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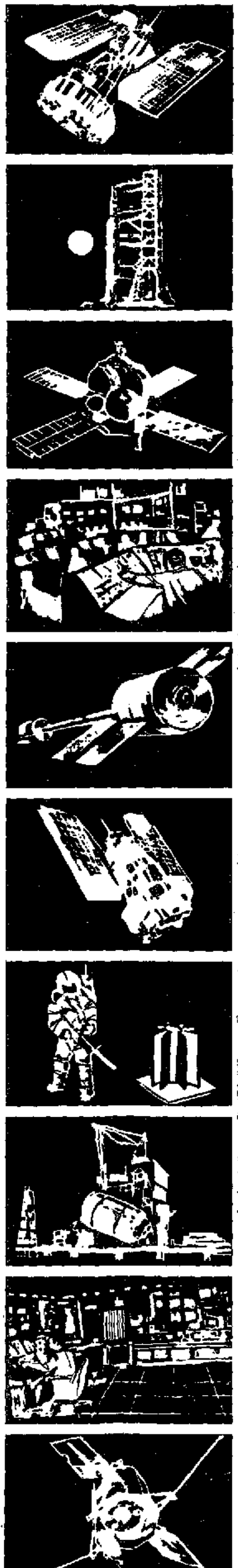

DIN 73SD4259

STUDY FOR IDENTIFICATION OF BENEFICIAL USES OF SPACE

(PHASE I)

FINAL REPORT - VOLUME II, BOOK 1
TECHNICAL REPORT - INTRODUCTION, METHODOLOGY, RESULTS

CONTRACT NAS8-28179

APRIL 23, 1973

SUBMITTED PER DPD #296,

DR #MA-04

GENERAL ELECTRIC

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STUDY FOR IDENTIFICATION OF BENEFICIAL USES OF SPACE (B.U.S.) (PHASE I)

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FINAL REPORT – VOLUME II, BOOK 1
TECHNICAL REPORT – INTRODUCTION, METHODOLOGY, RESULTS

SUBMITTED PER DPD #296, DR #MA–04

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PREFACE

This Final Report on Phase I of the Study for Identification of Beneficial Uses of Space (B.U.S.) is comprised of two volumes:

Volume I	-	Executive Summary
Volume II	-	Technical Report

Volume II is further subdivided;

Book 1	-	Section I, Introduction; through part of Section III, Specific Study Results.
Book 2	-	Remainder of Section III, Specific Study Results; through Section IV, Conclusions and Recommendations.
Book 3	-	Section V, Appendices A through F.
Book 4	-	Section V, Appendices G through N.

Phase I of the Study was conducted from December 1971 to December 1972 by General Electric's Space Division under contract from the Marshall Space Flight Center. Ninety-one working meetings were held with over 400 individuals representing a broad spectrum of U.S. technological capabilities. Participating commercial industries covered such diverse businesses as Aircraft, Building, Chemicals, Electrical Equipment and Utilities, Food, Metals, Paper, Petroleum, etc., Government agencies, universities, and research institutes have also contributed by providing support in such areas as Health, Oceanography and Economics. The methodology employed in gaining and maintaining this technological support, and the results of this effort are reported herein.

These participants initially identified over 100 Ideas for potential products, processes and services which might advantageously be developed or produced in space facilities. Further analysis reduced the number of Ideas by an order of magnitude, with those remaining representing a wide variety of technologies, ranging from high specificity separation techniques, tungsten X-ray targets, and surface acoustic wave components, to testing of prototype fractional horsepower electric motors.

Publication of this report neither implies NASA endorsement of any specific Idea generated during the B. U. S. Study, nor a NASA commitment to pursue any program based on these Ideas.

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SECTION I

INTRODUCTION TO TECHNICAL REPORT

This volume of the Final Report on Phase I of the Study for Identification of Beneficial Uses of Space contains the consolidated information developed during nearly a year's effort on that phase of work. Previous interim reports have, at various times, documented various stages of the study methodology, the current results obtained by that methodology, as well as sundry conclusions and recommendations we have derived from the overall effort. This portion of the Final Report is an orderly recapitulation of that information, updated with the latest inputs, and backed by the appropriate data, rationale, and analysis. In addition, we have provided, in Books 3 and 4 of this volume, copies of the original reports issued by Key Individuals who have analyzed various aspects of the Ideas generated during the Study.

The purpose of the Technical Report is to provide, for NASA and for potential Users:

1. An exposition of the Study methodology for possible future use in uncovering additional Ideas for space products, processes and services.

2. A data bank of such Ideas, which have been identified during the Phase I Study by specific organizations representing a wide spectrum of U.S. technologies.

3. Finally, the compilation of information,derived from analyses of these Ideas, that can serve as a baseline for planning of experiments, construction of program plans, and assembly of future business plans.

Because this reports incorporates the latest versions of data, analyses, etc., it supersedes all previously issued reports, presentations, etc.

I.1 REVIEW OF STUDY BACKGROUND

Previous analytical and experimental work, mainly performed or contracted by NASA-MSFC*, **, *** since 1966, has established the potential feasibility of a number of space processes. The possibility that such processes could be utilized to develop or produce new or better products, processes, or services for the public has been recognized by NASA, which has communicated that possibility to the U.S. technological community.

When combined with the relatively economical, frequent and safe transportation into space via the Space Shuttle, such processes are expected to offer the non-aerospace sector of the community the opportunity of exploiting new avenues of technology - to become Users of the space environment.

In further effort to stimulate serious consideration of such exploitation, NASA has engaged General Electric (GE) to conduct this Study in a program to search out such Users and, through a mutually supportive effort, to ascertain their applicable interests. Briefly, the program has required GE to devise and exercise a methodology which gained and maintained the participation of organizations in identifying specific non-aerospace products, processes and services that could be produced or developed in space for use by the public on the ground.

Guided by the prescribed Study Theme (Figure I-1) and Objectives, (Figure I-2) GE's overall method has drawn on a variety of its company resources to assess, first, the specific potential interests of specific internal organizations. Subsequently, through interfaces established with outside organizations representing nearly all the nation's basic industries, we have sought the same types of specific data from specific organizations external to GE.

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*Wuenscher, H. F., "Manufacturing in Space," Aeronautics and Astronautics, September, 1972.

**Wuenscher, H. F., "Manufacturing Technology Unique to Zero Gravity Environment, NASA-MSFC Symposium, November, 1968.

***Wuenscher, H. F., "Space Processing and Manufacturing," Symposium Papers, NASA-MSFC, October, 1969.

IDENTIFY PRODUCTS, PROCESSES OR SERVICES THAT WILL BE BEST DEVELOPED OR PRODUCED IN THE UNIQUE ENVIRONMENT OFFERED BY FUTURE SPACECRAFT

AND WILL BE USED DIRECTLY ON EARTH.

Figure I-1. Study Theme

- IDENTIFY SPECIFIC USERS OF SPACE KNOWLEDGE AND CAPABILITIES
- IDENTIFY SPECIFIC KNOWLEDGE OR CAPABILITIES REQUIRED BY USERS
- CORRELATE KNOWLEDGE OR CAPABILITIES WITH USERS
- ASSESS POTENTIAL BENEFITS TO BE DERIVED FROM USING KNOWLEDGE AND CAPABILITIES

Figure I-2. Objectives

A focus to GE's effort was established through the imposition of an initial constraint on the categories of products, processes and services for which the Study was to be carried out. Those categories are shown in Figure I-3.

CATEGORIES TO WHICH STUDY WAS INITIALLY CONSTRAINED
• COMMERCIAL PRODUCTS
• NEW MECHANICAL OR CHEMICAL PROCESSES
• IMPROVED MEDICINES
• NEW MEDICAL PROCEDURES AND EQUIPMENT

Figure I-3. Categories to Which Study Was Initially Constrained

As the Study progressed, review meetings were held with the NASA Steering Committee for the Study and with the GE Executive Advisory Group. From the critical review of methodology and data carried on at such meetings, we received additional direction, further insight into Study goals, and questions which reflected differences in individual committee and group member's viewpoints.

Although the statements in Figure I-4, extracted from those reviews, reflect definitive views on intent and desires for the Study, as well as on issues raised concerning post-study needs, the questions noted, particularly on current results, need some explanation. Basically, the questions were aimed at assuring the validity of the Study methods and approach. Thus, it is important to summarize the steps and facets of our methods and approach which answer those questions:

- As to the question of problems being overshadowed by space capabilities: User organization personnel generally were driven by their parochial technical problems rather than the limitations or capabilities of space. This is clearly evident in the following portion of this section where a large number of identified Ideas are noted as "terminated" for such reasons as "no requirements/properties match," "no apparent advantage to space operations," and "outside study constraints".

STUDY INTENT

". . . AN EXPERIMENT . . . IN SOPHISTICATED MARKETING FOR NASA"
". . . . . . TO CREATE SOME INITIATIVES IN PRIVATE COMPANIES"
". . . GOOD INFORMATION EXCHANGE BETWEEN NASA AND INDUSTRY"

DESIRED RESULTS

". . . STEPS (DEMONSTRATIONS, ANALYSIS, EXPERIMENTS, ETC.) NEEDED TO PERFECT IDEAS"
". . . VERY FORTUNATE IF WE COME UP WITH ANY NEW INNOVATIONS"
". . . HIGH TECHNOLOGY"
". . . NOT . . . ARBITRARY RESEARCH"

CURRENT RESULTS

". . . PROBLEMS OVERSHADOWED BY . . . . SPACE CAPABILITIES"?
". . . USERS CHALLENGING PROBLEMS"?
". . . STAFF HAVE ENOUGH TECHNICAL BACKGROUND"?
". . . LOOKING FOR PHYSICAL LAWS EARLY, TO DETERMINE IF SOLUTION IS FEASIBLE OR . . . POSSIBLE"?
". . . DISCARDING TOUGH PROBLEMS . . . ."?
". . . MORE ANALYSIS EARLY IN STUDY . . ."

POST-STUDY ISSUES

"GE AEROSPACE WON'T DO THE RESEARCH . . . . PEOPLE OUTSIDE OF AEROSPACE TO DO . . . RESEARCH . . . REQUIRED"
". . . NASA/INDUSTRY RELATIONSHIPS"?
". . . RISK VS INVESTMENT . . . BUSINESS PLAN"

Figure I-4. Steering Committee and Advisory Group Comments

- On challenging of problems and on technical depth: Our method of reviewing identified Ideas at subsequent meetings with other Key Individuals and with supporting personnel from GE Laboratories provided Study procedures for both challenging the Ideas, and for application of pertinent technical expertise.

- The question on review of physical laws: Such analyses within the technical disciplines involved in identified Ideas were extremely limited during the Study. Available time and funding constrained such in-depth treatment, and a very preliminary treatment is implied by the work "Identification" in the Study title. The Steering Committee agreed that the necessary in-depth analyses were properly a function of later studies. On the other hand, technology reviews of varying extent were held for each Idea to assess its applicability to the Study.

- Relative to the discarding of problems: To be sure, many of the identified Ideas were eventually dropped - not because the problems involved were difficult, but for specific technical reasons or mismatch with study ground rules as noted in Section I. 2. 1 of this report.

- The question of NASA/Industry post-Study relationships has major business rights and investment implications, particularly to the commercial sector of Industry. This subject is discussed in depth in Section II.

I. 2 SUMMARY OF THE STUDY

In compliance with the documented aims and guidelines of the Study as well as with direction provided by both the NASA C.O.R. and the NASA Steering Group for the Study, GE gained the participation of organizations representing a broad spectrum of U.S. technology, (see Figure I-5).

The success of that critical portion of the Study is due, largely, to GE's broad business base. That base, supported, typically, by 34 major laboratories, provided direct access to and support from, knowledgeable key GE individuals in a wide variety of disciplines and technologies. Furthermore, the 3400 different product lines currently in that business base have linked (either as buyer or supplier) GE to many other companies. Such links have been instrumental in establishing interfaces with organizations possessing Key Individuals in additional disciplines and technologies.

I. 2. 1 SPECIFIC USERS AND USES

The 80 organizations listed in Figure I-5 contributed to the Study through supporting meetings, analyses, reports, etc., involving 403 Key Individuals of those organizations.

As a result of such participation, 120 Ideas were initially noted by the Key Individuals as possible products, processes and services which might better, or only, be developed or produced in space facilities. Although such Ideas generally fit into the designated categories of the Study, as shown in Figure I-6, there were, as expected, some Ideas which generated no further discussion beyond their initial mention. The 19 Ideas so noted covered such subjects as generalized phenomena (magnetic field changes, Peltier cooling, Optical dipole dispersion, high voltage arcing, etc.), instruments and sensors (oceanographic sensors and electron microscope), materials (lithium, aluminum, ruby and sapphire, oxides), components (transducers, imaging tubes, low drift gyros), etc. The remaining 101 Ideas, when subjected to probing dialogs, increasingly rigorous examination and analyses in the specified tasks of the Study, were eventually filtered to 12 Ideas of potential merit. An overview of the disposition of these 101 Ideas during the Study is given in Figure I-7.

AIRCRAFT & AIRLINES
- EASTERN AIRLINES
- GE, (AIRCRAFT & ENGINE GROUP), (MATERIALS & PROCESSES LAB)

BUILDING
- KAISER ALUMINUM AND CHEMICAL
- ALUMINUM CORP. OF AMERICA
- GE, (ADVANCED HOUSING OP.), (CONSTRUCTION MATERIALS DIV.)

CHEMICALS
- PRINCETON ORGANICS
- WORTHINGTON BIOCHEMICAL
- AMCHEM DIV. OF ROHRER
- POLYSCIENCES INC.
- E.I. DuPONT
- ALUMINUM CORP. OF AMERICA
- KAISER ALUMINUM & CHEMICAL
- CHEVRON RESEARCH LAB. OF STANDARD OIL
- TENNECO CORPORATION
- APPLIED SCIENCE LABS
- FOOTE MINERAL
- EASTMAN KODAK
- IMPERIAL CHEMICAL CO.
- THIOKOL CHEMICAL CO.
- AIR PRODUCTS & CHEMICAL CO.
- A.H. THOMAS CO.
- SMITH, KLINE & FRENCH LABS
- CORNING GLASS WORKS
- PHILADELPHIA QUARTZ CO.
- GE, (CORPORATE R&D CENTER), (LAMINATED PRODUCTS DEP.), (LAMP GLASS DEP.)

ELECTRICAL EQUIPMENT
- CORNING GLASS WORKS
- SELAS CORP.
- GE, (APPLIANCE COMPONENTS LAB.), (ENERGY SYSTEMS PROGRAM), (INSULATING MAT'LS LAB.), (POWER GEN. DIV.), (HIGH VOLTAGE LAB.), (DIRECT ENERGY CONVERSION OP.), (LAMP PRODUCTS DEP.), (LIGHTING RESEARCH LAB.), (COMMERCIAL EQUIP. DEP.), (MAJOR APPLIANCE LAB.), (HERMETIC MOTORS DEP.), (SPECIALTY TRANSFORMER DEP.) (NUCLEAR ENERGY DIV.), (BATTERY BUSINESS SEC.), (ELEC. CAPACITOR & BATTERY PROD. DEP.), (INDUST. HEATING DEP.), (MEDICAL X-RAY DEP.), (MEDICAL DEVELOPMENT OP.)

ELECTRONICS
- OPTICAL SCANNING CORP.
- BECKMAN INDUSTRIES
- XEROX CORP.
- CORNING GLASS WORKS
- TEXAS INSTRUMENTS
- LEEDS AND NORTHRUP
- GENERAL ATRONICS DIV. OF MAGNAVOX
- HONEYWELL TEST INST. DIV.
- GE, (ELECTRONICS LAB.), (ELECTRONICS SYS. DIV.), (TUBE DEP.), (MEDICAL SYSTEMS DIV.), (ELECTRONIC COMPONENTS DIV.)

FOOD INDUSTRIES
- KRAFTCO
- CORNELL U. SCHOOL OF AGRICULTURE

MACHINERY & MACHINE TOOLS
- ALLEGHENY LUDLUM

METALS - NON-FERROUS
- ALUMINUM CORP. OF AMERICA
- KAISER ALUMINUM & CHEMICAL CO.
- GE, (LAMP METALS & COMPONENTS DEP.), (MAGNETIC MAT'L PRODUCTS SECT.), (METALLURGICAL PRODUCTS SECT.)

PAPER
- SCOTT PAPER CO.

PETROLEUM
- CHEVRON RESEARCH OF STANDARD OIL
- TENNECO CORP.

RAILROAD EQUIPMENT
- GE, (TRANSPORTATION DIV.)

RAYON
- E.I. DuPONT
- EASTMAN KODAK

RUBBER AND TIRES
- THIOKOL CHEMICAL CORP.
- E.I. DuPONT

STEEL AND IRON
- ALLEGHENY LUDLUM

BASIC INDUSTRIES NOT REPRESENTED:

AUTOMOBILES, CEMENT, COAL, COTTON, LEATHER AND SHOES, LIQUOR, LUMBER AND PLYWOOD, MEAT PACKING, RETAIL TRADE, SHIPPING AND SHIP BUILDING, SUGAR, TOBACCO.

OTHER PARTICIPANTS:

UTILITIES:	PHILADELPHIA ELECTRIC CO., PUBLIC SERVICE GAS & ELECTRIC
RESEARCH:	GULF UNIVERSITIES RESEARCH CORP., SCRIPPS INSTITUTE OF OCEANOGRAPHY, NATIONAL BUREAU OF STANDARDS, NATIONAL INSTITUTES OF HEALTH, UNIVERSITY OF MINNESOTA CHRONOBIOLOGY LAB., UNIVERSITY OF UTAH, DIVISION OF ARITIFCIAL ORGANS, GE (SPACE SCIENCES LAB)
SERVICES:	AMERICAN BIOMEDICAL CORP., GE (CONSULTING SERVICES), DREXEL UNIVERSITY

*PER MOODY'S INDUSTRIAL MANUAL - 1972

Figure I-5. Nation's Basic Industries* Represented by B.U.S. Studies

STUDY CATEGORY	NUMBER OF IDEAS NOTED
COMMERCIAL PRODUCTS	52
MECHANICAL/CHEMICAL PROCESSES	54
IMPROVED MEDICINES	4
MEDICAL PROCEDURES/EQUIPMENT	11
OUTSIDE OF STUDY CATEGORIES	2
	123*

*IDEAS TOTAL 120, BUT SEVERAL FIT 2 OR 3 CATEGORIES.

Figure I-6. Categorization of Ideas Initially Noted by Participants

Although details on each of the 101 Ideas are given in the body of this report, Section III, discussion of the various reasons listed in Figure I-7 for terminating work on Ideas is appropriate here. Thus, the following explanations apply to Figure I-7.

Analysis Indicates Not Feasible. Ideas terminated for this reason were found, upon further dialogs or deeper investigation, to depend upon a questionable technique or phenomenon. For example, single crystal lamp filaments, which require multiple helixes of 18 inches and longer, fall into this category, since projected state-of-the-art indicates low likelihood of growing crystals in helical shape.

STATUS	COMMENTS	IDEAS
TERMINATED	ANALYSIS INDICATES NOT FEASIBLE	2
TERMINATED	GENERAL	8
TERMINATED	NO REQUIREMENTS/ PROPERTIES MATCH	7
TERMINATED	APPEARS RESEARCH	4
TERMINATED	NO APPARENT ADVANTAGE TO SPACE OPERATIONS	17
TERMINATED	SPECIFIC USER NOT IDENTIFIABLE	7
TERMINATED	SPECIFIC REQUIREMENT NOT IDENTIFIED	18
TERMINATED	INCORPORATED INTO OTHER IDEA	7
TERMINATED	COVERED IN RELATED STUDY	5
TERMINATED	OUTSIDE STUDY CONSTRAINTS	2
TERMINATED	RECOMMEND FURTHER CONSIDERATION	12
CONTINUING	IDEAS SUPPORTED BY STUDY	12
NINETEEN IDEAS WHICH WERE MENTIONED ONLY INITIALLY, AND FOR WHICH NO FURTHER INTEREST WAS EXHIBITED ARE EXCLUDED FROM THIS TABULATION		

Figure I-7. Disposition of Identified Ideas - Total Number of Ideas Generated - 101

General. Ideas were terminated because of their generality, since the key word documented in Study objectives is specific. Ideas on such subjects as lyophilization, uniform dispersions, fiber reinforced composites, cemented composites, etc., for which no specific applications were identified, fall into this category.

No Requirements/Properties Match. When dialogs and analyses could identify no "property" of the space flight environment which could ameliorate or solve a specific problem inhibiting the development or production of an identified product, process or service, the idea was discarded. Typically, this category includes improved properties in transformer materials, improved materials for gas turbine mechanisms, silicon steel with better electrical characteristics, edge bonding of plastic sheet, etc.

Appears Research. Based on the NASA Steering Group directive to avoid, for this Study, Ideas which were research-oriented rather than applications-oriented, we eliminated several identified ideas. These include bone growth in zero "G", cavitation and surface wetting phenomena, mutation and growth of microorganisms, development aid in phono-cardiology.

No Apparent Advantage to Space Operations. Those Ideas for which space development or production were feasible, but for which dialogs and/or analyses could not identify significant economic, sociological or other advantages through such development or production, were eliminated. Typically such ideas include lead wire and filament materials for high intensity lamps (the higher purity and decreased grain boundaries were judged to offer little economic gain over present metallurgical "pinning"), magnetron tube manufacture (unlimited vacuum availability via shuttle would be too late for peak 1975 market, and harder vacuum offers only minor tube life gains), etc.

Specific User not Identifiable and Specific Requirement not Identified. Again, in compliance with the requirement for specifics, Ideas which were generated and discussed, but for which Users were subsequently not willing or able to be identified, were dropped. Similarly, Ideas which could not be related to a User need were also dropped. Ideas in this category which appeared to offer potential advantages were added to our repertoire for discussion with other Key Individuals. Ideas terminated under these categories include affinity chromatography, microsphere spectroscope and spectroscopy, plating of porous structures, coating of optical reflectors, improved dairy products, etc. Some of the Ideas in this category may be worth future reconsideration.

Incorporation into Other Idea. After some study, several identified Ideas were noted to be logically part of, or closely related to, other ideas, and were thus combined. Typically such ideas included development of high temperature/high strength alloys and eutectics (partially incorporated into Idea on gas turbine buckets), stress-free glass castings (included in an Idea on amorphous glasses), silicon impurities removal (included in an Idea on large silicon crystals), etc.

Covered in Related Study. When available information indicated related studies were providing benefits data related to some identified Ideas, we tended to discontinue our effort on such Ideas. Thus, we stopped efforts on gallium-indium-phosphide crystal growth (covered in "Economic Analysis of Crystal Growth in Space," NAS8-27942), viral insecticide manufacture (covered in "Manufacturing in Space" by L. McCreight and R. Griffin), improved vaccines (also covered in "Manufacturing in Space"), etc.

Outside Study Constraints. Two identified Ideas, which fell outside the areas noted in the Work Statement for this Study were referred to the NASA-C.O.R. for future consideration. These Ideas were on enhanced solar insolation, and safe disposal of radioactive wastes.

Recommend Future Consideration. A number of identified Ideas appeared to have considerable technical merit, but could not be completely evaluated because of a reasonable limitation on the number of organizations that could be contacted in the time frame of the Study, and the late surfacing of some Ideas. As a result, efforts were terminated on such Ideas as growth of eutectics for cold cathodes, higher purity fiber optics, improved bonding of wafers in fluidic stacks, large germanium crystals for gamma ray camera, etc.

Ideas Supported by the Study. Twelve Ideas, listed in Figure I-8, survived the dialogs, analyses, and evaluation carried on in the performance of this Study. This collection of Ideas form the backbone of the Study. The analysis of benefits was carried out for these ideas, as were the construction of time phasing, definition of driving requirements and commonality analysis.

SUBJECT	DESCRIPTION	USER/ KEY INDIVIDUALS
IMPRINTING CIRCUITRY ON CRYSTAL WAFERS FOR SURFACE ACOUSTIC WAVE ELECTRONICS	OPERATION IN MINIMUM-VIBRATION SPACE ENVIRONMENT TO IMPRINT CLOSELY-SPACED ($\frac{\lambda}{2}$ to $\frac{\lambda}{4}$) CIRCUIT ELEMENTS ON EXTREMELY HIGH FREQUENCY (> 30 GHz) ELECTRONIC COMPONENTS.	GE/S. TEHON, S. WANUGA
PARTICLE MANIPULATION BY SMALL FORCES	SEPARATION, EMPLACEMENT, ETC., OF MICRON-RANGE PARTICLES THROUGH SMALL FORCES GENERATED BY LIGHT, SOUND, HEAT, ETC., NORMALLY MASKED BY GRAVITY.	GE/H. SUMMERHAYES
VIBRATION TESTING OF SMALL MOTORS	ACQUISITION OF FRACTIONAL HORSEPOWER MOTOR VIBRATION DATA IN MINIMUM VIBRATION AND ZERO G ENVIRONMENT FOR CHEAPER AND MORE EFFICIENT DESIGN.	GE/F. PETERS, H. FRITZCHE, R. MacGREGOR
SINGLE CRYSTAL AND EUTECTIC HIGH TEMPERATURE TURBINE BUCKETS	GROWTH OF SUPER ALLOY AND REFRACTORY METAL CRYSTALS, AND SOLIDIFICATION OF EUTECTICS TO OBTAIN VIBRATION-RESISTANT, HIGH TEMPERATURE GAS TURBINE BLADES.	GE/L. JAHNKE, W. CHANG, L. TARSHIS
HIGH PURITY TUNGSTEN X-RAY TARGETS	LEVITATION MELTING AND COOLING OF TUNGSTEN TO OBTAIN UNIFORM X-RAY TARGETS WITHOUT CONTAMINANTS.	GE/W. LOVE
PRECISE SEPARATION OF RADIO ISOTOPES	USE OF SMALL FORCES TO OBTAIN MORE SPECIFIC SEPARATION OF RADIOISOTOPES FOR POWER AND MEDICAL USES.	GE/F. CHANNON, P. BROWN
SILICON CRYSTAL GROWTH	GROWTH OF LARGE CRYSTALS FOR POWER RECTIFICATION AND MEDICAL DETECTORS.	GE/R. HALL
EPITAXIAL GROWTH OF MAGNETIC BUBBLE MEMORY CRYSTAL FILM	GROWTH OF GARNET SINGLE CRYSTAL FILMS OF HIGH ACCURACY THICKNESS AND MAGNETIC PROPERTIES.	CORNING/G. SMITH, F. FEHLNER
AMORPHOUS GLASSES AND REFRACTORIES	LEVITATION MELTING AND SUPERCOOLING TO PRODUCE AMORPHOUS OXIDES WITH HIGHER IR TRANSMISSIVITY AND WITH SUPERIOR STRENGTH.	CORNING/G. SMITH, R. WASSON, J. MacDOWELL
BASIC HEAT TRANSFER DATA	MEASUREMENT OF THERMAL CONDUCTIVITY IN FLUIDS IN ABSENCE OF CONVECTION.	NATIONAL BUREAU OF STANDARDS/ PURDUE U., P. LILEY
SEPARATION OF ISOENZYMES	SEPARATION OF VERY SIMILAR ISOENZYMES WITHOUT DENATURATION THROUGH USE OF VERY SMALL FORCES AND LARGE PORE GELS FOR USE IN DIAGNOSIS AND THERAPY OF CERTAIN DISEASES.	POLYSCIENCES, INC./ B. HALPERN, K. AKKAPEDDI
UTILIZATION OF BIORHYTHMS	DETERMINATION OF RELATIONSHIP OF BIORHYTHMS TO TERRESTRIAL INFLUENCES FOR USE IN THERAPY, DIAGNOSTICS AND MODIFICATION OF HUMAN PERFORMANCE.	U. OF MINNESOTA/ NAT'L INSTITUTES OF HEALTH/ F. HALBERG, F. BARTTER

Figure I-8. Continuing Identified Ideas

I. 2. 2 BENEFITS

A brief summary of typical benefits for these 12 Ideas is given in Figure I-9, while the details on potential benefits associated with each Idea are documented in Section III. The benefits data documented herein must be considered conservative. Those data are, of course, speculative and optimistic insofar as being predicated upon successful solutions to the problems presently envisioned as inhibiting the production or development of the listed products, processes and services. On the other hand, not all the Ideas were completely analyzed for benefits in all areas and for all possible beneficiaries. Thus, the quoted values represent only some of the ideas and only some of the beneficiaries. Furthermore, conservative assumptions were utilized in calculating benefit values. For instance, space-developed or -produced products were not considered to be accepted and utilized by the total applicable market, but, rather, by only a small portion of that market, etc. Such conservative assumptions are noted in the body of this report, where applicable.

I. 2. 3 TIME-PHASING

Time-phasing of developments for the 12 continuing Ideas lost some of its value when an approved NASA future space program was not confirmed for use in the Study. The normal process of fitting User-desired experiments and tests into available "slots" of a planned program was, thus, omitted. The schedule given in Section III. 4 is based on assembly of User-generated timing of program elements. On that basis, a program to implement these 12 Ideas reflects a heavy emphasis on technology and discipline analyses in 1973 and 1974; an equally compact schedule of ground laboratory experiments in 1974 and 1975; and a wide variety of verification tests in the broad spectrum of ground, air, suborbital, and orbital test beds. The projected program indicates the possibility that all the Ideas could be brought to fruition in the 1981 to 1985 time period.

I. 2. 4 COMMONALITIES

Based on the rudimentary requirements data developed for analyzing the Ideas of this Study, a preliminary assessment was carried out of the potential commonalities among the implementation methods for the Ideas. The information available for such an analysis at this stage of development is such that a number of commonalities have been identified, but it

ECONOMIC VALUE OF NEW OR ADDED MARKETS: \$650 X 10^6 - \$1 X 10^9/YR.

FOR

- SURFACE ACOUSTIC WAVE COMPONENTS OF > 30 GHz FREQUENCY USED, FOR EXAMPLE, IN COMMUNICATIONS EQUIPMENT, AIRPORT AND AVOIDANCE RADAR.
- LONGER LIFE (1% TO 25%), QUIETER, LOW VIBRATION, FRACTIONAL HORSEPOWER ELECTRIC MOTORS.
- INCREASED AIRLINE PASSENGER REVENUE FROM (12%) WEIGHT SAVINGS OR THRUST INCREASE OF JET ENGINES UTILIZING HIGH TEMPERATURE SINGLE CRYSTAL OR EUTECTIC TURBINE BUCKETS.
- ELECTRIC POWER RECTIFIER DIODES UTILIZING 91 TO 182 KG/YEAR OF LARGE SILICON CRYSTALS - ALSO APPLICABLE TO LARGE, UNESTIMATED, MEDICAL DETECTOR MARKET.
- 53,000 KG OF MAGNETIC "BUBBLE" MEMORY DEVICES FOR COMPUTERS UTILIZING SINGLE CRYSTAL GARNET FILMS.
- LASER, THERMOGRAPHIC, RADIOGRAPHIC IR (5 TO 10 MICRON) OPTICS; AND SCIENTIFIC, LABORATORY, INDUSTRIAL GLASSWARE UTILIZING AMORPHOUS GLASSES.

ECONOMIC VALUE OF SAVINGS TO THE PUBLIC: ~ \$150 X 10^6/YR.

FOR

- SAVING OF REPLACEMENT COSTS THROUGH USE OF LONGER LIFE FRACTIONAL HORSEPOWER ELECTRIC MOTORS IN APPLIANCES, TOOLS, ETC.
- REDUCED FARES ON AIRCRAFT CAPABLE OF LARGER PAYLOADS THROUGH USE OF MORE EFFICIENT ENGINES DUE TO HIGHER (1650°C) INLET TEMPERATURE CAPABILITIES OF HIGH TEMPERATURE SINGLE CRYSTAL OR EUTECTIC TURBINE BUCKETS.
- SAVINGS IN REPLACEMENT OF X-RAY TUBES DUE TO FAILED (900/YEAR) TUNGSTEN TARGETS, BY USE OF HIGH PURITY TARGETS.
- SAVINGS IN COMPUTER USAGE COSTS THROUGH LOWER PRICED (< 0.01¢/BIT) "BUBBLE" MEMORIES USING SINGLE CRYSTAL GARNET FILM.

REDUCTION OF BALANCE OF PAYMENTS DEFICIT: \$122 X 10^6 - \$500 X 10^6/YR.

THROUGH

- REDUCED CRUDE OIL IMPORTS (47.6 MILLION BARRELS/YR) DUE TO JET FUEL SAVED BY EFFICIENCY OF AIRCRAFT GAS TURBINE ENGINES UTILIZING HIGH TEMPERATURE SINGLE CRYSTAL OR EUTECTIC TURBINE BUCKETS.
- INCREASED EXPORT OF HIGH PERFORMANCE JET ENGINES.
- EXPORT OF LARGE (100 TO 150 MM) SILICON CRYSTALS FOR POWER RECTIFICATION AND MEDICAL APPLICATIONS, "BUBBLE" MEMORY CHIPS, AMORPHOUS GLASSES, ETC.

OTHER BENEFITS

IN

- ADDED HUMAN COMFORT AND HEALTH FROM REDUCED VIBRATION AND NOISE, HIGHER RELIABILITY OF FRACTIONAL HORSEPOWER MOTORS DESIGNED FROM VIBRATION DATA OBTAINED IN SPACE FACILITY TESTS.
- REDUCED POLLUTION (7.8 X 10^6 KG/YR), OIL CONSERVATION THROUGH REDUCED NEED FOR JET FUEL BY AIRCRAFT ENGINES UTILIZING SINGLE CRYSTAL OR EUTECTIC HIGH TEMPERATURE TURBINE BUCKETS.
- MILITARY USE OF EXTREMELY HIGH FREQUENCY SURFACE ACOUSTIC WAVE COMPONENTS FOR RADAR AND COMMUNICATIONS, HIGH TEMPERATURE TURBINE BUCKETS FOR HIGH PERFORMANCE AIRCRAFT ENGINES, AMORPHOUS GLASSES AND OXIDES FOR OPTICS AND STRUCTURAL APPLICATIONS.
- DECREASED CHANCES FOR INJURY DURING X-RAY PROCEDURES THROUGH LOWER FAILURE PROBABILITY OF HIGH PURITY TUNGSTEN X-RAY TARGETS, AND FEWER RE-TAKE EXPOSURES.
- BETTER LOCATION AND IMAGES OF DISEASED TISSUE THROUGH USE OF MORE UNIFORM SILICON CRYSTALS.
- REDUCED DESIGN AND TEST EFFORTS, IMPROVED OPERATING CHARACTERISTICS AND COSTS OF EQUIPMENT INVOLVING FLUID THERMODYNAMICS THROUGH MORE ACCURATE DATA ON CONDUCTION IN FLUIDS IN ABSENCE OF CONVECTION.
- LIVES SAVED THROUGH EARLY DETECTION OF DISEASES (E.G., ~ 3,000 LIVES FOR BREAST AND CERVICAL CANCER) BY EMPLOYING HIGH SPECIFICITY ISOENZYMES SEPARATED IN LARGE PORE GELS.
- IMPROVED (+1.5%) WORK PERFORMANCE OF ROTATING SHIFT WORKERS AND MORE EFFICIENT LONG DISTANCE FLIGHT CREWS THROUGH KNOWLEDGE OF BIORHYTHM EFFECTS. ALSO IMPROVEMENT IN THERAPY.

Figure I-9. Typical Benefits Accruing from Potential Space-Produced or -Developed Products, Processes and Services must be cautioned that such presumed commonalities may not bear up under the closer scrutiny that should occur when more definitive data is generated in feasibility studies and concept definitions.

Typically, most of the Idea implementations appear to require zero "G" and to be equally insensitive to launch and orbit geometry. It is, of course, a fact that the zero "G" of orbital flight is not actually zero. The 10^{-4} to 10^{-10} "G" caused by residual drag in orbit may effect some of the implementation methods in minor to catastrophic ways, thus eliminating a presumed commonality. Similar situations exist for the high "commonality" hard vacuum, and contamination control. While the Study has identified these and other "commonalities", such identification is decidedly tentative.

I.3 SIGNIFICANT POINTS IN THE TECHNICAL REPORT

This Volume documents a number of key points resulting from the Phase I Study, which support the general Study conclusions listed below.

The validity of these conclusions is based on integration of the "Lessons Learned" in implementing the methodology employed in the Study, the response of participating Users, the data generated in such responses, and the essential information derived from User and Study Team analyses related to those data. The foregoing elements of the Study, depicted and discussed in specific Figures and Sections of this Report, are listed below in conjunction with the conclusions they support:

1. The dialog technique of eliciting non-aerospace User interest in space development or production of User-desired products, processes, or services, works well. The statement, of course, presumes utilization of the approach noted in Section II.1 in implementing the tasks of Section II.2 (as modified by the Lessons Learned).

2. We gained and maintained the active participation of a small, but representative, sample of U.S. technology. Figure I-5 lists 80 organizations, 72 of them in the nonaerospace sector, that participated in the Phase I Study. They represent 14 of the 27 Basic Industries. Four-hundred three of their Key Individuals met with us in 91 meetings, supplemented by over 1,000 telephone conversations and letters. The participating organizations listed in Figure I-5 represent over 90 percent of organizations initially contacted for possible participation. Even where no specific Ideas were identified at initial meetings, we frequently received subsequent telephone calls and letters to affirm continuing interest. Near the conclusion of Phase I, we continued to receive Ideas, some of which, we felt, warranted study, but which time constraints forced us to list as "terminated - recommend future consideration" in Figure III-1.

3. Given sufficient "gestation" time, selected types of organizations are willing and able to participate in "bridging the gap" between desired advanced non-aerospace products, processes, or services and the new capabilities offered in space. Of 120 Ideas noted in initial meetings with the participants, 101 Ideas for products, processes and services (listed in Figure III-1) warranted the further discussion given in Section III. Selection of the types of companies is discussed in Section II-1 and as before, the approach and methodology given in Section II are presumed.

4. Even at this early date, relative to shuttle operations, "specifies" of beneficial space uses can be identified, and planning for such application must begin. The 12 Ideas for specific products, processes and services, identified by specific Key Individuals of specific User organizations that have been carried through this

Phase I Study are listed in Figure I-8. Specific problem areas, needs, and issues to be resolved have also been identified in Section III. 1, as have the knowledge and capabilities required from Space operations to overcome such inhibitors. More importantly, perhaps, initial estimates of the development steps required to carry these Ideas to fruition has been attempted (see each Idea in Section III. 1, and the time-phasing in Section III. 4), and the results indicate the need to initiate early efforts and planning soon. Technology analyses, laboratory experiments, and ground and suborbital verification tests appear to be prime candidates for such treatment.

5. Commercial Industries appear to be as concerned about the administrative, legal and financial aspects of developing or producing products, processes, and services in space as the technical. Questions (Figure IV-2) raised in these areas by the various participants are seeking information which is logically a part of advanced business planning. That planning is comprised of three interactive analyses - technical, marketing, and resources. In order to arrive at decisions to pursue new ventures, such as space development or production, industry management must be able to assess the potential risk versus investment involved. The normal 5 to 10 year product planning efforts of most growth companies, coupled with the early R&D efforts previously mentioned, call for some early answers to these questions.

6. Specific potential benefits; economic, sociological, and other, are identifiable for specific space-developed or-produced products, processes and services. Working with particpating Users, we have, for a very limited sample of products, processes and services, and for representative "beneficiaries", identified such potential benefits (Figure I-9). The $\$1 \times 10^9$ new and added yearly markets, the $> \$150 \times 10^6$ yearly savings to the public, etc., are evidence of the likely economic attractiveness of space as a new commercial milieu. The potential medical benefits in the possibilities of at least several thousand lives saved per year, and improved diagnostic and therapeutic capabilities offer significant sociological gains, as does the case of possible reduction in atmospheric pollution.

   These estimated benefits are, of course, based on the optimistic assumption of successful development/production of the identified products, processes, and services. On the other hand, highly conservative assumptions have been made in estimating utilization factors of such products, processes and services.

7. Considerable analytical and experimental work must be accomplished before any of the Ideas documented herein can be considered feasible. The Phase I study called for "Identification" of Beneficial Uses of Space (Figure I. 1). The implication, subsequently reaffirmed in NASA Steering Group Reviews, was that in-depth, technical "analysis" of such uses was not part of the Study. The breadth of Users, goals, problem areas, Ideas, etc., to be investigated within the funding and time available precluded all but the most rudimentary investigation into the technology and disciplines involved in the Ideas identified. Although Section V - Appendices provides certain preliminary analyses, the bulk of detailed analyses, particularly

in such disciplines as fluid mechanics, thermodynamics, vibration, etc., must issue from later studies. For this Phase of Study, an Idea was accepted for "Identification" if it met all the Study requirements for "specific-ness"; if, in the judgment of the Study Team, the problems, needs, and issues that presently inhibited its completion could be justified technically by the experience of originating Key Individuals and other consultants; and if the Study Team could find a logical, potential match between such problems, needs or issues and the projected capabilities or knowledge our experience indicated could possibly be obtained in space. Thus, in lieu of the surer, more costly, more time-consuming technical analyses, we substituted User experience, and Study Team space judgment. In that light, it behooves the reader to exercise care in the use of the data contained herein.

More detailed conclusions, identified with supporting key points, will be found in Section IV.

I.4 SUMMARY OF RECOMMENDATIONS

As a result of the information generated during the Phase I Study, the four Quarterly Meetings with the NASA Steering Group, the three GE executive Advisory Group meetings, presentations to other NASA groups, and the dialogs with participating Key Individuals, there appear to be three categories of recommendations worthy of being considered. They are summarized in Figure I-10.

- DON'T STIR THE POT AND NOT FOLLOW UP."
  - MAINTAIN AND EXTEND USER CONTACTS
  - ANALYZE NEXT LEVEL OF STUDY IDEAS
- REVIEW RELEVANT NASA/GOVERNMENT POLICIES/POSTURE
- PUBLICIZE POTENTIAL AVAILABLE KNOWLEDGE/CAPABILITIES

  VS

  POTENTIAL PRODUCTS, PROCESSES,
  SERVICES AND BENEFITS

Figure I-10. Recommendations

The first category is headed by a quote from a NASA Steering Group Quarterly Review. The implication of the quote is that the momentum generated by the Phase I Study should not be allowed to deteriorate. The interest of non-aerospace organizations, vital to a broadly supported space program should be maintained. Among the alternative "follow up" recommendations were the following:

1. Continuation of the Phase I Effort

   Since the 80 participating organizations in Phase I are only a small percentage of possible users; since the methodology has been well exercised; and since the Lessons Learned during the Phase I effort have provided insight into more effective dialogs, such a continuation should uncover a higher percentage of worthwhile Ideas.

2. Initiation of Business Planning Studies with Participating Organizations

   For Ideas representing commercial products, processes, and services, such an effort would be aimed at demonstrating the standard technical, marketing and resource planning carried out by commercial industry in arriving at a decision to pursue new ventures.

   A major gain from such studies would be the establishment of required decisions and their timing, as well as the NASA/Industry relationships that must be resolved.

   One aspect of business planning that has been brought out in several meetings may warrant study in its own right--the cost of developing or producting specific products, processes or services in space. Such information was excluded from Phase I, and could likely impact the economic benefits derived therein for some of the Ideas.

3. Development of Experiment Requirements and Planning Data

   Essentially a limited compromise of increasing the technical information supporting Phase I ideas and providing planning information for industrial decision makers, this alternative will provide a follow-up of general utility to both NASA and the industrial participants.

   This alternative, for four continuing ideas of Phase I, has been accepted by the NASA C. O. R. as a Phase II Study. The Objectives, Study Logic, and Schedule for Phase II will be found in Section IV.

The second category of recommendations reflects commercial industry concern expressed by the questions in Figure IV-2 relating to NASA/Industry Legal, Administrative and Financial relationships in the event of commercial utilization of space facilities.

1. The recommendation is, thus, that NASA review the present policies and posture with regard to NASA/Industry relationships in the development and production of commercial products, processes and services in space in order to ascertain whether such policies and postures should not be modified. In any case, clarification and broad dissemination of NASA/Government intent regarding such relationships would be worthwhile from the viewpoint of establishing a baseline for business planning.

   Finally, lack of potential User's understanding of the information,conditions, operations, functions, etc., feasible for commercial exploitation in an orbiting facility has repeatedly surfaced during the Phase I Study. While not entirely unexpected, the universality of that deficiency was surprising.

2. NASA should, therefore, consider widening its public information campaign to include <u>the trade press of industries which likely could be Users of such facilities</u>. <u>Results of this Study could form a basis for selection of the appropriate media</u>. Data to be disseminated should stress, not so much the Shuttle or its Operation, but rather the <u>specific</u> conditions, capabilities, processes, etc., that the Shuttle will make accessible to the User in <u>each particular technological field</u>.

SECTION II

METHODOLOGY

This section is subdivided into two main portions.

1. Approach - the techniques utilized in implementing the mechanics of the Study.
2. Study Tasks - the mechanics, including the logic, of the Study, as modified by Lessons Learned (the aspects of the Study techniques, mechanics, pertinent background, etc., which, during the course of the Study, proved to be helpful or detrimental, and changes which improved, or could likely improve those aspects).

Although the aforementioned subjects form logical subdivisions, the considerable interplay between them during the Study results in the necessity to cross reference between them in the following discussions. For instance, the techniques utilized become very much a function of specific tasks, and modification of the techniques by certain of the Lessons Learned is of considerable importance. On that basis, the core of this Section is Section II.2, Study Tasks, which includes appropriate discussion of Approach and Lessons Learned as needed to exemplify and demonstrate the methodology.

II.1 APPROACH

The Study Theme (Figure I-1), Objectives (Figure I-2), and Categories (Figure I-3), open the study to such a breadth of User Interests, diversity of possible goals and objectives, variety of individuals and range of established advanced planning techniques that it was felt to be unlikely that a single, preplanned strategy would produce results of the desired scope. To compound that situation, the Study Team, though well versed in space knowledge, was bound to be lacking in many of the areas related to specific products, processes and services which were the province of specific Users.

On those bases, two major decisions were made:

1. To utilize a general and flexible Approach, as shown in Figure II-1 to initiate our efforts
2. To identify, and operate within, a set of roles for study participants which would utilize each to best advantage. The roles will be discussed shortly

SMALL, SPACE-ORIENTED CORE TEAM TO PROVIDE DIRECTION AND CATALYTIC ACTION THROUGH DIALOGS

WITH

BROAD GROUP OF DIVERSE, NON-AEROSPACE USER EXPERTS WORKING ON ADVANCED PRODUCTS AND PROCESSES.

THROUGH SUCH DIALOGS SEEK THE MATCH BETWEEN PROBLEMS INHIBITING DEVELOPMENT OF PRODUCTS, PROCESSES, AND THOSE SPACE "PROPERTIES" WHICH MAY ENABLE SOLUTION OF PROBLEMS.

KEY IS DIALOGS TO UNCOVER THE MATCH

NO SPECIFIC SET FORMULA. EACH CONTACT REQUIRES INDIVIDUAL TREATMENT

Figure II-1. Approach

The key to our Approach, as given in Figure II-1, was the program of dialogs carried on between the aerospace Core Team and the non-aerospace User organizations. These dialogs were initially "brainstorming" sessions in which we attempted to find a match between the technical problems, needs and issues inhibiting the User, and the unique advantages of space operations which could potentially overcome those inhibitions.

To be sure, such a "brainstorming" technique is not highly efficient. Many of the ideas that evolved were not relevant to the Study, others were not significant to the Users. The few that were viable were extracted through careful culling, carried out by the Core Team in consultation with Key Individuals. On the other hand, the dialog technique enabled us to establish a rapport with Key Individuals, not achievable with more efficient mass communication methods.

As the Study progressed, our technique improved. A NASA guideline for the Study was of considerable value in this process. That guideline required that initial Study efforts be carried out wholly within GE, or with outside organizations with whom operating relationships already existed. The anticipated candidness of Key Individuals from such related organizations provided the constructive criticism necessary to evaluate our Approach. Our essentially in-house developed technique was thus well exercised and modified, where required, before permission was given by the NASA C.O.R. to initiate outside contacts. Once the schedule of external contacts began, the cross-fertilization of Ideas between Key Individuals, their review of others' Ideas, and in-depth analyses of selected Ideas were utilized in identifying the more worthwhile Ideas. The analyses carried out by various Key Individuals proved especially useful. The frequent consultations required to "mesh" space capabilities, "properties", etc., with the technologies unique to the specific Ideas under study constructed a relationship of mutual support between the Core Team and various Key Individuals, and involved the Key Individuals and their organizations more deeply in the Study. Again, a NASA guideline for the Study proved advantageous here. That guideline called for subcontracting about one-half the Study effort to organizations outside the GE-Space Division. While, with the NASA C.O.R.'s permission, our subcontracting fell somewhat short of that goal, the ability to offer such subcontracts proved to be a stimulant to a number of organizations, who viewed that offer as evidence of the sincerity of the Study. Several of the organizations participating in the Study were sufficiently interested to carry on analyses without funding.

Although the preceding discussion cites general relationships among Study participants that were in effect during the Study, the specific roles and relationships that enabled our Study Approach to function are best pictured in Figure II-2. These include:

1. NASA. The C.O.R. has been the major functional interface with the Study. His decisions and approvals have provided the basic Study direction. In addition, his reviews have assured that the methods employed in the Study and the data resulting from the Study are consistent with NASA aims. The C.O.R's efforts have been supplemented with Quarterly Reviews held by the NASA Steering Group for the Study, wherein clarification of those aims, NASA-wide evaluation of Study results, and further direction for the Study have been developed. Although the main NASA interface has been with the Core Team, there have been occasional meetings of the C.O.R. and various NASA personnel with the GE Advisory Group, which have proved fruitful in developing mutual understanding of each others advanced planning methods.

2. General Electric Management Advisory Group. The Advisory Group comprised, mainly, of GE Vice Presidents in non-aerospace sectors of the company, provided an executive review function to assure the broad corporate view to the Study results. The Group, headed by Mr. Fink, General Manager of the Space Division, has

reviewed the Study at significant milestones and has communicated with the Core Team, with NASA and with cognizant GE personnel. Their corporate view and product area involvements have contributed to the realistic evaluation of corporate commitments for solved problems and for satisfied study requirements.

The active interest of company Vice-Presidents also proved of value in stimulating the interest and support of Key Individuals throughout the company. Furthermore, the Advisory Group was a major source of data on potential User organizations, Key Individuals, and goals and objectives, both within and outside the company.

3. Core Team. The Core Team has been the prime mover in this study and has provided the major interface with NASA. In leading the efforts of the key individuals participating in the study, the Core Team has maintained the direction of the study, developed the contacts, maintained the dialogs, integrated results, performed the necessary analyses and compilation of data, and prepared material as required for meetings and reports. Key functions in carrying out these responsibilities have been the establishment and maintenance of the flow of information to all key individuals, and the provision of the information exchange required to stimulate, and be evaluated by, the Key Individuals.

4. Key Individuals (GE Contacts, Experts and Spokesmen). The talents, ability and expertise of Key Individuals, representing a wide diversity of potential User areas, have been utilized directly throughout the study. For the initial study tasks, these individuals have primarily been recognized experts from the various commercial product and research laboratories of GE, together with selected non-GE individuals with whom a working relationship had already been established. However, during subsequent study tasks, additional individuals and organizations have participated. These experts and spokesmen, mainly from outside of GE, have been the key to the worth of the study. They have provided basic inputs to the study, have been provided with space experiment and implementation-oriented data, as required, and have been consulted on all critical study decisions regarding their areas of expertise. Such continuing dialogs have encouraged their active support, a key result of the study.

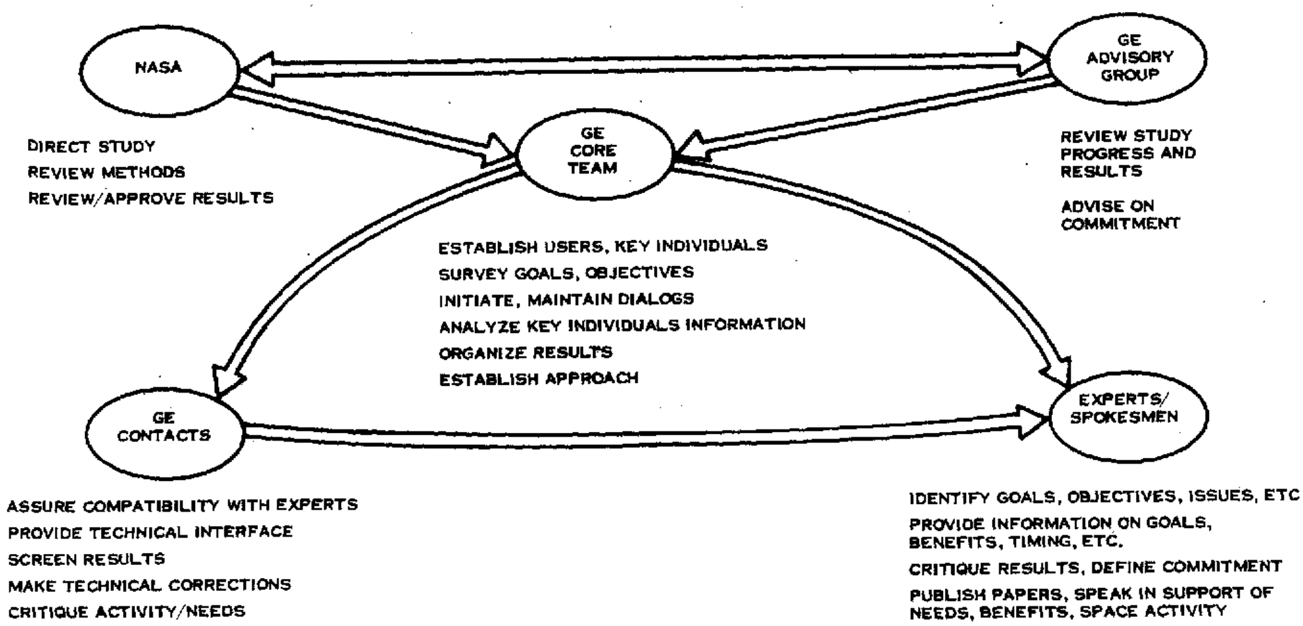

Figure II-2. Study Role and Relationships

II.2 STUDY TASKS

The contract for Phase I of the Study for Identification of Beneficial Uses of Space*, defined the overall tasks of the Study. In order to organize and initiate effort on those tasks, we analyzed them for work content and the information required to complete them. The results of that analysis were structured into a logic for the Study and into detailed direction of the work to be accomplished. The Logic and Tasks are discussed below.

II.2.1 STUDY LOGIC

The Study Logic, Figure II-3, derived from the objectives of the Study and the tasks given in the contract statement of work, is an expansion of those points of departure into definitive work packages at and below the subtask level. In addition, the Study Logic displays the flow of information among the subtasks. The logic, in relating the work packages and the information sources and sinks, provided all participants with a valuable overview of the places their particular data fit into the total scheme of the Study.

The relative importance of Task 1 as a data source for the remainder of the Study is exemplified by its breakdown to a level deeper than that of the other tasks.

As was expected, there was considerable feedback and iteration among the tasks and subtasks, particularly in the areas of time phasing, problem definition, knowledge/capability analysis, etc. Key feedback loops are shown. However, many have been deleted for clarity in presentation.

The first three subtasks of Task 1, which were carried on with GE personnel and others with whom working relationships existed, followed sequentially, and, as shown in the diagram, each subtask provided key results for NASA approval of further work.

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*A Study Entitled "Identification of Beneficial Uses of Space, Contract No. NAS8-28179, Purchase Request 1-1-21-00131 (IF), December 1971.

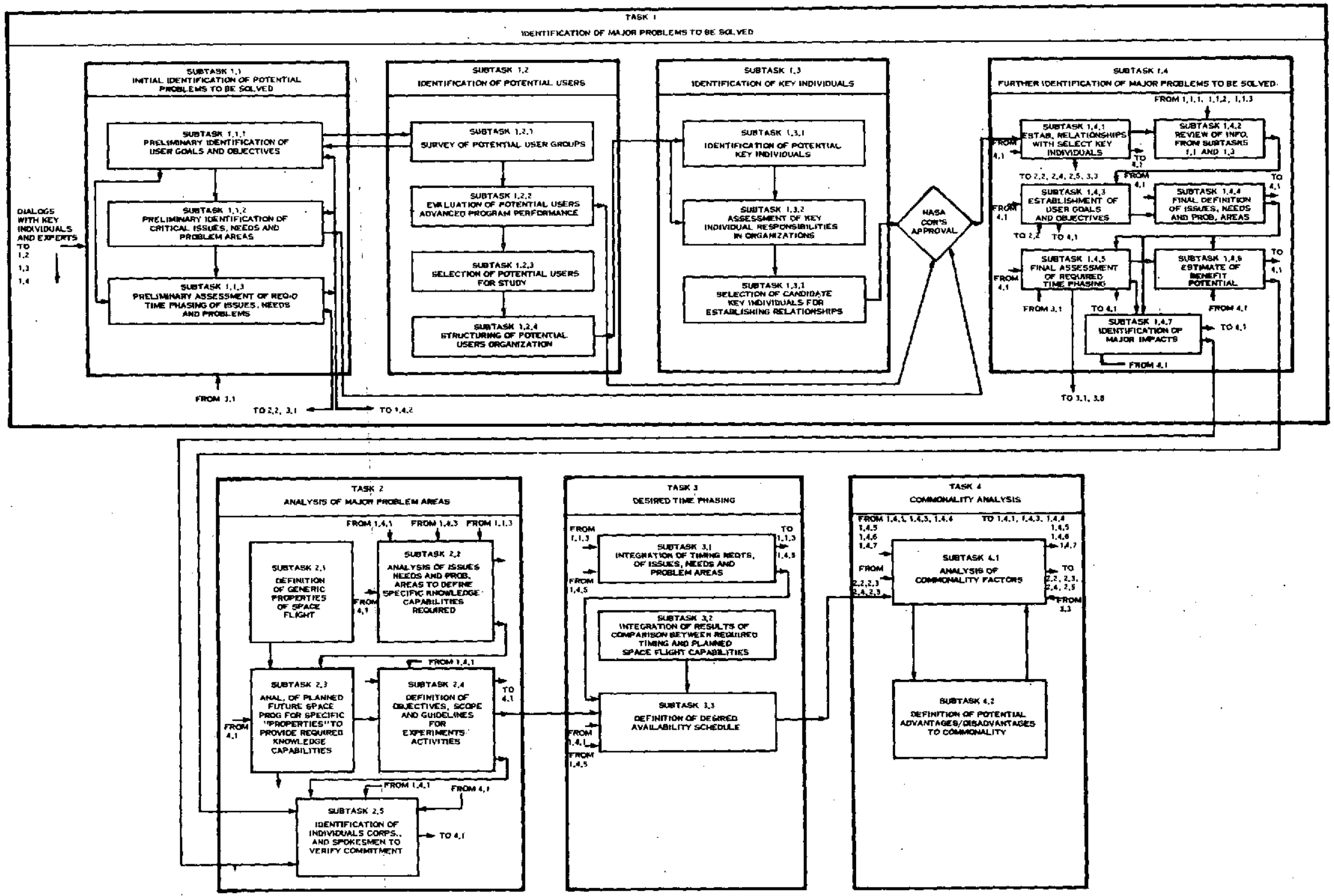

Figure II-3. Study Logic

Following NASA approval, the initial effort established and maintained relationships with Key Individuals outside of GE. Maintaining such relationships through dialogs concerning their areas of expertise was of major importance to the Study, because, as shown in the figure, their data offered potential impacts in all subsequent tasks.

II.2.2 TASKS

Although no set formula was established for acquiring and maintaining User participation in the Study, there was a mandatory requirement for specific data available in a general sequence in order to carry out the Study. The activities needed to meet that commitment are presented in the discussion of Tasks given below, and are summarized in the accompanying figures, which note the data needed, the methods utilized to obtain such data and the sources from which the data was obtained.

Task 1.0. Task 1 was carried out in two separate, sequential steps. The earlier Subtasks 1.1, 1.2 and 1.3, pictured in the upper portion of Figure II-4 were constrained by our contract to be carried out wholly within GE or with organizations with whom we had previously existing relationships. The subsequent Subtask 1.4, not so constrained, is depicted in the lower portion of the figure.

The basic information needed to initiate the Study evolved heavily from our analysis of current literature on industrial and governmental plans and projections. As noted in Figure II-4, from publications such as those which analyze national goals, federal funding, research and development in industry, utilities research and development etc., we obtained a broadly representative collection of the goals and objectives that the government, industry, institutes, and key analysts felt were important to continued improvement of the quality of life. Where such publications did not include the identification of specific organizations, specific needs, or the timing of those needs, we supplemented our literature survey with dialogs involving GE personnel associated with the advanced planning, new business, research, and forecasting functions. In any case, once we were able to identify types of organizations concerned with specific goals, needs, and timing, business literature enabled easy tabulation of candidate companies associated with each area of concern.

SUBTASK 1.1 INITIAL IDENTIFICATION OF POTENTIAL PROBLEMS

SUBTASK 1.2 IDENTIFICATION OF POTENTIAL USERS

SUBTASK 1.3 IDENTIFICATION OF KEY INDIVIDUALS

CONSTRAINT: WITHIN GE OR WITH SUBCONTRACTORS WITH WHOM WORKING RELATIONSHIP EXISTS

REQUIRED OUTPUTS	METHODS	SOURCES
USER GOALS AND OBJECTIVES CRITICAL ISSUES, NEEDS, PROBLEM AREAS PRELIMINARY TIMING	LITERATURE ANALYSIS	GOVERNMENT TRADE ASSOCIATIONS NEWS STUDIES
	DIALOGS	MARKETEERS MANAGEMENT BUSINESS PLANNERS KEY INDIVIDUALS COMPANY BUSINESS PLANS
USER GROUPS POTENTIAL USER ORGANIZATIONS	LITERATURE ANALYSIS	BUSINESS DIRECTORIES STOCKBROKER ADVISORIES
USER ORGANIZATION STRUCTURE		CO. ORGANIZATION DIRECTORIES
POTENTIAL KEY INDIVIDUALS INITIATION OF DIALOGS	DIALOGS	GE EXECUTIVES CONSULTANTS CONTACTS

SUBTASK 1.4. FURTHER IDENTIFICATION OF MAJOR PROBLEMS TO BE SOLVED

REQUIRED OUTPUTS	METHODS	SOURCES
RELATIONSHIPS WITH KEY INDIVIDUALS	DIALOGS MEETINGS TELEPHONE	CONTACTS USER MANAGEMENT DIRECT COMMUNICATION
REVIEW OF SUBTASKS 1.1, 1.3	DIALOGS	KEY INDIVIDUALS SUBTASK 1.1, 1.2, 1.3 RESULTS
USER GOALS AND OBJECTIVES	DIALOGS LITERATURE ANALYSIS	USER REPORTS KEY INDIVIDUALS
CRITICAL ISSUES, NEEDS, PROBLEM AREAS	USER ANALYSES (FUNDED, UNFUNDED)	"PROPERTIES" "SEEDS" "CLUES"
TIMING REQUIREMENTS	USER ANALYSES (FUNDED, UNFUNDED) DIALOGS	KEY INDIVIDUALS
POTENTIAL BENEFITS	USER ANALYSES CONSULTANT ANALYSES	CONSULTANTS KEY INDIVIDUALS
MAJOR IMPACTS	USER ANALYSES CONSULTANT ANALYSES	KEY INDIVIDUALS CONSULTANTS

Figure II-4. Task 1.0: Identification of Major Problems to be Solved

To obtain the required outputs noted in the upper portion of Figure II-4, expansion of, and deeper insight into, that information depended on dialogs with individuals involved in such areas. For instance, the selection of specific organizations outside GE for subsequent participation involved not only a review of trade journals in their specific business areas, and a review of their past and projected business performance (particularly in Research and Development), but also dialogs with various GE personnel familiar with those organizations.

Generally available corporate management structures, supplemented by dialogs with Key Individuals familiar with the performance and capabilities of a broad range of organizations, provided the necessary information for identifying Key Individuals in those organizations, and for enabling the subsequent contacts which initiated the dialogs required to perform the Study.

It became apparent, during work on Task 1.0, that an extensive hierarchy of potential users exists. Figure II-5 lists, on the left, the typical classes of users in that hierarchy. Typical examples of those classes given in the body of the figure, while not complete or all-inclusive, are intended to demonstrate the breadth and depth of that hierarchy.

We selected for contacts those levels of the hierarchy that we expected to provide the best opportunities for this Study, the organizations that are responsible for converting research information to advanced applications. These are shown enclosed in solid lines. Because most organizations are not rigidly segregated, however, and, because pursuit of a problem frequently led to other contacts, we also maintained dialogs with research organi zations and hardware groups, as shown enclosed by dashed lines.

At any given time, technical organizations toward the top of the hierarchy hold a technology lead over technical organizations toward the bottom. Thus, we learned that problems identified by lower level organizations must be traced upward through the organizational chain to see whether the problem is more basic than initially identified, whether a solution based on new technology is moving down the chain of organizations, and which organization is charged with solving the basic problem. After uncovering such circumstances, we found it efficacious

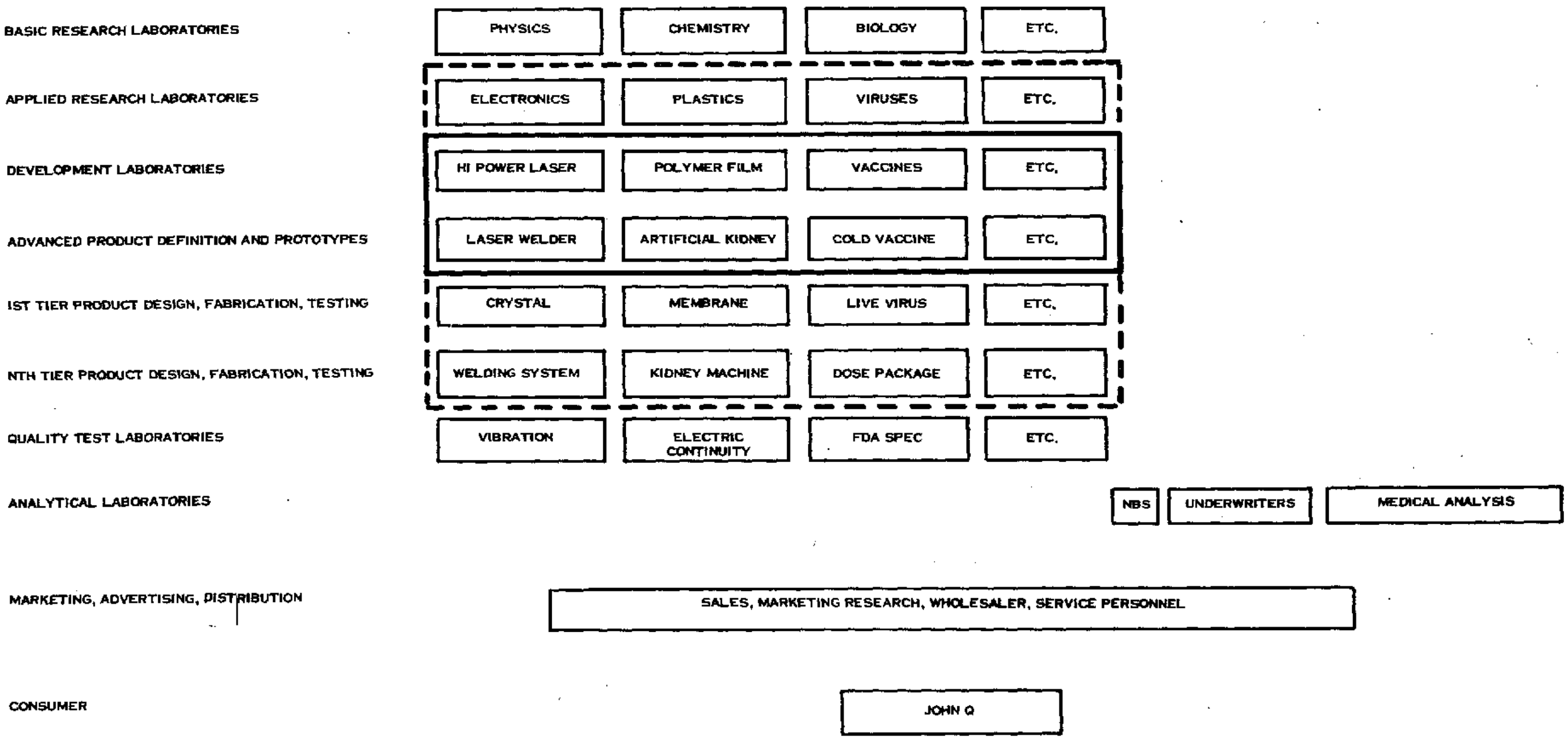

Figure II-5. User Hierarchy

to enlist the aid of contacts within and outside of GE and to consult with both technical and management personnel in order to ascertain cognizant organizations and individuals.

The key thread of the Study has been a series of sequential steps shown in Figure II-6, that starts with identified User Goals and Objectives. Recognizing that even the most simply defined goals and objectives can require a broad spectrum of complex technical, economic, and administrative efforts for their achievement, the first step of the analysis has been to break down each goal and/or objective into constituent, narrower endeavors. Each set of such constituents answers the questions "What critical issues must be resolved, what needs must be met, what problems must be solved, in order to accomplish the identified goal or objective? " This portion of the analysis has maintained an orientation toward issues, needs, and problems which might be amenable to contributions from future space flight capabilities. At this stage of analysis, this orientation was not imposed as an overly restrictive constraint, because other steps in the Study would provide more detailed information, and would call for imposition of tighter constraints.

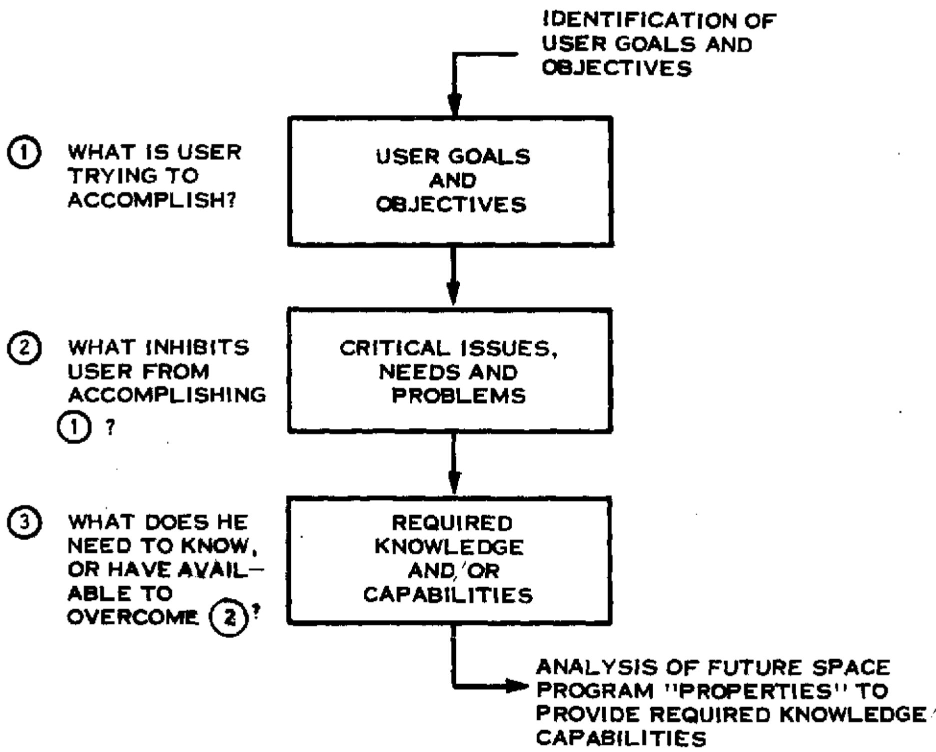

Figure II-6. Basic Analytical Process

The second analysis step provided a further breakdown of issues, needs and problems. The intent of this step was to reduce potentially multi-faceted issues, needs and problems to groupings of required individual items of data, operating conditions, facilities, etc. Each such grouping provided the answer to "What specific knowledge and/or capability is required to settle this critical issue, provide this need, and/or answer this problem ? " As before, an orientation was maintained toward knowledge and capabilities potentially amenable to space flight capabilities.

The foregoing paragraphs describe an important part of the Study, and have been utilized to establish a common understanding of the context of such words as goals and objectives, critical issues, needs, problems, knowledge and capabilities, and our view of their relationships.

After successful completion of Subtasks 1.1, 1.2, and 1.3, the COR approved our proceeding with Subtask 1.4. As shown in the lower portion of Figure II-4, we were required to establish working relationships with outside organizations. Many of these were those identified in Subtask 1.2; others were referrals from identified organizations. Through reviews with their Key Individuals on both our earlier derived results and their selected reports, we initiated the dialogs that led to identification of their goals, objectives, critical issues, timing etc.

To obtain much of the required output listed in the lower portion of Figure II-4, where requested, we funded preliminary analyses by selected Key Individuals to develop the additional data required for the Study. Occasionally, such analyses were performed without funding. Section V of this volume is comprised of Appendices, which are the reports issued by various Key Individuals as a result of their analyses. Such analyses, stimulated by our introductory information on the "properties" of space, "seed" Ideas of potential space processes such as those in Figure II-7, and "clues" as to what to look for in their organization's products, processes, and services have provided a large percentage of useful responses.

CATEGORIES OF PRODUCTS	BASIC PROCESS/PROPERTY
COMPOSITE MATERIALS	
FIBER REINFORCED MATERIALS	CONTROLLED FIBER ORIENTATION
PARTICLE DISPERSED MATERIALS	HOMOGENIZATION
CEMENTED COMPACTS	LIQUID PHASE SINTERING
CONTROLLED EUTECTIC STRUCTURE	DIRECTIONAL FREEZING
CONTROLLED MONOTECTIC STRUCTURE	MIXING (OF IMMISCIBLE MELTS)
SOLID FOAMS	GAS INJECTION, GAS TRAPPING, CHEMICAL GAS REACTION
FREEZE DRIED SUBSTANCES	LYOPHILIZATION
LIQUID DISPERSIONS	SLIP CASTING
CRYSTALS	
GROWN FROM SOLUTION	CRYSTALLIZATION
CONTROLLED DOPANT DISTRIBUTION	HOMOGENIZATION OF DOPANT
LARGE SINGLE CRYSTALS	DIFFUSION CONTROLLED SOLIDIFICATION (CZOCHRALSKI PULLING, FLOAT ZONE GROWTH, ETC.)
GLASSES	
OPTICAL MATERIALS	HOMOGENIZATION AND REFINING
NEW GLASSES (E.G., HIGH REFRACTIVE)	SOLIDIFICATION IN VITREOUS FORM
VERY SMOOTH OPTICAL SURFACES	SHAPING OF MOLTEN SUSPENSION
COLLOIDAL SUSPENSIONS	HOMOGENIZATION
SEPARATED SUBSTANCES	
HIGH PURITY LIQUIDS (E.G., VACCINES)	ELECTROPHORESIS
CHROMATOGRAPHS	SORPTION, ELUTION
FREE-CAST METALS	SHAPING OR CASTING WITHOUT CONTAINERS

Figure II-7. Examples of "Seeds"

For identifying critical issues, needs, and problem areas, as noted in both upper and lower portions of Figure II-4, we developed the filtering process shown in Figure II-8. The initiation and maintenance of dialogs with Key Individuals was, of course, the key to successful filtering.

Early in initial dialogs, it frequently became apparent that, while technical information was being exchanged, no problems were apparent, that space was not likely to be involved in solution of the problems, in that the Individual was proposing a piece of "interesting" research, for which no application was discernible. Such problems were frequently added to our data bank of "seeds" and "clues" for dialogs with other Key Individuals, or were discarded early in the process if no potential applications appeared likely.

After a time we became aware of more insidious difficulties, the need for ascertaining the validity of an identified problem and the equally important need for identifying Key Individuals whose experience related directly to such problems. We, therefore, added two key steps

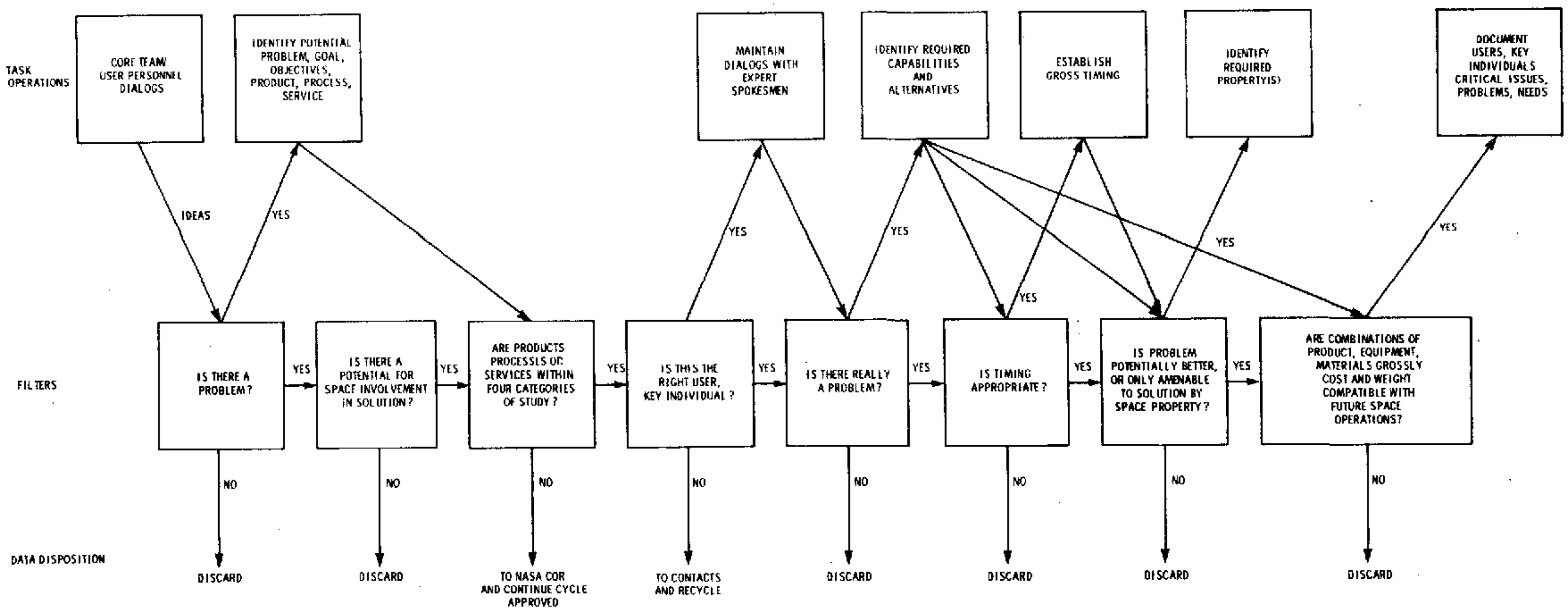

Figure II-8. Identifying the Problem

to the filter. These steps required thorough investigation of the questions "Are we talking to the right Key Individual, in the right user organization ? " and "Are we addressing the right problem?" The pursuit of these questions has, in several cases, led through very complex trails.

The fact that GE organizations and others whom we had previous working relationships were generating a higher percentage of the required outputs listed in Figure II-4 for Subtask 1.4 than were being generated by newly contacted organizations caused us to review our approach. The support we gained from involvement of GE Vice-Presidents in the Executive Advisory Group for the Study undoubtedly contributed to this circumstance, and we set our sights on higher level initial contacts in outside organizations. A major contributing factor in the relative number of Ideas was the three-month longer "gestation" period made available by the Study guideline restricting the Subtasks 1.1, 1.2, and 1.3 effort to GE and related organizations. In an effort to balance this difference, we extended the dates for final documentation of Ideas. Unfortunately, some Ideas were received too late for analysis. It would appear that, for many companies not normally involved in the aerospace sector, the "gestation" period of Ideas on space processing will be in the order of 3 to 9 months. Such a duration must be accounted for in future Studies unless, possibly, its extent is reducible by more intensive direct interaction with aerospace personnel, or by a planned educational publicity campaign in specific non-aerospace trade journals.

Since the majority of User organizations contacted during the Study are commercially oriented, it is, in retrospect, not surprising that frequent references and questions were raised regarding the non-technical aspects of the Study and post-Study relationships. The points raised regarding data and process rights, NASA/User and GE/User roles, future program finances, etc., were handled with temporizing statements that generally sufficed for Study purposes. There is no doubt, however, that more specific information for User planning of potential space ventures will be required, if commercial industry is to initiate the business planning analyses normally involved in their future business decision cycle. More details on these User concerns will be found in Section IV.

To satisfy the required outputs listed at the bottom of Figure II-4, an unsophisticated method was utilized in estimating the benefits, and identifying potential impacts that might accrue through solving the User's problems, satisfying his needs, or settling his issues. The rationale for selecting this simplified method was that, although a majority of the benefits were expected to be expressible in dollars, some benefits (primarily sociological) would not. Furthermore, cost of providing the products, processes, and services that accrued the identified benefits were specifically excluded from this Study. It was, therefore, decided that the complications of discounting, inflation, and cash flow analysis would add little meaningful data to the Study. We, thus, proceeded to determine potential benefits on the basis of conservative guidelines -- today's dollars, gross values, partial capture of available markets, etc. Each pertinent Idea in Section III lists the specific factors of conservatism utilized in the beneficial analysis of that Idea.

The general method employed in such analysis is shown in Figure II-9. A major initial effort for this analysis was, as shown at the lower left, to derive, with User's help, all of the steps involved in carrying through the complete program involved in each identified Idea. This was particularly important for those steps that follow the introduction of the product, process or service that has been developed or produced in space. Such a progression of steps assures identification of the complete hierarchy of Users who will benefit from the identified product, process, or service, and the estimated benefits will reflect values at each level of the hierarchy. For example, typical space-produced products, single crystal turbine buckets for aircraft gas turbines benefit not only GE, the manufacturer (Step 4), with longer guaranteed life worth additional dollars per engine, and benefit the U. S. Airlines, the operators (Step 5), with fewer bucket replacements worth some dollar savings per engine, but also benefit the public, the ultimate consumer, with tons less of solid emission pollutants per year.

To continue this analysis, a determination was next made by the User(s) as to the "novelty" of the identified product, process or service. This decision was simply used to determine the path for subsequent analysis of the value of such product, process or service. For

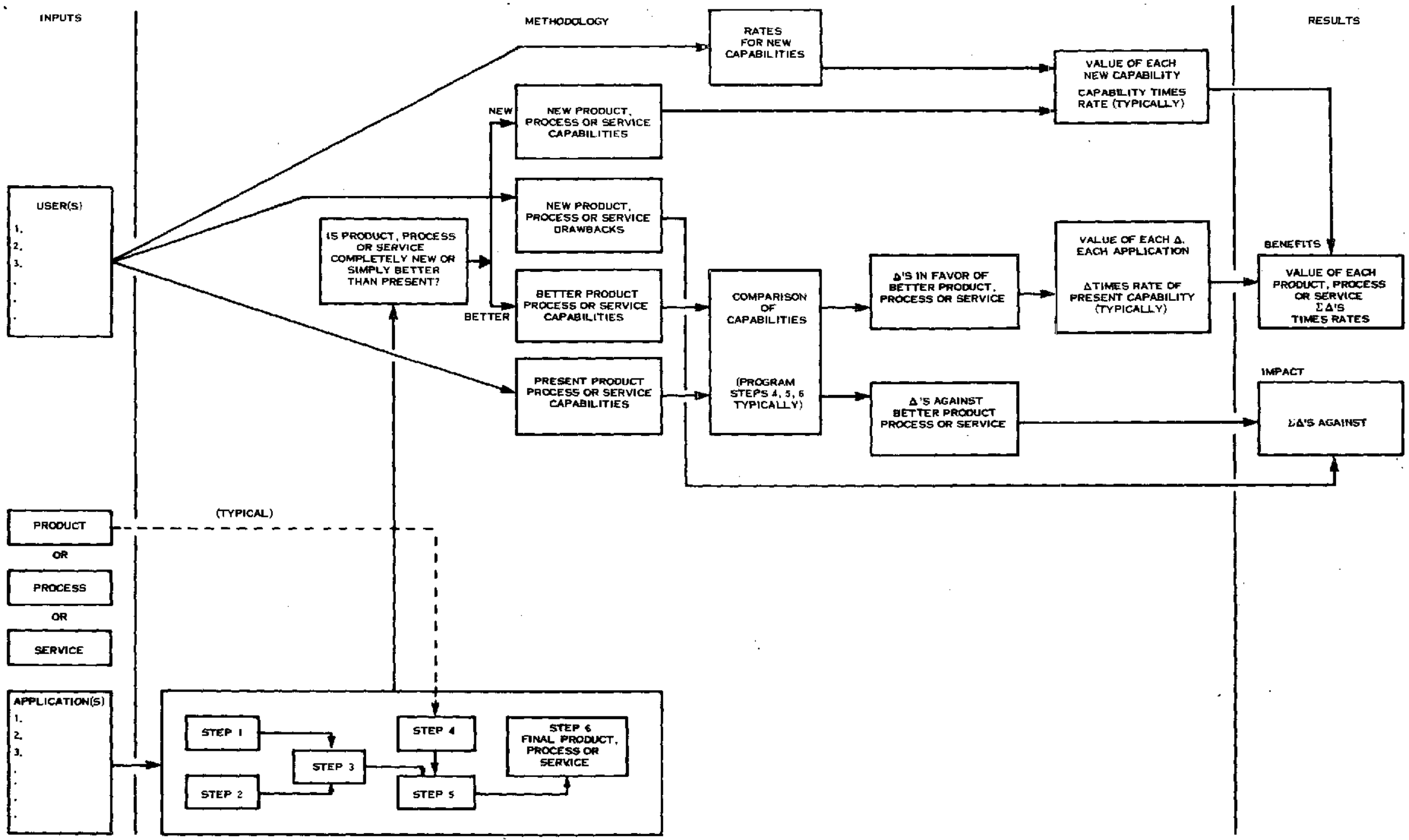

Figure II-9. Benefits Analysis Method

products, processes or services and services which were essentially new inventions, the path marked "new" would enable a gross estimate, since such estimates would have no comparable baseline, and would depend upon analogy or similitude for their construction.

For "better" items, the next block required the User's estimate of each capability of the "better" product, process or service, and, subsequently, the User's estimate of each of the present product, process or service capabilities. These were then carried through the point by point comparison of capabilities, based on the applications identified for each User in the hierarchy.

The analysis path then splits into one path which called for documentation of each advantage of the "better" product, process or service over the present product, process or service, and another path which required documentation of the disadvantages of the "better" product, process, or service.

Subsequently, rates of values were established for each advantage and values estimated for each advantage. Typically, rates were simply lifted from those of present products, processes or services; or extrapolated therefrom; or determined by some other logical method. In some cases, it was appropriate to skip estimates of rate and estimate values of certain advantages directly. Where such a procedure was followed, its logic was documented. In all cases, rates or values were conservative estimates.

The block marked "Benefits" provided for summation of values of like measure for each product, process or service, and summarized its benefits. Similarly, the block marked "impact" provided for summation of disadvantages of each product, process or service, and thus summarized its impacts.

For new products, processes or services, the path marked "New" provided for documentation of each capability of the product, process or service and estimates of rates for these new capabilities. These estimates were more difficult to come by, since there was no past experience. In similar fashion to the previously-discussed steps, the value of each new product, process or service was estimated, and the disadvantages were documented for subsequent summation of their impacts.

Task 2.0. Task 2, summarized in Figure II-10, was charged with reducing the issues, needs, and problem areas of Task 1 to the specific knowledge or capabilities required from a space facility in order to develop or produce the desired product, process, or service. The first step was, thus, to abstract and document space "properties" from existing literature on the space flight environment. Such a document has been assembled for this Study.*

SUBTASK 2.1	DEFINITION OF SPACE "PROPERTIES"
SUBTASK 2.2	DEFINITION OF REQUIRED KNOWLEDGE/CAPABILITIES
SUBTASK 2.3	MATCH OF PLANNED SPACE PROGRAM WITH KNOWLEDGE/ CAPABILITIES
	IDENTIFICATION OF DRIVING REQUIREMENTS
SUBTASK 2.4	DEFINITION OF OBJECTIVES, SCOPE, GUIDELINES FOR SPACE EXPERIMENTS/ACTIVITIES
SUBTASK 2.5	IDENTIFICATION OF COMMITMENTS FROM USERS, INDIVIDUALS, SPOKESMEN

REQUIRED OUTPUTS	METHOD	SOURCES
CATALOG OF PROPERTIES	LITERATURE ANALYSIS	SPACE ENVIRONMENT DOCUMENTS
REQUIRED KNOWLEDGE/ CAPABILITIES	DIALOGS, ANALYSIS OF PREVIOUS DATA	KEY INDIVIDUALS, TASK 1.4 RESULTS
SOURCES OF KNOWLEDGE/ CAPABILITIES	ANALYSIS OF PLANS	NASA FUTURE SPACE PROGRAM PLANS
PRELIMINARY DEFINITION OF EXPERIMENT/ACTIVITIES REQUIREMENTS	DIALOGS, ANALYSIS	KEY INDIVIDUALS
STATEMENTS ON COMMITMENTS	DIALOGS	KEY INDIVIDUALS

Figure II-10. Task 2-Analysis of Major Problems to be Solved

Through continuing dialogs with Key Individuals, we then matched the previously identified issues, needs, and problems with specific properties to extract the knowledge and/or capabilities, potentially available from space flight operations, that are required to settle the issues, provide the needs, and solve the problems. It is here that the Study Team judgement was most heavily exercised. That judgement was employed in deciding, without in-depth

*Miller, E.S., Reference Space Environment for B.U.S. Study, Document 1124-B.U.S.-017, March 13, 1972.

technology and discipline analyses, whether shuttle-borne payloads employing pallets, sortie labs, or automated spacecraft could, within normal understanding of physical laws and effects, as well as within projected design and operating techniques, reasonably be expected to meet the conditions and constraints required by the Users. Figure II-11 is a summary of some assumptions and judgements made in deriving required knowledge and capabilities.

PROBLEM AREAS, NEEDS, ISSUES	KNOWLEDGE/CAPABILITIES REQUIREMENTS	ASSUMPTIONS, JUDGEMENTS
ELIMINATION, MINIMIZATION OF GRAVITY EFFECTS LOADING MASKING OF OTHER FORCES CONTAINERLESS PROCESSING CONVECTION, LOCAL DE-SATURATION SEDIMENTATION	LONG TERM ZERO "G" FACILITY, PLATFORM OR CONTAINER SUFFICIENT TO ACCOMMODATE BOTH MANNED AND AUTOMATED PROCESSING EQUIPMENT AND UTILITIES.	"WEIGHTLESSNESS" OF ORBITING FLIGHT WILL NOMINALLY SATISFY PROBLEMS, NEEDS, ISSUES. DRAG-INDUCED "G" EITHER SUFFICIENTLY SMALL TO BE NEGLIGIBLE OR "FREE FLYING" EQUIPMENT WITHIN VEHICLE TO AVOID DRAG AND/OR THRUST APPLIED TO BALANCE DRAG.
ELIMINATION OF VIBRATION SEISMIC ACCOUSTIC COUPLING	LONG TERM FACILITY DECOUPLED PLATFORM, OR CONTAINER TO AVOID SEISMIC VIBRATION AND ACOUSTIC COUPLING IN MEASURING EQUIPMENT AND IN IMPRINTING EQUIPMENT.	FREE-FLYING SPACECRAFT, AUTOMATED AND WITHOUT ROTATING OR RECIPROCATING EQUIPMENT; AND/OR RIGIDLY CONTROLLED OPERATIONS (CREW MOVEMENT, ATTITUDE CONTROL OPERATION, ETC.) IS FEASIBLE.
CONTAMINATION CONTROL ENVIRONMENTAL PROCESS	ULTRACLEAN MATERIALS, PROCESSING EQUIPMENT, ENVIRONMENT. CONTAINERLESS OPERATIONS. REMOVAL OF PROCESS WASTES.	ULTRA-HARD VACUUM IN ORBIT AND OUT-GASSING FOR ULTRA-CLEANING. ALSO PROVIDES ULTRA-CLEAN ENVIRONMENT. SMALL FORCES IN WEIGHTLESSNESS CAN REMOVE PROCESS CONTAMINANTS FROM VICINITY OF PROCESS.
MINIMIZATION OF OTHER TERRESTRIAL INFLUENCES CYCLICAL	DATA ON PHYSICAL AND BEHAVIORAL WELL BEING DURING LONG TERM EXPOSURE TO CYCLICAL CONDITIONS (LUNAR CYCLE, MAGNETIC, GRAVITY) DIFFERENT FROM THOSE ON EARTH'S SURFACE.	SPACE FACILITIES PROVIDE (IN VARIOUS FLIGHT PATHS) VARIETY OF "NEW" CONDITIONS.

Figure II-11. Summary of Key Knowledge/Capabilities Requirements

The necessity for eventual rigorous analyses of the disciplines and technologies involved in the knowledge/capabilities judged to be attainable in space, as well as the feasibility of required design and operating capabilities, cannot be overemphasized, if Ideas identified in this Study are to be pursued further.

The knowledge/capabilities and experiment/activities requirements outputs listed in Figure II-11 called for considerable dialog between the Study Team and User Key Individuals in order that both groups understand the limitations, constraints and flexibility of the respective User needs and space program availabilities. Although some lack of knowledge of general space technology on the part of non-aerospace organizations was anticipated, the degree of that "information gap" was greater than we supposed. The addition of introductory material on Space Shuttle and automated spacecraft to our dialogs closed that gap for this Study. Future efforts could benefit from more extensive treatment of such subjects in non-aerospace trade media.

Had definitive future space program plans been available, we would have established preliminary timing and schedules for obtaining the previously extracted knowledge and capabilities. Lacking such data, we proceeded to the generation of driving requirements for experiments and/or space activities to obtain such knowledge and capabilities. Close contacts with Key Individuals were maintained during this effort to assure compatibility of experiments/space activities with their original needs, issues, and problems. Figure II-12 lists the major driving requirements imposed by the most worthwhile Ideas identified in the Study.

User interest in experiments which might be carried out in space was intense, and many general experiments were noted in our dialogs.

The need, however, to relate experiments to identified specific Ideas, and to fit them into progressions of activities that constitute development programs was more difficult.

In general, the novelty (to most of the Users) of the generated Ideas and paucity of "hard data" was such that there was an extreme tendency toward caution. Such caution frequently inhibited the projection of sequential steps in a program due to the difficulty of predicting the success or comparative results of a preceding step.

By generalizing, to some degree, and by directing projections to be "based on assumed success of preceding steps", we assembled the identification of space experiments/activities shown in Figure II-13. This identification has been provided in the form of objectives, scope and guidelines, with the gross timeframe noted for each such experiment/activity.

IDEA NO.	IDEAS IDENTIFIED	SPECIAL SUBSYSTEM REQUIREMENTS								ORBITS		SPECIAL EQUIPMENTS	SPECIAL ENVIRONMENTS USED	REMARKS
		STABILIZATION	POWER	PROPULSION	STRUCTURE	COMMUNICATION	RECOVERY	LIFE SUPPORT	CONTAMINANT CONTROL	ALTITUDE	INCLINATION			
1.	Imprinting Circuitry on Crystal Wafers For Surface Acoustic Wave Electronics.	XX			X	X	X		X			Electron Beam Gun	Vibration Isolation Vacuum	Minimum or Zero On-Board Rotating, Moving Equipment, Minimum or Zero Crew Movement
2.	Particle Manipulation By Small Forces	XX				X	X					Force Generators (Lasers, Sonic, Magnets, Hot Plates, RF, etc.)	Zero G Vibration Isolation Vacuum	Caution: Shielding or Insulation may be required for most force generators.
5.	Vibration Testing of Small Motors	XX			X	X	X					Laser Holography Equipment	Zero G Vibration Isolation Vacuum	Minimum or Zero On-Board Rotating, Moving Equipment, Minimum or Zero Crew Movement
6.	High Temperature Single Crystal & Eutectics Turbine Buckets	X	XX			X	X		X			Bucket Molds, Furnace	Zero G Vacuum	
30.	High Purity Tungsten X-Ray Targets		XX			X	X		X			Furnace, Levitation System	Zero G Vacuum	
42.	Precise Separation of Radioisotopes	X			X	X	X		X			Shielding, Sonic Generators	Zero G Vacuum	Caution: Radiation Source, Review Sensitivity of Other Payloads
46.	Silicon Crystal Growth	X	X			X	X		X			Furnace	Zero G	
59.	Epitaxial Growth of Magnetic Bubble Memory Crystals	X	X			X	X		X			Furnace, Magnetic Shielding	Zero G	Sensitivity to Magnetic Fields
60.	Amorphous Glasses & Refractories	X	X			X	X		X			Contaimination Control, Levitation System, Supercooling System, Furnace	Zero G Vacuum	
84.	Basic Heat Transfer Data	XX				X						Precision Instrumentation, Furnace	Zero G Vibration Isolation	
89.	Separation of Isoenzymes	XX				X	X		X			Large Pore Gel Electrophoretic Separator	Zero G	Possible Shelf Life Problem
96.	Utilization of Biorhythms	X				X	X	X		MULTI	MULTI	Life Support Equipment, Animal Lab Equipment	Environment Isolation	Experimental Biological Subjects

Figure II-12. Driving Factors Involved in Key Experiments/Activities

Figure II-13 lists, for each of the continuing Ideas of the Phase I Study, brief definitions of what was projected as required from space operations to carry each Idea from the necessary ground-based effort (analyses, laboratory experiments, zero "G" aircraft transjectories, drop tower tests, sounding rocket experiments) to eventual full scale production or operations in space.

As listed in the Figure:

Development tests of equipment or systems encompass that testing required to carry out the preliminary design, final design, fabrication, assembly, and qualification facets of a program.

Verification testing is noted where it was felt necessary to confirm the selection of a concept, or an alternative.

When experiments are listed early in a program, the implication is that insufficient data would probably be available from earlier analyses and ground experiments to warrant initiation of development effort.

Further discussion on the present state-of-art for the identified Ideas, and necessary developments will be found in Section III.2.

As the final output for Task 2 listed in Figure II-10, we attempted to obtain statements on potential commitments by Users in the event of successful experiments/space activities. Such statements and implications while occasionally verbalized by Key Individuals, have not been documented. The general attitudes that seemed prevalent among Users, even those contributing to the Study, were:

1. That the available data, both technical and business were insufficient and too speculative to warrant commitments

2. That the sudden, brief exposure to the whole Idea of ventures in space for companies not formerly involved in space programs, engendered a need for more consideration.

SPACE EXPERIMENTS/ACTIVITIES

IDEA	OBJECTIVES	SCOPE	GUIDELINES	TIME FRAME
1. Imprinting Circuitry for Surface Acoustic Wave Electronics	Development tests of imprinting process equipment: RF Sputter Etching or Scanning Electron Beam or X-Ray Lithography.	In-orbit phenomena measurements (vibration levels, contaminant levels, etc.) part and subsystem concept and design data acquisition (to compare the three processing approaches)	Specific tests to reflect evolution from analyses, ground experiments design, etc. Optimize data acquisition. Specimen return required. Data return via telemetry is acceptable.	1975-1980
	Development tests of vibration-free system: Pallet, lab, or automated spacecraft with isolation devices.	In-orbit phenomena (vibration levels) part and subsystem concept and design data acquisition.	Specific tests to reflect evolution from analyses, ground experiments, design, etc. Optimize data acquisition. Data return via telemetry is acceptable.	1978-1980
	Verification tests of imprinting process equipment.	In-orbit partial to complete process runs, exercise of subsystems, check of performance parameters. Real and simulated materials. Limited phenomena measurements.	Verify partial and total sequential process steps. Equipment and interim product return required. Performance and phenomena data return via telemetry is acceptable.	1980
	Prototype/Pilot Plant Demonstration	Sample runs, sufficient quantities to exercise imprinting process system, check of system functional performance, reproducibility and quality of circuitry.	Operational procedures to be followed. Sample output return required. Minimize data return.	1981
	Full Operation	Regular, quantity production of quality S.A.W. components for assembly into Communication, Radar Systems, etc.	Operations to be consistent with good business practices (economical, quality control, timely).	1983-1984
3. Particle Manipulation By Small Forces	Data acquisition and evaluation experiments on various force generators: Light, heat, microwaves (various frequencies), sound, particulate radiation, electrostatics, magnetism. Various media: Vacuum, air, water, others. Various particles & sizes: Radioisotopes, biologicals, others.	In-orbit measurement of forces (amplitude, flux, direction, field, etc.) & effects (particle acceleration, particle susceptibility, permeability of media, heating, etc.). Photographic recording of interim and final results.	Specific experiments to reflect evolution from analyses, ground experiments, etc. Optimize data acquisition. Photographic data return required.	1978-1979
	Verification tests of particle manipulation processes, and assembly of particle manipulation "tool box" data.	In-orbit tests of selected force generator designs. Demonstrations of separations, implantations, depositions, etc. of various particles in various media and various surfaces.	Force generators, particles, media selected from previous experiments. Range of conditions to bound applicability of process. Specimen return required.	1981-1983
5. Vibration Testing of Small Motors	Development tests of vibration-free holo-graphic vibration measuring system & pallet, lab, or automated spacecraft, with isolation devices.	In-orbit vibration measurements, response of holographic system, measurement system design data acquisition.	Specific equipment tests to reflect evolution from analyses, design, ground experiments and measurement techniques, limitations of terrestrial measurements. Maximize data acquisition. Environment data return via telemetry is acceptable. Holographic images must be recorded and returned.	1981

Figure II-13. Summary of Space Experiments/Activities Objectives, Scope, and Guidelines (Sheet 1 of 6)

IDEA	OBJECTIVES	SCOPE	GUIDELINES	TIME FRAME
5. Vibration Testing of Small Motors (Continued)	Verification tests of holographic vibration measuring system	In-orbit check of measurement performance using calibrated vibration sources and actual motors.	Verify vibration data accuracy and hologram fidelity. Maximize data acquisition. Vibration data via telemetry is acceptable. holographic images must be recorded and returned	1982
	Acquisition of fractional horsepower motor design data: for bearings, lubricants, rotors, stators	Regular tests of new motors. Holographic images for ground evaluation of design, for redesign and for design requirements.	Adoption as replacement for present vibration, acoustic testing program and design data acquisition testing.	1982-1984
6. Single Crystal and Eutectic High Temperature Turbine Buckets	Development tests of processing equipment for producing samples of: Ni-based alloy single crystals, directionally solidified eutectics, levitation melted refractory metals.	In-orbit phenomena measurements (temperatures, gradients, "G" levels, etc.), part and subsystem concept and design data acquisition.	Specific tests to reflect evolution from analyses, ground experiments, design, SKYLAB Experiments, etc. Optimize data acquisition. Specimen return required. Data return via telemetry is acceptable.	1977-1978
	Experiments in Zero "G" production of samples of single crystals, directionally solidified eutectics, levitation melted refractory metals.	Samples of wide range of alloys, refractory metals, eutectics for metallurgical testing. Limited phenomena measurements.	Specific material specimens for performance data comparisons. Optimize data acquisition. Specimen return required. Data return via telemetry is acceptable.	1979-1980
	Development tests of processing equipment (crystal growing, levitation melting) for producing turbine buckets.	In-orbit phenomena measurements (temperatures, gradients, etc.), part and subsystem design data acquisition.	Specific tests to reflect evolution from analyses, ground experiments, design SKYLAB experiments, sample processing equipment. Optimize data acquisition. Data return via telemetry is acceptable.	1980-1981
	Prototype/Pilot Plant Demonstration: Single crystal buckets, directionally solidified eutectics, refractory metals.	Sample runs; sufficient buckets to exercise bucket processing system; check of system functional performance, reproducibility and quality of buckets.	Operational procedures to be followed. Bucket sample run output return required. Minimize data return.	1981-1982
	Full Operation	Regular, quantity production of quality buckets for assembly into engines.	Operations consistent with good business practice (economical, quality control, timely)	1983-1985
30. High Purity Tungsten X-Ray Targets	Acquisition of X-ray target samples of levitation melted tungsten for metallurgical and operating conditions testing.	Sounding rocket tests; single samples; range of heating, cooling rates and durations, various initial purities. Phenomena measurements.	Each resulting sample for material properties and performance data. Optimize data acquisition. Each processed tungsten sample return required. Data return via telemetry is acceptable.	1974-1976
	Acquisition of levitation melted (possibly formed) tungsten x-ray targets for metallurgical and operating conditions testing.	Orbiting carrier; multiple samples, multiple conditions.	Sufficient samples and conditions to obtain statistically representative material properties and performance data. Optimize data acquisition. Processed tungsten samples return required. Data return via telemetry is acceptable.	1977
	Development tests of processing equipment for providing tungsten x-ray targets.	In-orbit phenomena measurements (temperatures, gradients, rates "G" levels, etc.), part & subsystem design data acquisition.	Specific tests to reflect design evolution and scale-up from sample production. Optimize data acquisition. Specimen return required. Data return via telemetry is acceptable.	1978-1979

Figure II-13. Summary of Space Experiments/Activities Objectives, Scope, and Guidelines (Sheet 2 of 6)

IDEA	OBJECTIVES	SCOPE	GUIDELINES	TIME FRAME
30. High Purity Tungsten X-ray Targets (Continued)	Prototype/Pilot plant demonstration of tungsten x-ray target production.	Sample runs of scaled-up and modified equipment; sufficient targets to exercise target processing system, check of system functional performance, reproducibility and quality of targets.	Operational procedures to be followed. Target sample run output return required. Minimize data return.	1980
	Full Operation	Regular, quantity production of quality targets for assembly into x-ray tubes.	Operations consistent with good business practice (economical, quality control, timely)	1981-1982
42. Precise Separation of Radioisotopes	Development tests of experimental radioisotope separation equipment: Laser array, tunable lasers.	In-orbit phenomena measurements: Forces (amplitude, flux, direction, field); effects (particle acceleration, particle susceptibility, permeability of media, heating, etc.) Part and subsystem concepts and design data acquisition.	Specific tests to reflect evolution from analyses, ground experiments, design, etc. Optimize data acquisition. Data return via telemetry is acceptable.	1981-1983
	Experiments to ascertain effectiveness of separation methods vis-a-vis force generators, particle generation methods.	In-orbit, laser array and tunable lasers, vaporization and volatilization of plutonium and compounds. Limited phenomena measurements. Collection of separated radioisotope specimens.	Specific tests of force generators/particle generation methods for performance data comparisons. Optimize data acquisition. Data return via telemetry is acceptable. Separated radioisotope specimens return is required.	1984
	Development tests of separation system to produce desired isotopes	In-orbit phenomena measurements: Force (amplitude, flux, field); effects (particle acceleration, heating, etc.). Part and subsystem concept, design, performance data acquisition.	Specific tests to reflect design evolution, and scale-up from experimental separation equipment. Optimize data acquisition. Data return via telemetry is acceptable.	1984-1985
	Prototype/Pilot plant demonstration of pure radioisotope production	Sample runs of scaled-up system; sufficient pure radioisotopes to exercise separation processing system, check of system functional performance, reproducibility, quality of isotope product.	Operational procedures to be followed. Separation run output return required. Minimize data return.	1985
	Full Operation	Regular, quantity production of pure isotopes.	Operations consistent with good business practice (economical, quality control, timely)	1986
46. Silicon Crystal Growth	Experiments to determine effects of various conditions on size and perfection of Si crystals	In-orbit, for selected growth approach (based on analysis, lab experiments, SKYLAB experiments). Varied conditions (temperatures, vacuum, initial material, etc.) to determine effects on size, rate of growth, perfection. Maximum phenomena measurements.	Tests under various specific, controlled conditions. Build on SKYLAB experiments and laboratory experiments. Maximize data acquisition. Data return via telemetry is acceptable. Crystal specimens return required.	1978

Figure II-13. Summary of Space Experiments/Activities Objectives, Scope, and Guidelines (Sheet 3 of 6)

IDEA	OBJECTIVES	SCOPE	GUIDELINES	TIME FRAME
46. Silicon Crystal Growth (Continued)	Development tests of full scale crystal-growing system	In-orbit phenomena measurements: (temperature, pressure, growth rates). Part and subsystem concept, design, performance data acquisition.	Specific tests to reflect design evolution and scale-up from experimental crystal-growing equipment. Optimize data acquisition. Data return via telemetry is acceptable.	1978-1979
	Prototype/Pilot plant demonstration of large Si crystal production	Sample runs of scaled-up system. Sufficient crystals to exercise growing system, check of system functional performance, reproducibility, quality of crystals.	Operational procedures to be followed. Crystal output return required. Minimize data return.	1979-1980
	Full Operation	Regular, quantity production of large, high perfection crystals.	Operations consistent with good business practice, (economical, quality control, timely)	1981-1982
59. Epitaxial Growth of Magnetic Bubble Memory Crystal Films	Acquisition of data on Epitaxial growth of garnet films in zero "G"	Sounding rocket experiments, multiple samples, various vapor generation methods, times, substrates, temperatures, etc. Maximum phenomena measurements: (Temperatures, gradients "G", time, vacuum, etc.)	Specific tests to reflect evolution from analyses, lab experiments. Each coated substrate for physical, magnetic properties data. Maximize data acquisition. All specimen return is required. Data return via telemetry is acceptable.	1976
	Development tests of experimental epitaxial garnet film growth equipment	In-orbit, maximum phenomena measurements (temperatures, gradients, "G", time, vacuum, etc.) Maximum part and subsystem design and performance data acquisition. Samples of selected vapor generation method, substrates.	Specific tests to reflect design evolution from sounding rocket tests. Maximize data acquisition. Specimen return is required.	1977
	Prototype/Pilot plant demonstration of expitaxial garnet film deposition system	Sample runs of scaled-up and modified equipment. Sufficient chips with deposited films to exercise deposition system, check system functional performance, reproducibility, and quality of films.	Operational procedures to be followed. Chip sample run output return required. Minimize data return.	1979
	Full Operation	Regular, quantity production of quality chips.	Operations consistent with good business practices (economical, quality control, timely).	1982
60. Amorphous Glasses and Oxides	Acquisition of levitation melted amorphous glass and oxide samples for analyses and lab testing.	Sounding rocket experiments; single samples; range of heating, cooling rates and durations, various initial purities. Phenomena measurements (temperature, time, "G", etc.)	Each resulting sample for properties data. Maximize data acquisition. Each amorphous glass and oxide sample return required. Data return via telemetry is acceptable.	1977
	Development tests of experimental amorphous glass and oxide levitation melting, cooling, processing equipment.	In-orbit phenomena measurements (temperatures, rates, gradients, etc.), Part and subsystem design data acquisition.	Specific tests to reflect design evolution from analyses, ground experiments, sounding rocket experiments. Maximize data acquisition. Specimen return required. Data return via telemetry is acceptable.	1978

Figure II-13. Summary of Space Experiments/Activities Objectives, Scope, and Guidelines
(Sheet 4 of 6)

IDEA	OBJECTIVES	SCOPE	GUIDELINES	TIME FRAME
60. Amorphous Glasses and Oxides (Continued)	Experiments in Zero G formation of specific amorphous glasses and oxides	In-orbit, for selected raw materials; heating, cooling rates and durations. Multiple specimens. Phenomena measurements (temperatures, time,etc.)	Experiments under range of specific, controlled conditions. Conditions, materials to reflect knowledge obtained from sounding rocket experiments. Maximize data acquisition. All specimen return required. Data return via telemetry is acceptable.	1979
	Prototype/Pilot plant demonstration of amorphous glass oxide production via levitation melting, forming, cooling	Sample runs of scaled-up and modified system. Sufficient samples to exercise selected melting, cooling methods and rates, as well as system. Check of system functional performance, reproducibility, quality of glass, oxides.	Operational procedures to be followed. Glass and oxide sample run output return required. Minimize data return.	1980
	Full Operation	Regular, quantity production of quality amorphous glass and oxides.	Operations consistent with good business practices (economical, quality control, timely).	1982
84. Basic Heat Transfer Data	Development tests of techniques, equipment for thermal conductivity measurements of liquids in zero "G"	In-orbit methods and apparatus data acquisition (heat transfer, convective flows). Phenomena measurements (temperatures, gradients, "G").	Specific equipment tests to reflect evolution from analyses, ground experiments, limitations of terrestrial techniques, design. Maximize data return. All data, measurements return via telemetry is acceptable.	1978-1979
	Acquisition of liquid thermal conductivity data	Regular program of measurements on liquids (low specific gravity to high)	Priority of liquids per NBS requirements and industry requests.	1982
89. Separation of Isoenzymes	Verification tests of electrophoretic techniques, applicable isoenzymes	In-orbit partial to complete process runs, exercise of subsystems, check of performance parameters, real and simulated isoenzymes. Concept data acquisition, maximum phenomena measurements (pressures, temperatures, gradients, time, etc.)	Verify partial and total sequencial process steps. Equipment and interim product return required. Performance and phenomena data return via telemetry is acceptable.	1976-1978
	Development tests of full-scale electrophoretic separation system	In-orbit phenomena measurements (temperatures, pressure, gradients, concentrations, time), photographs. Part and subsystem design data acquisition.	Specific tests to reflect evolution from analyses, ground tests, verification tests, design. Optimize data acquisition. Phenomena data return via telemetry is acceptable. Photographic data return required.	1979-1981
	Prototype/Pilot plant demonstration	Sample runs, sufficient quantities of separated pure isoenzymes to exercise system. Check of system functional performance, reproducibility, quality of results.	Operational procedures to be followed. Sample run output return required. Minimize data return.	1982
	Full Operation	Regular, quantity production of pure isoenzymes.	Operations to be consistent with good business practices (economical, quality control, timely.)	1983

Figure II-13. Summary of Space Experiments/Activities Objectives, Scope, and Guidelines (Sheet 5 of 6)

IDEA	OBJECTIVES	SCOPE	GUIDELINES	TIME FRAME
96. Utilization of Biorhythms	Development tests of circadian biorhythm investigation equipment in earth orbit.	In-orbit partial to complete system runs, exercise of subsystems, real and simulated subjects. Broad range of rhythm-related phenomena measurements.	Specific equipment tests to reflect evolution from analyses, ground tests, design. Compatibility with wide range of orbits (100 to 20,000 n miles). Control of, and variation of, test conditions. Maximize data acquisition. Measured data return via telemetry.	1976-1978
	Acquisition of Circadian biorhythm data in earth orbit.	Wide range of subjects (mice to man), range of orbits (200 to 40,000 km) Broad range of rhythm-related phenomena measurements.	Specific tests for health and behavioral data as functions of various rhythms and rhythm changes. Maximize data acquisition. All subjects return required. Data return via telemetry is acceptable.	1978-1979
	Development tests of Circadian biorhythm investigation equipment in solar orbit.	Partial to complete system runs. Exercise of subsystems, real and simulated subjects. Broad range of rhythm-related phenomena measurements.	Specific equipment tests to reflect evolution from earth orbit tests, design. Control of, and limited variation of test conditions. Maximize data acquisition. Measured data return via telemetry.	1977-1979
	Acquisition of circadian biorhythm data in solar orbit	Limited range of subjects. Broad range of rhythm-related phenomena measurements.	Specific tests to obtain health and behavioral data as functions of various rhythms and rhythm changes. Maximize data acquisition. All subjects return required. Data return via telemetry is acceptable.	1979-1980

Figure II-13. Summary of Space Experiments/Activities Objectives, Scope, and Guidelines (Sheet 6 of 6)

3. That answers are needed to a number of questions bearing on the decision process involved in planning future business. (Further discussion on these questions is found in Section IV).

Task 3.0. Task 3, summarized in Figure II-14, was aimed at providing an integrated schedule of when the knowledge and capabilities required to develop or produce identified products, processes, and services of value would be available. The method of integrating such information was to extract from the preceding task the previously derived requirements for knowledge and capabilities as well as their required timing, and to review those requirements against the NASA future space program plans.

SUBTASK 3.1	INTEGRATION OF REQUIRED TIMING OF ISSUES, NEEDS, PROBLEM AREAS
SUBTASK 3.2	INTEGRATION OF REQURED TIMING VS PLANNED SPACE CAPABILITIES
SUBTASK 3.3	DEFINITION OF REQUIRED KNOWLEDGE AND CAPABILITIES AVAILABILITY

REQUIRED OUTPUTS	METHODS	RESOURCES
SCHEDULE OF KNOWLEDGE/ CAPABILITY	ANALYSIS	TASK 2 RESULTS
AVAILABILITY	DIALOGS	KEY INDIVIDUALS

Figure II-14. Task 3.0: Desired Time Phasing

Based on the timing of planned experiment-bearing flights, the available weight and volume for experiment and test payloads, and the constraints imposed to maintain compatibility with planned payloads, the integration process was aimed at fitting the study-derived data into the planned program. In addition, where applicable, variations or modifications to the planned program were to be noted. An approved NASA Future Space Program Plan, however, was not issued for this Study.

There was, thus, no "shaping" of a schedule, which occurs when attempts are made to fit "required" tasks into "available" slots. The adjustments and compromises for such fitting would, normally, have involved interfacing with appropriate Key Individuals.

Essentially, this circumstance eliminated Subtasks 3.2 and 3.3. The remaining Subtask 3.1 was based on analysis of results of Task 2, and provided an integrated schedule of only the required timing.

In order to assemble those space experiments/activities required to result, ultimately, in products, processes, or services for use on the ground into an overall plan, Users were requested to consider a development "road map" which would contain most, or all, of the tasks listed in Figure II-15. It must be noted that the figure is generic in that it attempts to account for all the permutations of products, processes, and services, including such cases

ANALYSIS	TECHNOLOGY EXPERIMENTATION	ENGINEERING	MANUFACTURING	PRODUCT, PROCESS OR SERVICE TEST	OPERATIONS
TECHNOLOGY					
FEASIBILITY					
PRE-DESIGN	GROUND LABORATORY				
	DROP TOWER				
	SPACE EXPERIMENTS				
	ZERO "G" AIRCRAFT	DESIGN	GROUND		
	SOUNDING ROCKETS	GROUND DEVELOPMENT TESTS	PROCESSED MATERIALS		
			COMPONENTS		
	AUTOMATED SPACECRAFT	SPACE DEVELOPMENT TESTS	ASSEMBLIES	GROUND	GROUND
	SHUTTLE	SOUNDING ROCKETS	COMPLETE EQUIPMENT	QUALITY	TRAINING
		AUTOMATED SPACECRAFT		ACCEPTANCE	
		SHUTTLE		PROTOTYPE	INITIAL OPERATIONAL CAPABILITY
			SPACE		FULL OPERATION
			PROCESSED MATERIALS		
			COMPONENTS		
			ASSEMBLIES		
			COMPLETE EQUIPMENT	SPACE	SPACE
				QUALITY	TRAINING
				ACCEPTANCE	INITIAL OPERATIONAL CAPABILITY
				PROTOTYPE	FULL OPERATION

INCREASING PROGRAM MATURITY

INCREASING PROGRAM MATURITY

Figure II-15. Typical Development Program Tasks as those in which the final product, process, or service is produced in space, or in which the development task in space is only one step in a program which culminates in a ground-produced product, process, or service. Specific products, processes or services may require parallel tasks, or may, because of available knowhow, eliminate certain tasks, and, of course, there will be the inevitable feedback loops. The flow of tasks, however, will, in general, follow the items listed in order of increasing program maturity. The deep and early involvement of space experiments/activities in typical tasks is a clear indication of why business planning for products, processes and services of the nature under consideration here should be initiated relatively soon. Typically, even though "full operation", at the end of each program maturity cycle, may await 1982-1986 Space Shuttle operations, some earlier "Space Technology Experimentation", or "Space Development Tests", may not require shuttle capabilities, and, thus, be amenable to some earlier, sounding rocket or automated satellite flight.

The road map would, eventually, be considered the "skeleton" of a Development Plan. Further analysis of each specific task, accounting for potential space program contingencies, adjusting task timing to allow for specific information flow among tasks, and adjusting tasks on the basis of feedback from other planning elements would "put the flesh on the skeleton."

It should be noted that a Development Plan must account for all the technical alternatives and define the technical risks for each technical decision point in the plan. Such information is extremely necessary for subsequent resources planning and market analysis.

The foregoing background information served as a point of departure for User dialogs to construct the required schedule of space experiments/activities, and to establish the level of information desired.

Task 4.0. Task 4,0 summarized in Figure II-16, sought to establish the commalities among the requirements for the knowledge, capabilities, timing, and experiments/activities of

Tasks 2 and 3. The planning, economics and logistics involved in carrying out the multi-faceted program implied in the variety of potential products, processes, and services identified herein, lend themselves to considerable simplification, savings, and control, if advantage can be taken of commonalities.

SUBTASK 4.1 ANALYSIS OF COMMALITY FACTORS

SUBTASK 4.2 DEFINITION OF ADVANTAGES OF SPECIFIC COMMONALITIES

REQUIRED OUTPUTS	METHODS	SOURCES
COMMON FACTORS	ANALYSIS	TASK 2 AND TASK 3 RESULTS
TABULATED COMMONALITIES WITH ADVANTAGES, DISAD-VANTAGES	DIALOGS	KEY INDIVIDUALS

Figure II-16. Task 4.0: Commonality Analysis

For example, establishment of common orbits and time frames among a group of experiments could ease the problems of which experiments could be combined for a given flight. Accounting for commonized heating requirements and electrical power requirements could result in development of a few multi-purpose support subsystems rather than a number of individual units.

Preliminary versions of such commonalities have been identified in the Study. Two difficulties, however, prohibit optimistic acceptance of such data:

1. Although the Users understood the potential value of such commonalities, the in-depth analyses and concept generation needed for many of the commonalities were not a function of this Study, and consequently were not performed.

2. In some cases, those commonalities, such as zero "G" and hard vacuum, identified as required conditions for carrying out the process steps involved in many identified Ideas, are rather gross. "Zero "G" of orbital flight is not actually zero,

and the hard vaccum is not actually zero pressure. The small variance of actual conditions from perfect conditions will, no doubt, be more tolerable to some Ideas than others. The degree of such tolerance must eventually be investigated for each Idea. Until then any such "commonalities" must be viewed as questionable and labeled as "presumed commonality".

In order to initiate the identification of commonalities, we briefed Users on the potential benefits of such an approach, and, in dialogs, discussed the typical factors of commonality shown in Figure II-17.

• ORBIT GEOMETRY AND CONDITIONS	- ALTITUDE, SUN ANGLE, ETC.
• SPECIAL ENVIRONMENT	- LOW VIBRATION, ULTRA HARD VACUUM, ETC.
• MAJOR SUPPORT EQUIPMENT	- HIGH OUTPUT FURNACE, LARGE ELECTRICAL LOAD, ETC.
• SENSITIVITIES	- ELECTROMAGNETIC FIELDS, CONTAMINANTS, ETC.
• SHELF LIFE	- $<$7 DAYS
• WASTE PRODUCTS	- SOLID, LIQUID, GAS, REACTIVITY, ETC.
• AUTOMATION	- CREW SKILLS AND TIME, AUTOMATIC CONTROLS, ETC.
• BASIC SUPPORT	- POWER, LIGHT, COOLING, ETC.

Figure II-17. Commonality Factors

Although the 12 Ideas carried through the Study are only a limited sample of the potential Ideas that will very likely be recognized eventually, we have defined a number of common factors among them. Those commonalities and analysis of their advantages/disadvantages are discussed in Section III. 5.

SECTION III

BASIC DATA GENERATED AND SIGNIFICANT RESULTS

A total of 120 product, process or service Ideas were noted by Key Individuals contacted in 37 operating GE components and 43 organizations outside of GE. A total of 403 Key Individuals contributed to this phase of the Study, including 170 from within General Electric. Of the 120 Ideas noted, 19 evoked no further User interest. The remaining 101 Ideas have been grouped into three categories based on the further dialogs and analyses carried out as part of the Study, and on suggestions and recommendations of NASA and GE advisors. The most important of the suggested Ideas are included in the category "Continuing Identified Ideas"; these 12 Ideas, listed at the top of Figure III-1, represent those identified Ideas which, through subsequent dialogs and analyses, were supported by information which met the objectives of the Study, and which conformed to the required outputs of the Study Tasks, or which uncovered a process not previously documented. The second category "Identified Ideas Recommended for Future Consideration" consists of 12 Ideas wherein dialogs indicated the possibilities of beneficial products, processes, or services, but for which "specifics" of the study objectives were not identified, or for which insufficient time remained in the Study to carry out the required analyses. Finally, the third category, "Other Identified Ideas, contains 77 Ideas, which were discarded or discontinued at various points in the Study when found to be inconsistent with Study objectives or covered in related studies, combined into other Ideas, etc.

The following sections, organized according to these categories, present the key information derived from dialogs and analyses (where applicable) on each identified Idea. Identified Ideas are listed in each category by title and number, the latter being assigned to specific Ideas in approximately chronological order for data storage and handling purposes.

IDEA NO.	IDEA	DISPOSITION
	CONTINUING IDENTIFIED IDEAS	
1	IMPRINTING OF CIRCUITRY FOR SURFACE ACOUSTIC WAVE ELECTRONICS	COMPLETE - REPORT ISSUED BY GE-ELEC. LAB
3	PARTICLE MANIPULATION BY SMALL FORCES	COMPLETE - REPORT ISSUED BY GE-CR&D
5	VIBRATION TESTING FOR FRACTIONAL HP MOTORS	COMPLETE - REPORT ISSUED BY GE-APPL. COMP. LAB
6	SINGLE CRYSTAL HIGH TEMPERATURE TURBINE BUCKETS	COMPLETE - REPORTS ISSUED BY GE-AEG, EASTERN AIRLINES, DR. CHUNG
30	HIGH PURITY TUNGSTEN TARGET FOR X-RAY TUBES	COMPLETE - REPORT ISSUED BY GE-MED. SYS. DEPT.
42	PRECISE SEPARATION OF RADIOISOTOPES	COMPLETE - REPORT ISSUED BY GE-NUC. SYS. PROD.
46	LARGE Si CRYSTALS FOR POWER & MEDICAL APPLICATIONS	COMPLETE - ANALYSIS REPORT AVAILABLE
59	EPITAXIAL CRYSTAL GROWTH OF GARNET FILMS FOR MAGNETIC BUBBLE MEMORY	COMPLETE - REPORTS ISSUED BY GE-CR&D & CORNING
60	AMORPHOUS GLASSES AND REFRACTORIES	COMPLETE - REPORT ISSUED BY CORNING
84	THERMAL CONDUCTIVITY OF LIQUIDS	COMPLETE - REPORT ISSUED BY GE-CR&D
89	SEPARATION OF ISOENZYMES	COMPLETE - REPORT ISSUED BY POLYSCIENCES
96	UTILIZATION OF BIORHYTHMS	COMPLETE - REPORT ISSUED BY NIH & U. OF MINN.
	IDENTIFIED IDEAS RECOMMENDED FOR FUTURE CONSIDERATION	
11	GROWTH OF EUTECTICS FOR COLD CATHODES	DISCONTINUED - RECOMMEND FUTURE CONSIDERATION
14	HIGHER PURITY FIBER OPTICS MATERIALS	DISCONTINUED - RECOMMEND FUTURE CONSIDERATION
23	IMPROVED BONDING OF WAFERS IN FLUIDIC STACK	DISCONTINUED - RECOMMEND FUTURE CONSIDERATION
38	SAFE DISPOSAL OF RADIOACTIVE WASTES	DISCONTINUED - NOTED TO COR, OUTSIDE STUDY CONSTRAINTS
45	LARGE Ge CRYSTALS FOR γ-RAY CAMERA	DISCONTINUED - RECOMMEND FUTURE CONSIDERATION
57	BLOOD ANALYSIS SERVICE	DISCONTINUED - RECOMMEND FUTURE CONSIDERATION
90	IMPROVED BATTERIES AND CAPACITORS	DISCONTINUED - RECOMMEND FUTURE CONSIDERATION
92	OPTICAL FILTERS - TECHNOLOGY	DISCONTINUED - RECOMMEND POSSIBLE FUTURE CONSIDERATION
95	CORROSIVE RESISTANT ELECTRODES	DISCONTINUED - RECOMMEND FUTURE CONSIDERATION
97	HIGH STRENGTH CARBON-BASED FILAMENTS FOR PLASTIC REINFORCEMENT	DISCONTINUED - RECOMMEND FUTURE CONSIDERATION
98	NEW ANTIBIOTICS	DISCONTINUED - RECOMMEND FUTURE CONSIDERATION
101	ENHANCED SOLAR INSOLATION	DISCONTINUED - NOTED TO COR, OUTSIDE STUDY CONSTRAINT.
	OTHER IDENTIFIED IDEAS	
2	LEAD WIRE & FILAMENT MATERIALS FOR HIGH INTENSITY LAMPS	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
4	AFFINITY CHROMATOGRAPHY	DISCONTINUED - SPECIFIC USER NOT IDENTIFIABLE
7	MAGNETRON TUBE MANUFACTURE	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
8	SPECIALTY GLASS	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
9	MICROSPHERE SPECTROSCOPE AND SPECTROSCOPY	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
10	SEMICONDUCTOR PROCESSING	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
12	DEVELOPMENT OF HIGH TEMP. HIGH STRENGTH ALLOYS & EUTECTICS	DISCONTINUED - PARTIALLY INCORPORATED IN NO. 6
13	UNIFORM MIXING OF LEAD TELLURIDE	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
15	PLATING OF POROUS STRUCTURES	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
16	COATING OF OPTICAL REFLECTORS	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
17	HIGHER PURITY THERMOCOUPLE MATERIALS AND BONDS	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
18	[illegible]	[illegible]
19	IMPROVED UNIFORMITY IN POWDER METALLURGY	DISCARDED - MINOR APPARENT ADVANTAGE TO SPACE OPS
20	SEMICONDUCTOR SOLDERING TECHNIQUES	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
21	COATING IMPLANTABLE MEDICAL SENSORS	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
22	IMPROVED PROPERTIES IN TRANSFORMER MATERIALS	DISCARDED - NO MATCH BETWEEN PROBLEMS AND SPACE PROPERTIES
24	ULTRA UNIFORM GRAIN IN PHOTOGRAPHIC EMULSIONS	DISCONTINUED - SPECIFIC USER NOT IDENTIFIABLE
25	IMPROVED ENAMEL FILM ON COPPER WIRE	DISCONTINUED - SPECIFIC USER NOT IDENTIFIABLE
26	IMPROVED NUCLIPORE FILTER	DISCONTINUED - SPECIFIC USER NOT IDENTIFIABLE
27	PROSTHETIC MATERIAL FOR BONE GROWTH	DISCONTINUED - NO SPECIFIC USER REQUIREMENT IDENTIFIED
28	IMPROVED MATERIALS FOR GAS TURBINE MECHANISMS AND SERVOS	DISCARDED - NO MATCH BETWEEN PROBLEMS AND SPACE PROPERTIES
29	THIN FILMS FOR DIALYSIS AND/OR WATER PURIFICATION	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
31	SILICON STEEL WITH BETTER ELECTRICAL CHARACTERISTICS	DISCARDED - NO MATCH BETWEEN PROBLEMS AND SPACE PROPERTIES
32	DEVELOPMENT AID IN PHONOCARDIOLOGY	DISCONTINUED - APPEARS RESEARCH
33	PROTECTIVE COATINGS ON BEARING ROLLERS	DISCARDED - NO MATCH BETWEEN PROBLEMS AND SPACE PROPERTIES
34	HIGH QUALITY THERMOSTATIC CONTROLS	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
35	IMPROVED DAIRY PRODUCTS	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
36	BONE GROWTH IN ZERO "G" ENVIRONMENT	DISCONTINUED - APPEARS RESEARCH
37	ACCELERATED HOUSING MATERIALS EXPOSURE TESTING	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
39	ZIRCONIUM CLADDING OF NUCLEAR FUEL ELEMENTS	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS.
40	SPONGE "GETTER" ALLOYS FOR NUCLEAR GAS PRODUCTS	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
41	EVACUATION AND SEALING OF IR TUBES	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
43	CAVITATION AND SURFACE WETTING PHENOMENA	DISCONTINUED - APPEARS RESEARCH
44	WELDING OF SPECIAL MATERIALS, E.G., COPPER-ALUMINUM	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
47	FILAMENT STRUCTURES, METALLIC WHISKERS AND FIBERS	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
48	VIRAL INSECTICIDE MANUFACTURE	DISCONTINUED - COVERED IN RELATED STUDY
49	VACCINES, IMPROVED	DISCONTINUED - COVERED IN RELATED STUDY
50	LYOPHILIZATION (FREEZE DRYING)	DISCONTINUED - EARLIER GENERALIZED IDEA
51	UNIFORM DISPERSION OF PARTICLES	DISCONTINUED - EARLIER GENERALIZED IDEA
52	FIBER REINFORCED COMPOSITE MATERIALS	DISCONTINUED - EARLIER GENERALIZED IDEA
53	CEMENTED COMPOSITES	DISCONTINUED - EARLIER GENERALIZED IDEA
54	LIQUID DISPERSIONS - SLIP CASTING	DISCONTINUED - EARLIER GENERALIZED IDEA
55	FREE CASTING OF METALS IN ZERO "G" ENVIRONMENT	DISCONTINUED - EARLIER GENERALIZED IDEA
56	FINE GRAIN CASTING	DISCONTINUED - EARLIER GENERALIZED IDEA
58	MEMORY DEVICES BASED ON EUTECTIC STRUCTURES	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
61	FERROELECTRIC TRANSDUCERS	DISCONTINUED - RECOMMEND POSSIBLE FUTURE CONSIDERATION
62	PRECISION SHAPING OF MIRRORS	DISCARDED - NO MATCH BETWEEN PROBLEMS AND SPACE PROPERTIES
63	LEVITATION MELTING OF METAL	DISCONTINUED - EARLIER GENERALIZED IDEA
64	STRESS - FREE GLASS CASTINGS	DISCONTINUED - INCORPORATED IN IDEA NO. 60
65	SUPER THIN SAW BLADES FOR CRYSTALS	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
66	PARTICLE TRANSPORT IN VAN ALLEN BELT	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
67	X-RAY TUBE PHOSPHOR DEPOSITION	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
68	MUTATION AND GROWTH OF MICRO-ORGANISMS	DISCONTINUED - APPEARS RESEARCH
69	GLASS FIBERS IN LAMINANTS	DISCONTINUED - SPECIFIC USER NOT IDENTIFIABLE
70	SILICON IMPURITIES REMOVAL	DISCONTINUED - INCORPORATED IN IDEA NO. 46
71	GALLIUM-INDIUM-PHOSPHIDE CRYSTAL GROWTH	DISCONTINUED - COVERED IN RELATED STUDY
72	REMOVE BORON-OXIDE IMPURITIES	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
73	EMISSION SPECTROGRAPHY OF GLASS	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
74	FACILITY FOR PRECISE ALLOY FORMULATION & ALLOY ANALYSIS	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
75	THERMOGRAPHIC AND NUCLEAR SCANNING	DISCARDED - NO MATCH BETWEEN PROBLEMS AND SPACE PROPERTIES
76	EDGE BONDING PLASTIC SHEET	DISCARDED - NO MATCH BETWEEN PROBLEMS AND SPACE PROPERTIES
77	INTERRUPTER ASSEMBLY	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
78	ALLOY PREPARATION - REMOVAL OF OXYGEN	DISCONTINUED - INCORPORATED INTO IDEA NO. 74
79	CROSSLINK OF POLYMERS BY RADIATION	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
80	CRYOGENIC SUPERCONDUCTIVITY FACILITY	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
81	IMPROVED MAGNETIC MATERIALS	DISCONTINUED - NO SPECIFIC USER REQUIREMENT IDENTIFIED
82	COPPER DEPOSITION ON SUBSTRATE	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
83	GLASS AND CERAMIC TO METAL SEALS	DISCARDED - NO APPARENT ADVANTAGE TO SPACE OPS
85	ULTRA-FINE WIRE	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
86	MEDICAL TECHNIQUES	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
87	SMALL SPHERES - GROSS ATOMIZATION	DISCONTINUED - NO SPECIFIC USER REQUIREMENT
88	NUCLEAR REACTOR MATERIALS	DISCONTINUED - INCORPORATED IN IDEAS NOS. 39,42
91	CALIBRATION OF TEST EQUIPMENT	DISCONTINUED - SPECIFIC USER NOT IDENTIFIABLE
93	CERAMICS AND REFRACTORY MATERIALS	DISCONTINUED - PARTIALLY INCORPORATED INTO IDEAS NOS. 8, 60
94	METAL PURIFICATION	DISCONTINUED - INCORPORATED IN SPECIFIC IDEAS
99	MASS SPECTROMETRY IN SPACE	DISCONTINUED - RECOMMEND FUTURE CONSIDERATION
100	HIGH PURITY RARE EARTHS	DISCONTINUED - RECOMMEND FUTURE CONSIDERATION

IN ADDITION, 19 IDEAS WERE MENTIONED IN PASSING BY VARIOUS INDIVIDUALS, BUT WERE NOT CONSIDERED BY THEM TO BE SUFFICIENT APPLICABILITY TO WARRANT FURTHER DISCUSSION. SUCH IDEAS INCLUDED SEVERAL ON INSTRUMENTATION AND SENSORS. OTHERS ON BASIC PHYSICAL AND CHEMICAL PHENOMENA, AND A FEW ON HIGH VALUE MATERIALS.

Figure III-1. Identified Specific Ideas

III. 1 CONTINUING IDENTIFIED IDEAS

This portion of Section III summarizes the available data on those Ideas which were carried through the entire Phase I Study.

The 12 Ideas so treated include:

7 Ideas for Products

No. 1. Imprinting Circuitry on Crystal Wafers for Surface Acoustic Wave Electronic Components. Although the final product is likely completed in ground facilities, there are steps in the fabrication of such components for extremely high frequency use that would benefit from a vibration-free space facility and, secondarily, from the low ambient contaminants of the hard vacuum.

No. 6. Single Crystal and Eutectic High Temperature Gas Turbine Buckets. The zero "G" of a space facility is expected to allow the production of turbine blades of materials and microstructures not achievable in ground processes, due to convection in the molten materials, contamination from crucibles, and "G" load effects on liquid/solid interfaces.

No. 30. High Purity Tungsten X-Ray Targets. Levitation melting in the zero "G" of a space facility is expected to enable the production of high purity tungsten by avoiding contamination of the melt by a crucible. Other potential benefits may accrue from improved microstructure due to supercooling in zero "G" and/or target shaping in zero "G".

No. 42. Precise Separation of Radioisotopes. The zero "G" of a space facility is expected to make possible the use of small forces, normally masked by gravity, in order to perform very accurate separations among the high molecular weight radioisotopes.

No. 46. Growth of Large Silicon Crystals. It is generally anticipated that zero "G" will enable the growth of larger diameter crystals than in ground facilities. In addition, the reduction of convective currents in the melt is expected to increase the uniformity of such crystals which is a requirement for medical sensors. Space growth of such crystals will be followed by ground processing to produce such sensors and power rectifiers.

No. 59. Epitaxial Growth of Magnetic Bubble Memory Single Crystal Garnet Films. The zero "G" of a space facility is expected to aid the diffusion process of epitaxial deposition of a single crystal film by eliminating or minimizing convection which would adversely effect uniformity of film thickness, and, through local losses in supersaturation, uniformity of magnetic properties. The complete process for fabricating bubble memories will require ground-based steps both before and after the epitaxial deposition steps.

No. 60. Amorphous Glasses and Oxides. The zero "G" of a space facility is expected to aid in the production of high strength, high IR transmissive optics and windows through eliminating the devitrification "triggers" of convection and crucible walls. Some ground finishing may be required.

1 Idea for a Process

No. 3. Particle Manipulation by Small Forces. Laboratory experiments have demonstrated effects produced by the small forces generated by light, heat, sound, RF, etc. Since the force of gravity is of the same or greater magnitude, the "masking" of these small forces by gravity will be eliminated in a zero "G" facility. As a result, it appears possible that such small forces may prove useful in removing or emplacing particles in a medium, depositing particles on a surface, etc. The variety of possible force generators, and the range of susceptibilities of materials to such forces indicates the possibility of a "tool box" of in-space manipulative forces, from which selection could be made for specific materials.

3 Ideas for Services

No. 5. Vibration Testing of Small Motors. Isolation from terrestrial environments (vibration, "G", acoustic) in a space facility is expected to enable the accomplishment of a highly important sector of fractional horsepower electric motor testing - vibration testing at $\leq$ 4 cps. Ground fabricated, prototype parts would be vibration-tested in space, and the data utilized on the ground for design modification.

No. 84. Thermal Conductivity of Liquids. The zero "G" effect of eliminating convection would enable more accurate determination of thermal conductivity of fluids, for use in the ground-based design of machinery, piping, etc.

No. 96. Utilization of Biorhythms. Isolation from terrestrial environment and variation from 28 day lunar cycle inherent in an orbiting facility is expected to add to limited ground-based and space-acquired data on circadian rhythms, variables that affect those rhythms, effect of rhythms on physical and psychological reactions, in order to develop ground-applied techniques, for medical and behavioral diagnoses and therapies, as well as for improving work performance.

1 Idea for Products, Process, Services

No. 89. Separation of Isoenzymes. The zero "G" of a space facility is expected to enable the high specificity separation of isoenzymes without denaturation -- not presently performed to acceptable levels on the ground. The use of large pore gels in the space process will allow the separation process, electrophoresis, to be carried on with sufficiently weak potential as to prevent denaturation. In addition to Isoenzymes, other large molecule biologicals are expected to be possible products of this process, and, in the case of specific isoenzymes, they could be utilized to diagnose specific diseases.

The following pages provide a discussion on each of the aforementioned ideas, and include reference to appropriate appendices where User analyses on Ideas are reported.

III.1.1 IDEA NO. 1, IMPRINTING CIRCUITRY ON CRYSTAL WAFERS FOR SURFACE ACOUSTIC WAVE ELECTRONICS

Goals and Objectives

Ultra fine printed circuitry on crystals to produce very high frequency (>30 GHz) electronic components which utilize surface acoustic wave effects. The objective is to utilize space environments and isolation from earth disturbances to enable the printing of circuits requiring spacing of $\frac{\lambda}{4}$ to $\frac{\lambda}{2}$ with accuracy and reproducibility not practically achievable in completely earth-bound processes.

Users

Participating; General Electric, Electronics Laboratory, Syracuse, New York
Other possible; (IBM, Stanford Research Institute, DOD)

Key Individuals

Participating; Dr. S. Tehon, Dr. S. Wanuga; Electromagnetics Op., GE-ELAB

Discussion

An analysis in support of this idea has been performed by Dr. Tehon and Dr. Wanuga, and a report on that analysis is printed as Appendix H, in Volume II, Book 4.

Early use of ultrasonic devices to provide simple signal processing functions in electronic subsystems has, primarily, been limited to crystal resonators in oscillators and bandpass filters, and in more limited numbers as delay lines in volatile memories and circulating integrators. Such a device is, basically, comprised of a piezoelectric output transducer, an elastic body serving as a mechanical resonator or as a storage delay medium, and one or more piezoelectric output transducers appropriately placed on the elastic body. Such simple devices as resonators and filters are fabricated by processes which incorporate transducers and the elastic body in one monolithic structure, and produce low cost components of good reproducibility. More complex devices are fabricated by assembling separate transducers and elastic bodies, are more expensive and have proven to be less reproducible.

For about the past ten years, there has been an increasing interest in ultrasonic elements, in the form of acoustic surface wave devices, for the development of complex signal processing equipment. Such devices have shown order-of-magnitude improvements in performance over standard components. Indications are that the surface wave techniques can be employed to produce integrated circuits which perform entire system functions. Furthermore, initial efforts have demonstrated that the devices can be manufactured in batch reproducible quantities. Their advantages include:

1. High frequencies and large bandwidths
2. Easily formed complex structures
3. Integrated circuit manufacturing techniques
4. Precise reproducibility and design predictability

Fundamentals of Operation. The fundamental surface acoustic wave device is a piezoelectric crystal wafer with input and output transducer electrodes imprinted on it. Electronic impulses into the input tranducer electrodes on the crystal surfaces generate acoustic waves through the crystal itself. The slower (compared to electrical) acoustic velocity, in effect, provides signal compression and temporary storage until the acoustic wave reaches the output transducer where the crystal provides electrical signal outputs. The effective compression and storage of signals due to the acoustic signal slow velocity are the key phenomena of this technology. The signal storage and compression enable, with proper patterns of transducer electrodes, signal amplification, filtering, etc.

Problem Area. The problem of concern to this Study is the imprinting of very fine circuitry on the crystal for use is extremely high frequency electronic components - now beyond the state-of-the-art for the best printing or photographic processes on earth.

Surface acoustic wave electronic components currently being produced in ground facilities are limited, by interaction of the terrestrial environment (particularly vibration) with the equipment utilized in imprinting the circuitry, to operating at frequency less than 10 GHz.

It is felt that isolation from such vibration may be achievable in a properly designed spacecraft facility, thus enabling the use of an electron beam gun in the imprinting process to make it possible to produce components for frequencies greater than 30 GHz. Requirements have already been imposed for 30 GHz components and even higher frequencies are desired.

Materials and Processes. The substrates for surface acoustic wave devices may be piezoelectric or non-piezoelectric crystal wafers, and Appendix H provides the rationale as well as the properties for selecting crystal materials. For a typical device, the circuits are imprinted on the surface of the crystal wafer in a pattern analogous to the interlaced fingers of two hands with no fingers touching. One hand represents input circuits and the other output circuits. Because of the extremely high frequencies under consideration and required spacing of 1/4 to 1/2 wavelength, the very narrow and very close "fingers" are subject to vibration problems in the imprinting process.

As noted in Appendix H, the present processes for imprinting the circuits, and their limitations, include:

1. Sputtering, photoresist film plus etching
2. Photoresist film and exposure plus etching. Limitations in optics, photoresists, and processing resolution place the finger spacing near a micron, with corresponding upper frequency limits near 600 MHz.
3. An RF sputter etching technique allows minimum linewidth of approximately 1/2 micron.
4. Electron beam methods promise even better linewidths on surface acoustic wave crystals. Scanning electron beam microscopes can be focussed to 0.02 to 0.25 micron with improved high speed resolution by computer control of the beam digitally, or by using a flying spot scanner. IBM has used this technique to get linewidths of 0.15 micron for use at frequencies of 3.5 GHz. This is approaching the limits for current techniques on the ground.
5. Soft X-ray lithographic techniques have been used to achieve linewidths of 0.6 micron on 1.3-micron centers. This technique will probably be further developed.

All of the five methods described above have their usefulness in the fabrication of acoustic surface wave transducers. Method 1 is applicable where the frequencies are relatively low and the substrates fairly cheap to replenish should the chemical etching do any damage. The second technique offers a much higher yield with essentially the same amount of time required for the processing. Methods 3, 4, and 5 are all useful in achieving finer resolution and linewidths with resulting higher frequency of operation. Although the instrumentation is more costly and specialized, the larger bandwidths, improvement in yield and higher frequency performance offset the increased complexity required.

Appendix H discusses potential space manufacturing techniques for surface wave acoustic devices. In that report, it is emphasized that the crystal materials must be selected for their intended uses based on their inherent properties. The two major properties of interest are:

1. The actual composition and stoichometry of the material
2. The physical properties of the surface finish

Included in that report are a listing of candidate materials and data for calculating the relative figure of merit of each material. The material mustbe homogenous and the growth pattern of the crystal must the uniform and stress-free. The surface finish must be optically flat to 1/20th the wavelength of the frequency to be used, and stress-free. Among the materials of interest are synthetically grown lithium niobate or quartz, bismuth germanate, and natural quartz. Future high frequency components will require major improvements in crystal quality and preparation over those currently in production. Crystals grown in the gravity-free environment in space may provide these improved properties. A large demand for extremely high quality, large size crystals for surface acoustic wave devices is expected.

If the crystals can be grown in space along a selected plane, the necessity for optical polishing may be eliminated. If thin films of epitaxial crystals of piezoelectric materials can be grown in space on non-piezoelectric substrates, significantly improved high coupling transducers can be produced. Candidate materials for the piezoelectric epitaxial films are zinc oxide, aluminum nitride, and cadmium sulfide.

Most acoustic devices will require single crystal propagating mediums of high quality. The importance of epitaxial film growth on many substrates becomes very important. Many of the required substrates are non-piezolectric and therefore epitaxial growth of not only insulators but piezoelectric films becomes of great importance. These requirements are set forth because of the different properties each material displays in its respective role. For example, low loss materials are required for propagation, piezoelectric films for transduction actions. Tables of the important properties of relevant materials are given in Appendix H.

In summary, it appears that the growth of large crystals in space environments is probably essential, and that the growth of single crystal thin films on the substrates may also be essential, where these are required.

Complete production in space of high performance surface acoustic wave devices may be desirable to eliminate contamination problems, prevent swelling or shrinking of the resist layers due to moisture, and certainly to avoid vibration problems in imprinting of circuitry.

Appendix H discusses current fabrication practices and their limitations, such as the practical problems of achieving vibration isolation in earth facilities and gives some sample calculations. The problem is in eliminating very low frequency vibrations in the system on earth. Even with 200-ton concrete base plates, isolation at very low frequencies is not effective. For electrodes of 1 micron width, an accuracy of $\pm$ 0.1 micron should be maintained. For a vibration frequency of 1 Hz, with peak value of 10^{-4}G, the peak-to-peak amplitude of motion would be of the order of 50 microns, far larger than could be tolerated. In addition, the amplitude increases by approximately an order of magnitude for each 0.3 Hz decrease in vibration frequency. Aboard a spacecraft, it may be possible to eliminate these very low frequencies coupling into a photo-copying camera system or an electron beam gun.

<u>Applications.</u> A number of examples of acoustoelectronic devices are discussed in detail in Appendix H. These include programmable surface wave filters, as well as the field effect transducer using GaAs, which achieves transduction by means of piezoelectric coupling between the current modulation produced in the field effect transistor and the acoustic wave. Code-

Applicable Space Properties

The basic space properties required in this process would be the isolation in space from very low frequency vibrations; the use of space vacuum for electron beam printing and/or soft X-ray lithography; and the avoidance of contamination in processing. The zero gravity environment in space may be of secondary importance for imprinting circuitry on crystals, but if the complete processing is done in space, the growing of crystal substrates, and the formation of piezoelectric films through the growth of epitaxial crystal films on the substrates, would benefit from the zero gravity environment.

Development Plan

A tentative schedule for developing this technique aimed at a full operational capability for space production aboard the Shuttle in 1983 is shown in Figure III-2.

	ACTIVITY	YEAR
1.	ANALYSIS AND PLANNING	1973
2.	LABORATORY EXPERIMENTS	1974
3.	SPECIAL EQUIPMENT DEVELOPMENT	1975-80
4.	SHUTTLE VERIFICATION TESTING	1980
5.	OPERATIONAL DEMONSTRATION	1981
6.	FULL OPERATIONAL PRODUCTION IN SPACE	1983

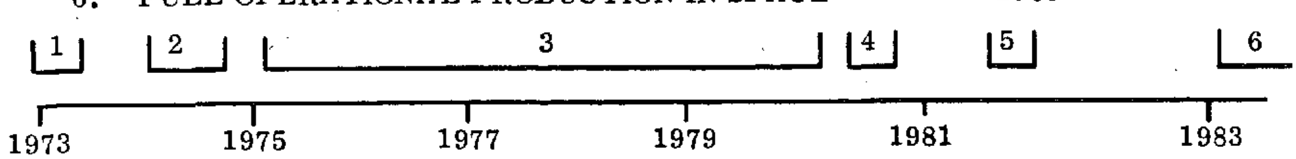

Figure III-2. Tentative Schedule for the Development of Printed Circuitry on Crystals for Acoustic Wave Electronics

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III.1.2 IDEA NO. 3, PARTICLE MANIPULATION BY SMALL FORCES

Goals and Objectives

The goal of this concept was to develop processes for the control, separation and/or dispersion of small particles in various media. The objective was to develop practical manipulation techniques from the force and effect relationships between various forces generated by selected controllable phenomena and their effects on the translational motions of particles of various sizes and physical characteristics. The phenomena selected for such consideration are those which, on the earth, produce forces that are of the same, or smaller, order of magnitude as the force of gravity, thus rendering them ineffective as particle manipulators on earth. When the earth's gravitational effect is counterbalanced, as in an orbiting spacecraft, very small force fields may be used to perform the various manipulations of very small particles that would be impracticable to accomplish on earth.

Users

Versions of this concept are used in Key Ideas No. 42, Precise Separation of Radioisotopes and No. 89, Separation of Isoenzymes.

Other uses are still to be determined.

Key Individuals

H.R. Summerhayes, M.S. Adler, S.D. Savkar; Physics & Electrical Engineering Lab., CR&D, General Electric, Schenectady, New York.

Discussion

An investigation of typical phenomena, forces, materials, and effects was carried out by the Key Individuals in support of the Phase I Study. The results of that investigation are included as Appendix E in Volume II of this Report. Those results consist, mainly, of a compilation of force and response equations, determination of the significant particle and media parameters, selected particle accelerations and velocities, conclusions as to the potential effectiveness of various forces, etc. The documented information has been utilized in dialogs with potential Users contacted during Phase I and is expected to generate considerable interest in the future as other potential Users begin to develop their space processing concepts.

The objective of the aforementioned investigation was to develop quantitative relationships between various force fields and their effects on the motion of particles of various sizes and physical characteristics. The effort was concerned, primarily, with weak force fields whose effects are ordinarily masked by the gravitational force field when generated in the earth-bound environment.

In a satellite where the gravitational field is balanced by centrifugal force, certain of these relatively weak forces can be strong enough to produce substantial particle motions which could be useful in sorting, separating or otherwise manipulating a variety of particle types and sizes. If the particles to be manipulated are suspended in an evacuated chamber, their acceleration will be the important parameter, and results show that substantial accelerations can be achieved in many cases. If the particles are confined in a container filled with a viscous medium such as air or water, they will ordinarily reach a drag-limited constant velocity in response to the applied force field so that velocity rather than initial acceleration is the significant parameter.

The particle accelerations produced in a vacuum or the particle velocities produced in a viscous medium are dependent on the nature and intensity of the force field, the viscous medium (if used), and the characteristics of the particle themselves. These dependencies offer a variety of potential means of sorting or separating mixed assemblages of particles. Combinations may be chosen which will produce motions primarily sensitive to any of a variety of electrical, optical, magnetic or other inherent properties, size, density, or combinations of the aforementioned parameters, depending on the nature of the force field and medium used.

The general expressions developed for these particle force field interactions, and the numerical examples worked out for typical cases in Appendix E provide preliminary information for Users of the space environment to initiate identification of effective manipulative forces in their manufacturing or processing areas. The data, therefore, can be considered as a first step in producing a "tool box" of manipulative forces of potential use in the search for beneficial products, processes, and services to be developed or produced in space.

The phenomena which have been explored for use as "tools" in manipulating particles are as follows:

1. Light
2. Heat
3. Microwaves
4. Sound Pressure
5. Particulate Radiation
6. Electrostatic Forces
7. Magnetic Forces

Brief Description and Comparison of Forces. Each of the first three phenomena listed is a form of an electromagnetic radiation. The net force produced on particles in the field of an electromagnetic wave results from the radiation pressure of the wave. These three forms of radiation, plus X-rays and gamma rays, which are also forms of electromagnetic radiation, are treated together in a single section of Appendix E on electromagnetic radiation effects. The force produced is shown to be proportional to the effective area of the particles times the intensity of the radiation.

Sound waves require a medium for transmission. Like electromagnetic waves, sound waves also produce a radiation pressure force which is proportional to the effective area of the particle and the intensity of the wave. In most cases, the particle is much smaller than the wavelength, and in this regime the effective size of the particle, as far as scattering of the wave is concerned, is much smaller than its actual size so that very little force is produced. This is discussed in Appendix E section on sound pressure, where another effect known as acoustic streaming (which may have more useful applications in particle manipulation) is also discussed.

An example of particulate radiation, the case of an electron beam impinging on particles, has been analyzed. As in electromagnetic pressure and sound pressure, the force produced is proportional to the particle area and to parameters related to the beam intensity. Electron beams differ from electromagnetic waves and sound waves in that the effective cross section area of the particle will generally be approximately equal to its actual cross section area, and the equations of motion would be expected to hold down to very small particles.

Large magnetic forces are developed on soft iron parts in relays and solenoids by relatively small electromagnets, but it is not so commonly realized that even diamagnetic and paramagnetic substances have magnetic permeabilities differing sufficiently from unity to produce appreciable motions in a magnetic field in zero gravity environment. The equations for magnetic forces and their resulting accelerations in a vacuum, or velocities in viscous media, have been developed as well as numerical examples for various substances.

The electrostatic force of dielectrophoresis is exactly similar in form to the magnetic force. It depends on the strength of the electric field and its degree of non-uniformity, the dielectric constant of the particle, and the volume of the particle, in exactly the same functional way that the magnetic force depends on the strength and the non-uniformity of the magnetic field, the magnetic permeability of the particle, and the volume of the particle.

These electrostatic and magnetic forces are dependent on particle volume rather than on cross-sectional area as in the case of the forces arising from electromagnetic waves, sound waves and particulate beams. Therefore, they furnish a sensitivity to different particle parameters which adds versatility to the application possibilities.

Limits and Constraints Imposed by Thermal Motion and Viscous Forces. There are environmental constraints that will apply in general to all of the forces discussed. The two issues to be considered are:

1. The competing effects of thermal motion.

2. The viscous forces that will be acting on the particles if they are in fluid.

A particle at an absolute temperature T will have a thermal kinetic energy $\langle 1/2\ Mc^2 \rangle = \frac{3}{2}$ KT, where K is Boltzmann's constant, M is the particle mass, v is the particle velocity, and the brackets indicate an average. If a gas of these particles is in a container, and a force F is applied in a direction perpendicular to a wall of the box, the equilibrium distribution of the particles is proportional to exp $(F\ \Delta X/KT)$, where X is the distance away from the wall. Approximately 70 percent of the particles will be located a distance ΔX away from the wall, much like the fact that 70 percent of the earth's atmosphere is located within 10 km of the earth's surface due to the force of gravity. It should be noted that this is an equilibrium distribution (the Maxwell-Boltzmann distribution) and does not contain any information as to the time necessary to establish the equilibrium. This time might, in fact, be very long if the medium were a viscous fluid.

In many cases the particles of interest will be imbedded in a viscous fluid or gas and it is then likely that the need for a reasonable particle velocity will determine the necessary force rather than the thermal considerations given above. Calculations indicate the need for a much higher initial acceleration than given from the thermal considerations.

It should be noted that the restriction of particle velocity in a viscous fluid is not necessarily a detrimental effect. The dependence of drift velocity in a viscous fluid on particle radius and force may actually become an additional means for achieving the separation of particles of different sizes if forces of sufficient magnitude can be achieved.

The minimum accelerations to overcome thermal motion and typical viscosities are plotted in Figure II-1 of Appendix E.

Figure III-3, Summary of Small Forces Formulae, taken from Appendix E, lists the basic formulas for the forces considered and indicates how the initial acceleration, drift velocity,

	ACCELERATION IN A VACUUM	DRIFT VELOCITY IN A VISCOUS FLUID	CONFINEMENT DISTANCE
1. DIELECTROPHORESIS			
	$\vec{Acc} = \frac{1}{\rho}\left(3\,\epsilon_1 \frac{(\epsilon_2-\epsilon_1)}{(\epsilon_2+2\epsilon_1)} \vec{E}_0 \Delta \vec{E}_0\right)$	$\vec{v} = \frac{a^2}{\eta}\left(\frac{2}{3}\,\epsilon_1 \frac{(\epsilon_2-\epsilon_1)}{(\epsilon_2+2\epsilon_1)} \vec{E}_0 \cdot \vec{E}_0\right)$	$\Delta x = \frac{KT/a^3}{\left(4\pi\epsilon_1 \frac{(\epsilon_2-\epsilon_1)}{(\epsilon_2+2\epsilon_1)} / \vec{E}_0 \cdot \Delta \vec{E} /\right)}$
	$\simeq$ 0.3 G's (ρ = 1 gm/cm^3)	$\simeq$ 0.003 cm/sec (a = 1μ, air)	$<$ a (a = 1μ)
2. MAGNETIC FORCE			
	$Acc = \frac{1}{\rho}\left(3\mu_0 \frac{(\mu-\mu_0)}{(\mu+2\mu_0)} \vec{H}_0 \cdot \Delta \vec{H}_0\right)$	$v = \frac{a^2}{\eta}\left(\frac{2}{3}\,\mu_0 \frac{(\mu-\mu_0)}{(\mu+2\mu_0)} \vec{H}_0 \cdot \Delta \vec{H}_0\right)$	$\Delta x = \frac{KT/a^3}{\left(4\pi\mu_0 \frac{(\mu-\mu_0)}{(\mu+2\mu_0)} / H_0 \Delta H_0 /\right)}$
	$\simeq$ 300 G's (magnetic, ρ = 8 gm/cm^3) $\simeq$ 0.001 G's (non-magnetic, ρ = 1 gm/cm^3)	$\simeq$ 30 cm/sec (a = 1μ, air) $\simeq 1 \times 10^{-5}$ cm/sec (a = 1μ, air)	$\ll$ a (a = 1μ) $\simeq$100 μ (a = 1μ)
3. E. M. RADIATION PRESSURE			
	$Acc = \frac{Q_{pr}(x,m)}{\rho\, a}\left(\frac{3}{4}\;\frac{W}{c}\right)$; $x = \frac{2\pi a}{\lambda}$	$v = \frac{Q_{pr}\, a}{\eta}\left(\frac{1}{6}\;\frac{W}{c}\right)$	$\Delta x = \frac{KT/(Q_{pr}\, a)}{\pi\, W/c}$
	$\simeq$ 3 G's (a = 0.1μ, W = 100W/cm^2) ρ = 1 gm/cm^3	$\simeq 3 \times 10^{-4}$ cm/sec (a = 0.1μ, air)	$\simeq$ 30μ (a = 0.1μ)
4. RESONANT RADIATION PRESSURE			
	$Acc = \frac{\pi\, h\, \nu_0^2}{M\, c\, \xi}$; $\xi = \nu_0/\Delta\nu$	$v = \frac{1}{\eta a}\left(\frac{1}{6}\;\frac{h\,\nu_0^2}{c\,\xi}\right)$	$\Delta x = \frac{KT}{\pi\, h\, \nu_0^2/c\,\xi}$
	$\simeq 10^5$ G's (atomic size)	$\simeq 1 \times 10^{-4}$ cm/sec (air)	$\simeq$ 1 cm
5. PARTICULATE RADIATION			
	$Acc = \frac{1.2\, JV^{1/2}}{\rho\, a}$	$v = \frac{a}{\eta}\; 0.27\, JV^{1/2}$	$\Delta x = \frac{KT/a^2}{1.6\, JV^{1/2}}$
	$\simeq$ 0.3 G's (a = 1μ, J = 10 ma/cm^2, ρ = 1 gm/cm^3 V = 100 volts)	$\simeq$ 0.003 cm/sec (a = 1μ, air)	$<$ a (a = 1μ)

Figure III-3. Summary of Small Forces Study (Sheet 1 of 2)

a	=	radius of particle
ρ	=	density of particle
η	=	viscosity of fluid
K	=	Boltzmann's constant
T	=	absolute temperature
ϵ_2	=	permittivity of particle
ϵ_1	=	permittivity of background
μ	=	permeability of particle
μ_0	=	permeability of free space
E_0	=	electric field
H_0	=	magnetic field
$\frac{\vec{E}_0 \cdot \Delta \vec{E}_0}{\lvert E_0 \rvert}$	=	electric field directional derivative
$\frac{\vec{H}_0 \cdot \Delta \vec{H}_0}{\lvert H_0 \rvert}$	=	magnetic field directional derivative
Q_{pr}	=	efficiency factor for radiation pressure
λ	=	wavelength of E. M. radiation
W	=	intensity of E. M. radiation $\frac{\text{(watts)}}{\text{cm}^2}$
c	=	speed of light
m	=	refractive index of particle
h	=	Planck's constant
ν_0	=	resonant frequency of atom
M	=	particle mass
ξ	=	quality factor of resonant line = $\nu_0/\Delta\nu$
J	=	current density
V	=	accelerating voltage of electrons
Δx	=	confinement distance for 70% of particles
$(a = .1\mu)$, $(a = 1\mu)$	=	(radius of particle = .1 micron), (radius of particle = 1 micron)

Figure III-3. Summary of Small Forces Study (Sheet 2 of 2) and ultimate particle density distribution is affected by particle characteristics, force inputs and environmental parameters.

The dielectrophoretic and magnetic forces are identical as to their dependence on particle size and unique in that the initial acceleration does not depend on particle size.

The electromagnetic radiation force has a strong dependence of the efficiency factor (Qpr) on particle size, and this affects the response of the particles in terms of acceleration, drift velocity, and the 70 percent confinement distance. Thus, electromagnetic radiation pressure offers the best possibilities for selectively moving particles on the basis of size alone.

Sound pressure was not included in this summary list because the force is complex and not readily amenable to short summarization. For further details on sound pressure effects, see Appendix E, Section IV.

It is interesting to note that, for all cases listed in Figure III-3, the drift velocity and the 70 percent confinement distance (ΔX) are independent of particle density because the particle forces are independent of mass.

Typical gross values are shown in Figure III-3 for the accelerations, drift velocities, and confinement distances for each of the forces listed; however, these parameters are dependent on the excitation levels of the forces used and the particle parameters. For a more complete appraisal of the possible response levels, particularly for the case of radiation pressure, see Appendix E.

It should be noted that the drift velocities formulae are the drift velocities in a viscous fluid as a function of initial acceleration in addition to consideration of the competing effects of thermal random motion.

Special attention is called to the fact that for the Magnetic Force entries in Figure III-3, acceleration, drift velocity and confinement distance are given in mks units while the equations used to describe magnetic effects in Section VII of Appendix E are in cgs units.

Potential Benefits

As previously stated, work on this Idea resulted in a compilation of formulae showing the interrelationships of various kinds of forces on small particles floating in space, with or without viscous media present. Unlike most of the Ideas carried through the B.U.S. Study, this Idea is basically a process, for which economic or sociological benefits can not be defined. On the other hand, these interrelationships may likely be applied as a technology in producing products, processes or services in space.

For discussions of typical applications of these interrelationships see the Ideas Numbers 42, and 89, Sections III.1.6 and III.1.11, respectively.

Applicable Space Properties

The space properties applicable for utilizing these small forces to manipulate small particles are zero gravity, the associated lack of buoyancy and sedimentation tendencies, and the absence of convection based on density gradients. Secondarily, space vacuum may be used for some applications, and it is conceivable that the earth's magnetic field, solar illumination and particulate radiation might also be used.

Development Planning

This Idea is aimed at developing a process. Few Ideas for products have surfaced which could potentially utilize the process, due, probably to the novelty of the Idea. The lack of such application, thus, imposes no driving requirement on when developments are required. On the other hand, early experiments, which could demonstrate the effectiveness of certain of the small forces discussed, could enhance the assembly of data for a "tool box" of force generators. Potential Users, requiring the separation, emplacement, deposition, etc., of specific particles in specific media, could then select the appropriate tool.

Planning for such utilization implies early generation of basic particle manipulation data, and subsequent development of force generator designs for the most effective forces.

The long duration generally required for most small forces to perform significant manipulation leads to requiring long duration missions thus reflecting shuttle transportation, and establishing 1979-1980 as the major data acquisition period (4), and 1981-1983 as reasonable timing for force generator testing (5). Preceding the shuttle-based data acquisition phase, there are the necessary in-depth analyses (1), possibly some fundamental laboratory testing (2), and the development of shuttle-based experiment equipment (3). Such a program might reasonably be expected to follow the schedule shown in Figure III-4.

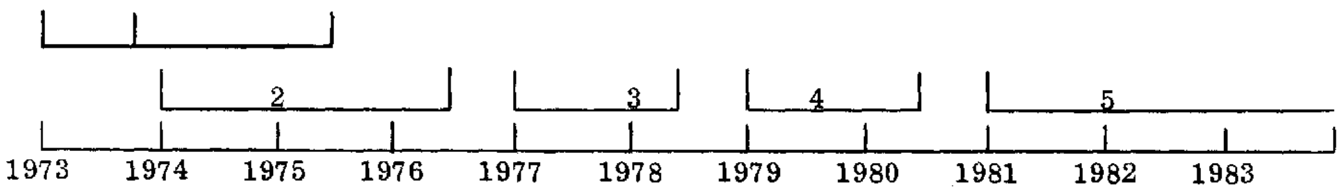

Figure III-4. Schedule

III. 1. 3 IDEA NO. 5, VIBRATION TESTING OF SMALL MOTORS

Goals and Objectives

The User goal is to obtain high reliability, long life electric motors for use in applicances. The specific objectives are to develop testing techniques and facilities in space for a more universal and mechanistic approach to solving motor noise and vibration problems. The zero "G" environment in a vibrationless spacecraft would allow more precise vibration measurements of components and complete motor, including the effects of bearings and oil films, which would be applicable to analysis of radial and torsional dynamics of small motors. The data would aid the design of better motor structures, bearings, and in the selection of lubricants. Isolation in a vibrationless spacecraft would facilitate the use of holographic interferometry for more precise measurements.

Users

Participating; General Electric, Appliance Components Division, Fort Wayne, Indiana.

Key Individuals

Mr. F.N. Peters, Mgr., Mechanical Laboratory, GE-ACD

Mr. R.T. McGregor, Dev. Engr., Noise and Vibration, GE-ACD

Discussion

The development of the Space Shuttle late in this decade will provide a potential capability for orbital operations in combined environments of zero gravity and the absence of vibration. This will be the first time that such a combination has ever been available to industrial and commercial users. The analysis, documented in Appendix I of Volume II, was directed to the determination of how this new environment might be used for the development of better fractional horsepower electric motors and an assessment of potential economic benefits which might result from such activities.

Areas of possible improvement through such development are noise and vibration, which in electric motors, are sources of wear that eventually lead to component failure. Although the phenomena have been under study for many years, refinements in techniques for measuring vibration and noise are slow. In spite of a good understanding of the basic physics involved, there appears to be a current lapse in the area of measurement and control of vibrations.

Fundamentals of Vibration Measurement and Control in Fractional Horsepower Electric Motors. Such control is usually accomplished through the design of mechanical and electromagnetic characteristics of the motors. If the forces causing vibration cannot be reduced or eliminated, then one seeks to reduce the response to such forces by providing damping and/or by detuning the system to the frequencies being experienced. These methods are most advantageous when an entire system is involved; however, because of the complexities involved and the current state of the art in vibration testing, this is possible only within certain limitations.

The forces and responses most often associated with motor noise and vibration are dependent on the dynamic operation of the motor. Unfortunately, neither the torsional resonant frequency nor its damping factor can be measured while the rotor is mounted normally in its bearings under nonrotating conditions. This is because the oil films in the bearings build up only when the rotor shaft is turning. When the rotor is not turning, the shaft sinks (due to gravity) through the oil film and rests directly upon the bearing surface, hence the resonant frequency in the static condition is affected. In the zero G of space flight, this would not occur.

Current torsional testing methods are usually based upon static (non-rotating) measurements. For torsional tests the rotor shaft is put under torque and vibrations are measured statically. A second approach is to use a variable frequency source in the winding and measure the response acoustically. This system requires a sounding board and the results are apt to be more indicative of the sounding board response than of the motor.

Static tests on a rotor, supported at the bearing points on knife edge V-blocks, can be performed by vibrating the system and measuring the response with accelerometers. This technique ignores any effects due to the bearings and/or the oil film in the bearings, and hence fails to account for stiffness or damping in the rotor shaft bearings. Although some measurements are made with the rotor assembled in the stator by exciting the stator windings with a low voltage, variable frequency, this approach still ignores the dynamics of the bearing and lubricant.

In both torsional and radial vibration modes, the effects of bearings is not of minor importance. Yet limitations of experimental approaches on earth make it difficult to assess. It would be desirable if the dynamics of the system could be obtained (or simulated) while retaining the accuracy and simplicity of static measurements. In a gravity-free environment this might be accomplished. Such an environment would allow the existence of a rotor shaft in its bearings with a fully developed oil film between the shaft and bearing in a non-rotating test. Measurements could be taken on such a static system which would reflect dynamic conditions.

The accuracy of vibration measurements using accelerometers and cathode ray tubes to display the Lissajous patterns, is reasonably good, but the presence of accelerometers attached to the test specimen create additional loads (and perhaps stiffness) which affect the vibrational modes of the equipment under test.

Test and Design Methods. A more complete and accurate picture of vibrational modes might be obtained using holographic interferometry; however, with the best current test facilities available it is impractible to isolate the motor load-vibrations and the terrestrial vibrations at the facility site from the holographic optics. Because of the nature of holographic interferometry, vibration displacements on the order of a few angstroms are too large to tolerate. (GE's anechoic chamber at Ft. Wayne, Indiana, one of the best in the country, resonates at 4 Hz. In addition, seismic vibrations in the bedrock of the site also can affect holographic measurements.) A facility could be built in space which would be isolated from terrestrial vibrations and, under zero G conditions holographic measurements might be more practical.

The program would include both rotor and stator integration studies. The objective of the rotor studies phase of a feasibility program would be to:

1. Establish a model of rotor flexure that includes damping

2. Establish a model of torsional vibration that includes damping

3. Design preliminary experiments to acquire information relating to the accuracy of the models

4. Outline measurement techniques that, if possible, could establish the damping parameter under dynamic conditions

5. Outline limitations of terrestrial experimentation and/or measurements that might be alleviated in an Orbiting Laboratory

Experimentation in an orbiting environment would follow this study and preparation phase. Upon completion of such a program, including the necessary orbital experiments, it is expected that there will be three primary results:

First, an in-depth understanding of rotor vibration, both radial and torsional, providing a more comprehensive model allowing accurate prediction of system response. In the area of appliance noise and vibration, considerable engineering and testing time is now spent in diagnosing and solving each problem on an individual basis. With this increased understanding, a reduction of time spent on individual problems should be realized.

Second, experimental and empirical results will establish the necessary preliminary work for:

1. Redesign of motor bearings for vibration damping

2. Classification of desirable damping characteristics of lubricants

This information then could be used to reduce the frequency of occurrence of certain classes of motor/appliance noise and vibration.

Third, it is expected that a spin-off of this program would be new and better measurement techniques for the determination of noise and vibration parameters. Such techniques will increase engineering efficiency and productivity. Also, new measurement techniques should give rise to a steady influx of new knowledge for a continuing updating of the description of motor noise and vibration phenomena.

The objective of a program to study <u>stator</u> vibrations would be to:

1. Investigate the potential of holography as a method for mapping stator vibrations
2. Determine the limitations of conducting holographic measurements of a stator as a function of:
   a. Gravity.
   b. Subsonic vibrations.
   c. Excitation of stator vibrations either form operating the motor or from an external means.
3. Design preliminary experiments to ascertain the advantages and practicality of conducting measurements in space.

The expected results of this work can be classified into two main areas.

<u>First</u>, successful positive results will evolve into a more realistic understanding and description of stator vibrations. This in turn will reflect lower cost for the solution of a class of motor noise problems associated with stator vibrations. This will occur because better or more informative initial design and also better knowledge with which to determine sensitive parameters for a solution to an existing problem or design.

<u>Second</u>, from this work should evolve more definitive measurement techniques for stator vibrations. This will give rise to continuing increase in the breadth and depth of understanding of stator vibration.

Unfortunately, the techniques which would be used for vibration testing in space are, as yet, undeveloped. Based upon current technology as used at GE-ACD, one is unable, at present, to predict with any degree of certainty, whether the results of space vibration developments would result in any appreciable increase in motor life expectancy or whether a decrease in materials used in motors might be achieved. It is conceivable that in some cases material would have to be added to the motors to stiffen structures and/or to damp-out vibrations. Such additions would obviously increase unit material costs.

Current problems in testing small electric motors and suggestions as to how these problems might be minimized by vibration tests in the space environment of zero gravity are discussed in the GE-Appliance Components Division's analysis entitled "Report on Beneficial Uses of Space in the Fractional Horsepower Motor Industry" (Volume II, Appendix I).

The problems of noise and vibration control are common to most classes of machinery in general and to all classes of rotating machinery with bearings in particular. A capability for studying these problems in space, under new environments not obtainable on earth, is almost certain to lead to new knowledge of the basic problems involved which will be of economic benefit to a wide spectrum of industrial concerns in addition to the fractional horsepower motor industry. The provision of such facilities in space as a service to American industries in general appears to be worthy of further consideration.

Potential Benefits

The provision of a vibration test facility in space would have direct benefits to a number of potential users as shown in Figure III-5.

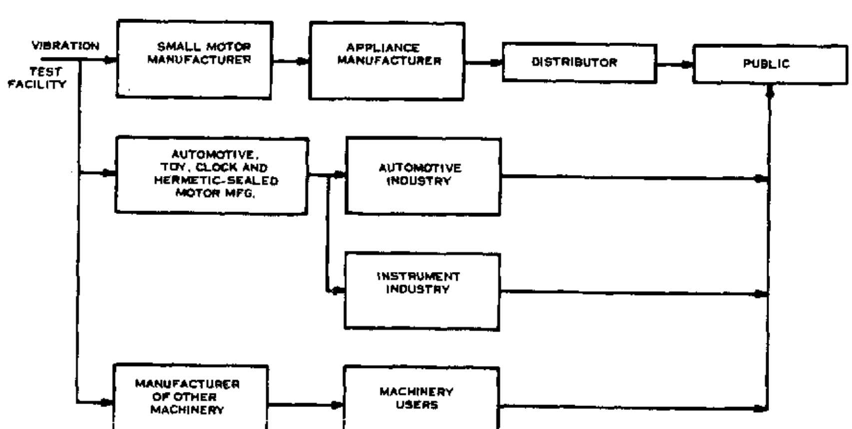

Figure III-5. Users Benefiting from Vibration Testing of Small Motors in Space

Current Industrial Reports, Series MA36H, published by the Bureau of the Census of the U.S. Department of Commerce shows the fractional horsepower motor market (< 746 watt motors) in 1970 was $748.3 million, exclusive of automotive, toy and clock and hermetically-sealed motors. Approximately 125 million motors of < 746 watts power are made in the U.S. each year. If better design data could be achieved through vibration testing of fractional horsepower motors in space, each cent of potential savings on each motor would be equal to $1.25 million per year. It has been estimated that perhaps 8¢ per motor might be saved on motors of <746 watts alone. This would be equal to $10 million dollars per year to the motor manufacturer.

Based on the size of the noise and vibration effort at GE-Appliance Components Division, (which is probably greater than the industry average) it is estimated that $375,000 annually is devoted to "firefighting" in the area of noise and vibration by the industry. It is anticipated that the answers obtained in a program such as the one outlined herein might reduce by half the expenditures required for such "firefighting." This would save approximately $187,500 annually in the U.S. small motor industry in the area of vibration reduction activities.

It has been estimated that if the improved motors resulting from decreased noise and vibration were bought by half of the potential users, and if they were willing to pay 10 percent more for these improved motors, this would result in an increase of $37.4 million per year sales for the motor manufacturer alone and similar increases in sales value for the appliance maker who uses these motors, and distributors and retailers who handle the appliances.

The public will benefit from the quiet, vibrationless operation of the appliances and probably from a longer trouble-free life of their appliances, a reduction in the frequency and cost of repairs, parts, and the eventual replacement of appliances. Retail sales of major household appliances with small motors in 1967 totaled $5.6 billion*. If better motors increased the life of these appliances even 1 percent it would amount to $56.1 million per year savings to the public users.

*The U.S. Book of Facts, Statistics & Information, 1969, Published by U.S. Government as Statistical Abstract of the U.S., by the U.S. Bureau of the Census, U.S. Dept. of Commerce, 89th Edition.

The production of automotive, clock, toy and hermetically sealed motors is at least as large as the production of small AC motors and similar benefits would be potentially available to the automotive industry, clock and toy industries, instrumentation industry, and to the public users of these motors.

In addition, the vibration test facility in space would be potentially applicable to all makers of machinery who have noise and vibration problems and these manufacturers, their distributors, and the ultimate users, the public, might all benefit.

Applicable Space Environments

A vibration test facility in space would utilize the vibration isolation from terrestrial sources and the zero gravity environment in space to simplify the study of vibrations and perhaps to improve the accuracy of measurements through the use of holography. Dynamic response of a rotor shaft, supported on bearings, with an oil film between the shaft and the bearing, would provide a better simulation than is available under current testing conditions on earth. The adverse effect of removing the normal earth gravity attraction as a load on the vibrating parts would have to be accounted for, but the mass effects in zero gravity would be the same.

Magnetic fields in low earth orbits would be variable as the spacecraft moves around the earth, but this variation is not expected to be important in most cases.

Since any structure has resonant frequencies, a spacecraft will not be vibrationless, especially when some piece of equipment is being vibrated in the spacecraft. Consequently, considerable design effort would be required to establish a spacecraft structure (or facility structure) which would be satisfactory for vibration test uses.

The potential for economic benefits to a large segment of industry which might result form the use of a vibration test facility in space appears to warrant further consideration.

Development Plan

The development plan and schedule for vibration testing of small motors in space is shown in Figure III-6.

SUBJECT: VIBRATION TESTING OF SMALL MOTORS

DESCRIPTION OF DEVELOPMENT PHASE	TIME PERIOD
ROTOR PROGRAM	
1. ESTABLISH TORSIONAL AND ROTOR RADIAL FLEXURE MODELS THAT INCLUDE DAMPING.	1973-74
2. DESIGN AND PERFORM PRELIMINARY EXPERIMENTS TO ACQUIRE INFORMATION FOR DETERMINING THE CONSTANTS RELATING TO THE FIRST GENERATION MODEL. TEST ACCURACY.	1975
3. OUTLINE MEASUREMENT TECHNIQUES THAT COULD ESTABLISH THE DAMPING PARAMETER UNDER DYNAMIC CONDITIONS.	1976
4. OUTLINE LIMITATIONS OF TERRESTRIAL EXPERIMENTATION AND/OR MEASUREMENTS THAT MIGHT BE ALLEVIATED IN AN ORBITING LABORATORY.	1977-78
5. OUTLINE ORBITING LABORATORY EXPERIMENTS. HYPOTHESIZE RESULTS FOR CHECK AND BALANCE.	1978-79
6. CONDUCT TERRESTRIAL EXPERIMENTS TO CONFIRM LIMITATIONS.	1979-81
7. CONDUCT ORBITING LABORATORY EXPERIMENTS.	1982-84
STATOR PROGRAM	
1. ESTABLISH A MODEL OF STATOR VIBRATIONS AS A FUNCTION OF (1) DIAMETER, (2) STACK LENGTH, (3) DC OR AC, (4) END SHIELDS.	1973-74
2. ESTABLISH MEANS OF MEASUREMENT VIA ACCELEROMETERS. DEMONSTRATE (1) DIFFICULTY IN MEASUREMENTS, (2) INABILITY TO ACQUIRE COMPLETE INFORMATION.	1975
3. INVESTIGATE THE POTENTIALS OF HOLOGRAPHY AS A MEANS OF DETERMINING STATOR VIBRATIONAL CHARACTERISTICS.	1976
4. DETERMINE POSSIBLE LIMITATIONS TO TERRESTRIAL HOLOGRAPHIC MEASUREMENTS OF STATOR VIBRATIONS.	1977
5. OUTLINE ORBITING LABORATORY EXPERIMENTS TO CIRCUMVENT TERRESTRIAL LIMITATIONS.	1978
6. CONDUCT TERRESTRIAL EXPERIMENTS TO EITHER (1) CONFIRM LIMITATIONS OF SUCH, (2) TO PROVE FEASIBILITY OF HOLOGRAPHIC MEASUREMENTS ON EARTH.	1979-80
7. CONDUCT ORBITING LABORATORY EXPERIMENTS.	1982-84

Figure III-6. Time Phasing of a Development Program for Vibration Measurements in Space

III. 1. 4 IDEA NO. 6, SINGLE CRYSTAL AND EUTECTIC HIGH TEMPERATURE TURBINE BUCKETS

Goals and Objectives

Develop and manufacture longer life turbine blades (particularly the first stage) capable of sustaining significantly higher turbine gas temperature for longer periods of time, compared to the temperature and component meanlife attainable through current and projected ground techniques. Gains in performance will undoubtedly continue to be achieved by turbojet engines through improved metallurgy and air cooling techniques. The goal here is to surpass the present rate and ultimate level of improvement by utilizing processes that take advantage of the applicable space properties. A conservative goal of $100^{\circ}K$ increment and 100 percent increase in mean-life were established in the study as being representative of the potential improvement attainable through space.

Users

1. Turbojet engine manufacturers: Participating; General Electric, Aircraft Engine Group, Cincinnati, Ohio; Other; United Aircraft.
2. Airline companies: Participating; Eastern Airlines, Miami, Florida; Others; Other airlines
3. The public: participating; Dr. A. M. Chung, Philadelphia, Penna.

Key Individuals

Participating;

Dr. L. P. Jahnke, Material and Process Technology Laboratories, GE-AEC.

Dr. W. H. Chang, Advanced Materials Technology, GE-AEG

Mr. B. L. Brock, Eastern Airlines, Engineering Division

Dr. L. A. Tarshis, Physical Metallurgy Branch, GE-CR&D

Dr. A. M. Chung, Management and Operations Research, Drexel University

Mr. W. B. Gist, GE-AEG

Discussion

The development of aircraft gas turbine engines has a normal cycle of approximately 13 years from the development of new technology until this technology is available in a production engine. Of those 13 years, it takes approximately seven years from the development of a new technology for it to be incorporated into components, and for these components to be used in a demonstration engine. At this point, the engine people and the airplane people can begin their studies on how the engine will be used. Normally, another six years of engine prototype development, testing, and qualification is required before a production engine is ready for service.

Historically, the development of jet aircraft started in 1942. Since then, if we use the parameter of turbine inlet temperature as an indicator of increasing capability, this parameter has increased from approximately 1115°K (1550°F) in 1942 to 1588°K (2400°F) in 1972.

Increasing turbine inlet temperature increases the efficiency of a turbine, but, in the normal development cycle, the properties of available materials limit the design temperatures which can be used.

Fundamentals of Operation. The development of new materials has provided, on the average, a capability for a 6°K (11°F) increase in turbine inlet temperature each year since 1942. The development of air cooling techniques for turbine blades, combined with new material developments, has provided an average 33°K (60°F) increase in turbine inlet temperature each year since 1960. A large portion of that improvement in temperature capability in the last few years is attributable to developments in turbine blade air-cooling techniques. However, it is important to note that an increase of 56°K (100°F) in blade metal temperature capability can allow an increase in average gas temperature of from 111°K to 222°K (200°F to 400°F), depending on whether the blade is uncooled or cooled with sophisticated techniques. The following sections deal with three development areas that potentially will benefit from space testing and manufacture, namely, single crystals, eutectic alloys, and refractory metals.

Single Crystals. The mechanical properties of polycrystalline turbine blade metal depend, to a significant extent, on the characteristics of the grain structure and inter-granular boundaries. Strength will be influenced by the coarseness of the grain, grain orientation, microporosity in the interdendritic spaces, and alloy heterogeneities, such as alloy second phases and inclusions in interdendritic areas. Sophisticated techniques involving directional solidification have been employed to control the grain characteristics*. Among these, the formation of single crystals is particularly attractive in turbine blade metallurgy because it eliminates grain boundaries. Single crystal turbine blades have been produced experimentally, and it will be important to perfect the production techniques - possibly through a more controlled environment - to render the process operational.

An important environmental factor that must be controlled during directional solidification is convection because this gives rise to internal casting defects referred to as "freckles." F. L. Versynder, characterizes these "freckles" as having an excess of eutectic material, second phase particles, porosity and small randomly oriented grains. It has been observed that these are caused by localized segregation due to convective upward flowing liquid jets in the molten metal. Although the effect of convection has been partially overcome by very careful control over the thermal gradient across the liquidus - solidus interface and the crystal growth rate, the following two conditions should be satisfied before going into commercial production:

1. The rate of crystal growth should be increased.
2. Better techniques should be found to eliminate "freckling" altogether.

During the survey performed with Key Individuals, in Task I of the Phase I Study, it was evident that there were several schools of thought concerning single crystal turbine blade processing. One of these views is that eliminating convection may present the unique advantage of speeding up crystal growth, in the same way that certain semiconductor crystals

*Vernsnyder, F. L., and Shank, M. E., The development of Columnar Grain and Single crystal High Temperature Materials through Directional Solidification, Materials Science and Engineering, March 1970.

are theorized to grow faster in a convectionless environment. Another view is that a convectionless environment would be the only viable way to stop "freckling," while still another view is that both speeding up the crystal growth process and eliminating "freckles" will eventually be the result of adequate control of thermal gradients during directional solidification. These questions are not resolved in this study, and it is doubtful that they will be resolved until detailed ground-based and space experiments are performed on directional solidification.

Directionally Solidified Eutectic Alloys. Composite materials are designed to obtain an combination of strength and ductility for structural applications. Three criteria must be satisfied to obtain effective reinforcement in a composite. These are:

1. The presence of a high strength constituent
2. Proper bonding of this phase to the more ductile matrix material
3. Alignment of the high-strength elements parallel to the intended stress axis

One approach to composites is the production of reinforced structures directly from a melt by the controlled solidification of eutectic alloys. Unidirectional solidification of binary eutectic alloys can result in the formation of an aligned microstructure possessing reinforcing characteristics. The binary eutectic reaction is the transformation of a liquid phase into two solid phases at a constant temperature. The reaction is invariant, because it occurs in a system only when each of the phases has a specific composition and only at one temperature. The eutectic composition has the lowest melting temperature of any solid composition for that binary system - not all binary systems have eutectic points.

The nature of the eutectic microstructure can be any of a variety of morphological shapes which vary from one binary system to another. For example there can be:

1. A continuous matrix surrounding discrete particles of the second phase.
2. Alternating platelets of the two phases; as rods, dendrites, swords, globs, etc.

For controlled solidification, however, the phases of the controlled microstructure, regardless of their shape, are aligned essentially parallel to the growth direction. Directionally solidified eutectics of several binary systems are of great interest in turbine blade development due to high strength imparted by the resulting rod-like structure or whiskers. The strength is largely dependent on the whiskers. Experience has shown that the whisker is the site of fracture rather than the matrix-fiber interface. In many eutectic systems, a unique crystallographic relationship exists between the two phases in a controlled microstructure. Specific crystal planes and directions in one phase are found to be parallel to specific sets of planes and directions in the other phase. This crystallographic matching of the phases may be a factor in the observed whisker-matrix bond strength. The high matrix-whisker bond strength results in an anisotropic material having a strength in the whisker direction dependent on the fracture strength of the whiskers, which may be very high for some binary systems.

There are certain limitations that impede wider utilization of eutectics. There is a limited set of binary systems from which one can form eutectic composites, and further, the eutectic composition in any one system is invariant. Segregation due to buoyancy, settling, or convection further restricts this set within the limits of practicality. Zero gravity would diminish the restrictions in the eutectic material combinations. Furthermore, it is suspected that spatial distribution and shape of the rod-like microstructure may be affected by thermal convection. The phenomena of transverse banding and stacking faults in rod-like or lamellar structures are attributable to thermal fluctuations and convective transport. This plays an important role in the mechanical properties as measured in the desired whisker direction. This is evidenced by the fact that stacking faults act like "super" dislocations contributing to greater plastic yielding in the desired whisker direction.

Refractory Metals. Achieving operational turbine inlet temperatures approaching the stoichiometric limit is highly desirable and will depend to a great extent on the development of refractory metal applications for turbine blades. Improved metallurgical processes must be sought to attain the desired properties of strength at high temperature, impact resistance, and lower oxidation rate in the refractory metal blades. Important among these processes is the development of melt techniques that will permit large yields of refractory metal with superior purity, homogeneity, controlled grain size, and fabricability. Following is a brief summary of current processing techniques, their limitations, future processing needs, and the potential advantages of space processing utilizing levitation melting, as discussed in more detail in Appendix M of Volume II.

The conventional powder metallurgy process involves the mixing of elemental powders to achieve the desired composition followed by a pressing operation and subsequent thermal treatment near the melting point of the powders to achieve a dense product of uniform composition. The final thermal treatment can be accomplished utilizing one or a combination of the following: self-resistance heating, radiation heating, and induction heating. Other techniques which have been used to consolidate powder compacts include high temperature gas pressure bonding, spark sintering, and direct mechanical deformation of the as-pressed compact; i.e., by forging, rolling, or extrusion.

There are several problems associated with the classic powder metallurgy approach described above and these are enumerated below:

1. Theoretical densities of the materials are difficult to achieve.

2. Homogenization of alloys containing large amounts of several different elements can be a problem due to both blending problems and the rather slow solid state diffusion process necessary to achieve a uniform composition.

3. Swelling of the compact due to unequal diffusion rates of the various elemental additions.

4. Powder metallurgy refractory metals usually have high concentration of interstitials.

5. High cost of utilizing high sintering temperatures for large size products. (Temperatures greater than about 3059°K (5046°F) usually must be reached by self resistance heating which can be very expensive for large size ingots.

6. Difficulty in obtaining uniform density in the cross-sections of the large diameter ingots.

Current techniques for high temperature melting of refractory metals include levitation melting of very small masses, cage melting, and drip melting. Of the three, drip melting is the only technique that is currently used extensively in the production of large amounts of refractory metal alloys. Within this general category of drip melting there are three subdivisions: arc melting, electron beam melting, and induction drip-cool melting. All of these processes involve the melting of a small portion of a consumable electrode and allowing the melted portion to drip into a cold crucible containing a small molten pool of the metal or alloy.

Advantages of refractory metals made via melting are:

1. High purity
2. The attainment of good homogeneity
3. The attainment of a large grain size which is helpful in limiting the erosion of rocket nozzles, improving the high temperature creep strength of the material, and increasing the resistance to thermal stresses.
4. The attainment of alloys that cannot be made successfully using normal powder metallurgy techniques (for example, tantalum base alloys).

Disadvantages associated with current techniques for melting refractory metals are:

1. Poor yield resulting from the necessity to machine away the rough outer layers of melted ingots which were in contact with the water-cooled crucibles.
2. Inability to keep the entire ingot in the molten condition. Usually, only a small portion of the resulting ingot remains molten during the melting process because of the cooling effects of the retaining crucible.
3. The necessity for multiple melting to get good homogeneity. (This is a result of the fact that only a small portion of the ingot is molten at a given time.)
4. Very slow melting rates (on the order of the 0.453 Kg, 1 pound, per hour for electron beam melting) are necessary in order to get sufficient purification.
5. Loss of some alloying additions which have high vapor pressures.

6. Inability to make large size ingots.

7. Inability to cast alloys into useful shapes.

Applications of present melting techniques:

1. Production of super pure materials (for example, high purity molybdenum).

2. Tantalum base alloys for space vehicles and hardware.

3. Manufacturing of fabricable rhenium material.

4. Manufacturer of columbium base alloys for nuclear power super-heater application and other applications requiring high temperature steam corrosion resistance.

5. Manufacturer of arc cast tungsten rocket nozzles.

Possible advantages of levitation melting of refractory metals for turbine blades processed in space are:

1. Improved purity, due to lack of contact with crucible and lack of gaseous impurities.

2. Improved homogeneity of alloys, due to even temperature distribution during levitation melting. By contrast, in current drip melting processes the inability to keep the entire ingot in the molten condition at any given time gives rise to temperature gradients and inhomogeneities in the ingot.

3. It is anticipated that there will be no surface instabilities on the levitated mass in zero-gravity. In 1-G, however, the interaction of electromagnetically induced currents, gravity, and surface tension produces surface instabilities such as ripples ("Kelvin Instabilities"), which causes pouring of the molten material through discontinuities on the melt surface. The effect of these instabilities increases with the size of the mass levitated in 1-G; this is one reason why ingots of practical size are not produced through levitation melting in a terrestrial environment.

4. The attainment of very large grain size materials and the possibility of obtaining very large single crystals of refractory metal alloys by utilizing directional solidification techniques. This advantage derives from the ability to control materials temperature very closely, as compared with the 1-G case in which temperature control is subjugated to levitation control.

5. Attainment of small cast grain size by utilizing ultrasonics or induction agitation of molten material during cooling. Alternatively, small grain size could be obtained by very fast cooling rates associated with a casting operation. Fast cooling rates would only be possible in zero-G, where the electromagnetic heaters could be removed rapidly without losing levitation.

6. Improved fabricability of refractory metal alloys. (This would primarily be a result of the first two advantages previously listed.)

Potential Benefits

The flow diagram in Figure III-7 depicts the interrelationship among the hierarchy of Users of turbine blades manufactured in space.

Estimates of benefits potentially accruing to the key Users in that hierarchy are subsequently discussed. More detail on those estimates and the assumptions involved will be found in Volume II, Appendices B, C and D.

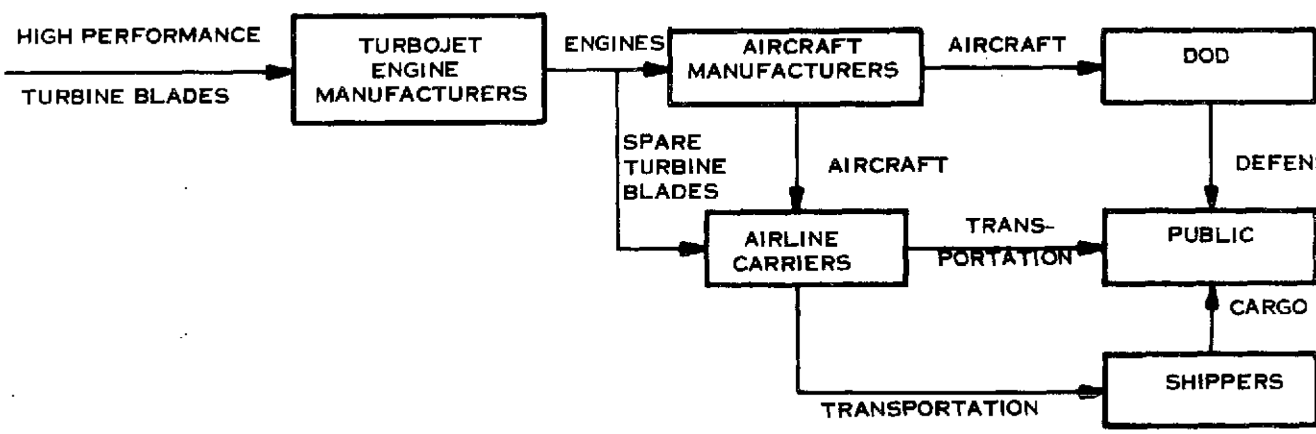

Figure III-7. Users for Space-Processed Turbine Blades

Benefits to U. S. Turbojet Engine Manufacturers. (See Volume II, Appendix B.) For a typical commercial engine manufacturer supplying both military and commercial high performance engines, the potential benefits from using the improved turbine buckets discussed herein result from one or both of the following:

1. Decreased development time (and possibly dollars) to achieve a given level of higher performance.

2. Increased sales potential due to higher performance engines and decrease in customer initial and operating costs.

For a military engine program, the profit to an engine manufacturer on each engine is limited by law. The improved materials application could result, in some cases, in increased cost-incentive-payments to the engine manufacturer; however, the primary benefit would be realized by the military customer in terms of better engine performance, and ultimately, by the taxpayer in the form of defense savings.

The aircraft jet engine buyer is primarily interested in engine dependability and reliability for trouble-free service. Late engine delivery to the aircraft manufacturer, or unscheduled removal of aircraft from airline service, are generally considered to be much more expensive than the cost of the engines or replacement parts. Operating economy is also an important consideration to the User. Only when all such factors are considered equal does the engine selling price become a decisive factor in the choice of engines for a new application. On that basis, experience has shown that a difference in engine selling prices of the order of 15 percent is usually not significant for engine salability.

Actual dollar benefits to an engine manufacturer which could result from the application of an improved material in turbine blades are likely to be as follows:

1. Materials improvements generally cost an engine manufacturer an average of approximately \$600, 000 per year for a 6°K (11°F) improvement each year. A 111°K (200°F) step improvement would, thus be equivalent to 18 years of such materials development or approximately \$11 million worth of effort.

2. The net cost of advancing the turbine inlet temperature capability of an engine 111°K through conventional development is currently estimated to be of the order of 2-1/2 years of advanced development (at an average of 80°F per year) at \$8 to \$10 million per year. Thus, a total of \$20 to \$25 million benefit in engine development costs could be realized by the engine manufacturer if a no-cost, abrupt material improvement affording the same 111°K turbine inlet temperature capability were available.

While initial engine costs are of generally less significance in marketing commercial aircraft jet engines, the contribution of turbine blade replacement to the far more important operating costs are a third area of potential benefits, which aids in the marketability of the engines.

3. The base price of a basic GE CF6-50C aircraft engine, as used on the DC-10-30 long range trijet and on the A300B European Airbus, is $944,734. Assuming that the improved material could reduce the cost of air-cooling sophistication in the manufacture of turbine blades, and hence save 3 percent of the initial engine price on the original purchase of the engine and again each time the air-cooled stage turbine blades were changed (average 6 changes assumed), then the savings during the life of a CF6-50C engine would be approximately $198,000. For a single DC-10-30 aircraft, the savings would be approximately three times that (3 engines) or $600,000 due to a simplified air-cooling of the turbine blades alone.

   If the improved technology were applied to future engines with more than 2 stages of air-cooled turbine blades in the core turbine, the 3 percent factor above might go to 7% x 7 sets of blades = 49% of the initial cost of the engine during its normal life.

If the previously discussed technology can provide the minimum expected 100 percent increase in the life of a set of turbine blades, the savings on purchased parts for air-cooled blades would be as above; however, the engine operator would have additional savings of 50 percent reduction in labor and "down-time" during replacement of blades. Also, the uncooled blade replacement costs would have a reduction factor of 2 if the new materials were applicable to them.

Benefit to the Airlines. (See Volume II, Appendix D.) These benefits were estimated on the basis of projections by GE's Dr. Chang that there would likely be a 2 to 4 percent increase in engine specific fuel consumption due to the $\sim 100^{\circ}K$ increase in the operating turbine inlet temperature of a high bypass subsonic fan engine such as the GE-CF6, and at least a 100 percent increase in its turbine blade mean life.

Increased efficiency projected for turbojet engines can potentially be utilized in several (not necessarily exclusive) ways: to save fuel (or increase range), to increase available payload through higher thrust, or to increase payload through decreased turbine weight (for the same thrust). In calculating the economic benefits of such utilizations, we decided to introduce the conservative assumptions that only 50 percent of potentially applicable aircraft would be equipped with engines using the higher capability turbine blades, and, where pertinent, that such aircraft would operate at 50 percent of load capacity.

Using Data from Volume II, Appendix D, we can summarize key economic benefits to the U. S. airlines: Fuel costs, we find, represent the second highest expense of an airline (after wages and salaries). In 1970, fuel costs accounted for 12 percent of Eastern's total operating expenses (Reference 4. 2. 10)*. Exhibit 4. 1. 8* shows Eastern is spending about $119 million a year on jet fuel. Since Eastern flies 9. 4 percent of U. S. airlines jet engine hours, we estimate the total industry annual fuel bill at $1. 6 billion. Therefore, a two to four percent improvement in engine efficiency and incorporation of such engines in only 50 percent of applicable aircraft would benefit U. S. airlines by about $16 to $32 million per year in decreased expenditures for fuel.

Reference 4. 2. 18* shows that a one percent increase in turbine entry temperature produces a 1. 16 percent increase in thrust for a modern high pressure ratio engine. Therefore, we could expect an 11. 6 percent increase in thrust for a 111^{o}K (200^{o}F) increase in turbine inlet temperature. Exhibit 4. 1. 10* shows an example of a 6. 5 percent increase in thrust permits an increase in gross weight of 10. 4 percent. Referring to Figure 2 of Exhibit 4. 1. 10* indicates an increase in passenger load from 134 to 189, or 40 percent, at about 2,963 Kilometers (1, 600 N miles). Dow, on the other hand, in Reference 4. 2. 6* estimates that a 10 percent increase in thrust will increase payload by 10 percent.

Although we believe this latter number to be very conservative, we used this figure and our assumptions of 50 percent incorporation and 50 percent use of the available capacity, to estimate an increase of about three percent in revenue. The total operating revenue of the U. S. airlines was $9. 6 billion in 1971; therefore, as one alternative approach to utilizing the gain from the higher temperature turbine buckets, we estimate a $288 million improvement in revenue potential due to the increased passenger payload capability achievable with the higher thrust engines employing the higher inlet temperature-tolerant turbine blades.

Another alternative, the trade-off favoring reduction of propulsion weight at no change in performance is difficult to assess. In paragraph 3. 4. 2 we estimate a 111^{o}K (200^{o}F)

*References and exhibits appear in Volume II, Appendix D.

increase in T4 would produce about a 12 percent increase in thrust. If we assume a constant thrust/weight ratio, we would expect a 12 percent decrease in propulsion weight. Since engine weights currently run in the area of 4 to 6 percent of gross aircraft, say 5 percent, we would expect to save 0.6 percent of gross aircraft weight. Since payload commonly runs one-fifth of gross weight, if we assume that the entire weight saving is useable as increased payload, we would predict a three percent improvement in payload. Using our standard assumptions of 50 percent load factor and 50 percent incorporation, we would predict a 0.75 percent revenue potential or $9.6 billion x 0.0075 = $72 million improvement in revenue potential for the alternative of utilizing the higher temperature capability to provide higher thrust engines, and, thus, carry an increased passenger payload.

Note that both the preceding alternatives do not account for modification or construction of aircraft, which would be required to accommodate the increased passenger payload.

The effect of doubling the life of the turbine blades was considered both in terms of saving replacement costs and reducing maintenance costs. Eastern Airlines shows that replacement cost is the predominant benefit factor. The following excerpts are from the Eastern Airlines Report (Appendix D):

> "In reference 4.2.4,* the F.A.A. reports that U.S. Jet-powered transport aircraft produced 1,582,860 engine flight hours during May 1972. Of these, JT8D engines produced 663,846 hours or 42 percent. If we assume that JT8D costs of about $1.00 per engine flight hour are representative of the cost of high pressure turbine blades, then a doubling of mean life is worth $0.50 per engine flight hour."

Continuing our assumption of 50 percent incorporation of space processed blades and engine operation of 1.5 million x 12 = 18.1 million hours per year, the industry savings would be $4.5 million for savings in blade replacement costs due to longer life blades.

*References and exhibits appear in Volume II, Appendix D.

> "At the present state of the art, we believe that there is little influence between parts lives and maintenance costs and down times. Most airlines now operate some form of 'on condition' maintenance program (which means few or no scheduled engine disassemblies) as defined by Dougherty of the F. A. A. in Reference 4. 2. 5*. Reference 4. 2. 7* shows a mean time between shop visits of 2, 553 hours during the first six months of 1972 with only 21 percent of these being scheduled. The only scheduled activity on most modern jet engines is the replacement of Low Cycle Fatigue Limited parts (disks, shafts, etc.). Since the minimum time on JT8D Life Limited Parts is 8, 000 hours in our service, we do not feel extending the mean life of turbine blades will have a major effect on maintenance costs and down times."

Another aspect that was taken into consideration in the study was the potential savings in other critical jet engine components. The premise here is that an improvement in turbine blade operating temperature will not be an isolated development; it will be accompanied by corresponding improvements in other turbine parts exposed to the higher temperatures. The turbine nozzle guide vanes, for instance, must be designed to accept the new turbine operating conditions. Eastern Airlines has suggested that the nozzle guide vanes would be good candidates for application of the same space-based metallurgical processes as those envisioned for the turbine blades, since their cost per operating hour is only surpassed by the turbine blades (i. e., \$0. 967 per hour for the nozzle guide vanes versus \$1. 03 per hour for the blades). If such processes on the nozzle guide vanes also were to increase their mean life by 100 percent, an <u>additional savings of \$4. 5 million a year could be realized</u>.

<u>Benefits to the Public, U. S. Economy, and U. S. Resources (see Volume II, Appendix C).</u> This portion of the benefits analysis was aimed at assessing the potential benefits to the public sector of the U. S., which might result from the previously discussed improvements in gas turbines blades. The analysis was based upon projection of current civil, military, and general aviation transport requirements to the year 1990.

*References and exhibits appear in Volume II, Appendix D.

Civil demand is exemplified by the projected revenues listed below.

Civil Air Transport Revenue (Billions of dollars)		
1970	1980	1990
$9.5	$35.9	$60.2

This projection utilized the Eastern Airlines current 1970 era figures (see Appendix D) and projected the results into the 1980 to 1990 time period when space manufacturing and commercial application of the improved turbine blades could be realistically expected to occur. Changes in price of air transportation and resulting changes in air transport demand were also analyzed.

In order to evaluate the military and general aviation applications of the improved technology, a projection of their jet fuel consumption was utilized in lieu of their unavailable operational data. The total jet fuel consumption projection is as follows:

	Jet Fuel Consumption (Billions of Gallons)		
	1970	1980	1990
Civil Air Transportation	10.1	32.7	54.9
Military	5.0	4.8	4.8
General Aviation	0.2	0.4	0.8
Total	15.3	37.9	60.5

It must be noted here that the benefits data shown in the following paragraphs continue to reflect the conservative assumptions that only 50 percent of possible aircraft will adopt engines utilizing the space-processed turbine blades.

Based on the previously noted projected demand for civil air transport and the projected consumption of jet fuel in military and general aviation use, an estimate of direct operating cost savings in civil air transport, military and general aviation resulting from the application of the new technology was projected. Such savings derive, as discussed earlier under "Benefits to the Airlines," from the 2 to 4 percent decrease in specific fuel consumption and the minimum expected 100 percent increase in turbine bucket life.

The conservative 100 percent increase in turbine blade life provides a potential saving in blade replacement costs. While the previously calculated saving for the U. S. airlines, based on current 1970 era data, was projected as $4. 5 million yearly, the potential yearly savings in blade replacement costs for total U. S. aviation (civil, military, general) is projected for 1980 and 1990 to be $29. 5 million and $47. 1 million, respectively. Of these amounts, the military and general aviation portions of those savings, estimated to be over $4. 0 million per year, are considered the direct benefits to the public.

As shown previously in the analysis of potential benefits to the airlines, the lower specific fuel consumption attainable through the use of turbine buckets which allow higher inlet temperature offers several alternative, but not necessarily mutually exclusive, benefits.

The most easily calculable benefit is that of savings in fuel costs. Based on the previous assumptions, the potential 2 to 4 percent decrease in specific fuel consumption is expected to save the total U. S. aviation $43 million to $86 million yearly in 1980, and $69 million to $138 million yearly in 1990 in lower fuel consumption. The military and general aviation portion of this saving, directly benefiting the public, is $5. 7 million to $11. 5 million in 1980 and $6. 3 to $12. 6 million in 1990.

As noted in the previous discussion on "Benefits to the Airlines," alternative approaches to utilizing the higher thrust capability inherent in jet engines operating with higher turbine inlet temperatures are:

1. Utilization of higher thrust to obtain larger payload capability with the same size engines.
2. Using lighter engines to obtain the same thrust and adding payload equivalent to the saving in engine weight.

The previously recommended 10 percent payload increase, which reflects the higher thrust engines alternative, provides military and general aviation with potential yearly savings in capital expenditures (for aircraft) and operating costs (for number of flights) projected to be $282 million in 1980 and $302 million in 1990.

If the second alternative of smaller engines is utilized the equivalent yearly savings are projected to be $84 million in 1980 and $90 million in 1990.

The benefits to the public which might accrue in the form of reduced air transportation prices as a result of the adoption of the improved turbine blades has been estimated and projected. The increase in air traffic demand due to decrease in price has been analyzed in Appendix C and is included in the overall projection of civil air transport demand. Applying the price effects shown in the analysis, and assuming the 50 percent adoption gain, a net saving to the public in civil air transport direct costs in 1990 of $19 million dollars is projected. Among the indirect benefits to the public, there are several resulting from increased use of air transport service generated by lower prices. Typically, the lower cost service improves the general welfare and the economy as a whole by providing more people with a fast means of transportation at lower cost. In addition, the potentially lower fares are also shown (see Appendix C) to result in a "Consumer Surplus" of $2, 055. 6 million dollars in 1990; that is, to make such a sum available for other purposes because it was not spent by the public for civil air transport.

Improvement in the U. S. balance of payments is a further potential benefit to the public that has been projected for the development of the new turbine blades. Such a benefit would accrue from the decreased imports of crude oil used in producing jet fuel, and also, possibly, from the increased export of jet aircraft, jet engines, and parts.

Extrapolation of the National Petroleum Council estimates indicates 1990 crude oil imports of 37, 000 trillion BTU's will cause a trade deficit for petroleum imported of approximately $32 billion. The jet fuel yield from crude oil extrapolated to 1990, indicates a yield of 12. 2 percent, and approximately 64 percent of the U. S. crude oil is imported. If we assume the previous 50 percent adoption factor and that 4 percent improvement in specific fuel consumption due to the improved technology results in 4 percent reduction in total crude oil consumed, then a \$122.2 million dollars decrease in the balance of payments deficit for petroleum could be expected in 1990.

The export of aircraft jet engines in 1971 was estimated at \$548 million, while the rate of increase in the export of aircraft shows a 21.6 percent average annual growth from 1965 to 1971. Obviously, if such a growth rate could be maintained it would do much to alleviate our current balance of payments deficits. However, there was insufficient data available during the period of the Study to enable reasonable projection of this potential benefit.

Two further types of potential benefits which were noted during the Study, but not analyzed, are the economic benefits of higher inlet temperature turbine blades to industrial gas turbines, and the performance benefits to the national defense.

Potential applications of improved jet engines for the industrial gas turbine market in 1980 bear serious consideration. This market for jet engines in the electric power industry alone is estimated at \$6 billion in 1980. The market in chemical processing and gas transmission in 1980 is estimated at an additional \$2 billion. Marine applications and possible utilization in the automotive and other industries would increase the benefits still further if the improved technology was applied.

The improved technology would also have obvious potential benefits in many military applications. Superior aircraft would, for example, affect the national defense capabilities in a number of areas.

A major sociological benefit is indicated in the reduction of pollution because of jet fuel not burned due to improved specific fuel consumption with the new turbine blades. Preliminary calculations indicate that the reduction could easily exceed 7.8×10^6 KG per year. It must be noted, however, that the higher temperature combustion reactions which improve the specific fuel consumption also increase the formation of oxides of nitrogen. This negative impact will require further study in the future.

The level of nitrous oxides in the jet engine exhausts will tend to increase with higher turbine combustion temperatures, all other factors remaining constant. Although this relationship between NO_x and turbine gas temperature would threaten to impede future development of higher turbine combustion temperatures, research and development being conducted at NASA and industry indicates that advances in combustion chamber design will permit adequate control of these emissions (Reference NASA Lewis Research Center: Aircraft Propulsion: The proceedings of a conference held at the center. NASA SP-259: Nov. 18-19, 1970). Eastern Airlines (Appendix D) states:

> "We conclude that the proposed increase in turbine inlet temperature would not be a serious handicap to the reduction of jet engine emissions."

Applicable Space Properties

Processing single crystal turbine blades and eutectics without imperfections will require a near zero gravity environment to minimize thermal convection. Although the level of acceleration that will be permissible needs to be established experimentally, it is estimated that 10^{-5}G will be satisfactory.

Developments related to the use of refractory metals will require both near zero gravity and high vacuum. Levitation of the molten metal will require slow position drift rates such as those resulting from acceleration of 10^{-4} G or less. Vacuums may be required in the 10^{-10} to 10^{-13} atmospheres range to permit stringent contamination controls.

Solar radiation may be useful in furnishing a significant portion of the required heat energy through the use of a solar furnace in the space system.

Development Steps

Figure III-8 shows a potential development program designed to satisfy the objectives of higher temperature and longer life capability in turbine blades. The development phases leading to space production of the blades includes ground-laboratory based analysis and space experimentation. The "Required Completion" dates are aimed at attaining the stated objective as soon as possible, within practical limitations of time and resources. Based on our discussions with the Key Individuals, we have established a target of one decade for full operational capability in space for the single crystal or eutectic blades. In the case of refractory metal blades, the time frame is in the order of 13 to 15 years due to the duration of attendant developments that must take place in areas of combustion, engine control, corrosion resistance, and cooling of structural components to handle near stoichiometric temperatures.

DEVELOPMENT PHASE	DESCRIPTION OF DEVELOPMENT PHASE	DURATION
1. ANALYSIS PHASE	a. ESTABLISH DEVELOPMENT APPROACHES FOR THE FOLLOWING PROGRAM IDEAS: *A. ELIMINATION OF GRAIN BOUNDARIES B. EUTECTICS AND DIRECTIONALLY SOLIDIFIED ALLOYS C. LEVITATION MELTING OF REFRACTORY METALS (*PRIMARY EMPHASIS ON DEVELOPMENT AREA A)	1 YR 9 MO
	b. PERFORM AN ECONOMIC FEASIBILITY ANALYSIS	6 MO
2. LABORATORY EXPERIMENTS	a. DEVELOP SINGLE CRYSTAL METAL PROCESSING TECHNIQUE FOR SUBSEQUENT TESTING IN ZERO GRAVITY.	1 YR
	b. OBTAIN SAMPLES OF SINGLE CRYSTALS OF VARIOUS NICKEL BASE ALLOYS ON EARTH FOR SUBSEQUENT COMPARISON WITH THOSE OBTAINED IN ZERO G	1 YR
3. EQUIPMENT DEVELOPMENT	a. DEVELOP EQUIPMENT FOR PROCESSING SINGLE CRYSTAL SAMPLES. EQUIPMENT SHOULD ALSO BE SUITABLE FOR DIRECTIONAL SOLIDIFICATIONS AND EUTECTICS INVESTIGATIONS IN SPACE.	1-1/2 YR
	b. DEVELOP EQUIPMENT FOR PROCESSING TURBINE BLADES AS IN ITEM 1 ABOVE	1-1/2 YR
	c. DEVELOP EQUIPMENT FOR PROCESSING REFRACTORY METALS THROUGH LEVITATION MELTING IN ZERO G.	2 YR
4. SPACE EXPERIMENT	a. ZERO-G PROCESSING TO OBTAIN AND TEST METALLURGICAL SAMPLES OF SINGLE CRYSTALS, EUTECTICS, AND DIRECTIONAL SOLIDIFICATIONS.	6 MO
	b. ZERO-G PROCESSING OF REFRACTORY METAL SAMPLES USING LEVITATION MELTING.	
5. OPERATIONAL DEMONSTRATION IN SPACE	a. PROCESS SETS OF SINGLE CRYSTAL TURBINE BLADES	6 MO
	b. PROCESS TURBINE BLADES THROUGH EUTECTICS DIRECTIONAL SOLIDIFICATION TECHNIQUES	
	c. PROCESS A SET OF TURBINE BLADES FROM REFRACTORY METALS	6 MO
6. FULL OPERATIONAL CAPABILITY IN SPACE	a. PRODUCTION OF IMPROVED TURBINE BLADES MADE OF NICKEL BASED ALLOYS	REQUIRED COMPLETION 1983
	b. PRODUCTION OF IMPROVED TURBINE BLADES MADE OF REFRACTORY METALS	REQUIRED COMPLETION 1986

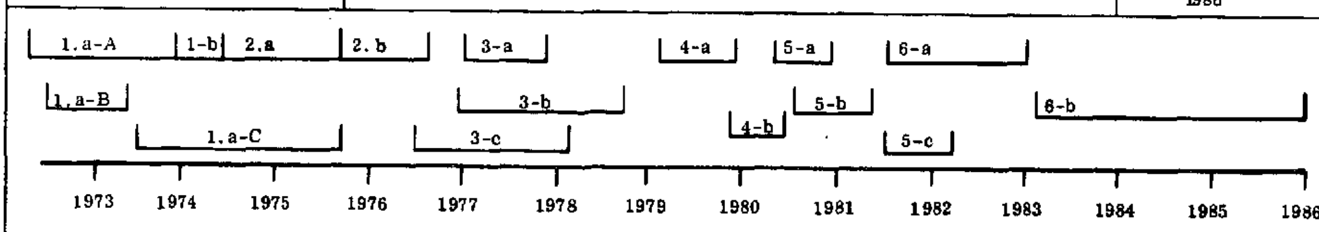

Figure III-8. Time Phasing of Development Program

III.1.5 IDEA NO. 30, HIGH PURITY TUNGSTEN X-RAY TARGETS

Objectives

Manufacture X-ray tube targets having longer operating life and enhanced safety. These improvements would be attained through the production of tungsten target material containing lower levels of interstitial impurities, particularly of oxygen and carbon, and, possibly, with better microstructure.

Users

Manufacturers of X-ray equipment. Participating; GE X-ray Department, Milwaukee, Wisconsin.

Others

Health service organizations.

Key Individuals

W.D. Love, R.E. Hueschen, G.E. X-ray Systems Products Department

Discussion

Background. Early dialogs with potential users indicated the possible advantages of crucibless melting of refractory metals and the possibility of outgassing impurities at melt or superheating temperatures, in a vacuum. This "seed" concept found fertile ground in discussions with W. Love and R. Hueschen, from the X-ray Department in GE Medical Systems Division. The potential match between that user's needs in the area of improved tungsten targets for X-ray tubes and the capabilities of space was established, and the X-ray Department joined the B.U.S. Study as a direct non-aerospace technical contributor.

In the operation of a Medical X-ray tube, the "targets" are bombarded with high intensity electrons to produce the useful X-rays at power levels as high as 10^7 watts per square centimeter. Criteria for improved design call for higher milliampere ratings with smaller and smaller focal spots for greater X-ray film detail. The high thermal stresses imposed by these conditions place increasingly rigorous requirements on the integrity of the target material.

The typical tungsten target is a disk-shaped rotating anode, as shown in the cross-section of Figure III-9. The X-rays are the result of secondary radiation due to the interaction of a focused electron beam on the absorbing target material. The properties of tungsten that suit it uniquely for X-ray tubes are the high atomic number (necessary to produce sufficient scattering of X-rays) and its high melting point (to prevent the surface deterioration under the thermal and physical loads imposed by operating conditions), as noted in Volume II, Appendix K:

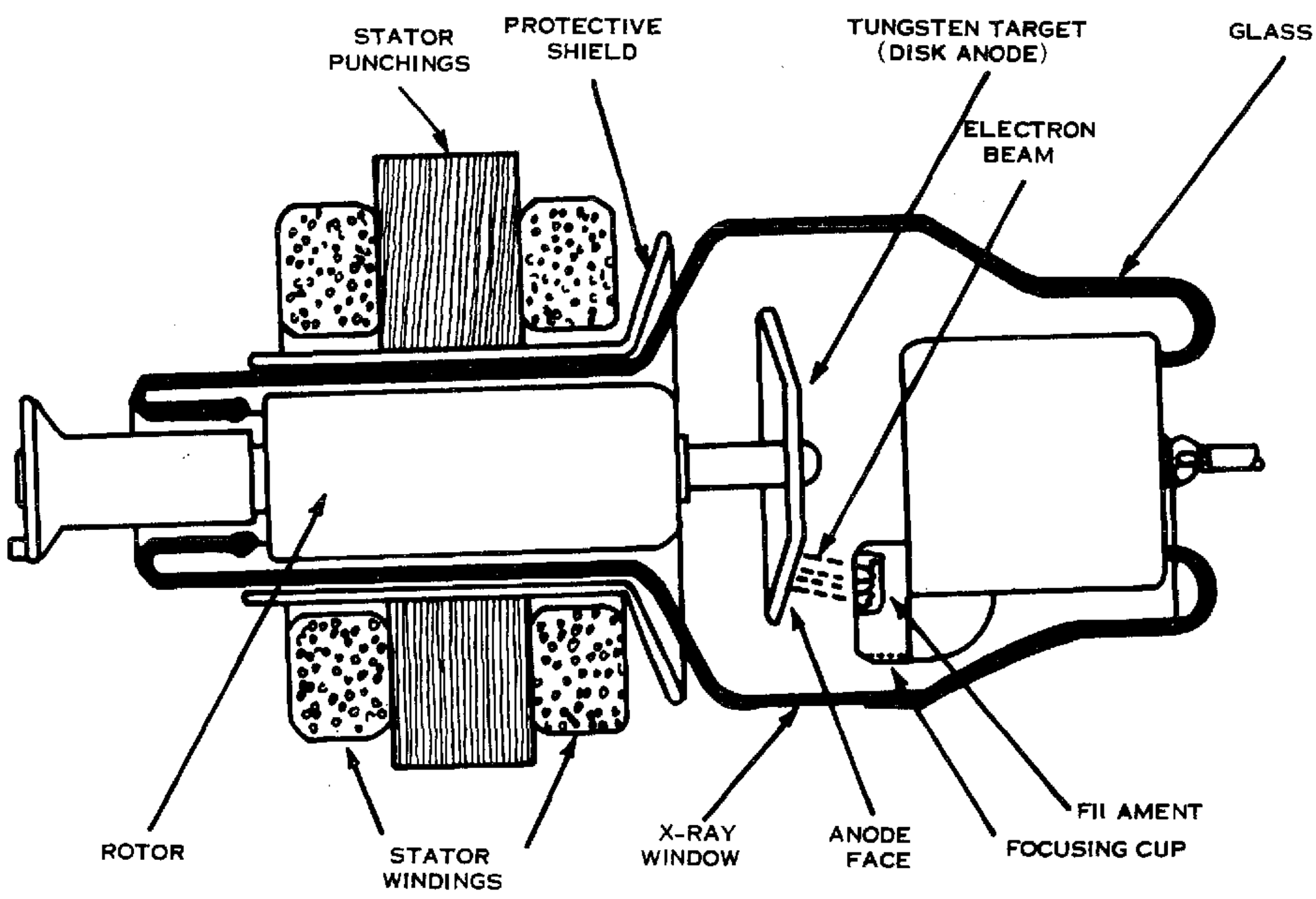

Figure III-9. Cross-Section of Typical X-ray Tube

"These fractures, or deep fissures in the target do not prevent X-ray production - but the X-rays produced in the valleys of the fractures are absorbed by the tungsten and are no longer useful X-rays. This degradation of X-ray output is extremely harmful to the efforts of all doctors and radiologists. In many cases it results in poor film quality and therefore additional X-ray exposure to the patient to produce a readable film."

The basic properties of tungsten that are sought through an improved metallurgical process are: (1) improved ductility characteristics, specifically, a decrease in the ductile-brittle transition temperature (DBTT) to render the tungsten material ductile throughout the entire range of temperatures from room ambient to operating conditions; (2) a particular grain structure which will permit proper mobility between grain boundaries without fracture, during the extreme temperature transient conditions attendant to electron beam impingement.

Materials and Processes. Currently manufactured targets use 10 percent rhenium in the tungsten to attain an adequate degree of ductility. The high cost of rhenium makes it necessary to use a small ring, typically one-inch wide by 0.050-inch deep of the 10 percent rhenium/tungsten, joined to a molybdenum/tungsten substrate. This technique which is widely used in the industry, is relatively expensive because of the various manufacturing steps that are required and the use of the expensive element rhenium. One possible approach to the attainment of the desired ductility characteristics (e.g., DBTT) is the elimination of impurities in the form of interstitials, particularly of oxygen and carbon, since these are known to reduce the ductility of refractory metals (see Figures III-10 and III-11). Thus, theoretically, a solid target made of pure tungsten would be sufficiently ductile to prevent fracture during extended operation, without the use of rhenium or other additives. The powder metallurgy (sintering) techniques used to produce the target preclude the attainment of the desired degree of purity or homegeneity of composition necessary for high ductility. Thus, the desirable properties of homogeneity and ductility suggest the need for an improved melt and purification process. The approach is to use levitation melting, and vaporizing the impurities by introducing vacuum or low partial pressure of an inert gas during the process.

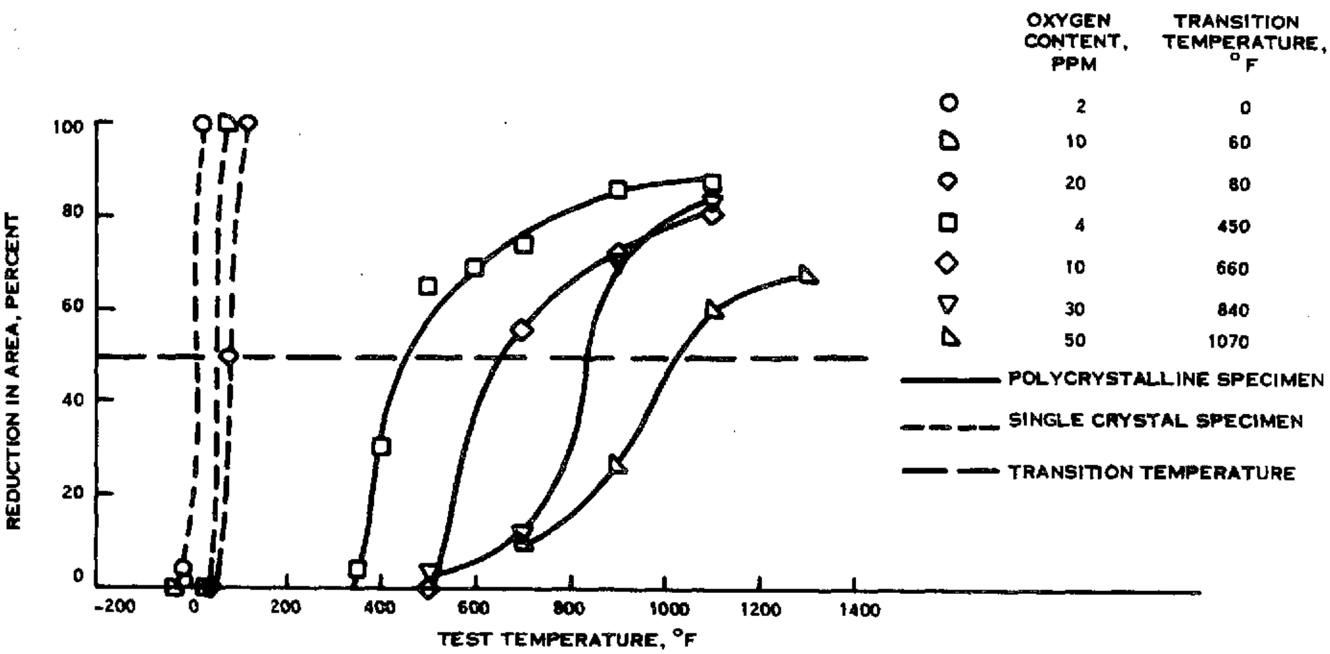

Figure III-10. Effect of Oxygen on Ductility of Tungsten
(J. Stephens, Lewis Research Center, NASA-TN-D-2287)

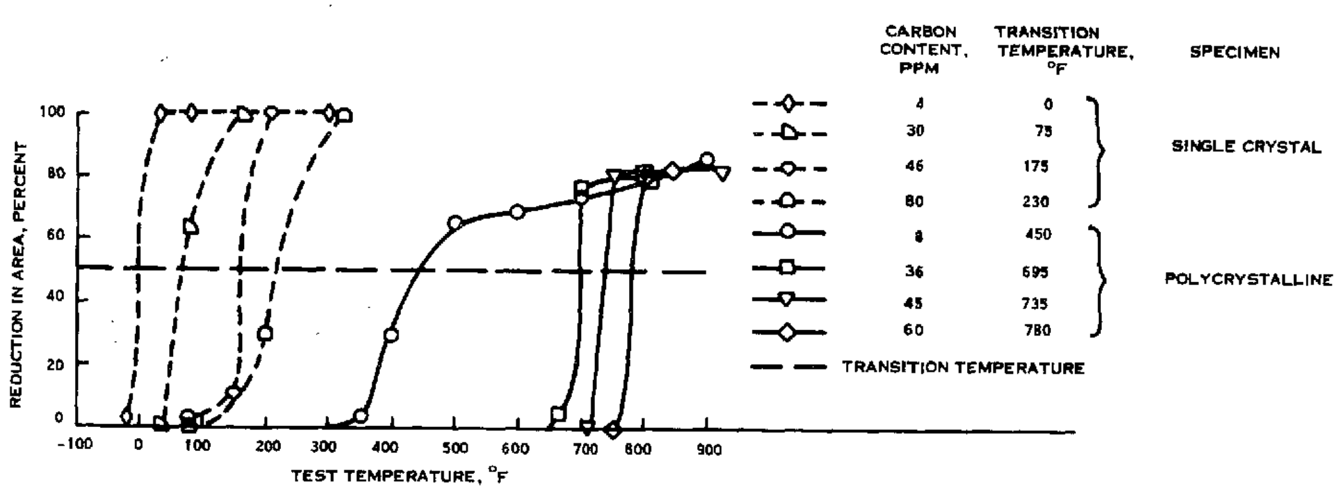

Figure III-11. Effect of Carbon on Ductility of Tungsten
(J. Stephens, Lewis Research Center, NASA-TN-D-2287)

Grain structure is an extremely important factor in determining the ductile-brittle transition temperature and the strength characteristics of tungsten (see Figure III-12). Among the approaches that were considered were the formation of very fine and uniform grain, single crystals and large uniformly oriented grains. During our discussions with the Key Individuals it was learned that single crystals and large grain size have not produced the desired ductility and strength characteristics in experimental target development tests. Although the meager available evidence points to preference for very fine grain structure, the ultimate process evolved should not preclude consideration of other grain structures. In order to attain the desired grain structure, it is essential that the temperature of the melt be closely controlled during solidification. For instance, rapid supercooling of tungsten may be attainable by rapidly removing the heat input to the melt while it is levitated. Uniform radiation in a vacuum while the molten tungsten is in a levitated state will improve the likelihood of attaining the desired fine grain.

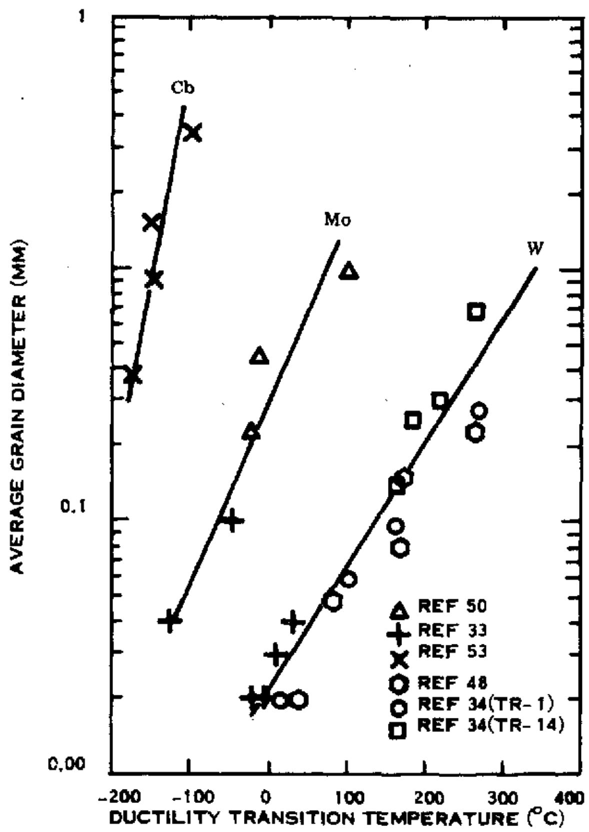

Figure III-12. Variation of Ductility Transition Temperature with Grain Size in Refractory Metal

Space Processing of Tungsten Targets

Some of the advantages of levitation melting in space which are of considerable importance for this application to medical X-ray tungsten targets are:

1. The specimen touches no crucible during heating, melting, and draining of impurities
2. The molten specimen could be further protected by a suitable atmosphere or vacuum.
3. Volatile impurities can be distilled or pumped away.
4. The molten metal can be drained gradually, solidified in suspension or even shaped to form without contamination.
5. The melt is thoroughly mixed by the electromagnetic action.
6. If alloying is desired, the specimens can consist of metal powders and alloying constituents mixed and sintered together.
7. Alloying additions can be made while the melt is suspended.

Levitation in a 1-G environment encounters the problems of stability and temperature. Okress* has successfully suspended titanium and aluminum. With his shaped coil the molten metal assumes the form of a child's top with a wide upper portion and a relatively narrow lower part resembling the formation of a large drop. Metals such as silver, which melt in air without forming an oxide coat tend to drip through the bottom. It has been suggested that the formation of an oxide coat prevented dripping of aluminum through the bottom of the coils. Polonis, Butters, and Parr** conclude that the tendency for the metal to drip depends on the ratio of surface tension to density. In the weightless environment, no levitation force is required and surface tension will make the melt assume a spheroidal shape. Electromagnetic forces would be required to position and hold the melt from drifting against container walls due to low acceleration levels and perturbations but far less power would be required.

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*Okress, E.C., Wroughton, D.M., "Electronmagnetic Levitation of Solid and Molten Metals " J. of Applied Physics, 23-5.

**Polonis, D.H., Butters, R.G., and Parr, J.G., "Some Techniques for Melting Reactive Metals", J. of Research, Vol. 7, pp 272-277.

Tungsten has a very high melting point (3382^{o}C) and requires more power for heating than aluminum or copper. In the weightless environment other heating facilities than RF induction or resistance heating may be feasible such as a solar furnace using the focused light from the sun to melt the tungsten. Solar furnaces have been experimentally used on the earth to melt refractory metals.

Since, in a 1-G environment, the heat input to the tungsten sample due to levitation by RF energy is very close to that required to melt the tungsten, the degree of temperature control possible through levitation in a 1-G environment is not adequate. In Zero G, the positioning forces (to compensate for spacecraft drift) are small, and will be independent of the heat input source, which could be RF or solar.

Potential Benefits

The potential beneficiaries from the production of high purity tungsten for X-ray cameras are shown in Figure III-13.

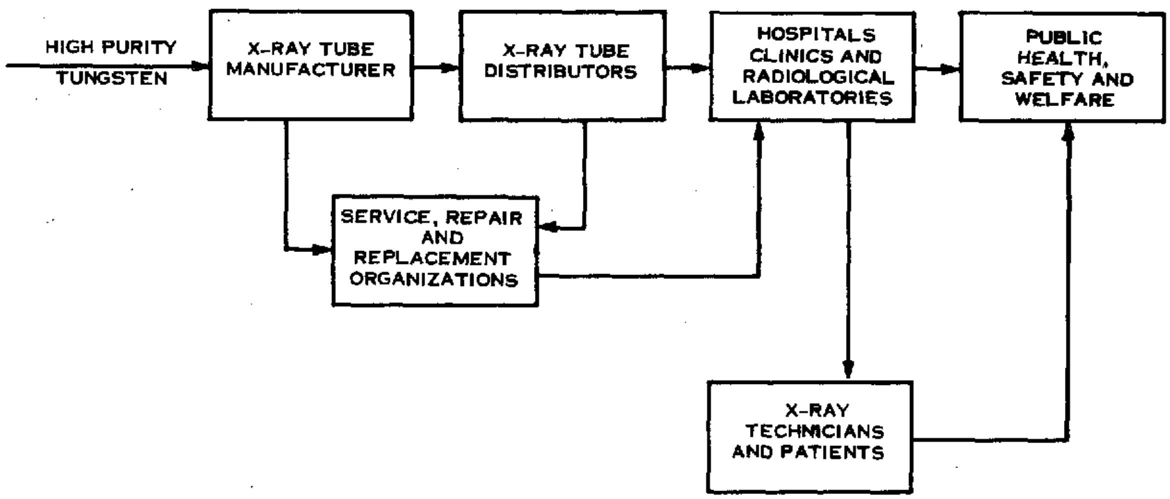

Figure III-13. Potential Benefits from High Purity Tungsten

Savings to the Manufacturer in Cost of Target Material. Present manufacturing techniques require addition of 10 percent rhenium to tungsten to make the target material ductile. Rhenium is very expensive, about \$ 3300 per KG. This addition could be reduced considerably, or, possibly, eliminated, provided that other impurities such as oxygen and carbon are decreased significantly. The following estimate of savings are based on the elimination of rhenium from 50 percent of the targets manufactured in the U.S.:

Target Size Category	Number of Targets Affected	Approximate Savings Per Target	Total Savings Per Year
Small, e.g., 10cm (4 in. Dia.)	12,000	$ 60	$ 720,000
Medium, e.g., 10cm (4 in. Dia.)	2,250	$ 80	$ 180,000
Large, e.g., 12.5cm (5 in. Dia.)	750	$100	$ 75,000
Total			$ 975,000

Benefits to the Manufacturer from Decreased Number of Targets Rejected. It is estimated that 2 to 3 percent of the manufactured targets may be rejected due to the presence of granular fractures. One to 2 percent of these will be caught in the manufacturing and testing cycle, while less than one percent will be returned from the field. Based on 30,000 targets manufactured in the U.S., the 3 percent loss represents a total of 900 targets. The total cost of replacing the rejected targets would be $152,000 (per year). These savings represent a small benefit compared to the added sales volume realized by individual companies able to demonstrate the added reliability in the tubes they manufacture.

Benefits to Health Services and the Public. X-ray tubes are generally guaranteed for a given number of exposures or a total number of hours of operation. Replacement cost within the guarantee are prorated in proportion to the number of exposures or hours of operation. For instance, GE guarantees its low energy tubes for 20,000 exposures and the high energy tubes for 10,000 exposures, where replacement cost is a direct function of the usage. The impact of using high purity tungsten upon the life of the tube cannot be quantitatively predicted at this early stage in the analysis; however, it is agreed that a significant increase in life would be realized. For purposes of this Study, we have assumed that the guarantee could be extended from 20,000 to 30,000 exposures, in the low mev range; and from 10,000 to 15,000 exposures, in the high mev range.

To estimate the savings to the consumer, the cost of replacing the tubes, up to the limit of the quarantee, are calculated. A useful ratio here is the X-ray tube cost per exposure, as follows:

Tube Category	Number of Tubes Manufactured	X-ray Tube Cost Per Exposure
Low energy	24000	\$ 0.09
High energy (A)	4500	\$ 0.40
High energy (B)	1500	\$ 0.70

Applying a 50 percent utilization factor, that is, only half of the tubes manufactured would have the increased life capability, the savings would be as follows:

Tube Category	Number of Tubes Affected	Cost Per Exposure	Additional Exposures Gained	Savings
Low energy	12000	\$ 0.09	1.2×10^8	\$ 10.8×10^6
High energy (A)	2250	\$ 0.40	1.1×10^7	\$ 4.4×10^6
High energy (B)	750	\$ 0.70	3.8×10^6	\$ 2.7×10^6
			Total Savings	\$ 17.9×10^6

The \$ 17.9 million in savings to organizational and public consumers takes into account the guarantee life span of tubes purchased on the first year of the availability of the improved tubes. This constitutes a rough estimate based on the current price structure and sales.

Benefits to the Public through Increased Safety. Catastrophic target failures that could endanger the safety of patients could be prevented through the development described in this report. In addition, the number of X-ray retakes would be decreased drastically, thus minimizing cumulative dosages in patients and potential hazards to the X-ray technicians. In addition, there would be potential savings of labor and material required for processing the retakes.

Applicable Space Properties

Levitation melting will require near-zero gravity. Slow position drifts such as those resulting from accelerations of 10^{-4} G or less will be permissible.

The development of techniques to vaporize the impurities may require investigation of a wide range of vacuum conditions, e.g., 1.33×10^{-4} to 1.33×10^{-11} N/m^2 (10^{-6} to 10^{-13} Torr).

Development Steps

Time phasing of the Development Program is shown in Figure III-14.

SUBJECT: HIGH PURITY TUNGSTEN TARGETS FOR X-RAY TUBES

DEVELOPMENT PHASE	DESCRIPTION OF DEVELOPMENT PHASE	DURATION
1. ANALYSIS	(A) ECONOMETRIC ANALYSIS OF SPACE MANUFACTURED TARGETS	6 MO.
2. LABORATORY EXPERIMENTS	(A) TEST OF HIGH PURITY TUNGSTEN MATERIAL PROCESSED ON EARTH	1 YR.
	(B) LEVITATION PROCESSING TESTS IN ONE G	3 MO.
	(C) DROP TOWER TEST (SUPERCOOLING)	3 MO.
3. SPACE EXPERIMENTS	(A) SOUNDING ROCKET TESTS	6 MO.
	(B) PROCESSING OF SAMPLES AT VARIOUS ENVIRONMENTAL CONDITIONS AND COOLING RATES. DETERMINE MECHANICAL PROPERTY DATA, INCLUDING DUCTILE BRITTLE TRANSITION TEMPERATURE.	1 YR.
4. DEVELOPMENT OF OPERATIONAL EQUIPMENT	ENGINEERING DEVELOPMENT, SCALE-UP OF TEST EQUIPMENT.	1 YR.
5. OPERATIONAL DEMONSTRATION IN SPACE	OBTAIN SETS OF TARGETS FOR OPERATIONAL TESTS IN ACTUAL X-RAY TUBES.	6 MO.
6. OPERATIONAL CAPABILITY IN SPACE	PRODUCTION OF TARGETS FOR OPERATIONAL USE.	REQUIRED BEFORE 1982

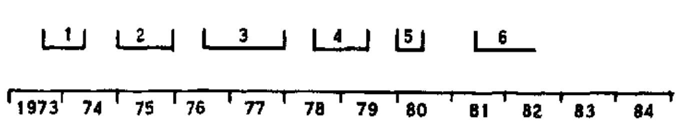

Figure III-14. Time Phasing of Development Program

III. 1.6 IDEA NO. 42, PRECISE SEPARATION OF RADIOISOTOPES

Goals and Objectives

Obtain purer isotopes for such uses as the nuclear-electric generator "fuel," and the power source of the "pacemaker" and the artificial heart. This is to be accomplished by more specific separation of radioisotopes that are very close in the periodic table.

Users

Participating:

Manufacturers of radioisotope devices for medical applications.

GE - Medical Systems Division, Milwaukee, Wisconsin

Manufacturers of power reactors and radioisotope "fuels."

GE - Nuclear Energy Division, San Jose, California

Key Individuals

F.R. Channon, Manager, Nuclear Development,

GE Nuclear Energy Division

H. Summerhayes, Physics and Electrical Engineering Laboratory,

GE Corporate Research and Development Laboratory

P.E. Brown, Isotope Power Systems, GE Space Division

Discussion

Current methods of separating isotopes of the same element are complex, expensive, and produce purity levels below those required in specialized applications. The physicochemical properties that form the basis for the current isotope separation techniques are mass difference, variable rate of diffusion through an orifice, variable thermal diffusion, and differences in vapor pressures. In the specialized case of deuterium, the ability to electrolyze water is of value in isotopic separations. Following are some of the more common separation processes employed today:

Mass Spectrometry. In this method, the isotopic material to be separated is vaporized and the vapor passes through a manifold to an arc-chamber region where it is dissociated and ionized in a partial vacuum. The ions are accelerated by a multi-kilovolt difference in potential between the ion source and an accelerating electrode. The ions pass through a field free region and travel in a nearly circular path whose radius is proportional to the mass. The separated isotopes are then received at specific regions in the collector. The quantity of isotopes separated through mass spectrometry is relatively small because of the slow collection rate. Certain substances are more difficult to ionize than others and therefore may present a problem in mass spectrometry. For instance, plutonium is more difficult to ionize than uranium; therefore, it requires a greater magnetic field or decreased feed rate through the ionizing arc chamber.

Diffusional Techniques. The principle involved is the variable diffusion of isotopic gases through orifices. The relative diffusion rates of isotopes through an orifice follow Graham's law and can be expressed as

$$S = (M_h/M_1)^{1/2}$$

where S is the separation factor, which varies from 1.0043 for isotopic uranium hexafluorides to 1.41 for hydrogen; M_h and M_1 are the molecular weights of the heavy and light isotopic species, respectively. Separations of the light elements by diffusion is relatively easy (e.g., for hydrogen and deuterium); separation of uranium hexafluoride requires a multistage process. Although this method is used extensively in the purification of uranium isotopes, alternative and less expensive techniques would be welcome in separations for applications such as isotopic heat sources, which involve smaller production quantities.

Centrifugation. In the earth's gravity, constituent isotopes in a fluid solution tend to settle at different rates, depending on their individual atomic masses. The 1-G force is not sufficiently large to permit a practical separation process for high molecular weight isotopes; therefore, a large acceleration field is established through centrifugation. An advantage of this method is that the ability to separate the isotopes is a function of the difference between their masses. The technique is becoming current in Western Europe as a technique for separating uranium. Nevertheless, the method involves relatively slow equilibrium times, and is mechanically complex due to the high centrifuge peripheral velocities required. This technique suggests that there may be other phenomena besides gravity which may apply significant forces that vary as a function of the isotopic physical characteristics.

Distillation. This process is based on the fact that the vapor pressure of various isotopes are different. For a given material temperature the kinetic energy of the molecules will impart a greater velocity to the lighter isotopes. The separation factor, a measure of the ability to differentiate between the isotopes, is a function of the ratio of the partial vapor pressure of the components to be separated. Here again, the lighter isotope species such as ${}^{1}H_2/{}^{2}H_2O$ which have a separation factor of 1.025, is much easier to distill than the heavier ${}^{235}UF_6/{}^{238}UF_6$ with a factor less than 1.0001. Thus, although this method is impractical for heavier elements, it is utilized in many separations to obtain isotopes such as ${}^{18}O$ and ${}^{13}C$-enriched carbon monoxide.

Possible Alternative Separation Forces. The increasing demand for radioisotopes for use in medicine and industry makes it advantageous to find processes that have potential for higher precision of separation at a competitive cost, and with less radiation hazard. Investigation of other phenomena that may produce discriminating forces for separating particles has led to some interesting alternatives. The analysis performed by GE Corporate Research and Development personnel and documented in Volume II, Appendix E ("Manipulation of Particles by Weak Forces in Zero G Environment"), describes several such forces and the basic relationships that will be useful in assessing their applicability to various particle separation problems. The particle manipulation processes described therein consider the possibilities of using one or a combination of forces generated through electromagnetics, acoustics, nuclear particulate radiation, magnetics, or electrostatics. In isotopic separations the differences in physical characteristics (i.e., atomic mass) necessary to perform the process are small; therefore, in some cases isolation from other disturbing forces may be required. Settling of particles in a vacuum, buoyancy of particles, and thermal convective forces acting in a fluid are examples of the disturbing influences that may be eliminated in a zero gravity environment.

Consider, for instance, an isotopic particle in equilibrium in a vacuum and being acted on by the aforementioned driving forces. Electromagnetic radiation in the form of light, microwaves, X-rays or gamma rays will produce a steady force that is proportional to the radiation intensity and the effective cross sectional area of the particle. The latter factor depends on the capacity for momentum transfer between the incident wave or ray and the particle, which, therefore accounts for the relationship between the wavelength of incident radiation, the effective particle size, and the particle physical characteristics that affect absorption and scattering.

The objective in the proposed separation process would be to produce differences in the velocity of individual isotope particles in accordance with variations in their physical properties. When dealing with isotope separations, the particles should consist of atoms or molecules of the various isotope species. Although there may be other important differences in properties that could merit investigation, the B.U.S. Study primarily considered the following:

1. The mass difference between the isotopes.
2. The difference in the atomic resonant absorption spectra pertaining to each isotope.

To exploit the first property, mass difference, it would be necessary to impart uniform kinetic energy to the isotope particles, so that the mass difference would produce proportional differences in the particle velocities. The separation method would be similar to conventional mass spectrometry, except that the moving force need not be confined to magnetic force acting upon ionized particles. The wavelength, radiation intensity and coherence of the source must be selected to yield the desired amount of kinetic energy to the particles. Considering the size of the atom of a heavy element such as plutonium, a few angstroms, it would seem that X-rays would be a suitable source of energy for this type of separation. Unfortunately the X-rays would be too penetrating to permit the necessary degree of force interaction with the atom. A more promising form of energy to impart translating force upon the isotope particles would be atomic resonant absorption of light in the visible wavelength range. As discussed in the section on "Resonance Radiation Pressure," in Appendix E, the cross section of the atom at the resonant wavelength increases several orders of magnitude, thus permitting the relatively long light waves to interact with the atoms. Preliminary estimates show that the particle accelerations theoretically attainable through the use of a laser beam or array of beams may be sufficiently high (above 10^5 G's), and the path lengths sufficiently small to minimize the effect of gravity upon the particle trajectory. However, viscosity effects of the gas will greatly limit the particle velocities attained. On the ground, the required uniformity in thermal energy, and the proper position relative to the light source optics would be significantly affected by gravitational effects such as thermal convection and settling.

The possible mechanisms for producing the isotope particles may include vaporization of the plutonium metal, or volatilization of plutonium compounds.

In order to exploit the difference in the atomic resonant absorption spectra to effect very precise separations, it is likely that a laser source would be necessary, with a precise resonant frequency of the radioisotope to be separated. This requirement may be attainable within the time frame of the proposed separation process development, with the advent of very precise tunable lasers. By utilizing this approach, instead of merely depending on mass difference, it may be feasible to produce accelerations on precisely the isotope of interest, thus increasing the resolution of the separation process. In other respects, the same problems would exist in ground applications of this process, as in previous descriptions which rely on mass difference for the separation. The potential advantage, therefore, of space processing to eliminate gravitational disturbances is equally applicable here.

Potential Benefits

Particle manipulation in space may permit highly specific isotope separations which are now unfeasible or impractical under earth surface environmental conditions. In addition, the isolation of the space environment might permit consideration of isotope separations that are very hazardous on earth. The greatest potential for improvement of separation through particle manipulation is among the heavy elements such as uranium, plutonium and neptunium. Plutonium, for instance, is highly valuable when obtained in highly pure form. The cost of $^{238}P_u$ above 95a/o purity is approximately $\$1x10^6$/KG to $\$3x10^6$/KG ($453,000 to $1,359,000 per pound). Apart from possible applications in national defense, the demand for high purity plutonium will be many kilograms a year to provide fissionable material in commercial power reactors.

If the new separation process were to make the cost of purified plutonium more economical (e.g., an order of magnitude), the demand may increase considerably. A portion of this demand would result from the use of ^{238}Pu in long life power sources for medical applications such as the artificial heart and the "pacemaker." Besides higher efficiency, the high purity ^{238}Pu would produce virtually no gamma background radiation, a feature that is important in the aforementioned medical applications. The probability for obtaining enriched ^{238}Pu for further separation by this process from a new and less expensive method will be enhanced in the period after 1985, when large quantities of plutonium containing less than 50 a/o ^{238}Pu will be produced as the by-product of highly enriched uranium reactors.

This level is too dilute for most applications, but separation of ^{238}Pu from the by-product might be less expensive than the current method of irradiation, separation and irradiation of ^{237}Np targets.*

The demand for highly purified ^{238}Pu for the "pacemaker" application is estimated at approximately 100,000 units/year beyond 1980. This demand is based on 10 percent utilization of the radioisotope power supply in units used by the one million persons who will need

*Plutonium-238 Fuel Availability and Utilization Study, National Aeronautics and Space Administration, Report No. GESP-7066, Rev. March 1, 1971.

pacemakers in the post-1980 time frame. It is also based on a one order of magnitude reduction from the current \$ $1x10^6$ to \$ $3x10^6$/KG price of highly purified ^{238}Pu. Thus, the cost of ^{238}Pu for 1000 units, each of which utilizes one gram of plutonium would be as follows:

Total Cost at Current Pu Prices:	\$100 - \$300 million/yr.
Total Cost at Projected Prices:	\$ 10 - \$ 30 million/yr.
Difference in Total Cost:	\$ 90 - \$270 million/yr.

It must be noted that the demand for this highly pure plutonium would be much less than 100,000 per year if the price reduction is not realized, thus, the \$ $100x10^6$ to \$ $300x10^6$ figures shown above are for comparison purposes only.

With respect to the artificial heart application, the demand uncertainty is very wide due to the large amount of ^{238}Pu needed in the power supply for that device: approximately 100 grams/unit. It is estimated that 20,000 units would be needed, therefore, based on the projected price of \$ $1x10^5$ - \$ $3x10^5$ per KG, the total cost of ^{238}Pu for that application could theoretically reach as high as \$200 million/year.

Applicable Space Properties

Zero gravity will be necessary to the aforementioned separation processes which involve particle clouds or solutions where settling, buoyancy, or the mixing effect of thermal convection are detrimental.

Space vacuum will be helpful in these processes since the presence of a viscous medium causes lower particle velocities.

There is always some small hazard of contamination of the earth's environment through possible malfunction or failure of an earth-based radioisotope separation facility. The geographical isolation offered by orbital flight may be helpful in reducing the hazard from processing.

Development Steps

Considerable analysis and development effort will be required in order to define the particle manipulation process that is best suited to heavy isotope separation problems. The ultimate goal is an economical manufacturing process; therefore, any candidate approaches would have to be subjected to detailed econometric analysis. Because large quantities of unrefined plutonium will not be available until 1985, the optimum time frame for making the subject separation process operational is in the mid-1980's. This could afford ample time for the extensive groundwork required before the space manufacturing venture. Advances in isotopic chemistry during the next decade may lead to improved particle structures (from micron size to the molecular level) that may prove more compatible with efficient particle manipulation processes in vacuum and zero gravity. Figure III-15 shows the proposed time phasing of the development program.

DEVELOPMENT PHASE	DESCRIPTION OF DEVELOPMENT PHASE	DURATION
1. ANALYSIS PHASE	A. ANALYSIS OF ISOTOPE AND ISOTOPIC COMPOUND PHYSICAL CHARACTERISTICS THAT ARE USEFUL IN SEPARATION PROCESSES.	6 MONTHS
	B. SELECT CANDIDATE PARTICLE SEPARATION TECHNIQUES TO BE INVESTIGATED.	6 MONTHS
	C. DEVELOP CONCEPTS OF THE SEPARATION PROCESSES USING THE CANDIDATE TECHNIQUES.	6 MONTHS
	D. PERFORM ECONOMETRIC ANALYSIS (PRELIMINARY) ON CANDIDATE PROCESSES.	1 YEAR
2. LABORATORY	A. PERFORM FEASIBILITY DEMONSTRATION TESTS USING PARTICLE MANIPULATION ON NON-ISOTOPIC PARTICLES.	1 YEAR
	B. SAME AS (A) ON ISOTOPIC MATERIAL.	1 YEAR
3. SHORT DURATION ZERO "G" TESTS	A. SELECT COST EFFECTIVE CARRIER TO CONDUCT SHORT DURATION TEST (E.G., KC-135 AIRCRAFT, SOUNDING ROCKET, DROP TOWER)	6 MONTHS
	B. DESIGN AND CONSTRUCT EQUIPMENT FOR SHORT DURATION TESTS.	1 YEAR
	C. CONDUCT TESTS AND ANALYZE DATA.	6 MONTHS
4. SPACE EXPERIMENT	A. DESIGN AND CONSTRUCT EQUIPMENT.	1 YEAR
	B. PERFORM EXPERIMENTAL SEPARATIONS IN SPACE AND ANALYZE DATA.	1 YEAR
5. OPERATIONAL DEMONSTRATION IN SPACE	A. DESIGN AND CONSTRUCT A SCALED-UP SEPARATION SYSTEM CAPABLE OF PRODUCING DESIRED ISOTOPES IN ORBIT REQUIRED COMPLETION DATE: 1985.	1 YEAR
	B. PERFORM PILOT SEPARATION PROCESS.	6 MONTHS
	C. PERFORM DETAILED ECONOMETRIC ANALYSES.	1 YEAR
6. FULL OPERATIONAL CAPABILITY	A. ESTABLISH SPACE FACILITY FOR ROUTINE LARGE SCALE SEPARATION PROCESSING.	--- (POST 1985)

Figure III-15. Proposed Time Phasing of Development Program

III.1.7 IDEA NO. 46, SILICON CRYSTAL GROWTH FOR POWER AND MEDICAL APPLICATIONS

Goals and Objectives

1. Manufacture of silicon crystals having improved resolution and signal to noise discrimination capability to be used in avalanche detectors for applications in radiological medicine. To be accomplished by growing crystals of more uniform composition by avoiding saturation anomalies caused by convection in the melt.

2. Manufacture of large diameter, superior performance silicon wafers for large scale electrical power rectification. To be accomplished by growing larger crystals in absence of gravity loading.

Users

Participating: GE - Power Delivery Group, Philadelphia, Penna.

GE - Space Products Division, Valley Forge, Penna.

Key Individuals

Dr. M.M. Solomon - Manager, Material and Fabrication Lab Operation
GE Power Delivery Group

P.A. Johnston - Product Manager, Nuclear Applications, GE Space Products Div.

Discussion

Medical Application. Silicon diode avalanche detectors can be used to detect radiation in many low energy nuclear applications in medicine. The high sensitivity of the avalanche detector makes it suitable in implanted sensor applications. For instance, blood flow Studies have been conducted using implanted needle-sensors in the circulatory stream, and sensing ^{55}Fe isotopic concentrations yielding energy levels of 6 keV. Exploratory probes have been used to survey regions of high isotopic absorption within body cavities. ^{45}Ca detection Studies have utilized the Si avalanche detector to determine arterial calcium uptake.

One of the principal requirements of the avalanche detector used in medical applications is uniformity of electrical characteristics across the silicon crystal. Uniformity of lateral (spatial) gain is essential to the ability to differentiate between a significant (signal) increase in count rate and fluctuations due to background noise. Variations in gain are characterized by corresponding changes in resistivity as measured at various sites on the sensing surface of the crystal. Uniformity of crystal resistivity is dependent on the distribution/concentration of dopant, trace impurities, and structural defects, all of which control the electrical field characteristics in the basic crystal. Local regions in the crystal containing higher dopant and trace impurity concentrations are subject to crystal structure deformation and higher defect density. While relatively low dislocation density, high purity crystals are available commercially, there is a continuing demand for greatly improved electrical uniformity in silicon crystals for medical applications.

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.

Present use of the avalanche detector is as a particle counter. It would be highly desirable - and theoretically possible - to use silicon detectors in spectrometric applications; however,

*R. T. Frost et al., Free Suspension Processing Systems for Space Manufacturing, Final Report DCN-1-0-64-27017.

the spectral resolution capability necessary to make this possible has not been achieved. This limitation is due to non-uniformity in the electrical field within the crystal, attributed to uneven distribution of dopants and impurities, as previously discussed.

In medical applications the high spectral resolution would translate into increased measurement sensitivity, through improvement in the capability to discriminate from unwanted energy levels. In applications for the detection of surface (or near surface) tumors, the selection of an appropriate energy "window" for the detected radioisotopic radiation may permit better differentiation between diseased tissue and healthy tissue. This improvement is due to the ability to operate on the difference in radiation level within a spectral interval; wherein extraneous background radiation noise is rejected, and possibly where the radiation absorption differential between the two conditions of the tissue are more pronounced.

Specific examples of applications where increased uniformity in the crystal would be beneficial are:

1. In the diagnosis of skin cancer
2. Detection of eye tumors
3. The measurement of the concentration of airborne plutonium in the lymph glands

In these applications, it is estimated that a reduction in resistivity variation across the crystal would have a profound effect on the degree of certainty associated with the diagnosis, and on the radioisotopic dosage that would have to be administered.

Laboratory investigation is recommended in this area to determine the effect of low crystal-dislocation-density on the application of avalanche detectors to deep-seated problems, such as detection of internal tumors and studies of the circulatory system.

A quantitative assessment of the benefits of this application is difficult at this time. Cognizant personnel from several health institutions were consulted.* The conclusion from these

*S. Kettering Institute, Memorial Hospital, N.Y.; Thomas Jefferson Hospital, Philadelphia, Pa.; New York Medical Center, N.Y.

discussions is that it would be premature to make a prediction of benefits without a better assessment of the effect of zero gravity on the uniformity of the resistivity in the crystal. Because of the time limitations in the Study, the detailed analysis necessary for this assessment was not possible.

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 applications 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:

$$P = \gamma \left(\frac{1}{R_1} + \frac{1}{R_2} \right)$$

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:

$$lm \simeq 2.8 \, (\gamma/\rho \, g)^{1/2}$$

*Pfann, W.G., Zone Melting, p. 109, second edition, John W. Cez & Sons, 1966.

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 suffieicntly 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

*New Brunswick, Canada, HVDC Facility

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.

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 U.S. 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.

Potential Benefits

The potential beneficiaries from the production of silicon crystals in space for medical and electrical power applications are shown in Figure III-16.

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

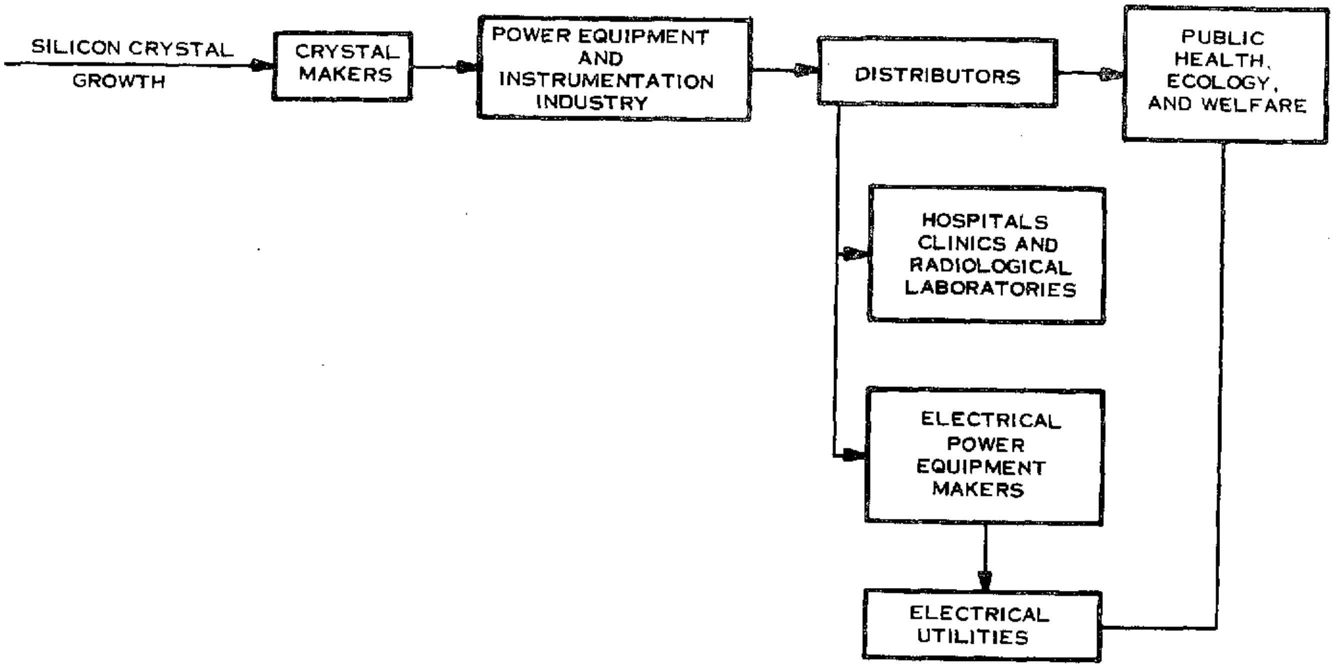

Figure III-16. Potential Beneficiaries from Space Production of Silicon Crystals for Medical and Electric Power Applications

would likely have applications in medicine and for electrical power rectification. It is estimated that 90.7 to 181.4×10^3 KG (100 to 200 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.

The value of silicon crystals for medical applications has not been estimated at this time.

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.

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

* Statistical Abstract of the United States (1971), U.S. Department of Commerce, p. 731.

rectification uses. To the instrument maker then, his total sales of diodes would be approximately $62.5 to $125 million per year.

<u>Electrical Utilities.</u> 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 quantities of power on high voltage DC underground lines, are beneficial because they require less peripheral equipment and hence less investment for equipment, installation, operation and maintenance.

In addition, the projected power demand in 1990 would double the acreage required for overhead transmission lines. If the silicon diodes made underground transmission practical through cryogenic and superconductor technology, there would be cost reductions for transmission right of ways which would be very significant, particularly in urban areas.

<u>Public Benefits.</u> The public could benefit from the availability of electrical power at reduced costs due to reduced capital required by the electric power companies, and from the improved ecological and aesthetic values possible with underground power cables. Some increase might be expected in public safety from buried cable instead of overhead transmission lines, etc.

The public would also benefit from increased export of large silicon crystals which would have a favorable effect on the U.S. balance of payments.

The production of more uniform silicon crystals may facilitate spectrometric applications not now practicable in the medical field.

The use of better silicon crystals as radiation counters will facilitate radiological examinations for up-take counts of radioisotopes in diseased organs, and the better differentiation of diseased versus healthy tissues for diagnoses. Their use should also improve the resolution and detail possible from implanted sensors measuring isotope radiation counts in blood flows; contamination from airborne isotopes in the lymph glands; the detection of eye tumors, thyroid malfunctions, etc. Although it is not possible to determine dollar values for such benefits in the medical diagnosis and treatment of disease the benefits in potential lives saved, improved personal and public health, and the improved well-being of large numbers of potential patients is likely to be extensive.

Applicable Space Property

Near-zero gravity conditions will make the proposed application possible in space. The steady-state gravity levels required are estimated at 10^{-4} to 10^{-5}G.

Development Steps

The time phasing of the Development Program is shown in Figure III-17.

SUBJECT: SILICON CRYSTAL GROWTH FOR POWER APPLICATION

DEVELOPMENT PHASE	DESCRIPTION OF DEVELOPMENT PHASE	DURATION	REQUIRED COMPLETION DATE
1. ANALYSIS PHASE	A. ESTABLISH SPECIFICATIONS FOR SILICON WAFER SIZE RANGE AND ELECTRICAL QUALITY. RELATE REQUIREMENTS TO STRUCTURAL CHARACTERISTICS OF THE CRYSTAL.	6 MO	1974
	B. PERFORM DETAILED ECONOMIC FEASIBILITY ANALYSIS FOR SPACE MANUFACTURING.	9 MO	1975
2. LABORATORY EXPERIMENTS	A. SILICON CRYSTAL GROWTH FROM A MELT. OBTAIN CONTROLLED STANDARDS FOR COMPARISON.	1-1/2 YR.	1975-76
	B. FLOAT ZONE REFINING OF SILICON. OBTAIN CONTROLLED STANDARDS	1-1/2 YR.	1976-77
3. SPACE EXPERIMENT	GROW SPECIMENS OF DIFFERENT SIZES AND PERFECTION UNDER VARYING PROCESSING CONDITIONS.	6 MO	1978
4. OPERATIONAL DEMONSTRATION	DEVELOP PROTOTYPE FULL-SCALE SYSTEM.	1 YR	1979
	ESTABLISH PILOT PRODUCTION FOR DEMONSTRATION OF PHYSICAL AND ECONOMIC FEASIBILITY.	6 MO	1980
5. FULL OPERATIONAL CAPABILITY	PRODUCTION OF LARGE QUANTITY OF CRYSTALS IN SPACE.	-	1981-82

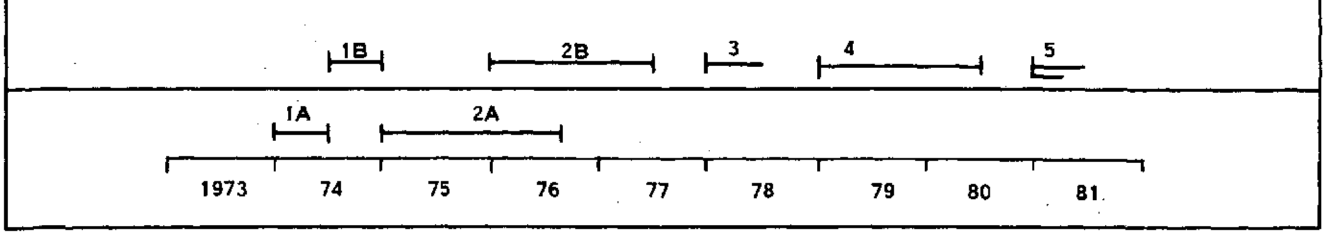

Figure III-17. Time Phasing of Development Program

III.1.8 IDEA NO. 59, EPITAXIAL GROWTH OF SINGLE CRYSTAL GARNET FILMS FOR MAGNETIC BUBBLE MEMORY DEVICES

Goals and Objectives

The goal is to produce single crystal garnet films with uniform thickness and magnetic characteristics for use in magnetic bubble memory devices in the computer industry. The objective is to produce larger area chips, with more uniform characteristics and with less spoilage in production, by taking advantage of the zero gravity environment in space to eliminate problems caused by convection in production processes on earth.

Users

Participating; Corning Glass Works, Corning, New York

Others; (IBM, Western Electric, Signetics, Monsanto, TI, National Semiconductors Fairchild Motorola, Hewlett-Packard, GT&E, UNIVAC, RCA, NAR, Raytheon)

Key Individuals

G. P. Smith, F. P. Fehlner, Corning Glass Works

Discussion

Dr. F. P. Fehlner provided the key information on the manufacture of epitaxial garnet films in the gravity-free environment of a space laboratory. His results are given in Volume II, Appendix F, of this report.

The technology for bubble memory devices was pioneered by Bell Telephone Laboratories. Such memories are expected to become available in the early 1970's, and to become a significant segment of the computer market by 1980.

In operation, such devices store information through the controlled presence (or absence) of cylindrical magnetic domains at specific locations in garnet crystal films which have been deposited on polished gadolinium gallium garnet substrates.

In present practice, such films are grown by liquid phase epitaxy (LPE) in a carefully controlled dipping of the substrates into a supersaturated solution of the rare earth garnet dissolved in a lead oxide flux contained in a platinum crucible, Figure III-18. Growth of the garnet film on the substrate proceeds at a rate of approximately one millionth of a meter per minute. Films of 6 to 10 millionths of a meter thickness are desired for domain diameters of 5 to 8 millionths of a meter.

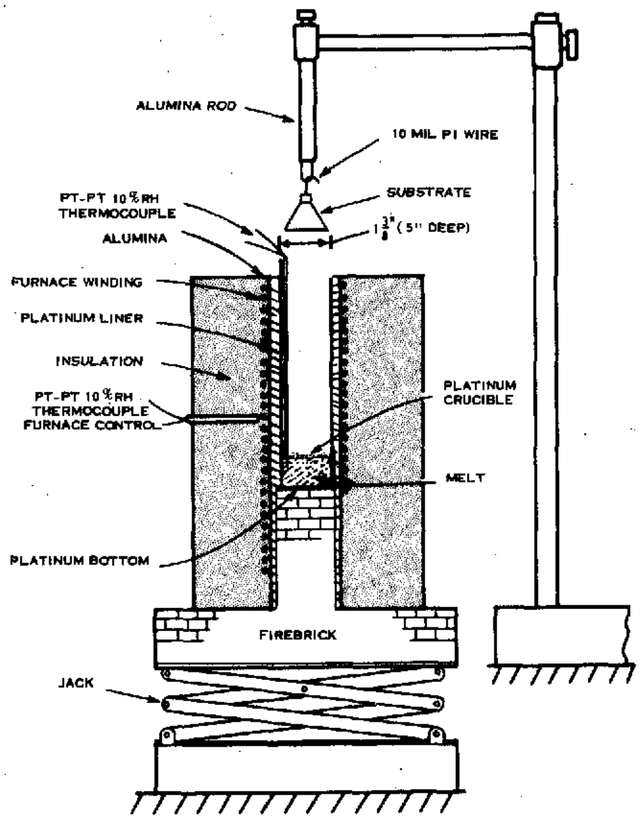

Figure III-18. Typical Layout for Growing Garnet Films on Substrates (after Levinstein et al.)

Current manufacturing tolerances for thin films in the electronics industry are of the order of 5 to 10 percent. It has been estimated that tolerances of $\pm$ 1 percent in both thickness and magnetic properties will be required for prototype bubble memory production units. Furthermore, spoilage in present manufacturing processes often runs as high as 90 percent. In order to be economical for production and sales, this spoilage rate must be reduced.

The most critical factor limiting film uniformity is felt to be the presence of convection currents in the molten flux. The LPE process results in a low density of normal crystal defects in the film, generally less than the 10 to 20 per square centimeter present on the polished substrates. Therefore, the limitation on film uniformity and, possibly, chip size is directly related to the non-uniformities caused by convection currents in production. Since a non-uniformity is just as detrimental as a crystallographic defect in actual device applications, control of convection in the melt is important in production. The cost of actual bubble memories is directly related to the size of the chips having uniform characteristics which can be produced, and to the yield obtained from the process. Typical yields for chips of various size for three grades (number of defects/cm^2) uniformly distributed, are shown in Figure III-19. For high grade chips (1 defect/cm^2) of 0.5 cm^2 area, the yield is approximately 50 percent, but as the area desired approaches 1 cm^2 the yield approaches to zero. A low convection production process will allow chips of high quality and larger size. This will provide more memory bits per chip and will reduce the cost per bit of memory units. The garnet bubble memories, in production are expected to offer better performance per dollar than devices currently used. Therefore, they are expected to take over virtually the entire market for small disk files and minicomputer memories by 1980.

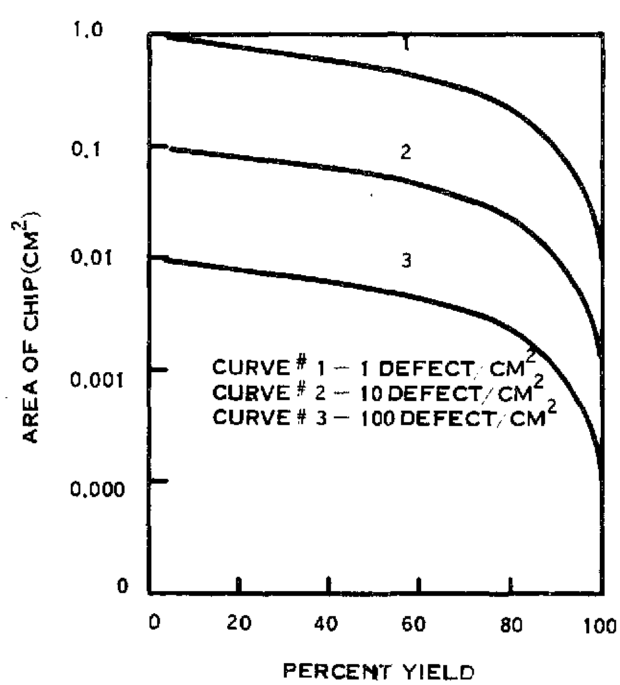

Figure III-19. Relationship Between Chip Area and Defects Per Unit Area (Uniformly Distributed)

It is possible that the 1 percent uniformity required for prototype memories may be achieved in production on earth through improvements in production techniques, but even better uniformity will be required for the second and third generation devices in the near future. The zero convection environment in space should make this possible. Theoretical studies have shown that Rayleigh Numbers of more than 1000 tend to cause large variations in growth rate and in the segregation of components making up the crystal. The thermo-hydrodynamic behavior of the molten flux in a zero gravity/zero convection environment will aid in obtaining low Rayleigh numbers, stable thermal gradients, and uniform deposition of the garnet film.

Potential Benefits

The block diagram in Figure III-20 indicates the major groups who would benefit from production of epitaxial grown magnetic bubble memory crystals.

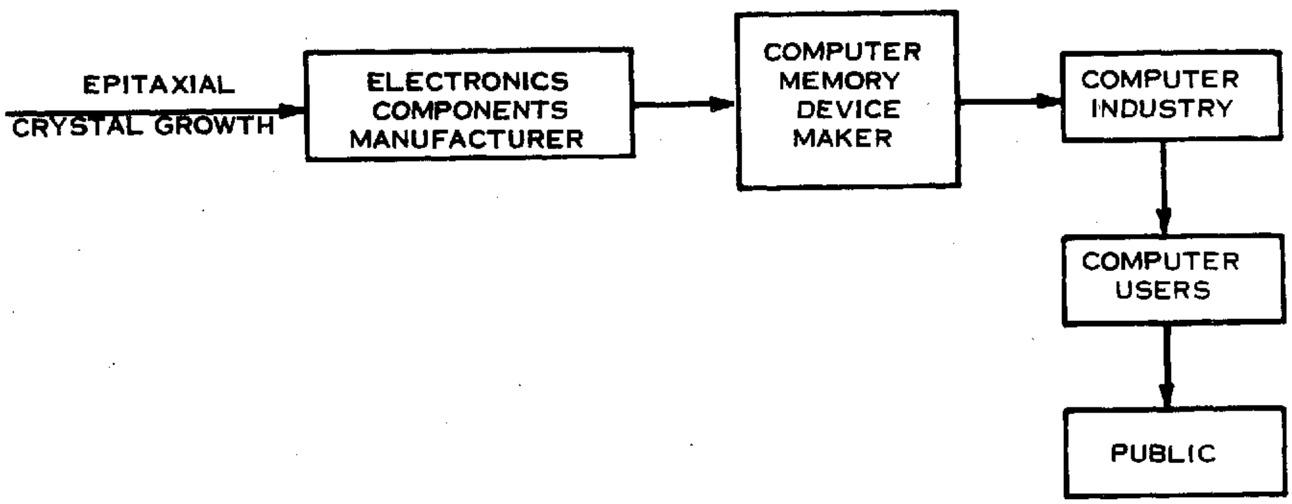

Figure III-20. Potential Beneficiaries from the Growth of Epitaxial Crystal Garnets in Space

Dr. Fehlner has estimated that substrate and films of one square centimeter size will weigh approximately 1 gram/cm^2 and will sell in large quantities at a price of \$2 to \$3 per square centimeter. This would be equivalent to \$2 to \$3,000 per kilogram (\$910 to \$1365 per pound) well above the projected cost of shuttle freight which was assumed to be \$330 to \$1,200 per kilogram (\$150 to \$500 per pound.)

A much more optimistic estimate has been prepared by the GE-Space Sciences Laboratory under Contract No. NAS8-27942 for NASA/MSFC, "Econometric Analysis of Crystal Growth in Space"*. Because of the current state of the art in the production of garnet films for magnetic bubble memories, the high investment involved, and the low yields of usable units, an estimate was made of $22,000 per kilogram ($10,000 per pound) for current value. Assuming that future production techniques and quantity production savings will reduce this cost in the future, it was estimated that the selling price in 1980 would be approximately $7040 per kilogram ($3200 per pound.)

The total sales for memory devices was approximately $900 million in 1971. The market in 1975 is projected to be $4.7 billion. By regression analysis and projection of trends, it was estimated that the demand for garnet bubble memory devices would be 53,090 kilograms (116,800 pounds) in 1980. This assumes that the low cost per bit for the garnets will result in their domination of the market by 1980. The result would be a total sales value for garnets of approximately $374 million in 1980. Of this total, it was estimated that approximately $50 million per year could be saved in 1980 by producing these garnet magnetic bubble memories in space*.

Applicable Space Environments

The zero gravity environment in an orbiting spacecraft will result in a zero gravity convection environment which would facilitate the growth of uniform garnet films in space.

Development Schedule

A tentative schedule leading to the use of a space vehicle for manufacture of garnet films is shown in Figure III-21.

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*Econometric Analysis of Crystal Growth in Space, NASA Contract No. NAS8-27942, Prepared for NASA/MSFC by GE.

EPITAXIAL GARNET FILM GROWTH PLAN

ANALYSIS AND PLANNING - '73

EPITAXIAL FILM GROWTH EXPERIMENTS ON EARTH - 1974-5

PROCESS VERIFICATION - DROP TOWER - 1975

BALLISTIC FLIGHT EXPERIMENTS - SOUNDING ROCKET - 1976

AUTOMATED SPACECRAFT EXPERIMENTS - 1977

ORBITAL PILOT PLANT - 1979

ORBITAL PRODUCTION TESTS - 1982 SHUTTLES

Figure III-21. Development Schedule

Late Note: February 23, 1973

Announcement today by IBM of a new "Amorphous Material" film for bubble memories, an order of magnitude more capable than garnet, and, allegedly less difficult to produce, may vitiate the utility of the preceding information.

III. 1. 9 IDEA NO. 60, AMORPHOUS OXIDES

Goals and Objectives

The goal is to develop new glass and refractory products whose properties and performance are improved when solidified in the amorphous form. The objective is to process glass and oxide materials such as alumina by levitation melting without a container, and with rapid cooling in order to control devitrification during solidification. Operations in zero gravity will aid the control of any tendency toward heterogenous nucleation, and the production of amorphous forms of the solid oxides.

Users

Participating; Corning Glass Works, Corning, New York

Others; Scientists, Optical Industry, Department of Defense, etc.

Key Individuals

G. P. Smith, J. F. MacDowell, Corning Glass Works

Discussion

The zero gravity levitation melting of materials such as alumina, zirconia, etc., free of any contamination from a container, followed by rapid cooling and some degree of super-cooling before solidification, should result in solid amorphous forms of the oxides. These would be new glassy materials and should have some new and useful characteristics not now available. A technical discussion on this subject by J. F. MacDowell, Corning Glass, is contained in Volume II, Appendix G.

Ground-based attempts to form these materials by melting and rapid quenching has generally been unsatisfactory; however, successful formation of certain unstable oxide mixtures in an amorphous form (BaO-SiO_2) can occur if all sources of heterogeneous nucleation are eliminated from the melt during solidification. Homogenous nucleation has never been observed in silica glass even from reheating, and it is to be expected that it might not occur in other single oxide glasses.

To prevent heterogeneous nucleation in the molten oxides, the molten material must be kept free of contaminations which could provide a source of nucleation. This implies, at least, ultra-clean surfaces, or, for this Study, the containerless melting of the oxide in a gravity-free environment. Nucleation can also be initiated by structural fluctuations, by phase separation of the melt, and by liquid-liquid immiscibilities. Normally, the addition of oxides such as titania or zirconia, to the molten oxides provides nucleation sources and results in crystalline glass ceramics rather than any amorphous form. In fact, melts of complex mixtures of oxides almost always phase-separate to some degree upon cooling.

The containerless melting of materials in zero gravity of space will eliminate three problems which have been almost insurmountable on earth. One is the problem of very high melting point materials where a container that does not melt is often not practicable. The second is in the area of high purity where the contamination of any container is significant. The third is in the area of supercooling. A containerless mass, most likely a sphere, of molten material at very high temperature can cool by radiation from its entire surface. Since the rate of cooling is proportional to the 4th power of the absolute temperature when radiating to a cold sink, the spherical surface will cool very rapidly. In the absence of any sources of nucleation to initiate crystallization, these materials should reach a high degree of supercooling before solidification, and then solidify almost instantaneously. The amorphous forms are expected to be the result of such rapid supercooling and solidification. Even if some sources of nucleation are present in the supercooled mass, the rapid solidification is expected to form new grain structures, and, perhaps, single crystals with unique properties heretofore unavailable. The potential is analogous to going from wrought iron to drop forged grain structures. That many unique material forms will, thus, become available is almost certain, although their specific uses and economic values are difficult to predict.

Alumina is a promising oxide to consider. Its low viscosity in the fluid state would be advantageous for rapid production of amorphous fibers and ribbons. They should have a high elastic modulus, and high strength, which would make them logical candidates for reinforcing fibers and for electronic substrates.

Alumina glass is likely to be transparent to infrared wavelengths above 5 microns where silica glass become opaque. Other oxides (Bi_2O_3, PbO) may be transparent beyond 10 microns in the amorphous state. Such materials are urgently needed in the area of optical communications. The high powered CO_2 lasers require infrared optics and current techniques for growing or fabricating crystalline optics of large size, high degree of perfection, and great strength are difficult and costly. An amorphous oxide with increased IR transmisivity would be a major step toward mass use of these new lasers. Their use in radiography and thermography would also be significant.

Although this particular idea concerns the formation of amorphous forms of the simple oxides, the technique might also be directly applicable to the formation of other materials including titanium-, zirconium-, and niobium oxides, the borides, tungstides, nitrides, and even to amorphous forms of the metals. Such materials would be expected to have properties which would be useful in the manufacture of armor, bearings, cryogenics, heat exchangers, electromagnetic windows, and lightweight structures. The borides would provide needed materials for hypersonic flight. Figure III-22, Potential Space Products, shows a list of potential uses of these materials taken from an article by Hans F. Wuenscher, NASA/MSFC, in Aeronautics and Astronautics, September, 1972.

NEAR TERM SPACE EXPERIMENTS WITH NEW MATERIALS AND SHAPES	POTENTIAL SPACE PRODUCT APPLICATIONS PROPOSED BY INDUSTRY AND OTHERS
GLASSES	
FREE OF HETEROGENOUS NUCLEATION	LASER GLASSES WITH HIGH DAMAGE THRESHOLD
FREE OF STRIATION	LOW INDEX, HIGH ABBE NO. GLASSES FOR ADVANCED OPTICAL SYSTEMS
WITH NEW OXIDE BASE	HIGH INDEX GLASSES FOR NEW OPTICAL SYSTEMS
THROUGH SUPERCOOLED SOLIDIFICATION	SINGLE CRYSTAL MATERIALS, PRESENTLY UNKNOWN
WITH SEMI-CONDUCTIVE AND PHOTO-CONDUCTIVE PARTICLE DISPERSION	NEW LIGHT FILTERS, CHRISTIANSEN FILTERS, PASSIVE Q-SWITCHES, PHOTOTROPIC GLASS, AND "STRIKING GLASS"
IN FREE-FORMED BLANKS AND SHAPES	LENSES AND MIRRORS WITH ADVANCED PERFORMANCES
	PERFECT PROOF MASS FOR ADVANCED ACCELEROMETERS AND G-SENSORS

(FROM AERONAUTICS AND ASTRONAUTICS MAGAZINE, SEPTEMBER, 1972, BY HANS WUENSCHER, NASA/MSFC)

Figure III-22. Potential Space Products

Potential Benefits

The potential beneficiaries from the production of amorphous oxides in space are shown in Figure III-23.

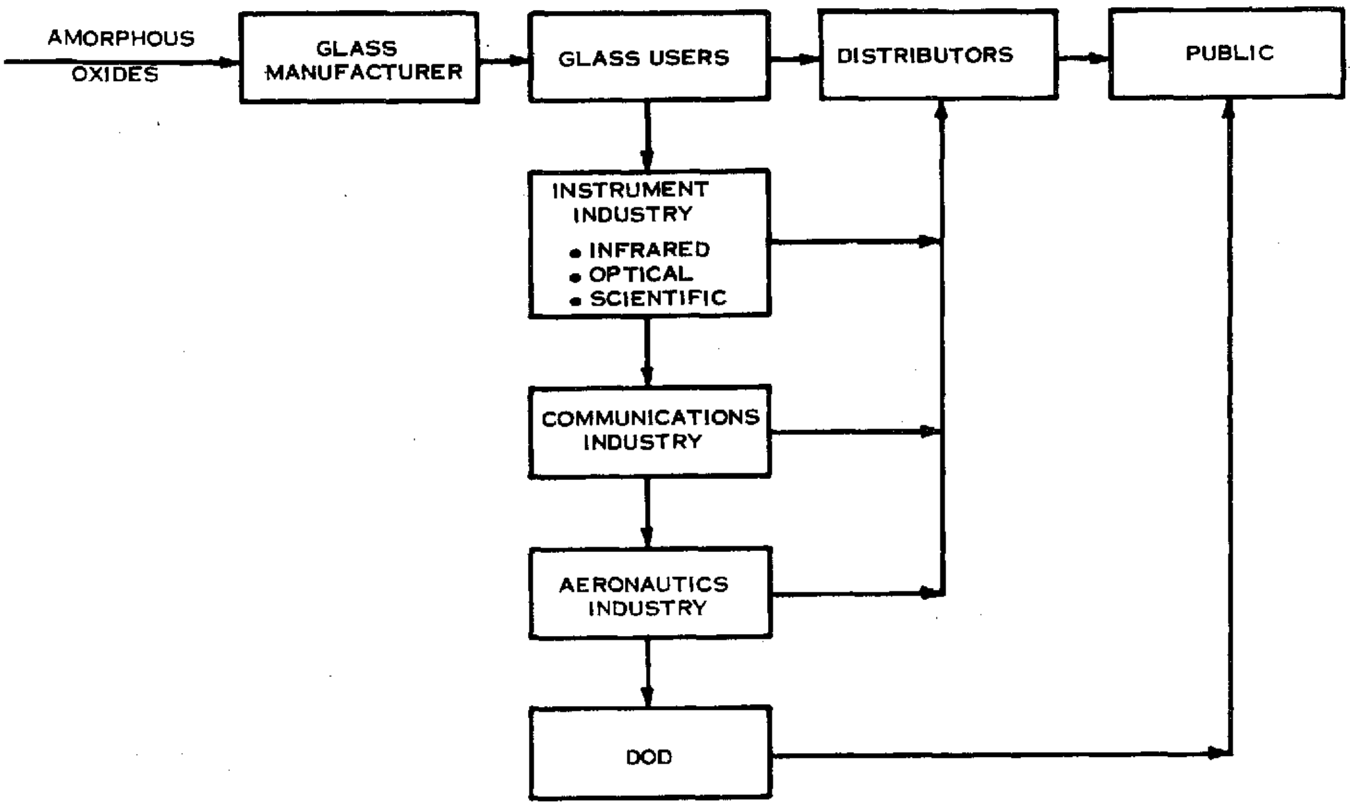


Figure III-23. Potential Beneficiaries from Production of Amorphous Oxides in Space

The potential benefits from these amorphous oxides is difficult to assess in terms of dollars because the exact properties of the materials, and, hence, their uses cannot be predicted exactly. Our benefits analysis first viewed the overall impact of these developments in the glass industry, and then one segment of the market within that industry; namely, infrared optical instrumentation and lenses.

The total value of glass shipments in 1969 was approximately \$3.5 billion. Of this, approximately \$900 million was for scientific and laboratory glassware, industrial and technical uses, and ophthalmic and optical glasses. New amorphous forms of oxides of alumina, zirconia, magnesia, etc., with new or better properties than existing glasses are sure to take a significant share of this market; it is estimated that 10 percent of this market, or \$90 million will be captured by these superior glasses. The amorphous forms of metals and new grain structures are sure to have large economic potential. In addition, the nitrides, borides, tungstides, etc., will open up new markets.

Within the last decade there have been significant advances in optical glass materials, particularly in extending the useful spectral range in the infrared region, including the absorption band from 2.7 to 4 microns. Estimation of the benefits that may accrue from further improvement in the transmissivity, refraction, and mechanical properties of these glasses must consider the complementary role of reflective optics in the larger and higher precision optical systems. For instance, many spectroscopes would utilize space manufactured optical glass in prisms and windows while other optical elements would be of the reflective type. It is estimated that approximately 10 percent of optical instrumentation components will effectively utilize very high quality optical glass material. It is further estimated that about one fifth of that high quality segment will require the optical properties in the infrared region that could be attained through space processing.

The value of that portion of glass shipments in 1969 pertaining to optical instrumentation and lenses was \$484 million, \$325 million of which constituted value added*. Thus, the estimated value of space processed optical glass components, based on the 1969 production figures, is (\$484 million x 10 percent effective utilization x 20 percent portion in the infrared region requiring space processing, or) \$9.7 million per year.

In conclusion, the estimated total value of new amorphous glasses is \$90 million per year. Approximately \$10 million of this would consist of infrared optical instrumentation, and the

*Statistical Abstract of the United States - 1971 U.S. Department of Commerce, Bureau of Census.

remainder would be applicable to other manufacturing areas such as armor, bearings, cryogenic components, heat exchangers, and lightweight structures.

Applicable Space Properties

The zero gravity environment in an orbiting spacecraft is the primary space property applicable to this concept. Corollary to this zero gravity environment, the absence of convection, sedimentation and buoyancy may be useful. The high vacuum in space may be useful for melting some materials, although it may be desirable to melt some of them in an inert gas. It is conceivable that the high solar energy in orbit might be used as a source for melting large masses of material. Radiation to space, essentially an infinite absorber at very low temperature, may be useful in achieving rapid cooling or supercooling.

Development Schedule

A tentative development schedule is shown in Figure III-24.

ANALYSIS AND PLANNING	1973
LEVIATATION MELTING ON EARTH	1974
LEVITATION MELTING AND COOLING-KC-135 AIRCRAFT	1975-6
BALLISTIC FLIGHT - SOUNDING ROCKET	1977
SHUTTLE SORTIE TESTS	1979
ORBITAL PILOT PLANT (OPERATIONAL DEMONSTRATION)	1980
ORBITAL PRODUCTION (OPERATIONAL CAPABILITY)	1982

Figure III-24. Tentative Development Plan for Amorphous Oxides

III. 1. 10 IDEA NO. 84, THERMAL CONDUCTIVITY OF LIQUIDS

Objectives

Improve the accuracy of thermal conductivity data for liquids, by means of obtaining measurements of such data for a variety of liquids in a space facility where zero "G" eliminates the convective effects.

Potential Users

Participating; National Bureau of Standards, Rockville, Md.

Others; Chemical Industry, Petroleum Refining Industry

Key Individuals

Dr. P. E. Liley, Thermophysical Properties Research Center, Purdue University

Dr. David Flynn, National Bureau of Standards

Dr. Sudhir D. Savkar, GE Corporate R&D

Discussion

The measurement of thermal conductivity in liquids is affected by the presence of convective currents in the fluid medium. Techniques have been developed for minimizing the effect of conductivity by proper control of temperature gradients. Careful analysis has shown that suitable measurements can generally be made, with a high degree of accuracy. There are some exceptions where measurement errors due to convection could be significant:

1. Measurements near the critical point of the fluid
2. Extremely dense or dilute fluids
3. (Possibly) for two-phase mixtures
4. In substances, such as oils, having low thermal diffusivity

For instance, with respect to the latter (thermal diffusivity), an analysis by Dr. Savkar, Volume II, Appendix J, shows that normal precautions concerning the temperature gradient across the medium to be measured may not suffice. Fluid motion due to very small convective currents or vibration can contribute to errors of 25 percent in the measurement of thermal conductivity. For instance, the fluid velocity that is necessary to produce 25 percent error in the thermal conductivity of certain oils is approximately 0.015 centimeter per second. The degree of temperature gradient control and vibration isolation necessary to prevent these tenuous fluid motions may be attainable in a convectionless environment of zero gravity, isolated from terrestrial disturbances.

Another important influence upon the accuracy of thermal conductivity measurements of liquids is radiation absorption by the fluid*. Preferential absorption in various wavelengths complicates the measuring process. Unlike the fluid motion problem discussed previously, the space environment has no particular advantage in the solution of the radiation absorption problem.

Potential Benefits

The National Bureau of Standards publishes extensive data on the thermal properties of materials, of which an estimated 20 percent deal with thermal conductivity. Industry is the largest user group of this data; other users are the Government and the academic community. A typical industrial user of this type information is the General Electric's Heat Transfer Products Business Section, which produces heat exchangers ranging from 250 to 500,000 pounds.

Inquiries in that organization to assess the impact of an increase in accuracy in the thermal conductivity of the oil used in some of their low capacity heat exchangers resulted in the consensus that additional accuracy is desirable but not very critical in the industry, since that is only one of many uncertainty factors that must be compensated for in the basic design of the heat exchanger. Actual test and field data, accumulated over several generations of heat exchangers serves to complement the available thermophysical data to attain good design results.

*Poltz, N. B. S Sp-32, 1968; Poltz, International Journal Heat Mass Transfer 5, 307, 1962).

Benefits to Oil Industry

The benefit that could be derived from better accuracy of measurements of the thermal conductivity of crude petroleum was analyzed by Dr. S. Savkar (Volume II, Appendix N). The specific subject of the analysis was the proposed pipeline that would run from Prudhoe Bay, in the North Slope, to the Pacific Port of Valdes.

Crude oil will be transported through a 1.22 meter (48 inches) diameter pipeline covered with several inches of polyurethane-based insulation. The heat transfer properties of various elements of the pipeline system are very important in the design of the insulation, and therefore it was theorized that the oil thermal conductivity value used in the thermodynamic equations would be very important. The objective of the analysis by Dr. Savkar was to determine the effect of a 25 percent error in thermal conductivity of oil, on the heat transfer characteristics of the insulated pipe, both in air and underground. The results of this analysis would then be translated in terms of amount of insulation that could be saved by reducing the extra insulation needed to compensate for the uncertainty in the heat transfer calculations. The analysis in Appendix N shows that a 25 percent improvement in the accuracy of the thermal conductivity measurement would mean only $\sim$ 1/2 percent improvement in the accuracy of the total heat transfer calculated for the system. This percentage is small compared with the effect of the uncertainty in the thermal conductivity of the ground/ice surrounding the pipe.

If the other unknowns could be reduced, the amount of insulation that could be saved through a 25 percent improvement in knowledge of thermal conductivity, over a span of 1287 km (800 miles) would be approximately 126,000 kilograms (286000 lb). The cost of this insulation is not known, because contracts for the pipeline system have not been initiated at the time of writing of this report. Certain types of pipe insulation may cost more than $1.00 per pound, based on past experience on similar applications. Therefore, the economic benefit could be as high as $286,000.

It may well be that no individual application of the more accurate data would probably justify the previously noted measurements in space. However, further study to combine the potential benefits to a broad spectrum of other industrial users, such as the manufacturers of transformers, refinery equipment, etc., would be highly advantageous.

Applicable Space Properties

Zero gravity and isolation from terrestrial disturbances are applicable in limiting fluid motion during the delicate measurement of thermal conductivity.

Development Steps

The time phasing of the Development Program is shown in Figure III-25.

SUBJECT: THERMAL CONDUCTIVITY OF LIQUIDS		
DEVELOPMENT PHASE	DESCRIPTION OF DEVELOPMENT PHASE	DURATION
1. ANALYSIS PHASE	A. PERFORM DETAILED MEASUREMENT ERROR ANALYSIS FOR A REPRESENTATIVE SET OF MATERIALS	1 YR
	B. PERFORM A LITERATURE SEARCH CONCERNING THE EFFECT OF GRAVITY AND VIBRATION UPON THE ACCURACY OF SUBJECT MEASUREMENTS	9 MOS
2. LAB EXPERIMENTS	A. INVESTIGATE THE EFFECTS OF CONVECTION AND VIBRATION ON THE SUBJECT MEASUREMENTS	1-1/2 YR
3. SPACE MEASUREMENTS	A. DEVELOP SPACE MEASUREMENT TECHNIQUES	1 YR
	B. PERFORM MEASUREMENTS ON LIQUIDS	1 YR

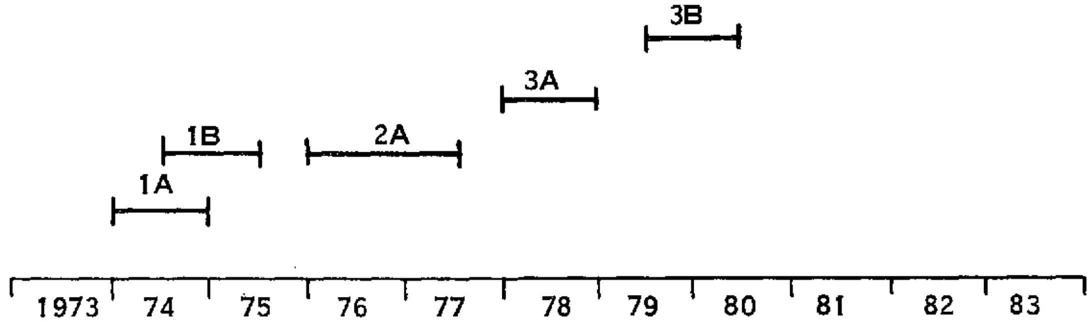


Figure III-25. Time Phasing of Development Program

III.1.11 IDEA NO. 89, SEPARATION OF ISOENZYMES

Goals and Objectives

The goal of this idea is the separation of specific isoenzymes for use in the diagnosis of diseases and for possible new pharmaceuticals. The objective is to develop a separation process for higher specificity separations of isoenzymes, than can presently be accomplished, and through the use of gentle separation forces to obtain larger amounts of the undenaturized isoenzymes.

Users

Participating; Polysciences, Inc., Warrington, Penna.

Others; Pharmaceutical Companies, Medical Laboratories, Physicians

Key Individuals

Dr. B. D. Halpern; Dr. M.K. Akkapeddi, Polysciences, Inc.; Dr. E. Mochan.

Discussion

This concept makes use of large pore gel electrophoresis in the zero "G" of the space environment to perform gentle separations/isolations of easily denaturized, medically important isoenzymes in pure forms. For complete details see Volume II, Appendix A, Large-Pore Gel Electrophoretic Isolation of Isoenzymes Under Outer Space Conditions, by B. D. Halpern, et al.

Background

Enzymes are biological catalysts, of which 2000 have been identified to date. Because each enzyme plays a specific role in specific chemical reactions in living organisms, even a slight deficiency or excess of a single enzyme may be an indicator of, or be manifested in the form of severe metabolic disorders and diseases.

Present protein isolation techniques have shown that some enzymes, thought originally to be of a single form are actually families of two to as many as 18 slightly different molecular forms. These alternate forms are called isoenzymes and, at present, approximately 100 enzyme families are known to have isoenzymes. Isoenzymes are globular proteins whose differences in structures can arise from slight and subtle variations in their primary, secondary, tertiary and quaternary structures (Figure III-26). Because the forces holding these structures together may be weak interaction forces between the groups on the protein chain, gentle means of separating isoenzymes must be used to avoid denaturization during the process of separation. These weak interaction forces are very easily disturbed by heat, chemical agents and electrical potentials (as in conventional electrophoresis at high voltage).

Isoenzymes appear to play specific roles in maintaining cellular operations and hence offer selective advantages as indicator of abnormal or diseased tissues or organs. Elevated levels of certain characteristic isoenzymes in the serum have been shown to accompany such abnormalities as myocardial infarction, muscular dystrophy, cancer, etc. Although there is still some reluctance relative to the isoenzyme role in some cases, the demonstration of genetic variability of some isoenzymes and the refinement of protein isolation techniques have been major factors in their present unequivocal acceptance in other cases.

Present Methods of Separation of Isoenzymes

These basic separation techniques have been developed:

1. Electrophoresis: paper; cellulose acetate, gel-starch, polyacrylamide, agar; column-starch, cellulose
2. Isoelectric Focusing: sucrose gradient, polyacrylamide gel
3. Chromatographic Techniques: ion exchange; gel filtration; hydroxapatite

Small-pore gel electrophoresis is the most commonly and successfully employed isoenzyme isolation technique. As techniques and materials have developed from cellulose acetate strips to starch and polyacrylamide gels to isoelectric focusing, the resolving power has been progressively improved. For example, L-amino oxidase previously thought to exist in three

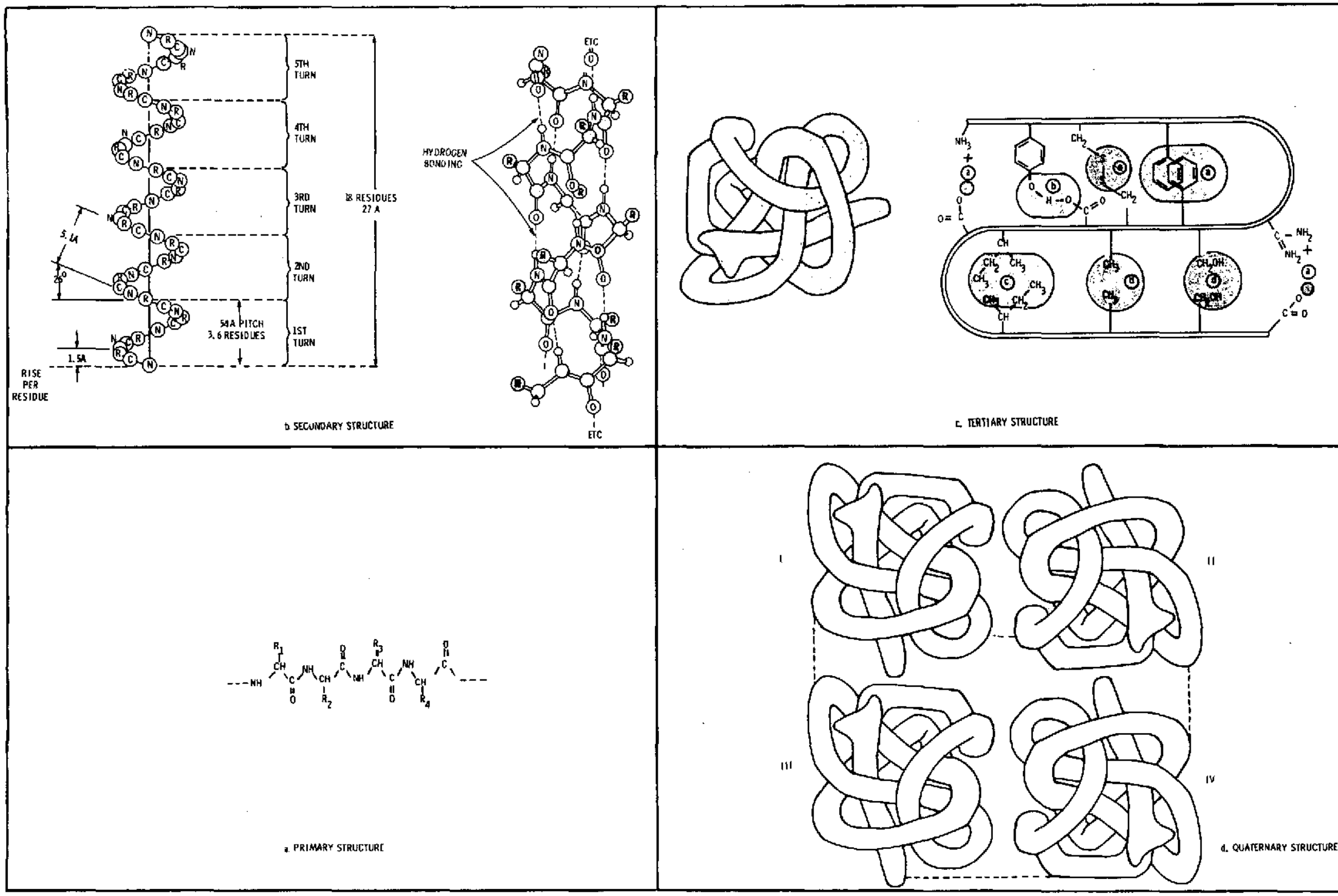


Figure III-26. Isoenzyme Structures

forms as a result of electrophoresis was shown to contain 18 isoenzymes by isoelectric focusing technique.

Progress inthe more wide spread exploitation of isoenzymes as clinical diagnostic tools is inhibited by:

1. The difficulty of isoenzyme isolation without denaturization in sufficient quantities of pure form for detailed Study.
2. Lack of convenient means for detecting very small levels of the "diseased or malfunction" indicating isoenzyme.

What is being sought, then, is an isolation method which could readily provide high yields of high purity isoenzymes. There is considerable optimism that successful development of such method would have a large impact on the early clinical diagnosis of various diseases.

Before attempting to develop a concept for higher specificity separations, let us summarize the problems with present methods:

1. Electrophoresis and Isoelectric Focusing;
   a. Sedimentation
   b. Convective mixing of the separated bands (medium)
   c. Limited pore size of the gel medium, thus excluding very large molecules
   d. Thermal effects due to high electrical resistance of the small-pore gel medium and need for high voltage
   e. Adsorption on the medium; small-pore gels are relatively high solids with relatively high internal surfaces
2. Chromatographic Techniques:
   a. Limited pore size (gel filtration)

b. Adsorption

c. Separation based only on molecular size (gel filtration)

d. Denaturization of enzyme due to surface action

Potential In-Space Separation Techniques (Figure III-27)

Drs. Halpern, Akkappeddi, and Mochan suggest that large-pore gel electrophoresis and isolelectric focusing may provide a high resolution isolation technique for isoenzymes if performed in the space environment. The zero gravity environment would result in less sedimentation and thermal convective mixing. Under these conditions, the lower required electrical driving current would diminish possible damage to proteins from heat and electrical potential. Using the fluid electrophoresis experiments previously performed in space (see NASA/MSFC Contract No. NAS8-27797, Electrophoresis Studies, GE, 1972; and NAS8-28365, Electrophoretic Separator, GE 1972), the authors feel that for the separation of isoenzymes, the addition of a large-pore, low-solids gel supportive system would have additional advantages both in electrophoresis and in isoelectric focusing. The electrophoresis in a large pore gel medium combines some of the advantages of free electrophoresis with that of a molecular sieving process.

POTENTIAL IN-SPACE SEPARATION TECHNIQUES

1. LARGE-PORE GEL ELECTROPHORESIS

2. LARGE-PORE GEL ISOELECTRIC FOCUSING

3. SEPARATION BY OTHER WEAK PROPELLING FORCES; MAGNETIC FLUX, ULTRASOUND, FRACTIONAL GRAVITATIONAL FORCE USING LARGE-PORE GELS. THESE SEVERAL EXAMPLES OF FIELD FORCES ARE CAPABLE OF CONTROLLED ATTENUATION AND ARE THOUGHT TO BE GENTLE ENOUGH TO AVOID THE DENATURIZATION OF THE NATIVE PROTEINS.

Figure III-27. Potential In-Space Separation Technique

In the isolectric focusing of the bipolymers, separation is based on the isoelectric point of the isoenzyme which is the pH at which the macromolecule has no net charge. In this system, each charged molecule migrates in a pH gradient under the electric field to form stationary bands along the column at positions where its net charge is zero. Proteins with small differences in isoelectric point have been successfully separated on the ground, where problems of the technique are similar to those of electrophoresis; that is, loss of resolution is largely due to thermal convection, sedimentation, and thermal gradients resulting from the electrical field strength.

For summary, the advantages of in-space separation of isoenzymes using large-pore gels in either of these separation methods are:

1. Higher resolving power due to sieving action of the gel as contrasted with no gel in free electrophoresis.
2. Lower electrical driving forces (more buffer and no gravity force to overcome).
3. Diminished thermal and electrical potential affects that might otherwise damage the isoenzymes.
4. Minimization of jarring and other disturbances to samples.
5. Easier handling after electrophoresis by allowing geometric fixation, slicing gel, etc.
6. Minimization of thermal diffusion by viscosity effects.
7. Some reduction in convective mixing.
8. Admittance of larger macromolecules than in small-pore gels (more open gel structure).

For additional details relative to the preparation of gels and the variations in their pore sizes see Volume II, Appendix A. This appendix also discusses some additives which are useful in separation of certain isoenzymes, and mentions techniques for aiding in the elution of the sample from the gels. There is also reference to possibilities, still under evaluation, for using other weak manipulative forces (see Volume II, Appendix E) to perform separations.

Applications of Highly Purified Isoenzymes

For this stage of Study, only diagnostic applications of isoenzymes have been considered, although it is conceivable that their use in therapy or in the production of commercial biologicals may eventually evolve. In addition, the large-pore-gel separation process may have equally valid application to such macromolecules as histones, ribosomes, interferons, repressor proteins, cell separations etc.

In the diagnostic applications of highly purified isoenzymes, two techniques appear to have merit:

1. Utilize specific pure isoenzymes to make very specific antibodies. (The purer the isoenzyme, the more specific the antibodies.) Inject the antibodies into the patient, where they will react with antigens to provide specific precipitins, which can then be assayed to determine the presence of specific diseases or body damage.

2. Similarly, cell specimens from a patient can be treated with such antibodies to detect the presence, or absence of specific isoenzymes which relate to specific diseases and damage.

Potential Benefits

The potential use of specific isoenzymes to produce antibodies for immunochemical assay could be advantageous for the early diagnosis and treatment of medical abnormalities. A few tenths of a cubic centimeter of a specific isoenzyme could be used to produce hundreds of cubic centimeters of antibodies which would be sufficient to diagnose thousands of patients.

As an example of the potential benefits which might accrue, consider only one of the listed diseases: cancer.

Cancer deaths in the U.S. alone average approximately 300,000 per year. Typically, a few years ago, the major killers were breast cancer (25,000) lung cancer (14,000) and cancer of the uterus (14,000).

Statistics show that early diagnosis and treatment of breast cancer can result in a survival rate 75 percent higher than if treated at later stages of the disease. If the immunochemical assay techniques resulting from a specific isoenzyme separation in space could result in early diagnosis of even 10 percent of the 25,000 breast cancer cases which cause fatalities each year, early treatment might save approximately 2,000 lives per year. Early diagnosis, while remedial surgery is still relatively simple and effective, could also save thousands of women from the more radical surgery involving the removal of the breast and associated tissues. The after effects of such surgical procedure have a tremendous impact on the lives and happiness of women and their families.

Similarly, in the case of cancer of the uterus where present methods of treatment are almost 100 percent effective if early diagnosis is achieved; if 10 percent of the average 14,000 fatalities each year were avoided, an additional 1,000 lives a year might be saved. Even if early diagnosis only improved the potential to treat the cancer without surgical removal of the uterus, the effect on the lives of thousands of women, their husbands and their children, bornc and unborne, would be enormous.

The preparation of pure isoenzymes would aid in the study of genetics, ontogeny and phylogeny and the better understanding of how these sciences can be more successfully applied for the benefit of mankind.

Better resolution in the separation of isoenzymes has al ıdy shown that many more specific isoenzymes exist than were previously known. The potential for finding new isoenzymes is great and their use in the preparation of antibodies which may provide immunity to specific diseases is possible. The potential benefits to be obtained from even one new vaccine would be significant for many generations to come.

In addition, the technique would be applicable to the separation of other biological macromolecules such as histones, ribisomes, interferons, nucleic acids, proteins, and cells, all of which will probably have associated benefits for mankind.

Applicable Space Properties

The zero gravity environment in space and the associated lack of buoyancy, sedimentation, and convection phenomena are essential to the ultimate realization of very high resolution separations of isoenzymes and other macromolecules by electrophoresis or isoelectric focusing. It will also be essential if other weak force fields are used for such processes.

Development Schedule

A tentative development schedule leading to the production of isoenzymes in space through electrophoretic separation abord the Shuttle in 1982 is shown in Figure III-28.

For the orbital experiments an experimental program is recommended which employs several proteins and isoenzymes with varying degrees of structural complexity. The initial experiment should be concerned with testing the resolving power of the electrophoresis apparatus. With later experiments, because of possible instability problems, special handling of some samples may be necessary.

1.	DEFINITION AND ANALYSES FOR DEVELOPMENT	1973
2.	LABORATORY DEVELOPMENT OF SELECTED TECHNIQUE	1974
3.	DEVELOPMENT OF ORBITAL EXPERIMENT EQUIPMENT	1975
4.	ORBITAL EXPERIMENTS	1976-78
5.	DEVELOPMENT OF PRODUCTION UNIT FOR SPACE	1979-81
6.	PROTOTYPE TESTING ON SHUTTLE	1982
7.	OPERATIONAL PRODUCTION IN SPACE	1983

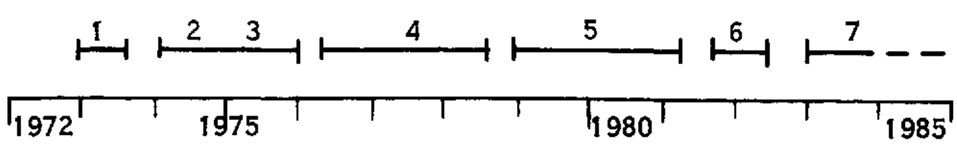


Figure III-28. Tentative Development Plan and Schedule for the Separation of Isoenzymes in Space Environment

Subsequently, electrophoretic experiments should be done on the hemeprotein cytochrome c. This protein is important in cellular oxidation reaction, has the advantage of being extremely stable and colored. In addition, the oxidized and reduced forms of this protein have similar electrophoretic behavior, and consequently are difficult to separate. Therefore, a comparison of the separation resolving powers on earth versus in orbit of the oxidized and reduced forms of this protein, which because of their characteristic colored forms can be easily detected, would be a simple and unequivocal test of the efficiency of the apparatus. Measurement of the biological activity of cytochrome c by standard procedures before and after space separation would assess any possible "separation damage".

Assuming that these preliminary results prove satisfactory, the next step would be to electrophorese a much larger colored protein (red blood cell catalase). This hemeprotein has a molecular weight of 240,000, being almost 20 times larger than cytochrome c and is composed of four subunits, and can exist in electrophoretically distinct forms. Once again, a comparison would be made of the efficiency and "harshness" of the electrophoretic technique on earth versus space processed results. Because of the larger size of the catalase molecule, electrophoresis on earth has proved difficult. Therefore, it is anticipated that a weak-gel electrophoresis system, only capable of operating under outer space conditions, would be advantageous for the electrophoretic separation of large biological molecules which, because of the concentrations of gels required for support on earth, tend to block their penetration.

The final experiments and the ultimate goal of the proposed project, would be concerned with the separation of isoenzymes which, as previously discussed would be of great clinical value. The immediate isoenzymes of medical significance to which these methods could be most successfully applied are creatine kinase and glycogen phosphorylase. The ability to obtain these isoenzymes in pure form could lead to the development of improved clinical diagnosis.

In a typical preparative electrophoretic experiment, several hundred milligram quantities of pure isoenzymes can be separated, which may then be used for the production of antibodies. Injection of only a very small quantity of isoenzymes induces the formation of relatively larger quantities of antibodies in the experimental animals. Thus, several hundred milliters of antisera can be prepared. These may then be used in small quantities for clinical diagnosis of diseases. The total quantity of antiserum so obtained would thus permit the diagnostic treatment of several thousand patients.

III. 1. 12 IDEA NO. 96, UTILIZATION OF BIORHYTHMS

Goals and Objectives

The goal of this project is to obtain a sufficiently better understanding of the exogenous factors affecting human rhythmic processes to devise more effective diagnostic and therapeutic routines, as well as work shift scheduling. The objectives are to perform chronobiological evaluations in extraterrestrial space to determine how the biorhythmic processes respond when the subjects are removed from the normal stimuli associated with a given geolunar location.

Users

Participating:

The National Institutes of Health, The National Health and Lung Institute, Bethesda Md.
The University of Minnesota, Chronobiology Laboratory, Minneapolis, Minn.

Others

Applications are probable in the following areas: Medicine, psychiatry, aviation, industry, public health, etc.

Key Individuals

Dr. Franz Halberg, Chronobiology Laboratory, University of Minnesota

Dr. Frederic C. Bartter, Clinical Director and Chief, Endocrinology Branch, National Heart and Lung Institute, N.I.H.

Discussion

Chronobiology is a branch of science which investigates biological timing mechanisms, including those underlying the rhythmic manifestations in biological processes. Rhythms with different frequencies are found at all levels of biologic integration from the production of enzymes in the protoplasm of a single cell, through the reproductive cycles of the human female, to the mortality rate from heart attacks in the USA, as throughout the world at large.

Dr. Bertram S. Brown, Director, National Institute of Mental Health has stated that "From the moment of conception until death, rhythm is as much part of our structure as our bones and flesh....No corner of medicine - from the laboratory testing of new drugs and procedures to clinical and public health programs - is likely to remain untouched by the new explorations into biological rhythms."

In concert with the turning earth, plants and animals exhibit a very pronounced daily rhythm. Often external cues synchronize living organisms into an exact tempo. However, when men and animals are isolated from their usual time cues, they do not keep to a precise solar day (24 hours) nor even to a precise lunar cycle (24.8 hours). Nonetheless, isolated creatures do show rhythms that do not deviate very much from 24 hours. This daily rhythm is denoted by the popular term circadian. It means about a day, from the Latin, circa dies. Volume II, Appendix L provides an expansion of the information which follows, as reported by the Key Individuals who participated in this study.

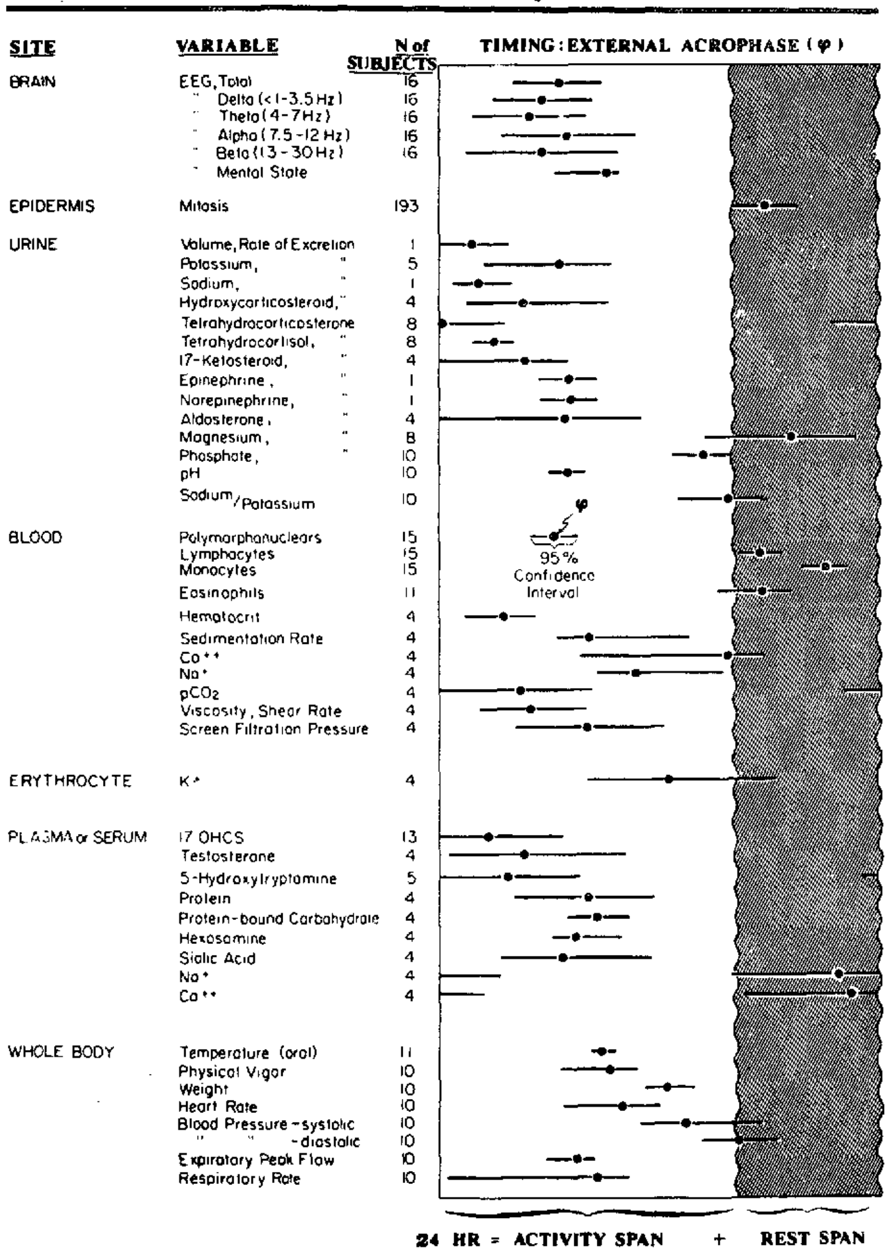
Background

Man may be unaware that his body temperature, blood pressure and pulse, respiration, blood sugar, hemoglobin and amino acids are changing in a circadian rhythm. The levels of adrenal hormones in his blood and concentrations of essential biochemicals throughout his nervous system also change in this rhythm. As two decades of laboratory research have disclosed, there is a rhythmic fluctuation in the contents of the urine and in almost every physiologic function, from the disposition of fat or sugar in the liver to the rate at which cells are dividing. Figure III-29 shows some of the biological functions in man and their acrophases (time of high values in each 24-hour period).

The consequence of all this circadian change is very dramatic because a creature's strength and weakness also varies depending upon his biological time of day. People perform differently on psychological and physiological tests at different hours. Drugs also affect us differently according to (the individual's) biological time of day. Biological time of day does not necessarily correspond with local clock time. For example, a person who works at night and sleeps by day is likely to be 180 degrees out of phase with the daytime workers of the

CIRCADIAN RHYTHMS OF VARIOUS HUMAN BIOLOGICAL FUNCTIONS SHOWING THE APPROXIMATE TIME OF MAXIMUM LEVELS FOR EACH FUNCTION WITH RESPECT TO THE INDIVIDUAL'S ACTIVITY AND REST PERIODS. LENGTH OF HORIZONTAL LINES INDICATE THE 95 PERCENT CONFIDENCE INTERVAL. FOR A STABILIZED INDIVIDUAL, EACH OF THESE FUNCTIONS INCREASES AND DECREASES ONCE EACH 24 HOURS, WITH WAVEY VARIATIONS IN BETWEEN.

Human Circadian System



Analyses in Chronobiology Laboratories, University of Minnesota, Minneapolis

Circadian acrophase chart showing timing in relation to light span, on top. The internal acrophase, ϕ, in relation to the rest-activity cycle, may roughly be approximated by reference to the bottom scale. For original data and/or references see Halberg *et al.*, 1969.

Figure III-29. Human Circadian System

world. He sleeps when they are awake. His temperature is falling when theirs is rising. His adrenal steroid levels are low when theirs are high. Such rhythmic changes indicate the individual's "biological time of day."

If one were able to look inside himself he might note that his body, like a most complex factory, operates on something analogous to an elaborate production schedule. Nutrients (raw materials) must arrive at organs (assembly stations) in sufficient quantities and at appropriate time. Moreover, the right quantity and the right time also are considerations in the function of nerves and hormones. Furthermore, without a properly timed surge in liver and kidney enzymes, we might conceivably be poisoned rather than nourished by the food we eat...The concentration of amino acids in the blood increases more after an 8 AM meal than after the same meal at 8 PM. Some bodily production control system must rhythmically adjust "rates of manufacture" to a spontaneously and periodically changing "inventory".

Alterations of normal circadian rhythms provide diagnostic clues or cues to some illnesses ....Changes in a circadian rhythm typify some illnesses....Irregularity within a single production line might have ramifications throughout (the body)....

Immunity to infection is also rhythmic, and for each of the many kinds of burdens a person is exposed to, there are (daily) times of maximum strength or weakness, hours or greater endurance, greater patience, keener perception, better hand-eye coordination, better performance of mental tasks, greater handgrip strength and even greater immunity to disease.

Mortality has been shown experimentally to depend not only on the amount (dosage) but upon the time of day, or rather the state in the circadian rhythm, when a rodent received X-rays or was injected with overdoses of drugs, bacterial poisons....

Although drug companies and the Federal Drug Administration judge the toxicity of drugs by ascertaining the dosage that kills half of a group of experimental animals (the famous LD50), this is incomplete information and may be gravely misleading without specifying the biological time (for the animals) of the determination.

For example, using mice or rats which were standardized in their environment, it has been shown (by verifiable and valid statistical assessments) that massive doses of the following drugs given at different times in their circadian cycles had the following results:

DRUG	TIME ADMINISTERED	% KILLED
ALCOHOL	AT START OF ACTIVE SPAN AT START OF REST SPAN	60 12
ANESTHETIC (HALOTHANE)	DURING HABITUAL ACTIVE SPAN IN REST SPAN	76 5
AMPHETAMINES	AT HEIGHT OF ACTIVE SPAN AT END OF ACTIVE SPAN	78 8
HEART STIMULANT (OUABAIN)	AT START OF ACTIVE SPAN AT START OF REST SPAN	15 75

Note: Mice and rats are nocturnal animals. Their active span is during darkness.

Animal and human time studies now suggest that the hour at which an infection is incurred may have a significant effect on intensity of illness.... Healthy volunteers, immunized against a Venezuelan equine encephalomyelitis, seemed better protected if they received their vaccine at 8 a.m. rather than 8 p.m.

A person whose blood pressure registers "normal" in the morning may be "hypertensive" by afternoon (every day)....A person who is "normal" in the morning may be "diabetic" in the afternoon every day due to normal biorhythmic variations in his metabolic processes. If he is working night shifts, or if he just flew from Tokyo to Washington, the values recorded might be just the opposite at the same time of day. Such variations, and those along the 1-year scale; e.g., in blood pressure, are obviously important to those who would set the premium to be charged for medical insurance. They are even more important to the individual who has high blood pressure or diabetes, particularly if his doctor only takes office calls in the morning or sees him once a year.

Animals, especially mice and rats, have been predictedly synchronized in many of their biological functions by light-dark cycles. Like men, mice or rats have a set of biological functions that follow a circadian rhythm with maxima which repeat on a daily basis. Given 12 hours of light and 12 hours of darkness, the mice synchronize (stabilize) their rhythms in a reproducible time relation to their environment. In the synchronization of his biological functions, man appears to be much more subject to socioecological stimuli, such as the alarm clock, meals, going to work, and habitual routines.

However, both mice and men, and other animals as well as plants, when isolated from synchronizing cues, e.g., in continuous darkness or in continuous light, maintain natural circadian rhythms that differ slightly from a solar day length of precisely 24 hours. Man, living for months on a self-selected schedule in a deep cave, tends to adopt a cycle period near 25 hours' duration, approximating a lunar day of 24.8 hours. The extent to which these biological timing features depend on external sources is not as yet established, although the proposition that they are at least partly endogenous to living creatures is accepted by most scientists in the field. Dr. Frank Brown, of Northwestern University, Evanston, Illinois, has been the most active proponent of the cosmic theory suggesting that an independent internal timing system for rhythms is not necessary to life because the environment is always generating rhythmic signals (solar light/dark cycles, terrestrial magnetism, electric fields, and background radiation and other signals such as gravitation) from which no creature on earth can be completely isolated. Experiments in space may succeed in isolating life forms from some of these (external) cycles (in solar orbits) or in changing their period at different distances from the moon.

When man's rhythms are synchronized to local conditions, his biological time can be completely altered by a flight to a new location in a different part of the world, or in some cases, by a shift in his work schedules, such as changing from night-shift to day-shift. When such a shift occurs, up to three weeks or more are required for him to adjust to the new local environment. His physiologic functions tend to maintain their time relations to the previous schedule for several cycles after the shift; but gradually, and at different rates for different functions (such as hormone production, blood pressure, hand-grip strength, etc.), each function resynchronizes to the new local time. During such spans of readjustment, body functions, performance capabilities, nervous reactions, responses to drugs, urine contents, etc., are all changing their time relations to the environmental cycles, and many of the relations among these rhythmic variables also change. Usually, for most of us, it takes longer to readjust if the flight is from west to east (in which case the flight, in effect, shortens one day) than from east to west (one longer day).

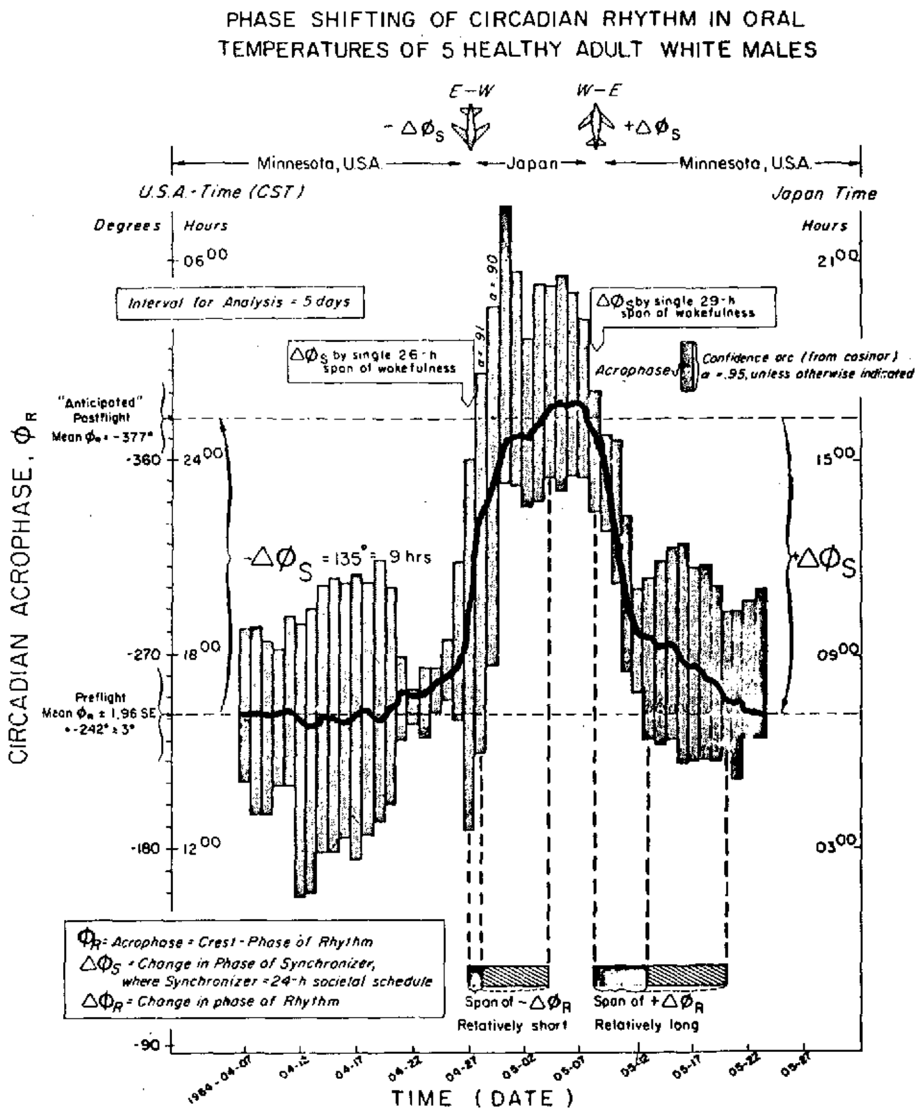
Similarly, it takes longer for rats to adjust if a shift in lighting schedule is accomplished by shortening a single "day" than if the shift involves lengthening a day. The body temperature rhythm of rats adjusts in 4 days if a single light span is shortened from 12 to 6 hours, and not before 8 to 12 days if a single light span is lengthened.

Essentially the same thing happens to a man if he stays up all day and then starts working a night-shift schedule. After such shifts, for mice or men, body functions must readjust to a new activity-rest cycle and this requires from several days to three weeks.

Figure III-30 shows the time required to reach a stable adjustment after a flight from Minneapolis, Minnesota, to Japan and the even longer time it took to readjust after a flight from Tokyo back to Minneapolis. This particular figure was based on data from a group of five healthy male adults who made the trip to Tokyo and back, and shows only their oral temperatures as the measured function. Other body functions were measured with similar results. Indeed, similar data on transmeridian flights have been obtained on many more people, and this figure is quite typical of the results.

In one study, a 12-hour shift in lighting, repeated regularly once a week, reduced the life span of mice by 6 percent. Many men make such shifts habitually. Airline flight crews, for example, often make such shifts twice a week for long spans of time. It has been demonstrated for men that 450 of 1000 shift workers never fully adjusted biologically when changing work shift once a week; their body temperature rhythm never stabilized. It was found that 340 of 1000 shift workers could not adjust to changing shifts every two days, either.

SHIFT-TIME IN THE ADJUSTMENT OF THE CIRCADIAN RHYTHM IN ORAL TEMPERATURE FOR FIVE HEALTHY ADULT MALES WHO FLEW TO TOKYO FROM MINNEAPOLIS AND RETURNED. IT TOOK MUCH LONGER TO ADJUST AFTER A FLIGHT FROM WEST TO EAST THAN AFTER A FLIGHT FROM EAST TO WEST, EVEN THOUGH THE MEN WERE RETURNED TO THEIR HOMES. SUCH A FINDING CAN BE REPRODUCED BY MANIPULATION OF THE LIGHTING REGIMEN IN A RAT COLONY. PHASE-SHIFTS OF HUMAN RHYTHMS ALSO CAN BE EXECUTED BY CHANGES IN SCHEDULE OF ACTIVITY AND REST, WITHOUT GEOGRAPHIC DISPLACEMENT.



Rhythm adjustment following a flight from east to west, involving social synchronizer delay, seems to be faster than that following a flight from west to east involving synchronizer advance – even though rhythm advance is associated with return to familiar home setting (see also Haus *et al.*, 1968).

Figure III-30. Phase Shifting of Circadian Rhythm in Oral Temperatures of 5 Healthy Adult White Males

Performance tests on pilots, using a supersonic jet aircraft simulator programmed for "emergencies", both before, during, and after actual flight from Germany to the U.S. and return, showed pronounced circadian rhythms. A simulated flight emergency handled in 53.4 seconds in early afternoon took 103.3 seconds at 3 a.m. Some individuals varied as much as 50 percent in their performance capabilities by day or night. After the west to east portion of the flight, the group showed a 9 percent decrement in performance, with much larger decrements by some individual pilots. Other tests have shown steady deterioration in flight crews during their round-trip between Frankfurt, Germany, and New York City as well as psychological signs compatible with internal desynchronization of their body functions.

The importance of biological rhythms in various medical fields and the current state of the art as currently utilized can best be emphasized by the following representative quotations extracted from position papers prepared for presentation at the meeting at Arkansas Medical Center, Little Rock, Arkansas, November 8-10, 1971 (underlining by this editor).

"Chronobiological approaches have been applied to the clinic and have been found to provide a most effective reference by which to measure the continuing health status of individuals. The chronobiological approach offers a greater possibility of determining deviations in rhythmic functions which may indicate that the individual is becoming "a risk" for occurrence of disease. The approach may also define specific disturbances in rhythmic functions produced by early evolving disease or during established disease. A chronobiologic spectrum of the individual's body functions may also permit an effective and more accurate therapeutic program--timed according to rhythms."

John A. Anderson, M.D., Ph.D., Professor and Chairman
Department of Pediatrics, University of Minnesota

"Of great importance is the therapeutic implications of biological cycles. The circadian rhythm in the activity of enzymes that metabolize drugs suggests that time of administration may be critical in determining the efficacy of a medication. This rhythm is dependent upon the plasma corticoid cycle and involves a wide spectrum of drugs. Circadian variations in response to cardiac glycosides, lidocaine and chloriazepoxide have already been demonstrated, and additional investigations will undoubtedly uncover more drugs that act in a similar manner."

Julius Axelrod, Ph.D., Nobel Laureate, Chief, Section of Pharmacology,
Laboratory of Clinical Sciences, National Institute of Mental Health, National
Institutes of Health, Bethesda, Maryland

So long as a quantification of health is lacking, the opinion prevails--justifiably when rhythms are ignored--that it is impossible to measure the "health" of a population (or of an individual) and that the best we can do is to measure "lack of health." Such an approach is a negative one; it restricts the kind and quality of medical action since it leads at best to distribution and delivery of care in response to crisis, or at least complaints. All too often such care is delivered only after a catastrophic event has occurred, when it may be too late chronologically to return the person to productivity or, for that matter, even to maintain life."

"Whether drug administration not only to patients with Addison's disease but also to those with high blood pressure or cancer, among other illnesses, will be more effective and/or less harmful depends at least in part upon the potential development of methods for timing therapy according to the individual's rhythms at several levels including those in the cell."

Franz Halberg, M.D., Professor Experimental Pathology, Physiology & Biology,
Chronobiology Laboratories
Department of Pathology, University of Minnesota, Minneapolis, Minnesota

"There is probably no such universally present phenomenon in biology, as generally accepted as the "biological clocks" and the rhythms which are dependent upon them (solar-day, tidal and monthly, and annual), for which our knowledge of their bases and mechanisms is so completely obscure and speculative and which has given way so little to conventional experimental approaches. Such universality and unconventionality, together with apparent critical roles at all biological levels, clearly suggest that any sound break-through in this area would provide the life sciences with a revolutionary new understanding of life with greater powers to regulate it, and to predict with more assurance consequences of environmental alterations."

Frank A. Brown, Jr., Ph.D., Morris Professor of Biology, Department of Biology,
Northwestern University, Evanston, Illinois

"These findings suggest that the impact of timing may be of great etiological, pathogenetic and therapeutic import in psychiatry, as they relate to child rearing practices, to schedules of work and transmeridian travel, sleep, exposure to light and darkness, other social schedules schedules, and timing of diagnostic and therapeutic interventions. If psychiatry is to move from empirical to rational approaches to treatment, a solid foundation for the understanding of the relevant chronobiological principles will be essential. To take a single example, in place of the current practice of administering at indiscriminate times massive doses of drugs with diffuse and poorly understood mechanisms of action, one may envision the administration of minute doses of drugs with relatively circumscribed effects, timed precisely relative to the appropriate biological oscillations so as to maximize therapeutic effects and minimize side effects, or perhaps timed so as to resynchronize a biological function which has lost its proper phase relationship to other rhythmic processes."

George C. Curtis, M.D., Professor of Psychiatry, School of Medicine,
University of Michigan, Ann Arbor, Michigan

"An attitude prevails among a few scientists that the only significant or relevant work in chronobiology is that which revolves around locating the controlling mechanism or the so-called "biological clock." I readily admit that explaining the mechanism of rhythmicity would be as big a scientific breakthrough as if one were to come up with an adequate explanation to the mechanism of cell division; to date very few attempts have been made along this line. Pharmacologists exploring the mechanism of drug action might have great success if they considered the concept of hours of changing resistance; again there has been little effort in this direction. Cancer chemotherapy has not attempted to utilize timed therapy to improve the action of drugs with potent side effects; this certainly should be attempted."

Lawrence E. Scheving, Ph.D., Professor of Anatomy,
University of Arkansas, Medical Center, Little Rock, Arkansas

Since this last quotation was prepared in 1971, timed therapy of mice inoculated with one million L1210 leukemia cells has been tested using arabinosyl cytosine. Comparison was made between a reference treatment of 240 mg, given in a 30 mg dose at three-hour intervals for 24 hours and repeated four times at four-day intervals, and a sinusoidal treatment (same total dose given in gradually increasing and decreasing amounts) based on previously mapped circadian and circannual times of peak host resistance to the drug. Mice on the latter treatment schedule survived for a statistically significant longer span. The scope of circadian rhythms in susceptibility to physical, chemical, and bacterial agents in experimental animals and in man was thus extended to include certain drugs used in the clinical chemotherapy of malignancies.

The gravitational effect of the moon on the earth is approximately 2.2 times the gravitational effect of the sun on the earth. The moon's gravitational pull is sufficient to raise the level of the ocean about 2 feet beneath the moon, out where the water is deep. Does this force affect biological rhythms? Perhaps man's tendency to adopt an approximately 24.8 hour "day" when deprived of time cues, and his faster adjustment following a westward flight as compared to an eastward flight indicate a lunar influence. For example, a 24.8 hour periodic lunar effect would probably make it relatively easy to adjust to a shift involving a single long day (westward flight).

With notable exceptions, the observation that it takes much longer to adjust after a west to east flight would be easier to explain if the lunar effect were real, because this tendency is toward a delay in phase. After a flight from west to east, this normal tendency toward a delay in phase would be opposite to the necessary advance in phase required to synchronize the biorhythmic processes to the earlier clock time (and hence, local environmental influences) at the eastern end of the flight. On the other hand, if life originated in the oceans, is the tendency toward a 24.8-hour periodicity simply an inherited characteristic reminiscent of the time when the ocean tides, caused by lunar gravity, were more important to living organisms? Which is all another way of asking to what extend are these features of biological rhythms governed by endogenous (built-in) characteristics of organisms, and to what extent are they exogenous (produced from without).

Data and Application

The approach for this program to extend knowledge and to develop utilization of biorhythms would be to carry out study in space on healthy men and on selected individuals who show tendencies to certain diseases (such as high blood pressure), as well as on rodents. The specific objective would be to discover basic information about terrestrial influences on circadian and other biorhythms which may be of potential value in work hygiene, preventive medicine or in the treatment of disease. It is not suggested that large numbers of people be transported into space for treatment, but the study of selected healthy and diseased patients in orbit should provide data which may be applicable to large numbers of people on the earth. One of the environments we desire to investigate is the isolation in space away from the many exogenous forces characteristic of a given geographical location on earth. By coupling this isolation (from local forces) with almost zero gravity effect from the earth (due to centripetal forces in earth orbits), and by selecting the orbital altitudes to provide exposure to lunar gravity at multiples of the normal period of the lunar day, we hope to establish whether or not lunar gravity is one of the exogenous forces which affect the synchronization of biological rhythms.

Statistical analysis of the pulse rate of American astronauts on the moon showed that biorhythms were maintained. Similarly, the analysis of cardiac cycles, diastole and systole, for American and Soviet men in earth orbit for several days also showed that biorhythms were maintained. However, available data do not stem from sampling under controlled conditions, and are not sufficient to establish the precise period or any other characteristics of rhythm.

It is conceivable that one might set up a host of facilities on earth to study the multitude of possible effects from all of the terrestrial factors possibly influencing biorhythms; but it appears much more reasonable to perform studies in a spacecraft in solar orbit, removed from most if not all influences from the earth/moon system, to determine the extent to which biorhythms may be dependent on (or influenced by) this system.

The considerable knowledge about biorhythms is at present not effectively utilized in medical diagnosis and therapy, in the improvement of human performance or in psychiatric treatment, nor more generally in agriculture and animal husbandry. On the contrary, this knowledge is typically ignored.

Although the background of relevant information is rapidly increasing, there are still areas where understanding of basic biological timing mechanisms and their regulators is incomplete and hence not applicable to the solution of everyday problems. The new knowledge which we would hope to get in space will be pertinent and useful in determining the factors underlying an individual's "normal" biorhythms. Only by knowing the individual's own biological time can these circadian rhythms be meaningfully interpreted. If unknown exogenous factors are controlling the resetting and regulation of an individual's biorhythms, application of chronobiologic information may remain a rather hit or miss activity.

Since even in the routine of giving a man a physical examination a realistic measurement of his biorhythms will require periodic measurements over a least 24 hours, the added complexity and time required and hence the cost of the examination will be much higher than in current practice. As long as there is doubt remaining as to exactly how his rhythms are synchronized to the local environment and/or phase-shifted by some exogenous stimuli, there will be little incentive for doctors to go to the added trouble and expense of the more complicated physical examinations. On the other hand, if these rhythms are truly endogenous, a physical examination which maps on individual's biorhythmic profiles in detail will provide a much better record of that individual's biological functions and their normal sequencing; thereby, for the first time, we would gain a valid index of his "state of health" instead of his "lack of health."

Leaders in the medical profession are already beginning to advocate that all people carry a copy of their own biorhythmic profile just as they carry a driver's license or social security number. Large industries such as GE have long had a company-sponsored program of medical examinations for executives and a requirement for medical examination of all potential employees before start of work. It is a fact that practically every one of these employees could be diagnosed as having either Addison's disease or Cushing's disease any day his physical is given, depending upon what biological time of day it is for him when the examination is made. Similarly, if all employees on day-shift get their physical examinations in the morning, the company may never know which employees have incipient "afternoon-high blood pressure" or "afternoon-diabetes". And when a key executive has a heart attack, his previous yearly physical examinations, as now conducted, may prove of little value to his physician. The potential benefits of determining an individual's biorhythmic profile and of periodically updating it is so self-evident that it is now beginning to be taught to school children so that they can do at least a part of it for themselves.

The diagnosis of many diseases can be aided by measurements assessing or at least controlling biorhythms -- to the extent that the variables used for diagnosis undergo predictable rhythms. Moreover, an irregularity of the rhythm in certain functions or an abnormally low or high value at certain circadian rhythm-determined clock hours may well be the first symptom of an incipient disease. As noted, if a man is beginning to develop obvious high blood pressure it probably would have shown up years earlier in the peak values of daily blood pressure, perhaps sometime in the late afternoon. With heart disease as one of our greatest killers, the need to diagnose a tendency to hypertension while it can still be effectively treated is obvious.

For rotating shift workers, a decrease in output of a night-shift as compared to a day-shift of up to 15 percent has been established in some studies. If space developments could provide even a 10 percent improvement in the performance of night-shift workers by aiding the quicker adjustment of their biorhythms after a periodic phase-shift to a new schedule, the result might be an increase of 1.5 percent in all night-shift production. In addition, such weekly phase-shifts have been shown to result in a 6 to 22 percent decrease in life expectancy for mice and insects, and many shift workers and flight crews are regularly subjected to such phase-shifts. Furthermore, the life-span of insects was reduced by repeated phase-shifting, regardless of whether the shift simulated an eastward or westward flight or alternated between the two directions.

Susceptibility to sickness, such as a convulsion and even to death from convulsion, in response to exposure to a fixed dosage of a certain agent has been shown to be higher after a phase-shift. The potential benefits to be obtained from a better understanding of the causes of such effects or even a rudimentary knowledge of how effects of phase-shifts could be modified in order to reduce susceptibility to disease, to the lethal effects of certain drugs or to the curative effects of other drugs, or, to reduce decrements in physical or mental performance would have wide applications on earth in many industries, in medicine, psychiatry, animal husbandry, agriculture, etc.

One cannot easily establish dollar values for lives saved, for improved public health or safety, for the increased efficiency of a diplomat or business man making improtant decisions, etc., but such activities may be beneficially affected by study of biorhythms in space environments. The health and physical well-being of many people will be improved by an understanding of how to utilize biorhythms and their adjustments after changes in local environments or to new time schedules of work and rest within the same environment. The knowledge would also be applicable to many biological species in addition to man and would affect the growing of plants, animals, insects, fish, etc.

Potential Benefits

Specific benefits could result if it can be established that phase shifting of an individual's biorhythms in space either validates or invalidates previous impressions from phase shifting studies on earth. For example, rhythms in blood pressure, on the one hand, and in biological factors underlying a tendency to high blood pressure (such as rhythms in the excretion of corticoids or catecholamines), on the other hand, may shift at different speeds, yet differences in shift time have not been definitely established on earth. If a dissociation in shift rate were demonstrated on selected patients in a shuttle, the applicability to differential diagnosis would bear upon the treatment of a large number of individuals on earth. With high blood pressure and its associated cardiac and coronary diseases being major killers at present, the potential benefits from such developments are obvious.

Similarly, the decrement in physical and mental performances which results from transmeridian travel and/or from periodic rotation of shift workers from day-shift to night shift has been clearly established and the changing biorhythms of the people involved is also established. If space developments could determine the causes of such decrements due to phase shifting of the biorhythms, or even shed light on how they might be manipulated effectively, benefits may result in the form of increased efficiency of aircrews and travelers on transmeridian flights, and of rotating shift workers in industry. One airline has estimated several hundred thousand dollars per year loss attributable to transmeridian dyschronism of its stewardesses alone. Actual measurements on flight crews have shown performance decrements averaging 9 to 15 percent on a single round trip, Europe to America and return, with some individual pilots showing decrements as high as 50 percent. Anything which would promite an individual's more rapid adjustment of his biorhythms to transmeridian phase changes could result in benefits in the form of more efficient performance of military missions by flight crews, safety of passengers on intercontinental flights, the performance of diplomats on long journeys, etc. Similar benefits could accrue to businessmen who make such journeys and who must make important decisions during short visits. In addition, the general health and physical well-being of all such persons could also be favorably affected.

Medical diagnosis (e.g., of hypertension or diabetes) and experimental cancer therapy have been shown to be improved by the utilization of circadian biorhythmic phenomena; however, this is still largely ignored by the medical profession. Study of organisms in space, separated from many of the biologic synchronizers inherent in a given geographical location on earth but exposed to the periodic influences of the moon, may well provide basic data on biological rhythms and their causes and effects. Similar measurements on rodents in solar orbit, far removed from the vicinity of earth/moon influences, may provide additional understanding as to what underlies biological rhythms, or at least, what it is that makes them gain or lose time. Even a confirmation of the "null hypothesis" (no change in biorhythms) in space would be a step up in our understanding of how biorhythms may be controlled and utilized. Previous data on American and Soviet astronauts indicate that biorhythms do persist, both on the moon and in orbit around the earth, and further studies in space offer unique opportunities to acquire new knowledge which cannot be obtained on earth. The potential benefits appear to justify the effort required to accomplish this task. When a man is sick, the treatment of his condition may well be enhanced if the drugs are administered in selected quantities and at selected times of day to be most effective in combatting his disease. Because of the normal rhythmic sequencing of biological functions drugs such as an antihypertensive agent--chlorothiazide--will be more effective in smaller doses, or certain otherwise toxic treatments, such as radiotherapy, will be better tolerated in larger doses, if properly timed to the individual's "biological time of day." The benefits derived by easing his pain, curing his disease, and prolonging his life are, again, tremendous. The indirect benefits to his family, his employer, his insurance company, etc., are even greater.

Applicable Space Properties

The applicable space properties for biorhythm investigation include zero gravity in earth orbits and in solar orbits and exposure to lunar gravity and other earth/moon influences in a repetitive basis of 1, 2, 4, 8 and 16 times in 24 hours. This exposure would be obtained by flying earth orbits at selected altitudes from approximately 200 to 40,000 KM.

The second phase of the investigation would include zero gravity in a solar orbit away from earth/moon influences, to determine the biorhythmic responses of rodents removed from the influences of geolunar stimuli.

Development Steps

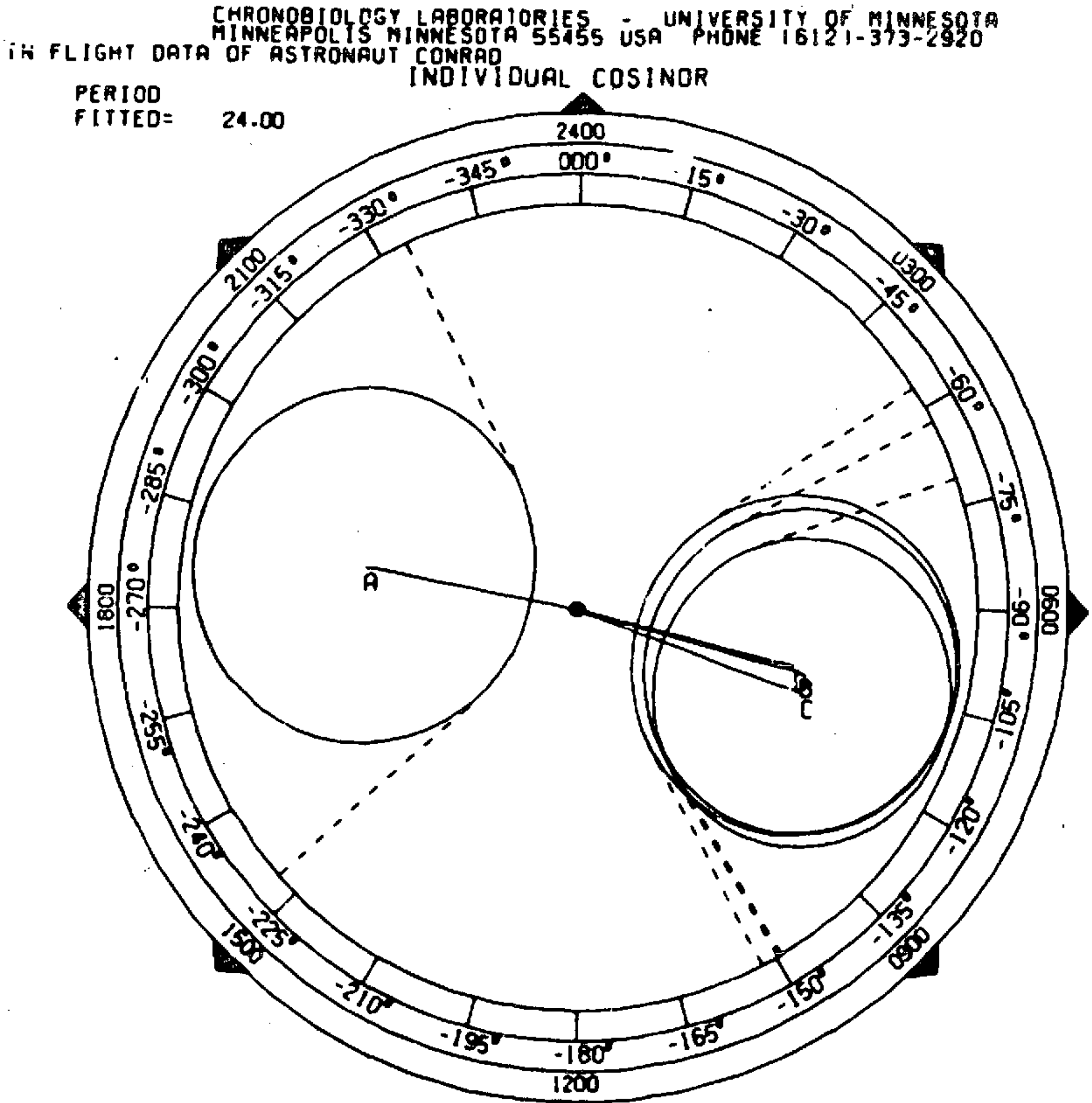
Much of the preliminary ground-based research and some of the actual space hardware development has already been accomplished; the Franz Halberg/Grover Pitts rat experiment hardware has been qualified for flight (but never flown), on the NASA/GE Biosatellite Program.

Much of the success in the study of biorhythms can be attributed to the pioneer work done by Dr. Halberg and his associates at the University of Minnesota and the techniques developed to separate biological periodicities from the usual high noise level in biological measurements. These computer techniques have been used to demonstrate persisting biorhythms of man on the moon and in earth orbits and they strongly suggest that further investigations in space will provide statistically valid, important and useful results.

The cosinor display shown in Figure III-31 is an example of these analytical techniques. This figure shows Astronaut Conrad's circadian biorhythms in earth orbit. It includes his pulse, cardiac cycle duration (CARCY), electromechanical systole (EMSYS) and duration of diastole (DSTOLE). This display clearly shows that his biorhythms were maintained in orbit and the important rhythm characteristics for each function. These characteristics are the percent rhythm "mesor" (a rhythm adjusted mean), amplitude, acrophase (a measure of the rhythm's timing given in degrees with 24 hours = 360 degrees), 95 percent confidence ellipse, and finally, a probability value (P) expressing the likelihood that the results are due to chance alone if there was really no rhythm involved. These techniques have been eminently successful in separating the periodicities of biological measurements from the background noise which is always a major problem in biological research. In addition, these techniques permit testing to assure that the results are statistically significant and also provide a measure of the uncertainty to be attached to numerical rhythm characteristics.

The effects of the different lighting regimens on biorhythms constitute a major feature of the proposed study. In the case of earth orbit studies where recovery of the animals is possible, this would include studies on animal body composition and the endocrines in particular. These effects would be investigated on all animals in so far as telemetry is concerned, at least once.

Test sequences comprised of one to seven stages could provide useful information. Thus, a phase-shift study could be executed on an orbital flight lasting only seven days. For longer duration flights, the different stages in a test sequence and the criteria determining their durations are shown in the future. For further details of this proposed experiment, see Space Life Sciences, Volume II (1971) 437-471.



SERIES IDENT	VARIABLE (see text)	% RHYTHM	MESOR	(S.E)	AMPLITUDE (95% C.L)	ACROPHASE (95% C.L)	P
A	PULSE	15	77.5	(2.46)	10.93 (2.34, 19.52)	-280(-228,-334)	.009
B	CARCY	19	816.7	(23.05)	119.1(38.61,199.6)	-105 (-61,-149)	.002
C	EMSYS	22	372.6	(4.35)	24.45 (9.24,39.66)	-110 (-70,-149)	.001
D	DSTOL	17	444.1	(19.79)	94.77(25.66,163.8)	-104 (-56,-152)	.004

Figure III-31. Cosinor Display of Astronaut Conrad's Biorhythms in Orbit

A tentative schedule for the development of space experiments directed toward determining the extraterrestrial exogenous factors influencing biorhythms is shown in Figure III-32. This program includes both earth orbital and solar orbit flights.

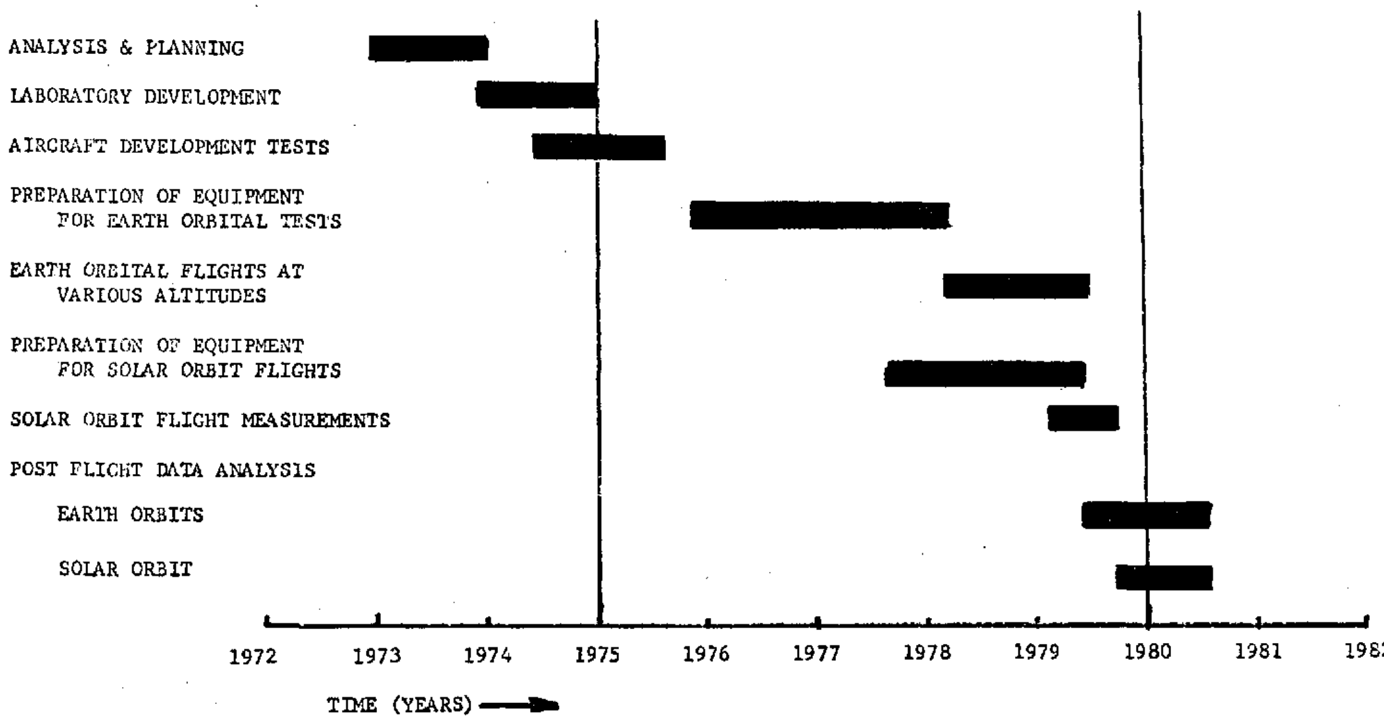


Figure III-32. Tentative Development Program and Schedule for Investigations of Exogenous Factors in Space Affecting Circadian Biorhythms