orbit could also be accommodated by means of communication relays. However, it may be necessary, in the course of 30 or more years of operating life, to fly a small fraction of the reflectors continuously to a service station to be recoated, repaired, and otherwise maintained. If this is the case, or if an increasing number of oceanic Biosolettas should be employed, interference with communication could become a serious problem. In this case, however, the oceanic Biosoletta should be placed into an inclined circular geosynchronous orbit or in an orbit above the geosynchronous altitude.

Another alternative is the use of an elliptic geosynchronous orbit to place the apogee over the primary area for longer intervals in increase the system's productive efficiency. A suitable orbit inclination is 63.5°. This choice permits the oceanic Biosoletta to cover fertile upwelling areas near the Antarctic and at high northern latitudes (both of which lack adequate sunshine). This inclination is attractive because the major axis does not rotate due to terrestrial perturbation. Therefore, perigee and apogee remain over the same latitudes. For a given period, the choice of perigee distance determines the apogee altitude and therewith the reflector size.

A 24-hour elliptical orbit for Biosoletta is shown in Figure 68. In view of its inclination and ellipticity, placement of the perigee within the equatorial geosynchronous altitude is presently assumed to be acceptable to geosynchronous communications operations as well as with the Molniya communication system of the U.S.S.R. (which operates in an equally inclined 12-hour ellipse between 1.08 and 7.27 earth radii with apogee above the Northern Hemisphere).

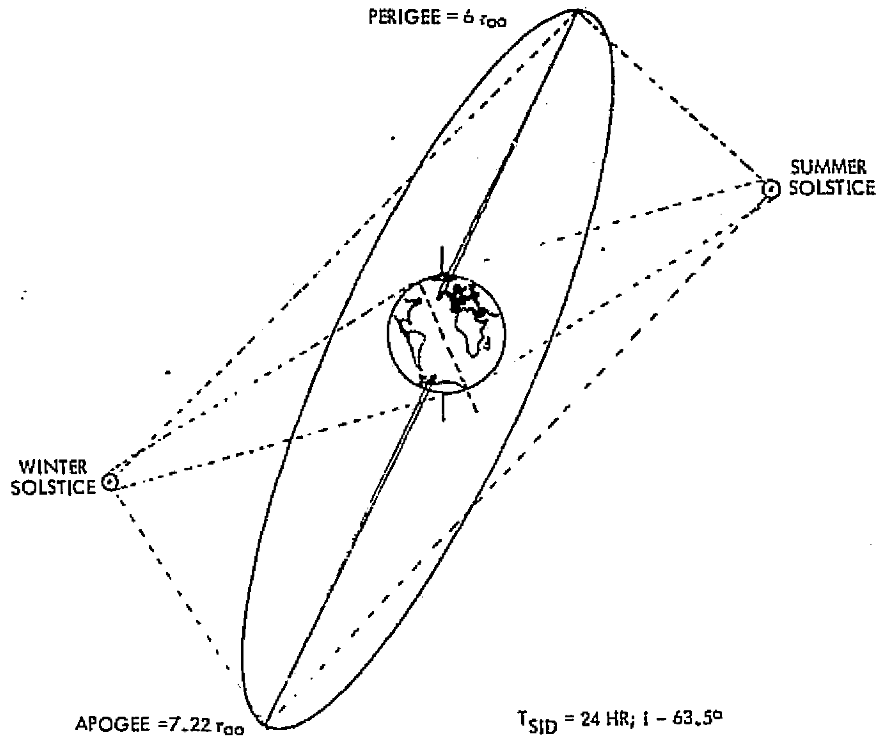


Figure 68. Biosoletta Orbit for Seafood Production

To illustrate the food production potential of Biosoletta, oceanic carbon assimilation is used as an example because oceans offer large contiguous areas for intense illumination without covering inhabited or wilderness areas. The coastal upwelling associated with the Peru Coastal Current generates one of the world's most productive fisheries, producing about 20,000,000 tons of commercial fish annually over a 1250 km by 50 km strip. This corresponds to about 333 tons per km^2. The annual harvest is about 10,000,000 tons; mortality due to predation from sea life and guano birds accounts for another 10,000,000 tons. In the Peru strip, food supply due to upwelling and abundant sunshine produces particularly favorable conditions. It would be of interest to examine how much further this yield could be increased by *midnight sun* illumination.

The productive capacity of Antarctic waters is less well known. The area in which upwelling conditions exist appears to measure 160,000 km^2 or less, making it, nevertheless, the world's largest contiguous area of this kind. Kasahara estimated the annual krill production in this area to be at least 24 to 36 million tons. Other estimates are higher. Recent German estimates, based on extensive sonar measurements by two fishing research vessels in 1975 and 1976, place the annual krill production in the Antarctic at about 200 million tons. At an annual production of 300 grams of carbon per square water, 1.5 tropic levels and 20 percent ecological efficiency, the area of 160,000 km^2 could produce 50 million tons of seafood. But Ryther doubts that such production levels can be achieved in a region where photosynthesis is possible during only half the year. However, since only 160,000 km^2, or roughly 25 percent of the circumference of Antarctica seaward for a distance of 30 km is highly fertile, even half of the above mentioned German estimate would indicate a production in excess of 50 million tons annually in this area. Biosoletta in an elliptical 24-hour orbit can illuminate a 100,000 km^2 area for 12 hours nightly. At an illuminance level of one sun, it is as effective as the sun under the same overcast conditions. Thus, during the Antarctic summer day, the area would alternately be irradiated by one sun for 12 hours and by two suns during the other 12 hours. During the Antarctic winter night, it would receive one sun every other 12 hours. In other words, the influx of radiation energy into the 100,000 km^2 area would be about tripled.

Assuming a carbon production of 60 percent of maximum of 180 grams of carbon per $meter^2$ per year without Soletta I, then with Soletta I, the carbon production could rise to 540 grams per $meter^2$ per year. With Biosoletta accounting for a difference of 360 grams per $meter^2$ per year, the Soletta-based production could amount to 36 million tons.

Seafood production cannot compete with land food production in terms of calories per unit area. But it is a vital protein supplement. About 36 grams of high-quality protein per day (such as from seafood) are considered adequate. Ten million tons of fish contain about 2 million tons of protein. However, of 10,000,000 tons of fish landed, only about 1.7 million tons of usable protein are actually recovered. Assuming 16.4 percent of the landed weight, a daily protein supply of 36 grams is roughly equivalent to a daily intake of 220 grams of landed weight. Assume further a catch fraction of 50 percent of the fish produced and an additional loss factor of 0.8 to deduct that portion of the protein-containing material which is suitable primarily as animal food (a portion of which, of course, serves human nutrition in the form of animal protein; but this yield is neglected here, to be conservative). Then the useful fish food produced by Soletta would be 14.4 million tons annually. In *packages* of 220 grams, this amount provides the required daily protein supply for some 180,000,000 people annually. At a reflector area of 100,000 km^2, this amounts to a protein yield of 18 persons per hectare reflector area.

This figure probably is close to optimum conditions for one hemisphere. In practice, the protein supply yield factor may amount to between 9 and 15 persons per hectare (Figure 68). However, from this orbit, Biosoletta can *photofertilize* both hemispheres, adding to the solar input during the summer and being the primary or only source of light energy during spring, fall and winter. Taking the overall radiation input into account, the protein yield is in the order of 18 to 24 persons per hectare of reflector area.

Economic Aspects of Biosoletta and Powersoletta

Biosoletta supplies light energy directly for biotechnical conversion to protein and carbohydrates. The *ground station* is a small part of the biosphere. Since no industrial ground facility is involved and since the Biosoletta is the larger of the two Solettas, its economic performance is described first. Except for ground facilities, the Biosoletta represents the technological *umbrella* covering the Powersoletta's requirements as well.

It should be pointed out here that neither system is optimized as yet. In fact, some costly requirements (such as a new coating for all reflectors every

- REGION: ANTARCTIC (70°-75°S) (UPWELLING CONDITIONS)
- SOLAR IRRADIATION: ABOUT 0.5 YR (4400 HRS)
- PRODUCTION: ~ $18 \cdot 10^6$ TONS/YR
- SOLETTA I: ORBIT: ELLIPTIC (24 HR; PERIGEE $6\gamma_{00}$; APOGEE $7.22\gamma_{00}$; i = 63.5°)
  - IRRADIATION: 12 HR PER 24 HR; AV IMAGE SIZE; 100,000 KM^2
  - REFLECTING AREA: 100,000 KM^2; ILLUMINANCE ~ 1S
- SOLAR & SOLETTA IRRADIATION: ABOUT 13,200 HRS/YR
- PRODUCTION: ~ $54 \cdot 10^6$ TONS/YR; ATTRIBUTABLE TO SOLETTA: $36 \cdot 10^6$ TONS/YR
- CATCH FRACTION: 0.5; OTHER LOSS FACTOR: 0.8;
- DAILY HI-QUALITY PROTEIN INPUT: 36g = 220 g FISH AT 16.4% USEFUL PROTEIN WEIGHT
- DAILY PROTEIN SUPPLY ANNUALLY FOR: $180 \cdot 10^6$ PERSONS
- YIELD FACTOR: 18 PERSONS PER HECTARE OF SOLETTA AREA
- ACTUAL VALUES UNDER NON-OPTIMUM CONDITIONS PROBABLY: 9-14 PERSONS/HECTARE

Figure 69. Biosoletta - Oceanic Food Production

10 years) postulated here, may possibly be reduced when more space data are available. Some potential performance boosters (such as the retroreflection mode for the Powersoletta) have not been included to retain some reserve capabilities.

The left hand side of Figure 70 shows a transportation load breakdown for three separate cases. The pie charts show that in Case I, the interorbital propellant is the dominant parameter. In Cases II and III, it is Biosoletta. The enormous propellant burden in Case I is also reflected in the transportation cost chart (top right). Also shown on the right side are the release of combustion products and thermal energy into the atmosphere. About 95 percent of the combustion products are in the form of water vapor, of which about one third is released into the stratosphere and exosphere.

The water release and the thermal burden are particularly large in the first case. At a construction time of 15 years, the heat released into the atmosphere equals that released by about 20 electric power stations operating at 1-Gwe load throughout the year at a conversion efficiency of 35 percent. A thermal input of 20 Gwe-years 13 equivalent to only a small fraction of the present world output of thermal energy resulting from the generating electrical power. Thus, cost, the amount of water vapor, and the very large number of Aerospace Freighters are the principal drawbacks of Case I.

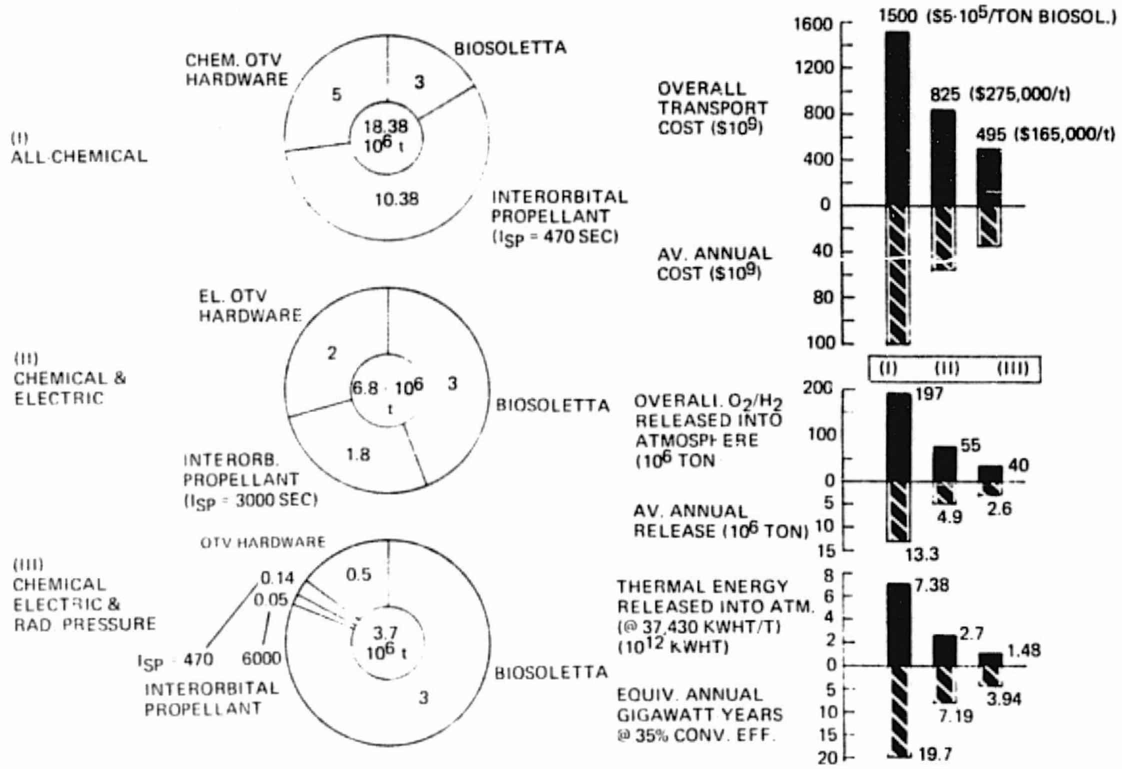


Figure 70. Comparison of Three Transportation Alternatives for Biosoletta (10^5 km^2; 15-Year Construction Period)

Case II is more satisfactory in many respects. It has the advantage of being somewhat independent of the reflector weight. Case III is predicated on keeping the area weight very low. This interrelation increases the technological risk. But, aside from the self-evident reasons for keeping the reflector weight as low as possible, the low transportation cost of a combined solar pressure and electric thrust drive is a significant incentive.

The solar radiation pressure is very small. To rise above drag forces that exceed the radiation pressure, the reflector must depart from an orbit of about 1100 km altitude. Since this altitude is within the lower limits of the radiation belt, most of the assembly will occur at lower altitudes. The semi-deployed system is then lifted to 1100 km altitude along with a temporary crew, and fully unfolded. The crew returns to lower orbit, and the reflector begins to sail outward.

The Biosoletta-related cost component suggests a new time constant, not yet experienced in human technology. Biosoletta, probably the largest single project of its kind in the earth-moon system, becomes highly economical after operating times stretching beyond 30 years to perhaps a century. Through Biosoletta, mankind enters into the longer time scales associated with cosmic industries.

Further investigations and small-scale Biosoletta experiments over suitable ocean regions are needed to verify the assumption that the total sea life production raised by the above Biosoletta on both hemispheres can amount to 40 million tons of commercial fish annually — that is, 16 percent to 20 percent of the present estimated annual production of 200 to 240 million tons. These figures are global averages, involving large areas of poor or no productivity. Biosoletta concentrates on the most lucrative areas which are hampered by lack of solar energy and whose productivity in the presence of sunlight is demonstratively higher than that assumed here under Biosoletta photofertilization. It also appears reasonable to assume that an area of 100,000 km^2 is representative from the standpoint of ecosystems. The extraction of 16 million tons of consumable seafood (fish, krill, etc.) represents about 25 percent of the present annual catch.

The principal drawback of Biosoletta is the large initial investment of at least $1 trillion (or $67 billion annually) over a 15-year period. However, the reflectors built early would be put to revenue-producing use (primarily as Powersoletta components in three-hour orbit). Moreover, it is difficult to visualize Biosoletta as anything but an international program. Thus, the annual costs would be shared by many nations. Raising the present fishing yield requires also increasing investments from which the return will diminish per unit equipment, because the additional fish to be caught will be more dispersed and, on the whole, less valuable. Biosoletta offers increased production in more concentrated form (one might call it an oceanic seafood farm), likely to yield valuable catches because of production in the most fertile upwell areas.

The *Powersoletta* example assumes a retrograde three-hour orbit (Figure 71). The three-track mode is assumed; that is, one third of the reflectors needed in a reference orbit is installed in each of three track orbits, as explained earlier. A total of four or more track orbits is involved.

The results of a fairly detailed economic analysis are presented in Figures 71 and 72. The left side of the pie charts in Figure 71 show the initial cost breakdown. The right-hand side depicts the operating cost distribution. As can be seen, the cost of the space sector dominates the picture in both cases and for both the initial and the operational phase. However, if two ground stations are serviced, the ground component approaches 50 percent of the overall initial or operational cost in the case of the 50 ton per km^2 reflectors and exceeds 50 percent for the Powersoletta with 30 ton per km^2 reflectors. Not surprisingly, in the initial cost of the space sector, transportation costs are the largest single component, even though a combination of electric drives and radiation pressure was assumed in both cases for the interorbital transfer beyond 1100 km altitude. The main reason is the reduction in payload due to the retrograde orbits involved. As pointed out before, with more ground stations involved, the orbit can be changed to about 45° inclination, which would cut the earth-to-orbit transportation costs roughly in half.

Of equal importance with transportation is the cost of sodium coating in space. This represents a sizeable factor in the initial cost, although not necessarily a bigger cost than coating on the ground, considering the savings in reflector area (about 700 km^2) and the lighter weight of the thinner sodium coating; it is also the dominant cost item during the operating phase. The underlying assumption is that each reflector is flown back to the 1100-km orbit an average of once every 10 years for recoating and maintenance. The need for a new sodium coating every 10 years remains to be verified.

Figure 71 compares the initial capital requirement and the cost of the electrical energy provided by the Power soletta for the three ground stations individually as well as for two and all three of the ground stations supplied by the same orbital reflector system. Two additional cases are shown for purposes of comparison. The one on the left shows the cost data for a conventionally operating photovoltaic solar power station of equal conversion efficiency and with $200/kwe added for an energy storage system. The one on the far right is based on those reflectors that are operative at the time; that is, those that are beaming energy to their own ground power station. These values signify the minimal cost asymptote for a Powersoletta system as it can be approached from 12-hour or 24-hour orbit when a given set of reflectors irradiates a ground station throughout the night. These cost values can also be approached from sub-synchronous orbits when a larger number of ground stations is irradiated consecutively.

Figure 72 suggests that Powersoletta offers the potential for a new earth-space integrated technology to bring economical solar-electric energy to countries at various geographic locations. This potential stems primarily from the fact that reflectors in sub-synchronous orbits can serve a number of ground stations and eventually could serve a simple large ground station at high efficiency. The additional potential for increasing the reflector utilization by retroreflection of radiation energy to power stations on the daylight side constitutes an additional potential for cost reduction.

SPACE FUSION POWER

The development of fusion as primary energy source is perhaps the most important single advance for the industrial development of extraterrestrial environments. Some of the attractive features of controlled fusion systems are summarized in Figure 73.

Once fusion is developed, it will be a cheaper and more versatile energy source than sunlight for a number of reasons. It is more compact. Its high energy density makes it more readily transportable. It is independent of solar distance, eclipses, or night periods. It is the only energy source capable of transferring a significant faction of the world's industrial productivity into space and it is the most effective power source for the large-scale, economic extraction of lunar and other extraterrestrial resources. Fusion can be converted into a greater variety of energy forms including heat and electricity, as well as different forms of directed energy. These include advanced propulsion as well as plasma beams and laser beams for mining and material processing in the vacuum of outer space. Finally, fusion is the only economically practical energy source that can provide the strong magnetic fields required to shield navigable human settlements exposed to solar flares and cosmic radiation.

It is safe to assume that the industrial utilization of space will necessarily lead to the development of controlled fusion power. Space offers the most natural environment for the generation and processing of fusion energy. The important properties include unlimited vacuum and a biologically insensitive environment. In fact, the space environment is dominated by the particle flux of one *leaking* fusion reactor in the center of our solar system as well as of

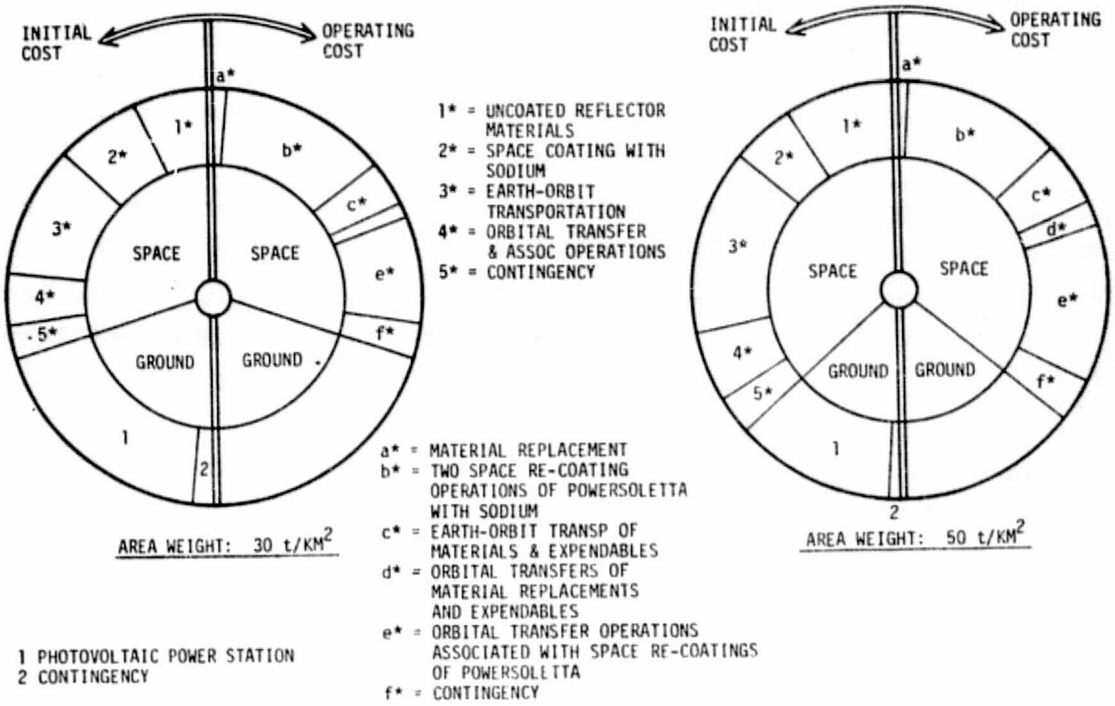


Figure 71. Powersoletta System Cost Distribution (Sun-Synchronous 3-Hour Orbit)

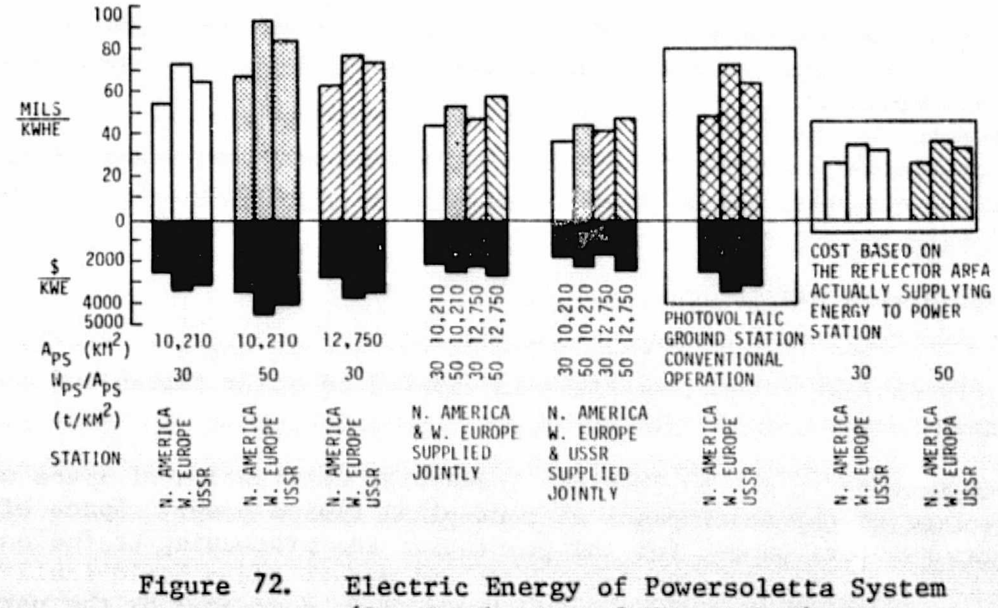


Figure 72. Electric Energy of Powersoletta System (Sun-Synchronous 3-Hour Orbit)

other more distant *fusion reactors*. Some of the attractive features of fusion systems are indicated in Figure 73. These features clearly place fusion high in the category of key technologies of space industrialization.

Two basic approaches to controlled fusion power generation are possible — the non-steady detonative and the magnetic confinement approach. Both methods can be applied on the moon and also in orbit, where sufficiently large confinement structures can be built to accommodate small fusion detonations triggered by laser or ion beams.

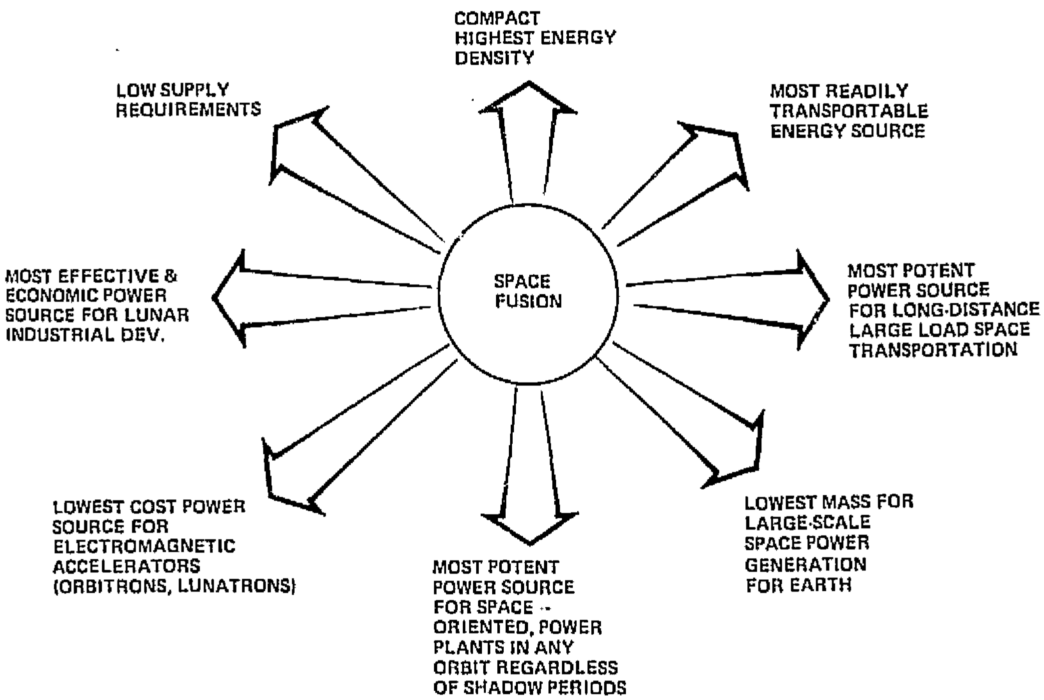


Figure 73. Central Importance of Controlled Fusion for Space Industries

The characteristics of magnetic confinement fusion reactors of the Tokamak reactor, mirror reactor, and theta pinch reactor variety are beginning to emerge from the laboratory. The Tokamak reactor, a concept originally advanced in the U.S.S.R. and subsequently developed in many other places, clearly leads in the drive toward achieving a Lawson number of 10^{14} — the criterion for achieving a net positive power output from deuterium-tritium fusion reaction.

But even with the achievement of the Lawson criterion, which may occur in the early 1980's, many engineering problems remain to be solved. Important requirements and problems with fusion reactors are concentrated in three broad areas:

ORIGINAL PAGE IS
OF POOR QUALITY

- Sufficiently long stable plasma confinement
- The maintenance of a high and *pure* vacuum
- Materials development, overall system integration including maintenance and repair, and the need for large superconducting coils

The smaller the reactor size, the more severe and mutually reinforcing these problems become.

Steady-state plasma confinement problems so far have been solved most successfully by the combination of helical toroidal magnetic field and poloidal magnetic field in the Tokamak reactor. However, the Tokamak has the lowest ratio of plasma density to average magnetic field energy density of all three types. This means that it requires the highest magnetic field pressure which, in turn, emphasizes the importance of vacuum impurity control, superconductivity, and size of the reactor chamber.

A pure vacuum is of fundamental importance. A vacuum of at least 10^{-6} torr is required. At higher pressures, the plasma pressure becomes impractically high. When the deuterium-tritium reaction takes place, 80 percent of the energy is in neutrons; 20 percent is in ions which are leaving the reactor. When they hit the walls surrounding the vacuum chamber, they release impurities from the wall. When these impurities get into the plasma, their presence causes increased radiation of energy to the walls. This radiation cools the plasma and, consequently, can cause plasma instabilities or it can squelch the reaction.

Severe material problems are created by the fact that a deuterium-tritium fusion reactor is a copious source of 14-Mev neutrons, as well as of other particles and of radiation. These can cause severe damage in the blanket structure surrounding the plasma and in the intervening vacuum, due to the particle-wall interaction. Dimensional limitations of the vacuum chamber make it desirable for the material to sustain a fluence level of 10^{22} neutrons/cm^2 for a 20-year life. This is much higher than the fluence level tolerance required for fuel cladding in a fission reactor.

Space offers two characteristics which would tend to alleviate many of these problems: high vacuum and large size. Space offers a vacuum of 10^{-8} torr, greatly reducing the plasma pressure and, hence, the required magnetic pressure. Providing large vacuum chambers in space presents no principal problems. If the vacuum chamber can be enlarged, stable plasma confinement problems are reduced. Also, at larger size, the fluence density becomes smaller. Consequently, thermal stresses, displacement damage, blistering, and embrittlement are minimized, thus facilitating maintenance and prolonging the useful life of the material structure. Less radiation damage also will reduce the problem of increase in resistivity of the stabilizing material in the superconducting magnet system.

Larger chamber size means greater distance of the fusion plasma reaction zone from the first wall, hence, a larger volume *buffer* between the two. With more internal volume available and with the high external vacuum, it should be possible to remove impurities more effectively.

Fusion reactors are complex systems with complex auxiliary systems for plasma heating and fueling, complicated blanket and shield structures, energy storage and tritium recovery and handling. Nevertheless, it appears that operation in space can reduce the magnitude of many of the most difficult engineering problems, where, again different degrees of problem alleviation and different problem foci can be anticipated between orbital and lunar surface space.

Additional support may be derived from space manufactured stronger refractory metals or from new alloys with superior capability of approaching the requirements for an ideal inner wall material. Such material should have low atomic numbers for less effect of impurities and would be well annealed with a high melting point. Finally, availability of a space fusion reactor for orbital and lunar industrial activities would, among other advantages, result in a smaller and lighter power generation satellite.

THE SPS

The SPS (Satellite Power System) is a relatively recent approach to the Production of energy from the Sun that removes the energy collection system from the earth's surface to geosynchronous earth orbit. Several approaches have been considered for SPS, including solar-thermal or solar-photovoltaic conversion of solar energy to electrical power or use of a nuclear source. The SPS concept is illustrated in Figure 74 for a typical photovoltaic satellite approach. Solar energy is converted to electric energy using large solar arrays having reflectors that concentrate the energy on solar cells. The solar cells convert the solar energy to dc electrical which is conducted to a centrally located microwave antenna. The microwave antenna transforms the dc power to RF microwave energy and beams the energy to a receiving antenna (rectenna) on the ground. The rectenna converts the RF energy, at a very high efficiency, to dc electrical energy which is input to the utility system for distribution.

Typically, a single satellite system provides 5 GW of essentially continuous power to the rectenna located on the ground. This amount of power is sufficient to meet the electrical needs of a large city such as Los Angeles or Chicago. Because launching heavy weights into orbit is so costly, it is necessary to construct the satellite on orbit where the zero-gravity condition allows very low structural masses. A typical photovoltaic SPS has a solar collector area of about 75 km^2 and a mass of about 35 million kilograms. The ground rectenna is nominally an elliptical array 10 km by 13 km. At the earth's surface, the microwave beam has a maximum intensity in the center of 23 mW/cm^2 (less than one-fourth the energy content of ordinary sunlight) and an intensity of less than 1 mW/cm^2 outside the rectenna fenceline (one-tenth of the current U.S. exposure limit).

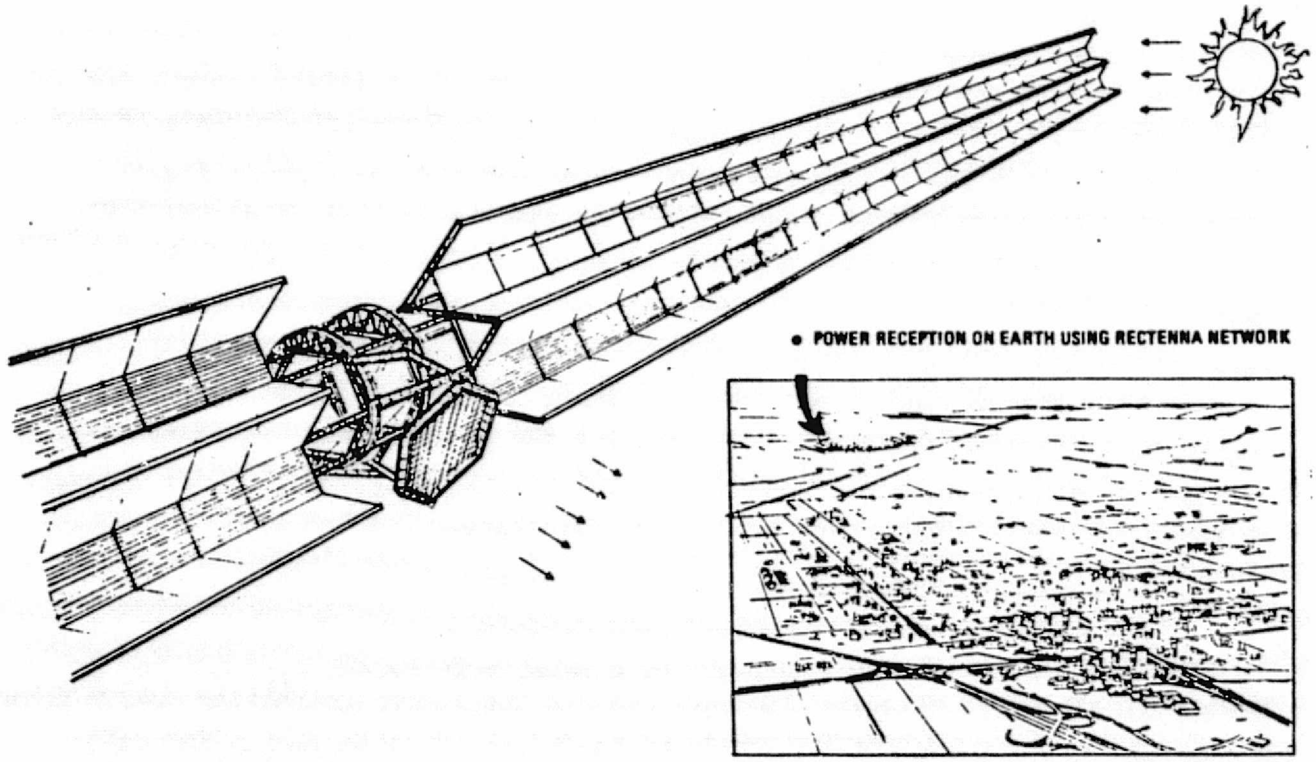


Figure 74 The Solar Satellite Power System Concept

Fundamental Concepts

A family of viable SPS concepts is shown in Figure 75. These include solar-photovoltaic concepts with silicon and gallium aluminum arsenide (GaAlAs) solar cells, a Brayton-cycle solar thermal concept, and a thermionic concept. In addition, the concepts include a Rankine-cycle solar thermal concept, a very high concentration ratio (400:1) GaAlAs solar photovoltaic concept, and a nuclear concept using a Brayton cycle with a pebble-bed breeder reactor. As a result of early evaluations, it was determined that the thermionic and the high concentration ratio GaAlAs concepts have much higher specific weights than the other concepts (e.g., 18 kg/kW for the thermionic concept and 13 kg/kW for the high concentration ratio GaAlAs concept, as compared to approximately 7 kg/kW for the low concentration ratio GaAlAs concepts). For this reason, the thermionic and high concentration ratio GaAlAs concepts were eliminated from further consideration.

The resulting matrix of concepts selected for additional analyses and trade studies is shown in Figure 75. Both silicon and GaAlAs solar blankets were considered with a concentration ratio of 1 to 1. At higher concentration ratios, only GaAlAs blankets were considered because of the sharp drop-off in silicon cell performance at higher cell operating temperatures related to concentrator concepts.

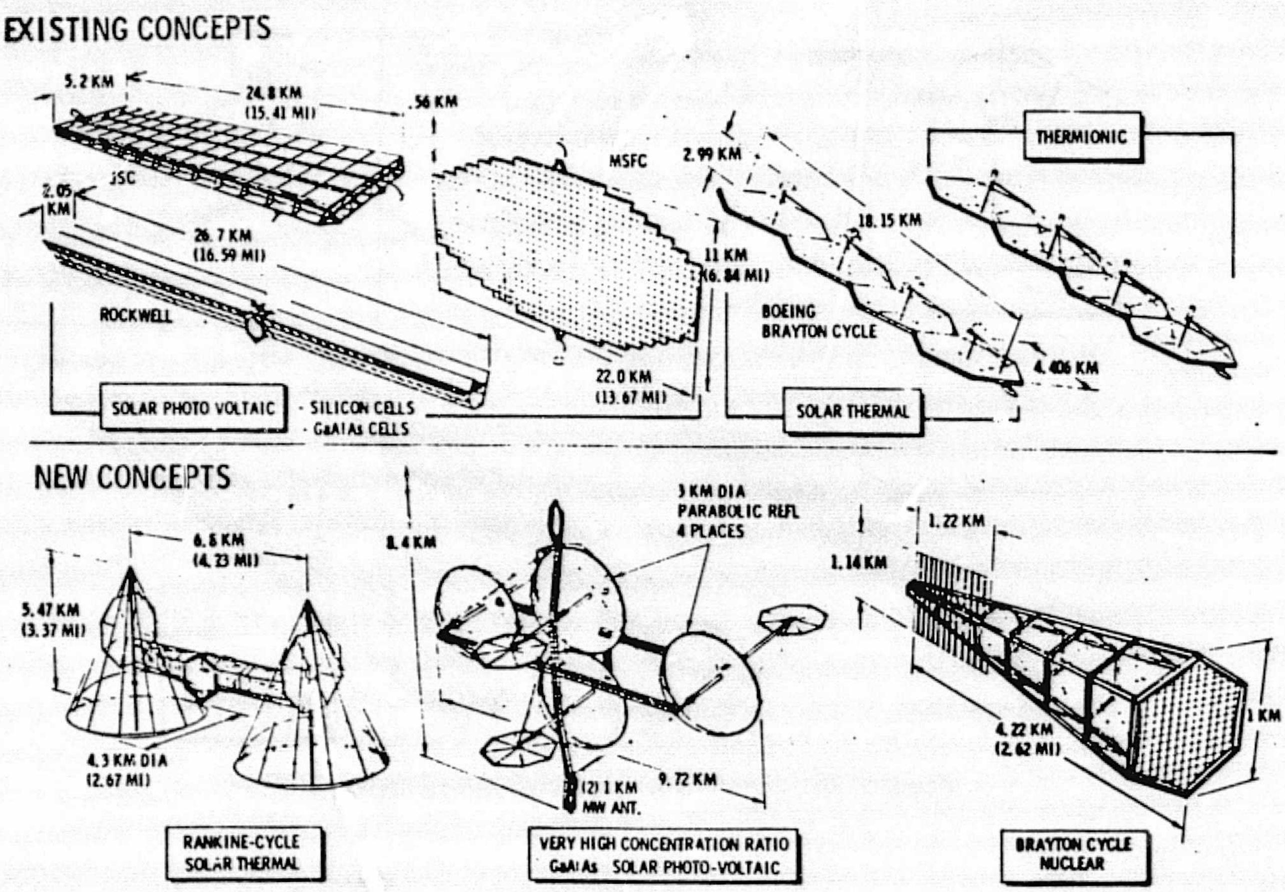


Figure 75 Initial Concepts Matrix

Solar Photovoltaic Satellites

Figure 76 summarizes the design and operational characteristics of the photovoltaic satellites resulting from the analyses and trade studies. All of these concepts are sized for 5-GW power output at the utility interface on the ground and all of them are assumed to be constructed in geosynchronous orbit.

Energy Conversion. At a concentration ratio of 1 to 1, either GaAlAs or silicon solar cells may be used. At higher concentration ratios, the operating temperature increases and the efficiency of the cells is greatly reduced. Hence silicon solar cells do not appear to be competative at concentration ratios of 2 or 5.

GaAlAs cells have several advantages when compared to silicon cells. Some of these advantages are summarized in Figure 77. As can be seen the GaAlAs cells have a higher efficiency from silicon cells at much lower cell thicknesses (e.g., 22 percent of 1 μm for GaAlAs as compared to 20 percent at about 30 μm for silicon). This results in a much lower blanket weight. In

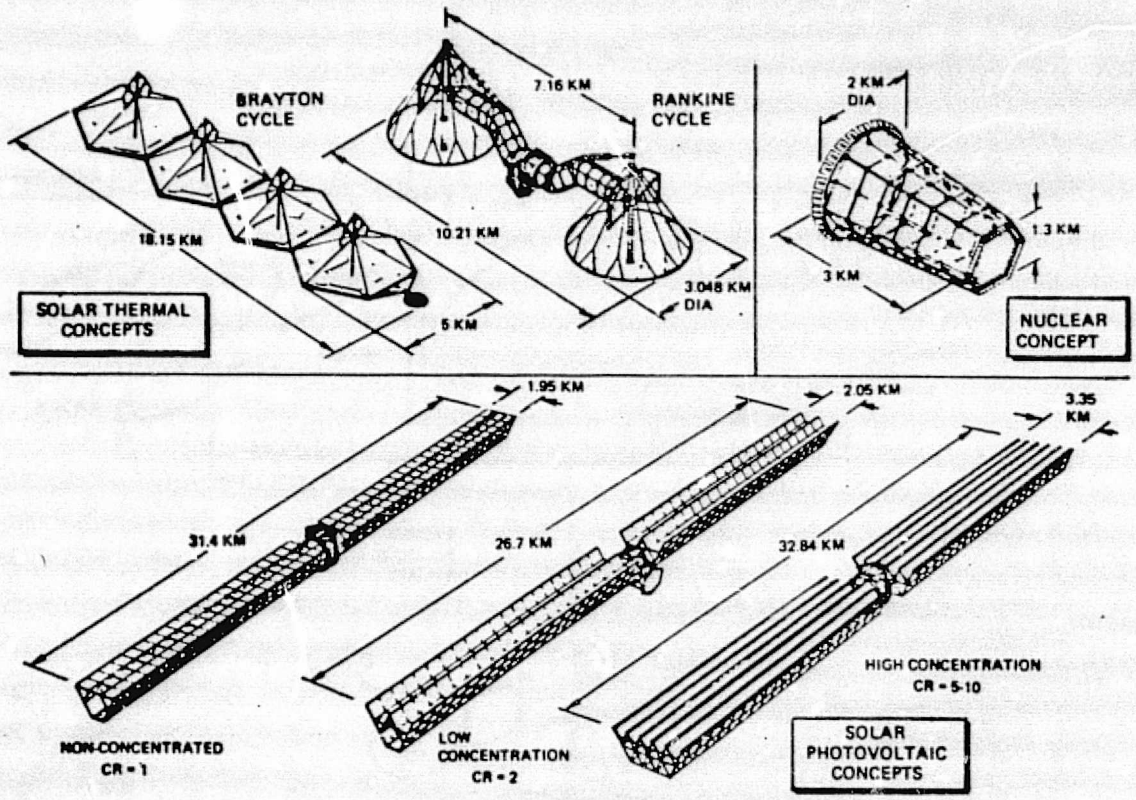
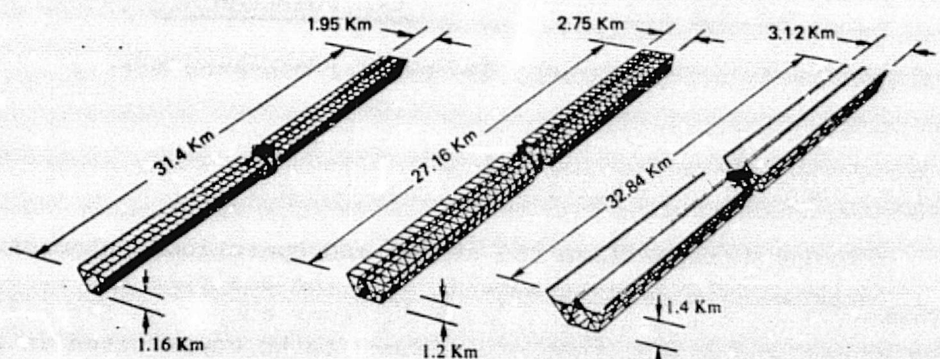


Figure 76 Concepts Selected for Trade Studies



	CONCENTRATION RATIO=1	CONCENTRATION RATIO=2	CONCENTRATION RATIO=5
CELL SELECTION	GaAlAs (Si AIT)	GaAlAs	GaAlAs
SELF-ANNEALING	NO	YES	YES
BAND PASS FILTER	NO	NO	YES
POINTING REQUIRE (ROLL)	±2°	± 0.10	± 0.025
FLIGHT PLANE ORIENT	EQUATORIAL	EQUATORIAL	EQUATORIAL
FLIGHT ATTITUDE	Y-POP, X-IOP	Y-POP, X-IOP	Y-POP, X-IOP
ATTITUDE CONTROL TYPE	ELECTRIC THRUSTERS	ELECTRIC THRUSTERS	ELECTRIC THRUSTERS
LENGTH/WIDTH	16.1	9.9	10.5
LENGTH/DEPTH	27.0	22.6	23.5
SYST SP WT (KG/KW)	7.35	6.65	8.15

Figure 77 Solar Photovoltaic System Characteristics (Geosynchronous Orbit Construction)

addition, recent experiments show that GaAlAs solar cells are resistant to natural space radiation damage and are virtually self-annealing (tend to return to their original cell efficiency) at cell temperatures of about 125°C. Silicon cells are prone to greater damage from electrons, and annealing of the cells to approximate their original efficiency requires annealing temperatures of greater than 500°C. At concentration ratios of 2 and above, GaAlAs cells will normally operate at temperatures in excess of 125°C, thus providing potential for continuous self-annealing of radiation damage. Furthermore, it is desirable to have higher concentration ratios on GaAlAs cells to reduce costs because their efficiency is not degraded seriously and the cost of 1/2-mil aluminized kapton reflectors is considerably less per unit area than solar cells.

Two areas of concern for GaAlAs cells are the availability and cost. Current GaAlAs cells utilize GaAs as the substrate material. As shown in Figure 78 it is expected that sufficient gallium can be recovered from available bauxite, used for aluminum production, to produce five satellites per year if they are built with a concentration ratio of 3 to 1. Although sufficient information is not yet available on substitute substrate materials, it is anticipated that a synthetic sapphire material will still provide good cell efficiency while reducing the required gallium by a factor of 5. As shown in Figure 78, sufficient gallium should be available at any concentration ratio for this cell concept. Gallium is currently produced only in small quantities, consequently, it costs about $900 per kilogram. It seems certain that this price will decrease significantly when the large quantities related to SPS are produced.

In order to reduce the operating temperature of the solar cells, bandpass filters may be used on the reflectors to reduce incident radiation in regions of the solar spectrum where they are ineffective. As a result of the trade studies, it was concluded that GaAlAs cell temperatures should be maintained at about 125°C to assure self-annealing from radiation damage. At a concentration ratio of 2 to 1 the cells will reach an equilibrium temperature of approximately 125°C without bandpass filters. For this reason, bandpass filters are not recommended at in this case. However, in the case in which the concentration ratio is 5 to 1 are needed to reduce cell temperatures and increase efficiency. Even with bandpass filters, the temperature will reach approximately 180°C. Although this is not optimum it is a tollerable temperature range.

Selection of Flight Conditions. Selection of flight conditions at geosynchronous altitude encompassed the selection of inclination and vehicle attitude.

Orbit planes considered for the SPS (see Figure 79), include the ecliptic, equatorial, and a 7.3-degree inclined orbit which eliminates the north-south stationkeeping ΔV requirement. Collector pointing, always normal to the sun, can be achieved in the ecliptic plane with a "wings level" (Y-POP)

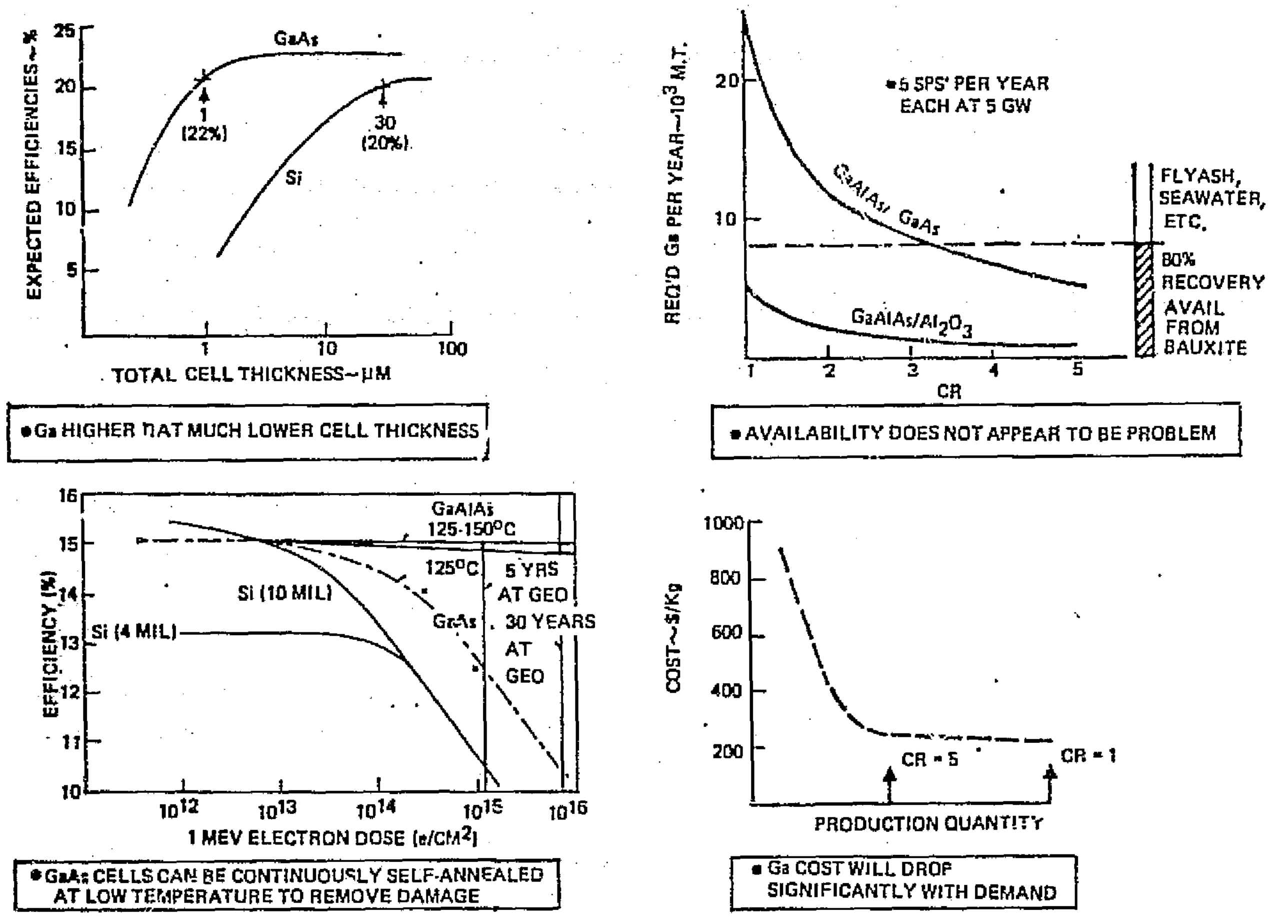


Figure 78 Advantages of GaAlAs Solar Cells

attitude which minimizes the gravity gradient induced RCS propellant consumption. This orbit results in a daily earth eclipse period. The equatorial plane produces photovoltaic collector losses up to 8 percent for the wings-level attitude. Trade study results indicate that the equatorial orbit is preferred, primarily due to the dominant cost impacts of the increased rectenna sizes for the ecliptic and 7.3-degree inclined orbits, and the daily eclipse in the ecliptic orbit.

Three attitude orientations (illustrated in Figure 79) have been evaluated in top level trade studies. The wings-level attitude (Y perpendicular to orbit plane, X in orbit plane) is preferred over the Z-sun, X-IOP attitude due to the large savings in RCS propellant resupply. The X-sun, X-IOP attitude places the long axis of the vehicle in the orbit plane. This orientation requires two microwave antennas in order to prevent interference of the microwave beam with the spacecraft structure and to obtain acceptable solar pressure torque balancing. Two antennas result in double-sizing of the spacecraft, leading to additional complexity and power distribution mass penalties. On this basis the Y-POP, X-IOP is the preferred orientation.

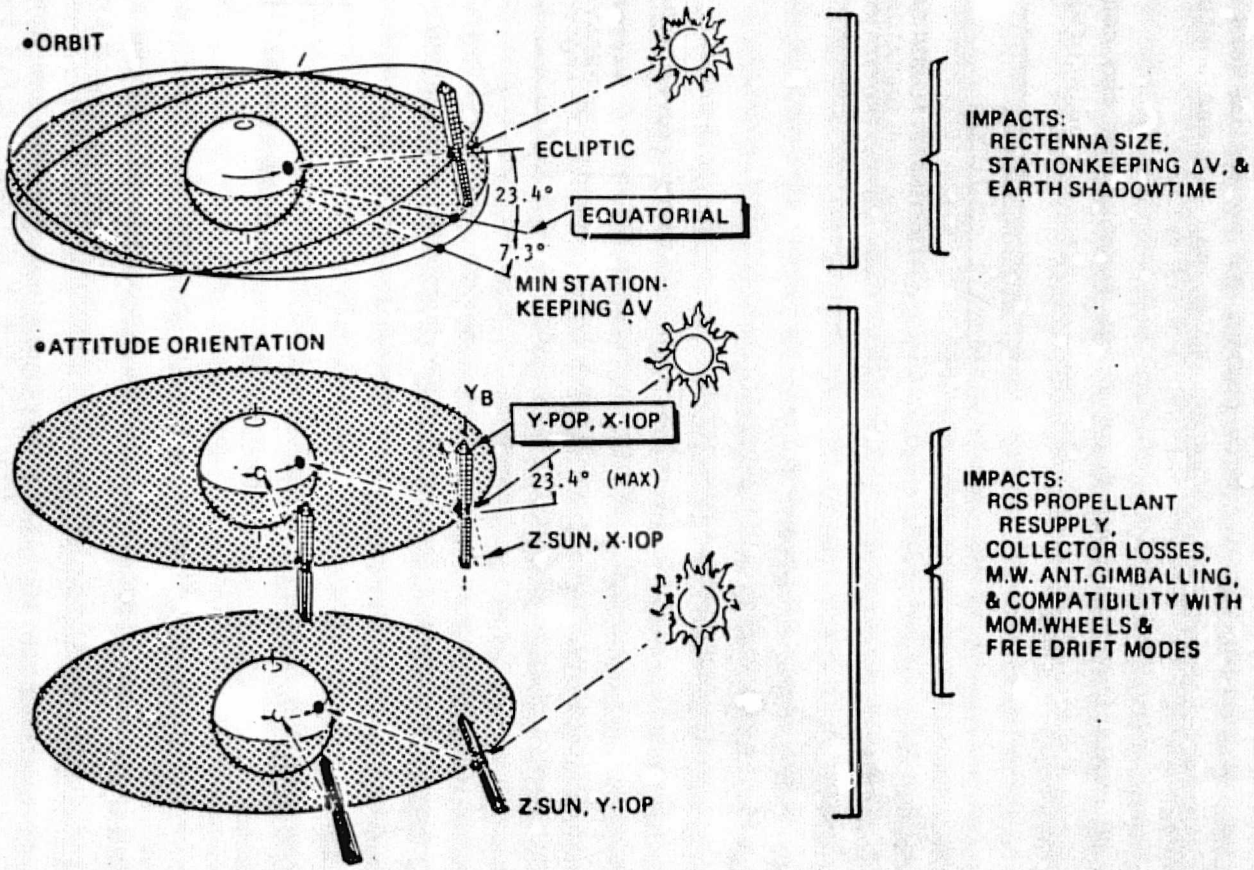


Figure 79. Selection of Flight Conditions

Solar Thermal Concepts

Two basically different cycle approaches were considered for the solar thermal system--the Brayton cycle and the Rankine cycle. The primary difference between them is that the Brayton cycle occurs entirely in the gas phase, and the Rankine cycle occurs in gas and liquid phases. The Brayton cycle utilizes helium as the working fluid. Both cesium and potassium were considered as primary working fluids for the Rankine cycle, and a steam bottoming cycle was also studied to assess overall performance advantages.

Figure 80 summarizes areas of major trade studies for the concentrator, power conversion subsystem, and thermal control system (radiators). The results are discussed below.

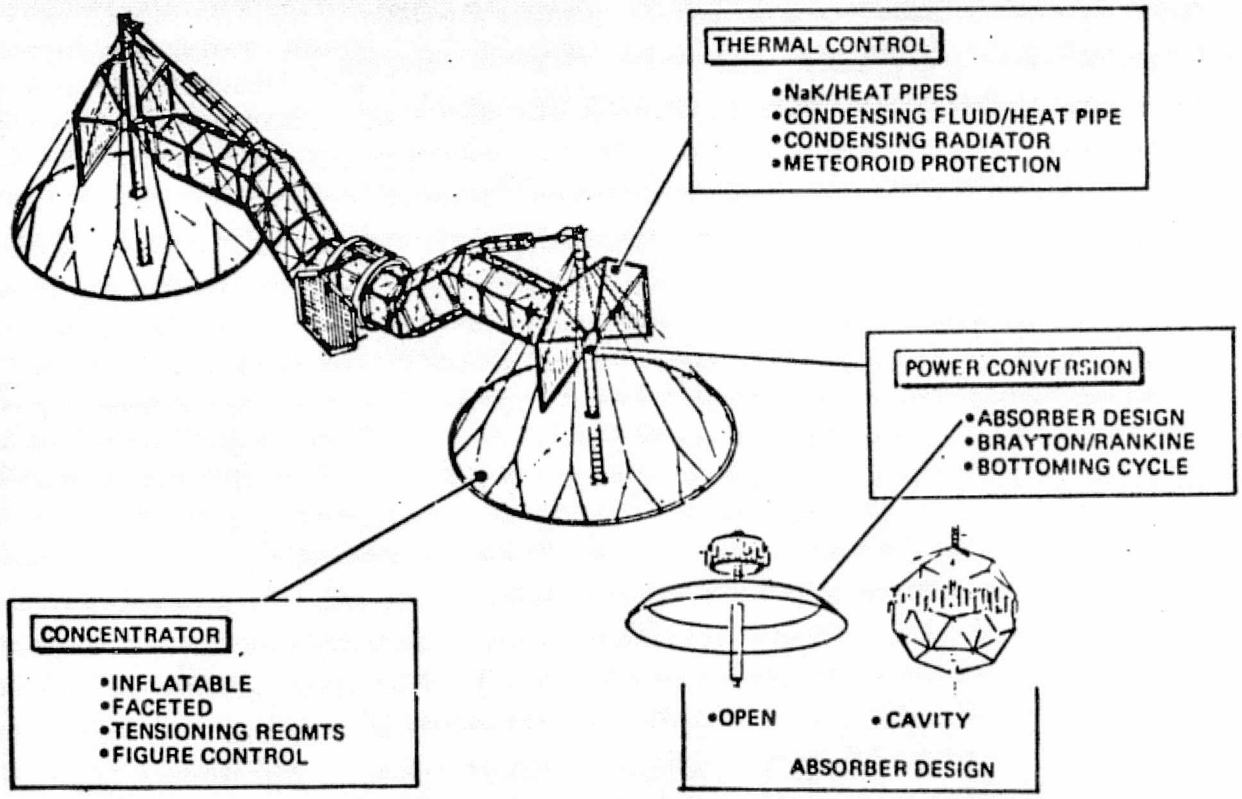
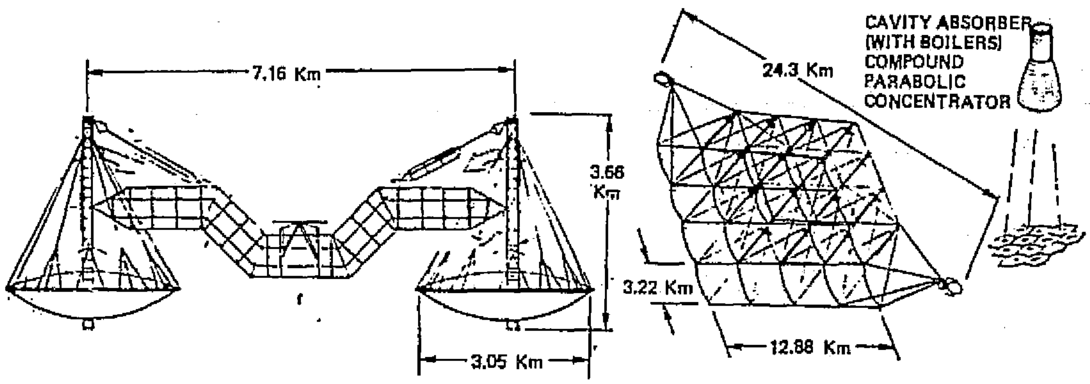


Figure 80 Solar Thermal Major Trade Areas

Concentrator. Two approaches have been considered for the concentrator: a multi-faceted approach that uses many flat surfaces to concentrate sunlight and an inflatable approach that uses large pressure-stabilized parabolic reflectors to concentrate sunlight. Concepts using these two approaches are illustrated in Figure 81. The inflatable approach was devised by Rockwell, and the multi-faceted approach was introduced by Boeing. In both cases, the need to maintain the concept in a wings-level attitude, because of gravity-gradient impacts on attitude control, results in a need to steer the reflectors to a normal incidence to the sun by articulation of the reflectors. Alternatively, the satellites could be operated in an ecliptic-plane 24-hour orbit



	BRAYTON	RANKINE	RANKINE	RANKINE
WORKING FLUID	HELIUM/XENON	CESIUM	CESIUM/STEAM	POTASSIUM
AREA (REFLECTOR) KM^2	24	30.32	23	30.32
η OA %	15	12	16	12
CYCLE η%	45	36	47	36
TURBINE INLET TEMP°C	1379	1038	1038	1038
GENERATOR SIZE MW	30	30	30	30
SAT. ORIENT	Y-POP, X-IOP	Y-POP, X-IOP	Y-POP, X-IOP	Y-POP, X-IOP
RADIATOR AREA KM^2	2.35	1.35	2.2	1.35
SYSTEM SP. WT. KG/KW	8.65	8.35	6.9	11.0

Figure 81 Solar Thermal System Characteristics

to avoid articulation of the reflectors. However, the previously cited disadvantages of this orbit (enlarged rectenna and daily solar eclipse) favor articulation of the reflectors. As shown in Figure 81, the two large pressurized reflectors on the Rockwell concept are rotated along with their absorbers and radiators by an electric actuator. The rotational rate is very slow (93.6 degrees per year).

Each of the facets on the multi-faceted concept must be individually moved to track the sun. The major concern with the pressurized concept is the reflector tension needed to maintain good reflective characteristics. Tests conducted during the study on small samples indicated that 300 psi is adequate. The gas required to pressurize the reflectors is less than one percent of the satellite mass over a 30-year operational period, including the losses due to meteoroid punctures.

Thermal Cycles. Figure 81 compares the characteristics of the thermal cycles. One of the major differences between the Brayton and Rankine cycles is the turbine inlet temperature. In order to be competitive in terms of system specific weight (kg/kW), it is necessary to run at a high turbine inlet temperature with a Brayton cycle (1379°C) when compared to the Rankine cycle (1038°C). The result of this higher temperature is a more advanced technology requirement for the Brayton cycle (use of ceramics in the turbomachinery). Although the overall efficiency is lower for the cesium Rankine cycle without steam bottoming (12 percent) than for the Brayton cycle (15 percent), the system specific weight is lower due to lower-weight turbomachinery and radiators. As shown, the cesium Rankine cycle with steam bottoming has a significantly improved overall efficiency (16 percent) and the lowest specific weight (6.9 kg/kW).

Both the cesium-Rankine and the helium-Brayton concept utilize a condensing steam radiator with a heat exchanger between the water and the working fluid. A condensing steam radiator was also used with the cesium Rankine having a steam bottoming cycle.

Microwave Antenna

The microwave antenna design is virtually independent of overall satellite design. Its basic function is to transform electrical energy from the power source into microwave radio frequency energy and to propagate the microwave beam to a receiving antenna (rectenna) located on the ground.

Devices that were considered for dc-to-RF conversion included amplitrons, klystrons, and transistors. Of these, only the amplitrons have been rejected on the basis of their low efficiency and high driver complexity. The klystron, operating at a frequency of 2.45 GHz, has an efficiency of 85 percent and a power level of 50 kW. This device is the current baseline. Solid-state transistors are also being considered, but additional effort is required to define their impact on the SPS design. It may be necessary to operate these devices at 0.915 GHz and with a larger-diameter antenna in order to satisfy thermal operating constraints of the transistors and the maximum microwave density (23 mW/cm^2) dictated by atmospheric interactions.

The microwave transmission system is the key element of the SPS. Several constraints must be placed on its design in order to satisfy potential environmental concerns. Major concerns by environmentalists include: excessive heating of the D and F layers of the atmosphere, biological effects of the low level microwave radiation outside of the controlled rectenna area, interference with other radio-frequency receivers and sources, and land requirements for the rectenna. Atmospheric heating effects cause ionization of the D and F layers which, in turn, causes interference with certain radio-frequency transmissions. Since insufficient test data are available to set a definite upper limit, a preliminary conservative limit of 23 mW/cm^2 has been specified. Biological considerations have resulted in a current limit of 1 mW/cm^2 outside of the controlled rectenna area. The problem of interference with other radio-frequency receivers and sources has not yet been adequately defined. These investigations, along with other environmental concerns, are a portion of a study effort planned by the Department of Energy.

Several design approaches may be devised to work around these problem areas including modifications of the antenna taper, microwave antenna diameter, transmitted power, and basic beam shape. Two different basic beam shapes have been studied--a Gaussian shape and a Bessel-J shape (see Figure 82). Both types of patterns are designed to deliver 5 GW of power at the utility interface on the ground. The significant feature of the Bessel-J distribution is much lower minimum power density for the same delivered power. However, as shown, the rectenna for the Bessel-J beam is about 7.5 km radius (to 1 mW/cm^2) as compared to about 5 km radius for the Gaussian beam.

In order to arrive at the best combination of conditions, it was necessary to conduct a combined antenna/rectenna cost trade study. The results of such a study are summarized in Figure 83 for klystrons and a 2.45-GHz frequency.

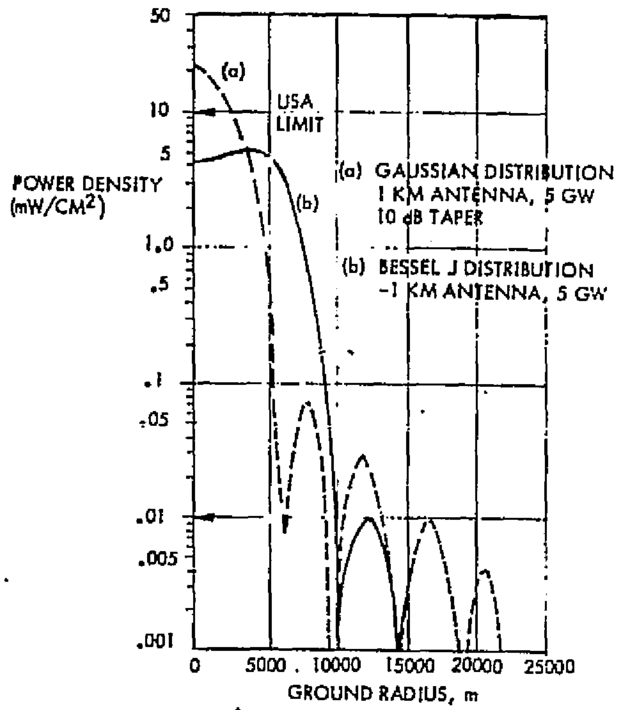


Figure 82 Microwave Radiation Problem Areas and Approaches

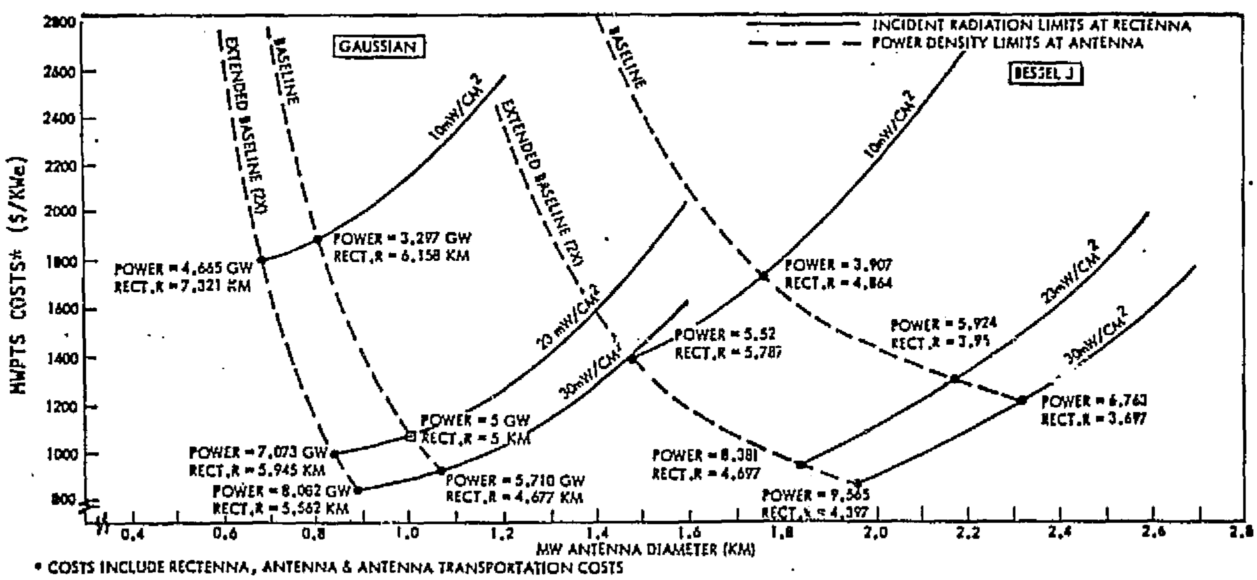


Figure 83 MWPTS Cost Trades Comparison

ORIGINAL PAGE IS
OF POOR QUALITY

This figure shows that two regimes exist, with largely different antenna diameters for the Gaussian and Bessel-J beams. Lines of constant maximum beam density (mW/cm^2) are shown by the solid lines running from the upper right to the lower left. Dashed lines intersecting the solid lines are lines of constant maximum heat flux which must be rejected at the center of the beam. A heat flux of 5.3 kW/m^2 is assumed as the baseline. Points of intersection of the dashed and solid lines result in minimum achievable cost. For the current maximum beam density of 23 mW/cm^2 and the baseline heat flux, the resulting rectenna diameter is 1.0 km, the rectenna radius is 5.0 km, and the power at the utility interface is 5 GW. At the same beam density and baseline heat flux, the Bessel-J has a higher total cost per kW, an antenna diameter of 2.2 km, a rectenna radius of 3.95 km, and 5.9 GW of power at the utility interface. The Bessel-J beam has the lowest cost at lower maximum beam densities such as 10 mW/cm^2.

Rectenna Concepts

The rectenna system is comprised of row-on-row of arrays which are oriented normal to the incoming microwave beam. Major attention to date has been given to arrays comprised of individual dipole antennas, each with its own diode rectifier. The major problems with this approach are the low rectification efficiency of the diodes at the low power densities that exist near the edge of the rectenna (where the major areas exist), and the large number of diodes that are required.

Alternate approaches could overcome the collection inefficiency and reduce the number of diodes required. One of these is the stripline pattern of bow-tie dipoles, illustrated in Figure 84. The stripline track collects the dipole

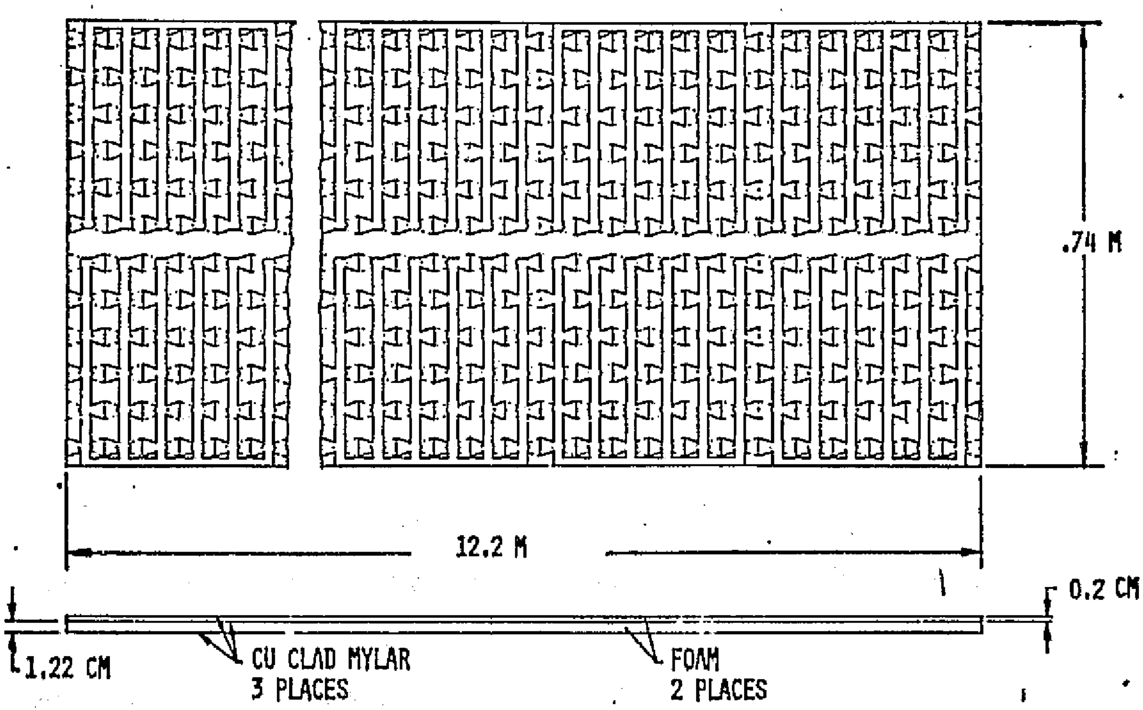


Figure 84 Stripline Rectenna Module (High-Density Area)

signals at a common outlet where it is converted to dc by a diode rectifier. The bow-tie panels offer ease of manufacturing, excellent weather resistance, and low diode count. The diode count for this approach is only 2 percent of that required by the individual dipole approach. Because this approach results in a phased array, angular accuracy requirements of the beam are increased. This does not appear to pose any significant constraints on the satellite.

Satellite Construction Site Concepts

Two basic approaches for satellite construction have been considered. One of these concepts assumes that the entire satellite is constructed in geosynchronous orbit. In this case the necessary construction material is transported from low earth orbit to geosynchronous orbit using orbit transfer vehicles (OTV's). The other concept assumes that the satellite is either partially or totally constructed in a low altitude earth orbit and then propelled to geosynchronous earth orbit using power from the satellite's solar arrays to power ion-electric thrusters. If the satellite is only partially constructed in the low altitude orbit the remainder of material required for completion of construction in at the geosynchronous altitude is placed on board the satellite. The operations and timelines associated with these options are illustrated in Figures 85 and 86.

Impacts on Overall Concept

Major differences exist in the environment at the two proposed construction altitudes. Two paramount differences are the gravity-gradient torques and the natural frequencies at the two locations. Figure 87 illustrates the impacts of these on the satellite configuration. The original GaAlAs solar cell photovoltaic concept having a concentration ratio of 2 had two troughs. Studies of construction location indicated that a satellite partially constructed in a low altitude orbit has to accommodate much larger gravity-gradient torques

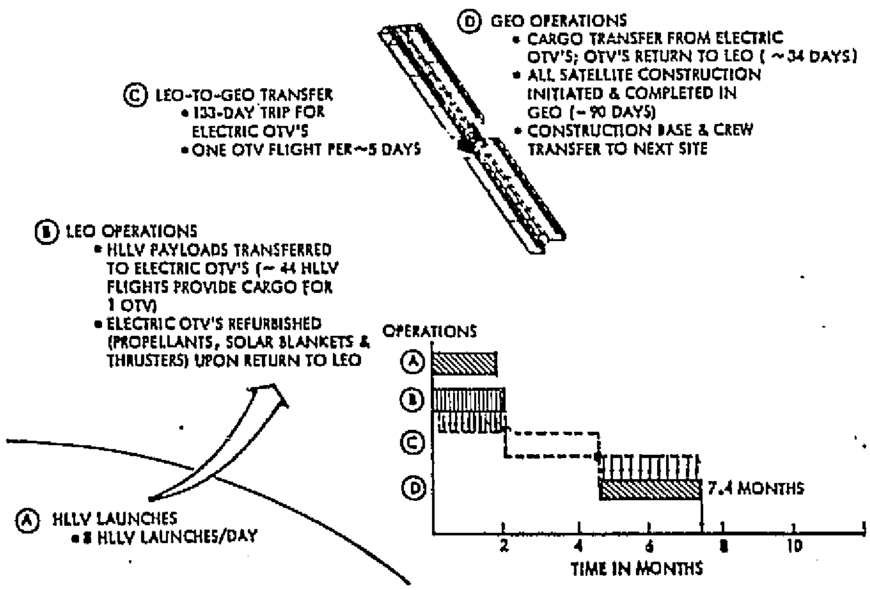


Figure 85 GEO Satellite Construction Scenario

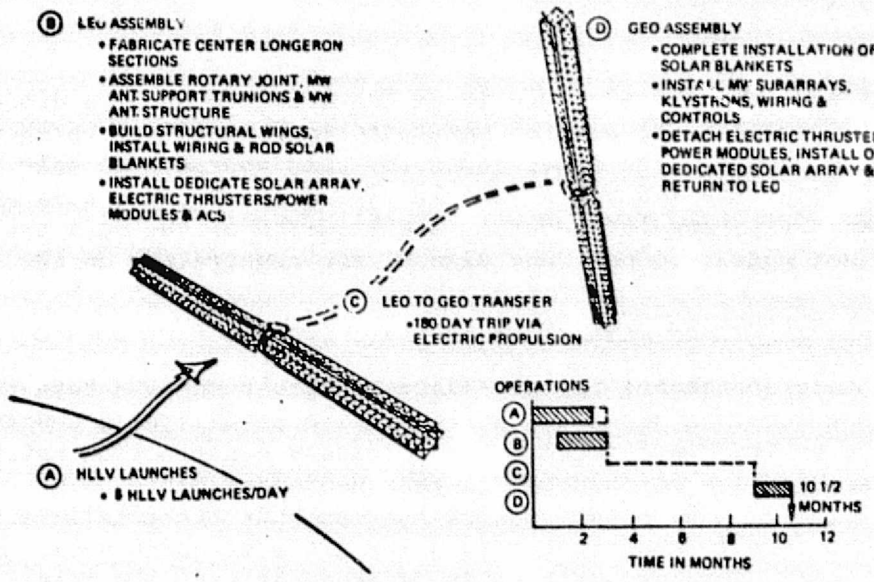


Figure 86. LEO-CEO Satellite Construction Scenario

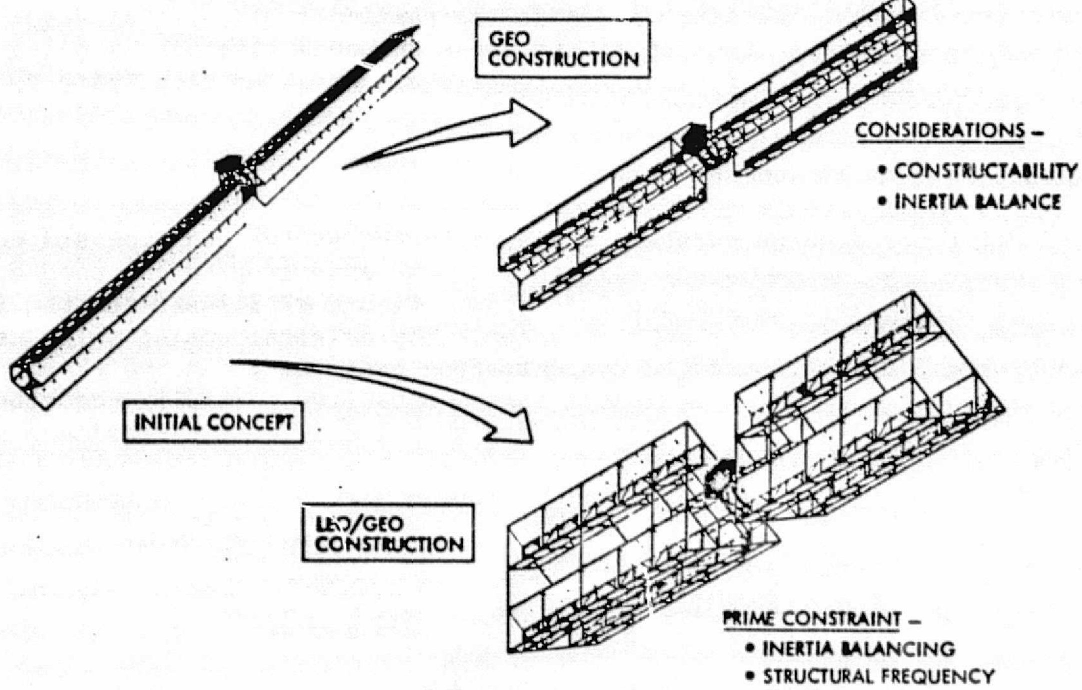


Figure 87 Photovoltaic Point Design Evolution

during construction and during much of the transfer during self-propulsion to its final destination at the geosynchronous altitude. This results in attitude control penalties for concepts which are poorly balanced about the Y-axis (axis perpendicular to the orbit plane during operations). The concept shown for combined construction at the two altitudes has three troughs arranged (end view) like an equilateral triangle, which gives the desired balance about the Y-axis. Because of the spread-out (about the Y-axis) nature of this configuration, it appears that construction would be more difficult. Because the rotational period is lower in the low altitude orbit, a stiffer configuration is required, leading to a deeper structure.

When construction is accomplished totally at the geosynchronous altitude, large gravity gradients are no longer as significant a problem. As a result, the concept shown for geosynchronous construction represents a compromise between Y-axis balancing and constructability. Although the concept still has three troughs, they are not arranged in an equilateral triangle and the resulting concept is more compact about the Y-axis. Although not perfectly balanced, the balance is adequate to reduce operational attitude control requirements due to gravity-gradient torque to a low level.

Cost Impacts

Another major area that was considered in comparing the construction site approaches is cost. Table 5 summarizes the results of the cost analysis using "delta" costs rather than total costs.

Table 5. Cost Differences for Geosynchronous and Combined-Altitude Construction (GaAlAs Photovoltaic Satellite)

	Chemical OTV	Electric OTV	
	GEO Construction	LEO/GEO Constr	GEO Construction
No. of HLLV launches	1092	434	453
Earth launch costs	$\$2597 \times 10^6$	$\$988 \times 10^6$	$\$2029 \times 10^6$
Elec. prop. module replacement costs	–	$\$128 \times 10^6$	$\$156 \times 10^6$
Interest Costs (7.5%)	–	$\$272 \times 10^6$	$\$255 \times 10^6$
Totals	$\$2597 \times 10^6$	$\$1388 \times 10^6$	$\$1410 \times 10^6$

Two OTV approaches are shown for all-GEO construction: an LO_2/LH_2 chemical OTV and an electric OTV. For partial construction, at the two altitudes electric propulsion is also used, but the partially-constructed SPS provides the power to the electric thrusters and transports the mass to be used for partial GEO construction to GEO (self-propulsion). Although long-duration travel is involved through the Van Allen Belt for both electric propulsion concepts (the electric OTV and self-propelled SPS), radiation damage to the solar cells was assumed to be self-annealed (GaAlAs solar cells). Interest costs are included because of the long trip time for electric propulsion transfer.

A comparison of the totals shows that geosynchronous construction using a chemical OTV for cargo the transfer costs about $1.2 billion more than either electric OTV option. Costs of the self-powered (combined-location construction) and the geosynchronous construction options with an electric OTV are about the same.

Other Considerations

In addition to the above considerations, trade studies also considered other factors of construction site related to the subsystems, transportation systems, and operations; these are summarized in Table 6. The accumulation of these factors tend to favor geosynchronous construction.

Table 6. Additional Trade Study Results

Area of Investigation	LEO Preferred	GEO Preferred	Reasons
SPS Subsystems			
Microwave		X	Open tubes, no efficiency loss due to multipaction
Thermal		X	Less frequent temperature changes
Structural		X	Less stiffness
Stability and control		X	Less control torque and occultation problems
Power conversion		X	No cell degradation and total array deployment (without self-annealing)
Power distribution		X	Needs only single system at 40 KV
Crew systems	X		No major discriminators
Flight and orbital mechanics		X	Orbital transfer of SPS
Transportation Systems	X		Relieves OTV selection
Operations	X		Fewer HLLV flights

Transportation Concepts

The transportation requirements for SPS vary as a function of program phase. Figure 88, illustrates the necessary SPS transportation requirements. During the verification planning period (1981-1987), the baseline Shuttle is used to conduct sortie missions. Later in the verification program, an extended-duration orbiter configuration is necessary to conduct on-orbit experiments related to on-orbit construction. Following the verification phase, from 1988 to 1998, the mass to orbit will increase significantly to support construction of a large-scale (possibly 1-GW) prototype demonstration. In order to reduce launch costs, a Shuttle-derived heavy-lift launch vehicle (HLLV) will be needed. Additionally, during this period, a Shuttle-derived manned orbit transfer vehicle (MOTV) will be required to carry personnel to geosynchronous orbit. When commercialization of SPS is initiated in about 1998, the masses to orbit will again increase by large amounts and it will

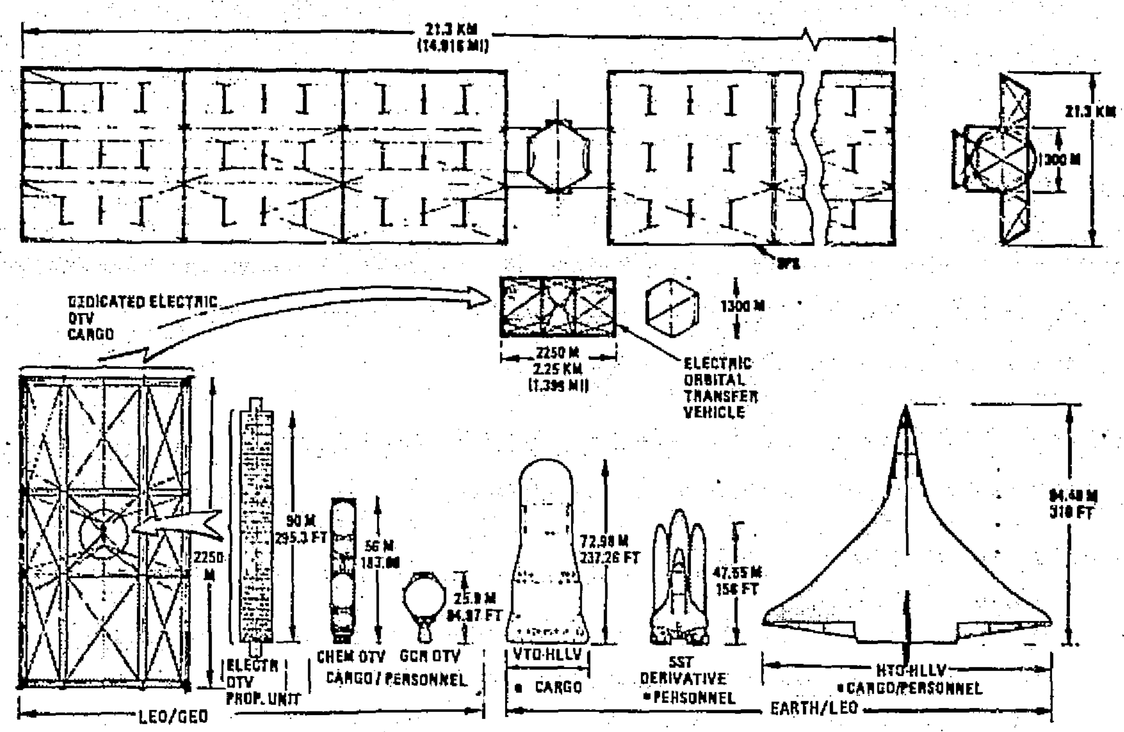


Figure 88 Comparison of Transportation System Options

be necessary to have a transportation system specially suited for SPS, including manned and cargo orbit transfer vehicles and a heavy-lift launch vehicle for earth to low orbit transportation with launch costs of approximately $22 per kilogram (1977 dollars). This study concentrated on the transportation requirements during the post-1998 period. The results of these analyses are presented in the following paragraphs.

Operational Transportation Requirements

Some of the basic transportation system requirements include orbital attitudes and inclinations, mass flow to orbit, environmental concerns, and cost.

Geosynchronous orbit is the eventual destination of SPS construction equipment and supplies, unless the SPS is built entirely in a low altitude orbit. Under any circumstances, it will be necessary to transport the crew from earth to a low altitude orbit and from this orbit to geosync. During the period of SPS operations, cargo for maintenance and crew will have to be transported along the same route. Two low earth orbits were considered—a 500-km orbital altitude at approximately 28.5 degrees inclination, and an equatorial orbit of 550 km. The desired orbital location is a function of earth launch vehicle concept selection.

The minimum mass flow to orbit for a mature program ranges from 200×10^6 to 350×10^6 kg/year for the electric OTV concept, and as high as 10^9 kg/year for a chemical OTV. Dependent upon HLLV payload capability, this results in HLLV flight rates ranging from 500 to 4000 per year.

Because of the large quantities of fuels consumed by the HLLV, environmental consideration must be given to fuel consumption and storage hazards, atmospheric contamination in localized areas, and the maximum allowable noise levels in the area of the launch site. In addition, since a significant mass will be required for packaging of payload elements, the ultimate disposition of this mass in orbit must be considered.

Since the operational cost of the transportation system represents a major portion of SPS costs, transportation system selection is dominated by launch costs. Costs of the order of \$22/kg to a low altitude orbit are required to meet the economic goals of SPS. This implies rapid turnaround time, low-cost recovery and refurbishment, and virtually complete reusability of system components.

Transportation System Options

Table 7 lists the options that have received serious consideration for SPS in three separate flight regimes. The low altitude orbit launch concepts are arranged from top to bottom in the order of increasing technology and decreasing operational complexity. The first two concepts take off vertically (the ballistic also land vertically), and the last two take off and land horizontally. The two-stage ballistic launch vehicle is intended to carry cargo into orbit, and it would require a Shuttle derivative to carry personnel and priority cargo. The other three HLLV options can carry both cargo and personnel.

Table 7. Transportation System Options

Cargo	Personnel/Priority Cargo
Earth – LEO	
• Two-stage ballistic	• Shuttle derivative
• Two-stage winged – VTO	• Two-stage Winged – VTO
• HTO – two stage	• HTO – two stage
• HTO – SSTO	• HTO – SSTO
LEO – GEO	
• Chemical	• Chemical
• Nuclear – GCR	• Nuclear – GCR
• Electric – Self propelled – Dedicated	
On Orbit	
• Chemical	• Chemical

Three basic approaches have been considered for interorbital transportation: chemical (LH_2/LO_2), nuclear (gas core reactor), and electric propulsion systems. The chemical and nuclear systems both have high thrust and, therefore, short flight times. Consequently, they can transport both cargo and personnel. The electric systems include both self-propelled (in the event the SPS is partially or totally constructed in a low altitude orbit) and dedicated concepts (in the event the SPS is built at geosync). For either electric propulsion concept, it is necessary to have either a chemical or nuclear vehicle to transport crew. The chemical concept appears to be the best candidate in conjunction with electric propulsion because of the relatively low mass-flow of crew and priority cargo compared to construction cargo. The only option analyzed for on-orbit propulsion in this study was an LO_2/LH_2 chemical system.

Figure 88 illustrates some of the concepts described above. The HTO-HLLV depicted is a single-stage concept with a payload capability of 91,000 kg to a low altitude equatorial orbit. The two-stage ballistic VTO-HLLV has a payload capability of approximately 400,000 kg to low altitude at 28.5 degrees inclination. The chemical and nuclear gaseous core reactor are sized to deliver a 91,000-kg of interorbital payload. The dedicated electric OTV is sized to deliver approximately 4 x 10^6 kg. The upper portion of the figure compares its size with the SPS satellite.

Rockwell International
Space Division

REFERENCES

1. Oberth, H., Wege zue Raumschiffahrt. R. Oldenbourg, Munchen and Berlin (1929).

2. Ehricke, K. A., Statement before Committee on Science and Astronautics, U. S. House of Representatives, Hearings before the Subcommittee on Manned Space Flight, 92nd Congress, on H.R. 12824. U. S. Government Printing Office, Washington D.C., 8 March 1972 (1972), pp. 375-428.

3. Ehricke, K. A., *Space Industrial Productivity, New Options for the Future.* Presentation to Committee on Science and Technology and the Subcommittee on Space Science and Applications. Hearings on Future Space Programs, 94th Congress, July 1975, U. S. Government Printing Office, Washington, D.C. (1975).

4. Ehricke, K. A., Cost Reductions in Energy Supply Through Space Operations, paper presented at 27th International Astronautical Congress, Anaheim, California, U.S.A., Session 34, Paper IAF-A-76-24 (1976) [to be published in Acta Astronautica].

5. Ehricke, K. A., Presentation on Panel *Making Space Common Place* (J. Yardley, NASA Deputy Administrator on Manned Space Flight, Chairman), 13th Annual Meeting, Institute of Aeronautics and Astronautics, Washington (Jan. 1976).

6. Ehricke, K. A., Space Industrial Productivity (New Options for the Future) in publication by Mashinostroeniye Publishers, Moscow, U.S.S.R.

7. Buckingham, A. G., and H. M. Watson, The Uses of Orbiting Reflector Satellites, American Astronautical Society Preprint No. AA67-118 (1967).

8. Allan, C. W., Astrophysical Quantities, University of London, The Athlone Press (1963).

9. World Bank, Annual Report (1975).

10. deJong, B., Net Radiation Received by a Horizontal Surface at the Earth. Monograph published by Delft University Press, Netherlands (1973).

11. Ryther, J. H., *Photosynthesis and Fish Production in the Sea,* Science, Vol. 166, (Oct. 3, 1969), pp. 72-76.

12. Kasahava, H., Proceedings, The International Congress of Nutrition, Hamburg, Pergamon, New York, Vol. 4 (1966), p. 958.

13. U. S. President's Science Advisory Committee (1967), p. 262.

14. Pike, S. T., and A. Spilhaus. Marine Resources, National Academy of Sciences, National Research Council Publication 1000-E, Washington D.C. (1962).

15. Ehricke, K. A., *Lunar Industries and Their Value for the Human Environment on Earth*, ACTA Astronautical, Vol. 1, No. 5-6. Presented at the 23rd International Astronautical Congress, Vienna (October 1972), pp. 585-622.

16. Ehricke, K. A., The Socio-Economic Role of the Moon in the Development and Operation of Large Structures for Lunetta and Soletta Power Systems for Earth. Presented at the 28th International Astronautical Congress, Prague, Czechoslovakia (October 1977).

17. Furth, H., *Tokamak Research*, Nuclear Fusion, Vol. 15 (1975), pp. 487-534.

18. Kaminsky, M. S., *Plasma Contamination and Wall Erosion in Controlled Thermonuclear Fusion Devices and Reactors*, Proceedings of 5th International Conference on Plasma Physics and Controlled Nuclear Fusion Research, Tokyo, Japan, Vol. II (November 1974), pp. 287-299.

19. Bebrizch, R., and B. B. Kadomtsev, *Plasma Impurities and Their Significance in Fusion Reactors*, loc. cit. [18], pp. 229-246.

20. Hopkins, G. R., *Silicon Carbide and Graphite Materials for Fusion Reactors*, loc. cit. ref. [18], pp. 275-285.

21. Powell, J. R., et al., Minimum Activity Blanket for Commercial and Experimental Power Reactors. Brookhaven National Laboratory Report BNL-18439 (1973).

22. Kulcinski, G. L., *Radiation Damage by Neutrons to Materials in DT Fusion Reactors*, loc. cit. ref. [18], pp. 251-273.

23. Steiner, D., *The Technological Requirements for Power by Fusion*, Nuclear Science and Engineering, Vol. 58 (1975), pp. 107-165.

24. Drummond, J. E., *Thermal Stability of Earth's Ionosphere under Power Transmitting Satellites*, IEEE Transactions of Plasma Science, PS-4, p. 228.

25. Perkins, F. W., and E. J. Valeo, *Thermal Self-Focusing of Electromagnetic Waves in Plasmas*, Physics Review Lett. 32, 1234 (June 1974).

26. Glaser, P., *Power from the Sun: Its Future*, American Association of Advanced Science, Vol. 162 (Nov. 22, 1968).

27. Ehricke, K. A., *Space Flight*, Vol. II, Dynamics. Van Nostrand Publishing Company, New York (1962).

1. Therapeutic and Recreational Possibilities
2. Science—Intensive Space Activities

SPACE OPPORTUNITIES
HUMAN ACTIVITIES

SPACE OPPORTUNITIES - HUMAN ACTIVITIES

The possibilities for large-scale human activities in space have excited man's imagination for generations and still make the headlines far more frequently than the most other facets of the Space Program. Space colonization has many similarities to *space industrialization*, but with a fundamentally different motive. It is our opinion that a flourishing *space industrialization* program will do much to turn these dreams into reality, but over a longer interval of time than is envisioned by the standfast advocates of space colonization.

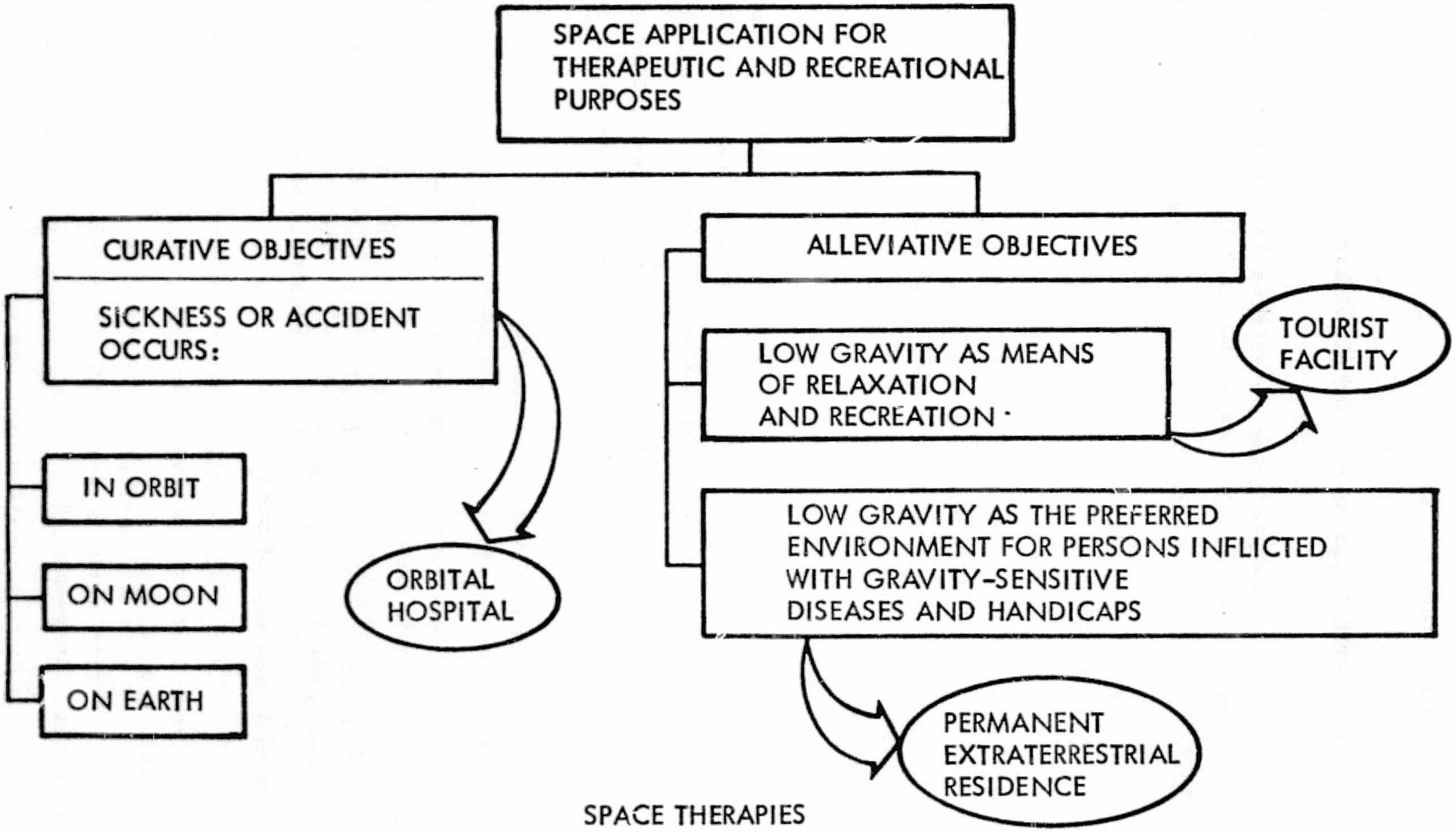
Eventually, man will return to the moon — probably first to acquire oxygen for inter-orbit transport and later to acquire other materials such as aluminum and silicon. However, the timing and the justification for renewed lunar activities will come as a result of genuine needs rather than as a result of the desire for lunar exploration for its own sake. Of course, in the same time frame there will also be human activities in space closer to the earth.

THERAPEUTIC AND RECREATIONAL POSSIBILITIES

Space medicine is one intriguing aspect of life science technology as practiced in space. The category of experiments that would foster this advanced technology comprises biomedical and behavioral research, man/system integration, life support and protective systems development. The goal of these activities is to develop a full understanding of Man's reaction to the spaceflight environment in order to determine not only his role and function in long-duration spaceflight, but also the prospects of utilizing space for therapeutic purposes.

Broadly speaking, the objectives of therapeutic utilization of space can be divided into two categories: <u>curative</u> and <u>alleviative</u>. (See Figure 89.) Physiologically speaking, the human body is a chemical factory in equilibrium with its environment. Extremes in the environmental continuum produce specific reactions as the body attempts to adjust to the characteristics of its immediate environment. The most important extreme contributed by the space environment is, of course, variable gravity down to null-gravity. The gravity level produces definite and specific physiological changes. The full extent of these changes is not yet known and, therefore, their therapeutic effects, if any, cannot yet be assessed with confidence.

However, some possible or even probable space therapies can be recognized even today. If the more important of these, plus a few that are not yet recognized, become viable, the orbital dispensary for space crews could conceivably evolve into full-fledged orbital hospitals. In that case, an appropriate *ambulance shuttle* capability might be developed, consistent with the requirements for transporting sick people into space who have greatly reduced physical tolerance. However, another possibility is the *packaging* of the patients so that they could withstand the g-levels of the Space Shuttle for the brief interval of flight into space. For tourist traffic, of course, much less stringent requirements could be imposed. Indeed, the flight environment of the present Shuttle may be adequate.



SPACE THERAPIES

- RELIEF OF HEART PUMP LOAD
- RELIEF OF HYPERTENSION
- RELIEF OF FLUID BALANCE PROBLEMS
- CORRECTION OF FAULTY MUSCLE CONTROL
- CORRECTION OF MALFORMED BONES
- RELEASE OF PINCHED NERVES AND DISKS
- CONTROLLED OVERGROWTH FOR SURGICAL IMPLANTS

Figure 89. Therapeutic and Recreational Activities in Space

SCIENCE-INTENSIVE SPACE ACTIVITIES

The recreational and therapeutic applications of space may be one promising outgrowth of a basic life sciences program. Others may involve the development of materials and the development of new breeds of plant and animal life in space. The basic goal of a life sciences program must be based on a solid data base and a solid knowledge base provided by the life sciences program itself.

The Shuttle Orbiter, the Spacelab and the Biosatellite are obvious tools for such a program. In addition, a mini-space station or a related type of space habitat will be required. This, in turn, implies a need for the assembly and handling of large structures in space.

Some of the implementations of such a program are summarized in Figure 90. As can be seen, they cut through the fields of biochemistry, biology, physiology, medicine and even psychology. They should result in new capabilities, new products, and new tools (e.g., space suits and transportation systems) which will be highly useful to many other goals of *space industrialization*.

END OBJECTIVES	UTILIZE SPACE ENVIRONMENT FOR BETTER UNDERSTANDING OF LIFE PROCESSES, PHARMACEUTICAL PRODUCTS, FOR HUMAN INVOLVEMENT IN SPACE INDUSTRIALIZATION, FOR THERAPEUTIC PURPOSES AND EXOPONICS
PROGRAM	SPACE LIFE SCIENCES
MAJOR TOOLS	• SHUTTLE ORBITER • SPACELAB • BIOSATELLITE • MINI-SPACE STATION
IMPLEMENTATION	• SPACE ENVIRONMENTAL EFFECTS ON BASIC LIFE PROCESSES IN PLANTS, ANIMALS, MAN • UTILIZE SPACE ENVIRONMENT FOR CONTROLLED CHANGES IN PHYSIOLOGY, BIOLOGY, GENETICS OF LIFE FORMS • ISOLATE VITAL HORMONAL, BLOOD, GENETIC SUBSTANCES AND LAY THE BIOLOGICAL FOUNDATIONS FOR A PHARMACOLOGY OF SPACE • DEVELOP MEDICAL STANDARDS (INCL. RADIATION PROTECTION) FOR ORBITER PILOTS AND IN-SPACE PERSONNEL • DEVELOP ADVANCED LIFE SUPPORT SYSTEMS & SPACE SUITS FOR EVA • DEVELOP MEDICAL STATIONS AND EMERGENCY TREATMENTS FOR SPACE PERSONNEL • CONTRIBUTE TO SPECIFICATIONS FOR DESIGN & OPERATION OF FUTURE SPACE STATIONS AND ORBITING CONSTRUCTION BASES • IDENTIFY SPACE THERAPEUTICAL METHODS OF PROVEN EFFECTIVENESS AS BASIS FOR FUTURE ORBITING HOSPITAL • SET MEDICAL SPECIFICATION AND CONSTRAINTS FOR AN AMBULANCE SHUTTLE • DEVELOPMENT OF FOOD PRODUCTION IN ORBIT AND ON THE MOON (EXOPONICS)

Figure 90. Science-Intensive Space Activities Serving Basic Terrestrial Needs – 3

Rockwell International
Space Division