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BENEFICIAL USES OF SPACE

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ABSTRACT

Paper summarizes Bioprocessing - related results of recently completed three-year, three phase study, "Identification of Beneficial Uses of Space", for NASA-MSFC under Contract NAS8-28179.

First phase of study elicited over 100 ideas for Space Processing. Of the elicited ideas, more than 20% involved processing of biologicals, or related medical and life sciences applications. Among these were High Purity Separation of Isoenzymes, and Development of Biorhythms applications data.

Second phase of study focussed on program planning for four products, for which required experimentation and testing resulted in definition of nearly 70 series of tests in ground-based laboratories, sounding rockets, etc., and Space Shuttle. Development schedules established timing and interrelationships of decisions involved in carrying these products to the point of production.

Final phase of study determined potential profitability of the four products. Resources needed to achieve full scale production included use of Shuttle for transportation, for which a cost apportionment model was developed. R&D resources for the four products totalled $46,000,000 with Isoenzymes requiring the smallest expenditure, $4,000,000. A computerized profitability model (INVEST) was used to determine the measures of profitability of each product. Isoenzymes exhibited relative commercial attractiveness (e.g., up to 30% return on investment, $12,000,000 present value, and breakeven at 7 years from first major investment).

Conclusions are that, while specific Space Processing Applications so far identified may not be those that are ultimate "payoff" from space, results build confidence that there will be a payoff.

INTRODUCTION

At the General Electric Space Division we have recently completed a 3 year, three-phase study "Identification of Beneficial Uses of Space" (Figure 1) under contract NAS8-28179 from NASA's Marshall Space Flight Center.

This effort was aimed at defining and exercising a methodology for:

- Initially, identifying a community of potential Space Processing Users - specific organizations represented by specific individuals, who are involved in solving specific earth-based technological problems which can be related to specific knowledge and capabilities obtainable in spaceflight
- Secondly, involving such Users in defining the plans of specific technical steps and administrative processes required in carrying out such projects
- Finally, continuing the Users involvement in contributing to realistic assessments of (1) the resources required to carry out the planned projects; (2) the returns which may be realized from such a venture; and (3) its resultant profitability.

Where such steps indicate a good business potential, entrepreneurial users will eventually follow.

With the enthusiastic support of Messrs. R. Spencer and K. Taylor, MSFC's Contracting Officer's Representatives, and with the cooperation of over 400 Key Individuals from 80 organizations participating in the Study, we have developed a successful methodology, which includes survey and User contact methods, planned presentations and dialogs, as well as documents and formats for eliciting and maintaining the interest, support and aid of potential Space Processing Users. This methodology also includes operational analyses for comparison and selection of key technical alternatives, and the integration of that data with management planning data. Furthermore, our methodology provides several key commercial business analysis and evaluation techniques, adapted from ground processing business methods, for assessing market data, estimating R&D and production needs, and comprehensively analyzing the business worth of products.

The primary results of the Study have evolved from application of the aforementioned methods and techniques to the above-noted potential User organizations, and to their ideas for potential space processes, products, and services. Those results are briefly summarized in this paper, organized according to the three Phases of the Study.

PHASE I OF THE STUDY

As noted in Figure 1, Phase I has concentrated on User Identification. The development of peer-level, personal contacts; trial and error evolution of an introductory, educational idea-stimulating kick-off presentation; establishment of an overall dialog plan; and promotion of mutually supportive analyses have been the major methodologies in this Phase.

As a result of these efforts, our search for potential space-developed products, processes and/or services initially uncovered over 100 ideas. The complete list of these ideas, together with the goals and objectives sought by the potential Users is given in Reference 1.

A sampling of those ideas that are of possible interest to this Bioprocessing Colloquium are shown in Figure 2. Observation reveals the wide spectrum of User interests. Typical products for which Users anticipated possible improvements due to the so-called "zero gravity" of spaceflight include such biologicals as high specificity isoenzymes and high purity insecticides; and such medical electronics materials as large germanium crystals and low-defect silicon crystals. Users also felt that processes such as thinner, defect-free coating of implantable sensors, and "enzyme engineering" using some adaptation of affinity chromatography might also accrue from weightlessness and lack of convection. Nor was research neglected - bone growth in "zero gravity" was viewed as an area of possible investigation for treatment of major fractures and for bone surgery, while the potential synergistic effects of "zero gravity" and space radiation on the mutation of micro-organisms (including those utilized in the dairy industry and in producing antibiotics) were of interest to several participants.

While almost all of the 100 ideas in this initial identification were considered as valid User needs, consultation with technology experts, analyses in various disciplines (both aerospace and non-aerospace), and various degrees of engineering judgement enabled us to extract 12 ideas with high potential for eventual implementation. These surviving ideas are shown in Figure 3, with details of the specific aims sought by the Users and the specific applicability of Space Processing. Twelve other ideas exhibited sufficient promise to warrant further evaluation at a later date. The remaining ideas were excluded from further study, due to conflict with Study Guidelines, overlapping objectives, analytical or empirical indications of scientific invalidity, etc.

Further Phase I effort on the 12 best ideas developed tentative experimental and operational alternatives for providing the required information, environments, and/or facilities found likely to meet the Users aims. This activity established early indications of the "mix" of ground and space operations involved in precursor experimentation and eventual commercial Space Processing.

Among the significant results of Phase I, shown in Figure 4, the early estimates of the $1 billion to $2 billion value of the 12 current ideas aroused considerable interest, but also raised questions as to the details of necessary pre-production research and development, and, perhaps even more important, as to legal, financial and administrative arrangements. Typical of these latter questions are those listed in Figure 5.

A major conclusion of this phase, therefore, was that further commitments by potential Users would require more information on ground rules and mechanisms which would govern the legal, financial and technical relationships between NASA and commercial industry, and which would, therefore, interact with key technical and administrative decisions and their timing.

PHASE II OF THE STUDY

These requirements helped formulate objectives for the second phase of study, in which we aimed to obtain in-depth technical planning data for typical products from Phase I, as well as program scheduling and decision information for management planning. Details of this phase of the study are found in Reference 2.

Due to timing and funding limitations, this phase of study was limited to the four products listed in Figure 6, and carried out with the support of the listed organizations, who aided the analyses of those products in Phase I.

For the four products, with the four participating User organizations, we evaluated nearly 130 alternative processing approaches prior to selecting those offering the best chances for successful development. With the Users, we then defined specific experiments and tests necessary to such development. This research and development program required a broad spectrum of facilities, both ground-based and spaceborne. Figure 7 lists the required facilities and number of test runs.

The large number of experiment runs in ground laboratories is indicative of the state-of-the-art in the listed areas, and acknowledges that a comprehensive ground-based program is a necessary part of the typical space processing program.

The program leading to high specificity separations of isoenzymes by large pore gel electrophoresis and/or isoelectric focussing calls for the largest number of experiment runs, although later work shows that it is the least costly program. For example, much of the testing, especially the centrifuge tests, centers around the effects of spaceflight operations on the large pore gels. It is important to understand the susceptibility of the gels, with and without separated specimens, to prelaunch handling, launch loads, and re-entry loads. Centrifuge data will answer many of the questions involved, at very low cost.

The details of the experiments and tests listed here were fitted into development timelines, which included all of the research, engineering, ground development tests, and flight testing (including Shuttle flights) to achieve a production capability in the early 1980's. These details included preliminary experiment and test protocols, estimates of equipment needs, as well as dates and duration. The resulting sequence and timing of technical tasks together with the indicated need for commitment of facilities, equipment and manpower enabled the Users, working in the Study Team, to formulate the flow of decisions necessary to implement each development program.

Figure 8 presents a typical decision flow for the Isoenzymes development program. Both technical and management decisions are shown.' Their interrelationships are readily visible, as are key nodes in the flow of decisions. Major alternatives are indicated in the table, estimates (by the Users) as to the probability of each alternative are given, as are the preferred (by the User) alternative.

In summary, Phase II, produced a wealth of technical (processing approaches, experiment and test definitions, facility and equipment needs) and management (milestones, decisions, probabilities) results, Figure 9. However, many of the questions of Figure 5 were still being asked. Furthermore, while Phase II assembled data reflecting specific planning for evolving from concepts to experiments, to initiating commercial operations, a key element was not addressed in those phases... the business potential of Space Processing.

PHASE III OF THE STUDY

Can Space Processing be a profitable business venture? This question was the problem for Phase III. We continued working with the same four products and essentially the same Users to arrive at the answers.

The essence of our task in Phase III (reported in Reference 3) was to acquire sufficient technical and economic information to carry out the financial analysis pictured in Figure 10.

An examination of that figure reveals the scope of analyses we have carried out. For example, blocks listed as "Unit Price", "Total Market" and "Market Share" spell out the need for a comprehensive market analysis. "Unit Manufacturing Cost", and "Annual Plant and Equipment" reveal a requirement for thorough understanding of the commercial manufacturing flow and productivity (both ground-and space-based). "R&D Expense" calls for details of the precursor experimentation and development testing, with major emphasis on the timing and costs of facilities and equipment.

Typically, Figure 11 lists the major equipments needed to carry out the Isoenzyme Separation experiments and tests, briefly summarizes their development status, and notes quantities needed at various points in the development schedule.

A key part of our R&D analysis was the assessment of Shuttle/Spacelab utilization costs. This required construction of a cost allocation model.

Our cost model, given in Reference 3, provides for recovery of all operating costs, allocates costs on the basis of Shuttle resources utilized, and provides incentives (or dis-incentives) to encourage (or discourage) use of various resources. Using our recommended utilization rates, we show, in Figure 12, the cost rates by which a payload User may be allocated his fair share of a typical $10.7 million flight cost.

Similar depth and scope of analysis have been carried out for the production phase of each of the 4 products under study. Using life cycle market demands estimated for each product, in-depth conceptual design of equipments and payloads, comprehensive "throughput" analyses of each step in the production process, with the aid of the User participants, we generated the required data for the final profitability analyses.

The plots on Figure 13, for the Isoenzyme business venture represent the data generated for all four products. A detailed treatment is given in Reference 3.

Case A includes the User funding the total R&D program, $3.8M; nominal forecasted market and market share; conservative unit cost of producing product; nominal selling price. Space production of high specificity Isoenzymes was not an attractive venture under these conditions.

For Case B, Mr. K. Taylor suggested that, since basic processes would have broader application than the individual products under study, it could be likely that the basic process feasibility would be proved under government funding. User, in Case B therefore, would only pick up those R&D costs that specifically provide prototype/pilot plant capability. Under these conditions, NASA (as the agent of the government) provides early R&D funds, and the Isoenzyme processing appears attractive.

In summary (Figure 14) for Phase III, our development planning data includes detailed formats describing and timing all Work Elements. Each element of work is backed by documentation of the human, facility, and materials resources required to perform that work, and the cost of such resources.

In Phase III, Users historical data and prognostications provided market forecasts, and the resulting needs defined production levels, which helped to establish size and performance requirements for processing equipment.

We identified resources required of the Space Program, such as the 85-600 kilowatt hours of energy required per flight for Space Processing R&D on the four products studied. Figure 14 summarizes such typical resources, and the costs of those resources for the R&D effort.

Finally, Figure 14 shows that Space Processing of Isoenzymes tends to be an attractive business venture, once the feasibility of large pore gel electrophoresis in space has been demonstrated. However, the long period before breakeven inhibits the attractiveness of Tungsten processing and Transparent Oxides. Reducing the unit manufacturing cost by 20% (rated a possibility, since several logical approaches for reducing on-orbit energy costs, have recently been brought to our attention by the Study C.O.R.) could reverse those conditions.

SUMMARY OF LESSONS LEARNED

It is appropriate, here, to review what we have learned from all phases of the Study.

Typical specific Lessons Learned from Phase I are briefly depicted in Figure 15.

- The successful identification of Beneficial Uses of Space in Phase I, was based on gaining the interest of potential Space Applications Users through dialogs.

- Considerable Study Team/User mutual education occurred during this Phase through the interchange of Aerospace/Non-Aerospace and Commercial/Government vendor data.

- Since dialogs sometimes did not evoke immediate potential Users ideas, because of the novelty of the space environment to non-Aerospace organizations, we broadened and deepened our initial briefing data in order to lessen this effect.

- Furthermore, the development of User concepts for Space Processing appears to be a time dependent process, and future studies should allow 6 months or more for the process of generating ideas.

Phase II, which carried the study from "identification" to "planning" also taught us some lessons. Figure 16 shows two conclusions for Phase II carried over from the earlier phase: one on User education and another on Legal/Financial issues.

- Phase II results verify that a mutually supportive effort, progressing toward specific concepts, maintains two-way communications between the aerospace community and non-aerospace industry.

- The wide spectrum of current technical unknowns evolving from the limited amount of available data, and the unpredictability of the state-of-the-art in the 1980's, are reflected in a necessarily broad scope of requirements for experiments and tests.

- Preliminary schedules of development programs are "comfortable" and can accommodate moderate redirection, where necessary.

As important as the results of Phase III are the lessons we have learned, Figure 17. Some simply verify or reiterate lessons from the preceding Phases (e.g., the value of dialogs, the requirement for blending aerospace/non-aerospace methods rather than imposing one on the other, etc.). Others are either new, or have become more apparent at this stage of effort, and, thus, bear some discussion.

- We note two key problems in Figure 17 for instance - that of acquiring a Space Processing Program User constituency, and a related need for a policy to determine the tariff for use of space facilities. In the dialogs with the commercial industry community, we have found that the prospect of deriving new or improved products through Space research and development does not supplant, but rather competes with prospects of current, low cost, often historically successful ground-based research programs. Thus, the technical competitiveness of Space Processing will have to be matched with economic competitiveness, and the combination used as a marketing "tool" to acquire the necessary User constituency.

- During the profitability analysis in this Study, two key space operations functions were found to exert profound effects on the production costs of the space products - (1) energy (primarily for heating and melting process steps), and (2) the launch of production facilities for each production run. As a result, one of our conclusions is that

a major effort must be undertaken to develop a low-cost, high power, in-orbit energy source

if space products which require high temperature heating and melting are to be profitable. In addition,

a long term, on-orbit automated, or semi-automated production facility will be required,

if repetitive production runs are to be performed without incurring the prohibitive expense of repeatedly launching the necessary processing equipment.

REFERENCES

1. Study for Identification of Beneficial Uses of Space (Phase I) Final Report, Contract NAS8-28179, GE Document No. 73SD4259, December 10, 1972 and April 23, 1973.

2. Study for Identification of Beneficial Uses of Space (Phase II) Final Report, Contract NAS8-28179, GE Document No. 73SD4281, November 1, 1973.

3. Study for Identification of Beneficial Uses of Space (Phase III) Final Report, Contract NAS8-28179, GE Document No. 75SD4281.

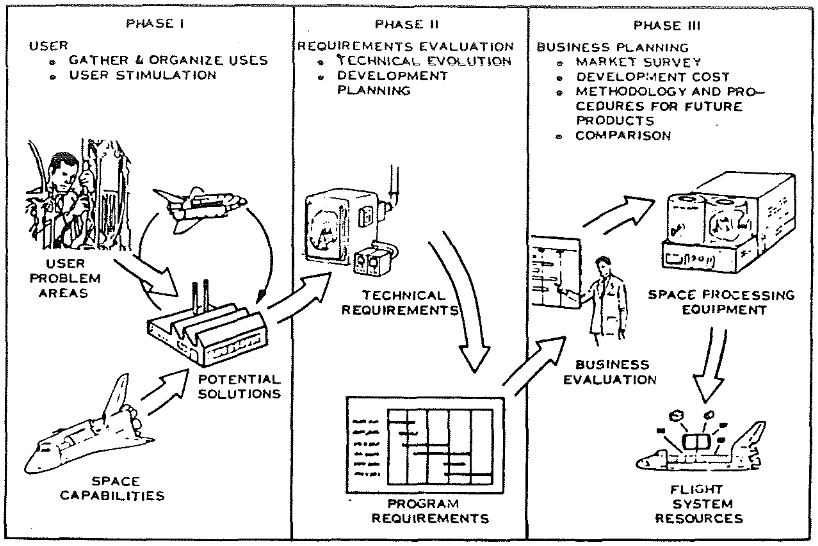


Figure 1.- Relationships of BUS study phases I, II, and III.

- COATING OF IMPLANTABLE SENSORS
- PROSTHETIC MATERIAL FOR BONE GROWTH
- AFFINITY CHROMATOGRAPHY
- THIN FILMS FOR DIALYSIS
- HIGH DUCTILITY TUNGSTEN X-RAY TARGETS
- DEVELOPMENT DATA FOR PHONOCARD-IOLOGY
- IMPROVEMENTS IN DAIRY PRODUCTS
- BONE GROWTH IN ZERO "G"
- LARGE GERMANIUM CRYSTALS FOR GAMMA RAY CAMERA
- HIGH QUALITY SILICON CRYSTALS FOR MEDICAL APPLICATIONS
- VIRAL INSECTICIDE MANUFACTURE
- LYOPHILIZATION
- BLOOD ANALYSIS SERVICE
- MUTATION AND GROWTH OF MICRO-ORGANISMS
- THERMAL CONDUCTIVITY OF LIQUIDS
- SEPARATION OF ISOENZYMES
- UTILIZATION OF BIORHYTHMS
- NEW ANTIBIOTICS
- CULTURING OF BIOLOGICALS

Figure 2.- User ideas of typical beneficial uses of space for bioprocessing.

PRODUCTS	BASIC SPACE PROCESSES REQUIRED
HIGH PURITY VACCINES	ELECTROPHORESIS
HIGH SPECIFICITY VIRAL INSECTICIDES	ELECTROPHORESIS (FREE FLOW)
MULTI-GIGAHERTZ FREQUENCY SURFACE ACOUSTIC WAVE ELECTRONIC COMPONENTS	LARGE CRYSTAL GROWTH AND VIBRATION-FREE LITHOGRAPHY
SINGLE CRYSTAL AND/OR EUTECTIC HIGH TEMPERATURE TURBINE BUCKETS	LARGE CRYSTAL GROWTH AND/OR CON-VECTIONLESS SOLIDIFICATION
HIGH PURITY, DUCTILE TUNGSTEN X-RAY TARGETS	LEVITATION MELTING AND SUPERCOOLING
HIGH PURITY RADIOISOTOPES	PARTICLE MANIPULATION BY SMALL FORCES
LARGE, UNIFORM SILICON SINGLE CRYSTALS	LARGE CRYSTAL GROWTH AND/OR CON-VECTIONLESS SOLIDIFICATION
UNIFORM GARNET SINGLE CRYSTAL FILMS	CONVECTIONLESS EPITAXIAL CRYSTAL GROWTH
TRANSPARENT METAL OXIDES	LEVITATION MELTING AND UNIFORM SUPERCOOLING
HIGH SPECIFICITY ISOENZYMES	ELECTROPHORESIS (LARGE PORE GEL) OR ISOELECTRIC FOCUSSING

Figure 3.- Twelve ideas with high potential.

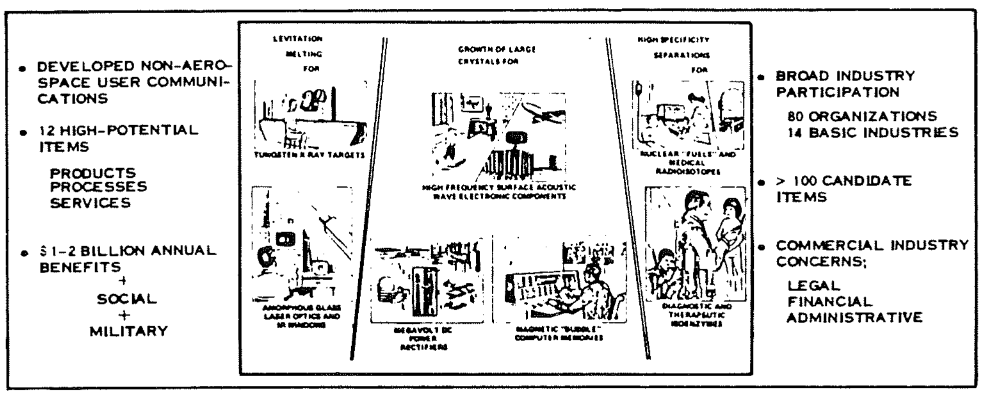


Figure 4.- Typical questions from phase I.

HOW WILL NASA HANDLE MY PROPRIETARY DATA (OR EQUIPMENT)?

WHAT RIGHTS WOULD NASA RETAIN ON MY DATA (OR PATENTS, OR PRODUCTS)?

WHO PAYS FOR SPACE EXPERIMENTS (OR TEST, OR EQUIPMENT) TO DEVELOP MY PRODUCT (OR PROCESS OR SERVICE)?

WHAT ROLE DOES NASA (OR GE) PLAY IN PROGRAM SUBSEQUENT TO B. U. S.?

WHAT IS THE PROBABILITY THAT THERE WILL BE A SHUTTLE (OR SPACE FACILITY)?

WHEN DO DECISIONS TO GO AHEAD NEED TO BE MADE?

HOW MUCH WILL IT COST TO RUN AN EXPERIMENT OR OBTAIN FACILITY SPACE?

Figure 5.- Products analyzed in phase II.

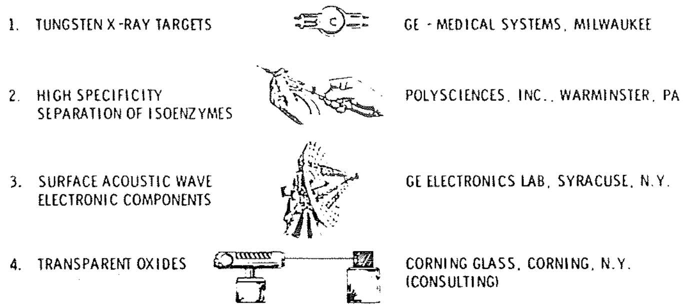
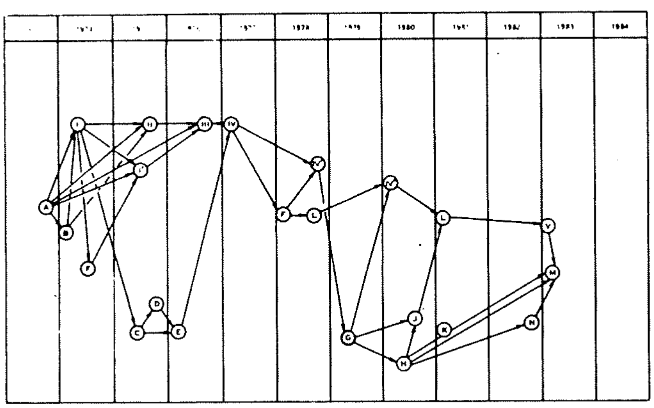


Figure 6.- Products analyzed in phase II.

FACILITY \ IDEA	SEPARATION OF ISOENZYMES	TRANSPARENT OXIDE PROCESSING	HIGH PURITY TUNGSTEN X-RAY TARGETS	FABRICATION OF SURFACE ACOUSTIC WAVE COMPONENTS	TOTAL
GROUND LAB	8	6	4	4	22
CENTRIFUGE	2	--	--	--	2
ENGINEERING TEST LAB	2	1	1	1	5
DROP TOWER	--	1	1	1	3
KC-135	3	1	1	3	8
SOUNDING ROCKET	--	2	3	2	7
SPACECRAFT	7	--	--	1	8
SHUTTLE SORTIE LAB	4	3	2	2	11
TOTAL	26	14	12	14	66

EACH NUMERICAL ENTRY REPRESENTS A SERIES OF TESTS RANGING FROM 1 TO 120 RUNS

Figure 7.- Amount of experiments or tests needed.



KEY	DECISION TO BE MADE	ALTERNATES	PROBABILITY	BEST ALTERNATIVE
A.	FUNDING FOR EXP. SERIES I-III	A. IN-HOUSE FUNDING B. NASA FUNDING	10 90	•(B)
B.	ASSIGNMENT OF PERSONNEL	A. REASSIGN AVAIL. PERSONNEL B. HIRE NEW PERSONNEL	30 70	•(B)
C.	FUNDING FOR EXP. SERIES IV	A. NO FUNDING B. IN-HOUSE FUNDING C. NASA FUNDING	10 10 80	•(C)
D.	NEW LAB SPACE	A. ADAPT EXISTING B. BUILD NEW, SEPARATE C. ADDITION TO PRESENT	20 10 70	•(C)
E.	HIRING OF PERSONNEL	A. HIRE NEW PERSONNEL B. SUBCONTRACT	30 70	•(B)

KEY	DECISION TO BE MADE	ALTERNATES	PROBABILITY	BEST ALTERNATIVE
F.	RESERVE FLIGHT OPPORTUNITY ON AUTOMATED SPACECRAFT	A. RESERVE B. CANNOT RESERVE	80 20	•(A)
G.	PATENT RIGHTS FOR EQUIPMENT OF EXP. SERIES IV	A. POLYSC. OWN OUTRIGHT B. NASA OWNS C. POLYSC. LICENSE	30 30 40	•(A)
H.	DEFINE OWNERSHIP FINANCES OF COMMERCIAL SPACE PRODUCTION	A. POLYSC. OWNS B. NASA OWNS C. LICENSE TO CONTRACTORS	10 50 40	•(A)
J.	FUNDING FOR DESIGN, FABRIC. AND TESTING OF EXP. SERIES V	A. IN-HOUSE FUNDING B. NASA FUNDING	10 90	•(B)
K.	MAKE/BUY FOR INITIAL BIOLOGICALS	A. POLYSC. PRODUCE B. POLYSC. SUBCONTRACTS FOR PRODUCTION C. POLYSC. BUY FROM ESTAB. SOURCE	10 80 10	•(B)
L.	RESERVE FL. ACCOMMODA-TION ON SHUTTLE	A. RESERVE B. CANNOT RESERVE	80 20	•(A)
M.	INITIATE COMMERCIAL SPACE PRODUCTION	A. IN-HOUSE B. SUBCONTRACT FOR PROCESSING	50 50	•(A)
I.	VALUE OF PHENOMENOLOGY RESULTS FROM TEST SERIES I	A. ALL SUPPORT SPACE PROCESSING B. SUFFICIENT SUPPORT C. INSUFFICIENT SUPPORT OF SPACE PROCESSING	20 70 10	•(B)
II.	EVALUATION OF SEPARATION CONCEPTS IN TEST SERIES II	A. LIKELY CANDIDATE INDICATED B. NOT INDICATED	80 20	•(A)
III.	EFFECTS OF NON-SPACE ENVIRONMENT IN TEST SERIES III	A. EFFECTS DETRIMENTAL B. NOT DETRIMENTAL	10 90	•(B)
IV.	EVALUATION OF PERFORMANCE OF PROCESSING EQUIPMENT IN TEST SERIES IV	A. ACCEPTABLE B. UNACCEPTABLE	70 30	•(A)
V.	PROOF OF PROCESS QUALITY, TIMING	A. SUFFICIENT FOR COMMERCIAL PROCESS B. INSUFFICIENT	80 20	•(A)
I'	VERIFICATION OF PHENOMENOLOGY IN SPACECRAFT TEST	A. VERIFIED B. NOT VERIFIED	80 20	•(A)
IV'	VERIFICATION OF SELECTED PROCESS EQUIPMENT DESIGN DATA IN ZERO "G" AIRCRAFT AND SHUTTLE FLIGHT	A. VERIFIED B. NOT VERIFIED	80 20	•(A)
IV"	VERIFICATION OF PROCESS EQUIPMENT PERFORMANCE IN SHUTTLE FLIGHT	A. VERIFIED B. NOT VERIFIED	90 10	•(A)

Figure 8.- Decision flow for isoenzymes.

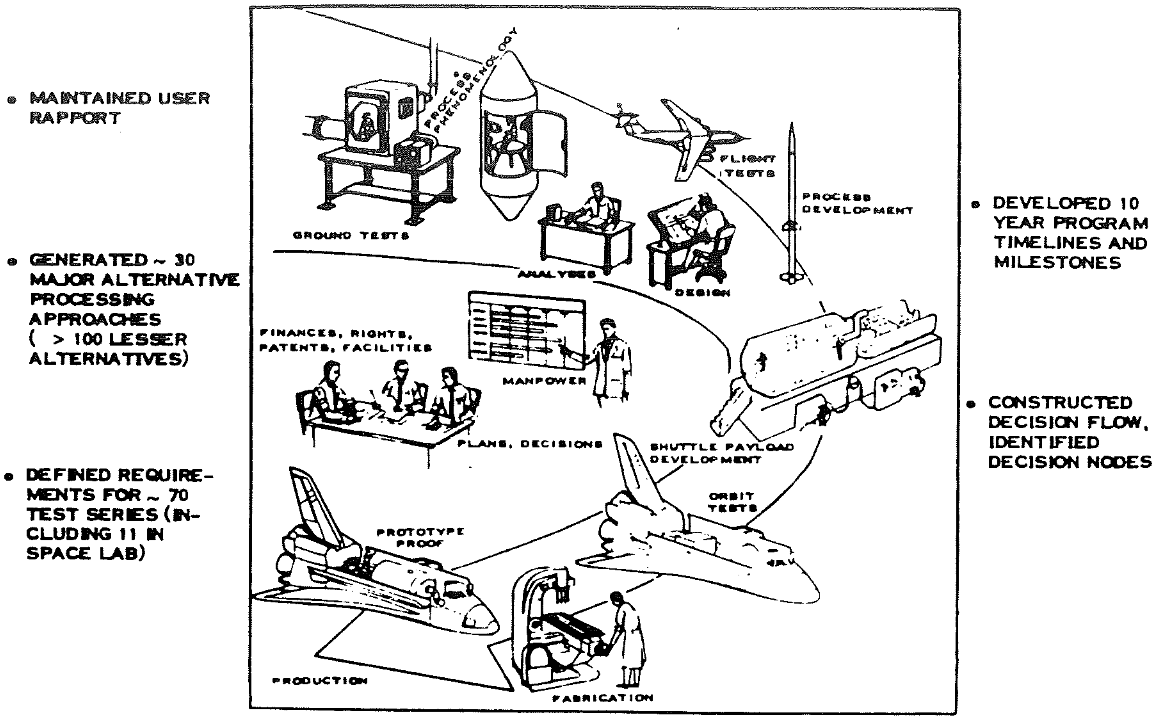


Figure 9.- Phase II results.

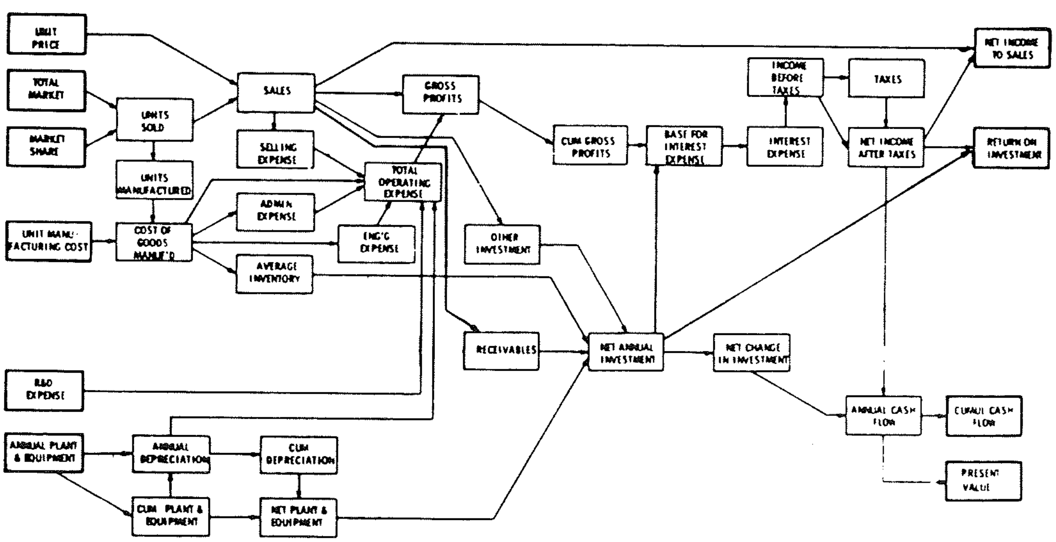


Figure 10.- Financial-analysis method for assessment of space processing opportunities.

Item	Space Development Required?	Quantity Required Initial (Ground Test)	Quantity Required Prototype	Quantity Required Pilot	Quantity Required Production
Analytical 12 Col. Electrophoresis Separator	Yes	1	–	–	–
Preparative 1-Col. Separator	Yes	1	1	1	2
Power Supply, Electrophoresis	Yes	1	1	1	2
Cooling Bath (Circulating) & Pump	Yes	1	1	1	2
Copying Camera	No	1	1	1	–
Storage Refrigerator	Yes	1	1	1	1
Deep Freeze	Yes	1	1	1	1
Freeze Drying Unit	Yes	1	1	1	–
Vacuum Pump	No	1	1	1	1
Circulating Hot Water Bath	Yes	1	1	1	1
Thermocouples & Meters	No	1 set	1	1	1
Gas Chromatograph	No	1	1	–	–
Centrifuge (Clinical)	No	1	–	–	–
Homogenizer	No	1	–	–	–
Microscope	No	1	–	–	–
UV Spectrophotometer	No	1	–	–	–
Fraction Collector	Yes	1	1	1	1

Figure 11.- Equipment list for isoenzyme separation.

SHUTTLE RESOURCE UTILIZED	RATES UTILIZED IN STUDY*
Up-Transport Volume	$13,760/cubic meter
Up-Transport Weight	$108.81/kg
On-Orbit Energy	$1721/KWH
On-Orbit Crew	$6446/Man Hr
On-Orbit Data Transmission	$4286/MHz of RF Bandwidth
On-Orbit Data Processing	$2.36/word of Experiment Computer Storage
Down-Transport Weight	$184.44/kg.
Ground Operations, Mechanical Handling	$1,276/cubic meter
Ground Operations, Electronic Handling	$20.89/word of Experiment Computer Storage

*Based on C_M, Average per-mission Operational Cost = $\$10.7 \times 10^6$.

Figure 12.- Recommended user cost allocation rates for Shuttle/Spacelab.

	CASE A	CASE B
% NI/S (1992)	21%	21%
% ROI (1992)	71%	73%
PRESENT VALUE	$11M	$17M
USER R&D COST	$3.8M	$1.4M
NASA R&D COST	–	$2.4M
BREAKEVEN POINT	11 YRS	7 YRS

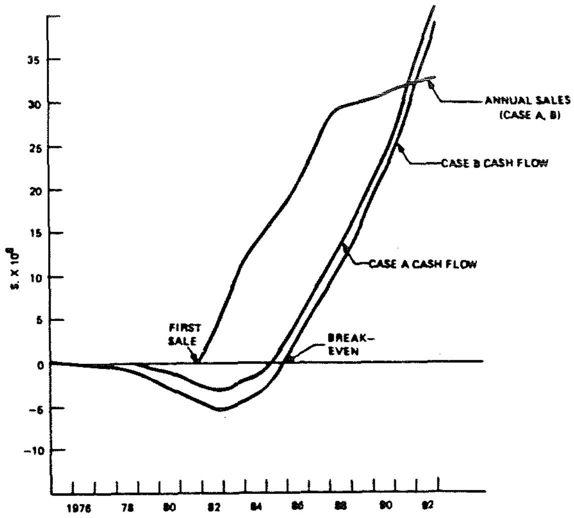
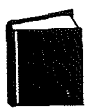


Figure 13.- Isoenzymes cash flow.



- DETAILED DEVELOPMENT PLANS FOR SPACE PROCESSED TUNGSTEN, ISOENZYMES, SURFACE ACOUSTIC WAVE DEVICES, & TRANSPARENT OXIDES

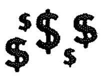
  R&D PROGRAM 1975 TO 1983
  GROUND BASED EXPERIMENTS AND TESTS 1975 TO 1979
  SHUTTLE-BASED EXPERIMENTS AND TESTS 1980 TO 1983

- PRELIMINARY MARKET FORECASTS FOR THE FOUR PRODUCTS

  TUNGSTEN TARGETS TO 31,200 TARGETS IN 1986; – 40,000 IN 1888
  ISOENZYME KITS TO 1,200,000/PER YEAR IN 1985; – 5,000,000 IN 1992
  SURFACE ACOUSTIC WAVE BANDPASS FILTERS TO 250,000 PER YEAR IN 1992
  TRANSPARENT OXIDE OPTICAL ELEMENTS TO 5,000 PER YEAR IN 1985

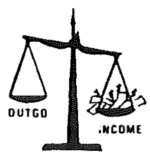
- RESOURCE REQUIREMENTS – GROUND AND SPACE

  ELECTRICAL POWER: R&D, 85-600 KW HRS PER FLIGHT; PRODUCTION, 2,300 TO 68,000 KW HRS/YR
  SHUTTLE FLIGHTS: R&D 18; PRODUCTION 23/YR
  GROUND FACILITIES: THREE EXPANDED, ONE NEW FACILITY (ISOENZYMES)
  SPACE FACILITIES (PRODUCTION): 16 SPACE PROCESSORS



- COST ANALYSIS

  R&D: TUNGSTEN – $9,000,000
  ISOENZYMES – $4,000,000
  TRANSPARENT OXIDES – $18,000,000
  S.A.W. – $15,000,000



- PROFITABILITY ANALYSIS

  ISOENZYMES; RELATIVELY ATTRACTIVE, BREAK EVEN AT 7 YEARS
  TUNGSTEN; RELATIVELY UNATTRACTIVE AT 9 YEAR BREAK EVEN. UNIT COST AND R&D COSTS ARE CURRENT PROBLEM
  S.A.W.; RELATIVELY UNATTRACTIVE AT 13 YEAR BREAK EVEN. MARKET SIZE, R&D COSTS, ARE CURRENT PROBLEM
  TRANSPARENT OXIDES; UNATTRACTIVE AT 9 YEAR BREAK EVEN. R&D COSTS, MARKET SIZE, ARE CURRENT PROBLEM

Figure 14.- Phase III results.

- A NON-AEROSPACE COMMUNITY WITH ACTIVE INTEREST IN SPACE PROCESSING EXISTS (80 PARTICIPANTS > 100 IDEAS)
- POTENTIALLY BENEFICIAL SPACE PRODUCTS, PROCESSES, SERVICES HAVE BEEN IDENTIFIED (> 12 IDEAS, VALUE ~ $2 X 10^9^)
- THE DIALOG METHOD OF ELICITING POTENTIAL USER RESPONSE, WORKS (SPECIFICS MAKE THE DIFFERENCE)
- THE COMMERCIAL SECTOR OF INDUSTRY IS AS MUCH CONCERNED WITH LEGAL/ADMINISTRATIVE/ FINANCIAL PROBLEMS OF SPACE PROCESSING AS WITH TECHNICAL
- "IDENTIFICATION" INCLUDES FINDING THE REAL PROBLEM, REAL KEY INDIVIDUAL, REAL APPLICATION
- LIKE LIVING THINGS, COMMERCIAL SPACE PROCESSING IDEAS NEED GESTATION PERIOD
- NON-AEROSPACE USER COMMUNITY NEEDS DIRECTED SPACE PROCESSING INPUTS

Figure 15.- Lessons learned in phase I.

- IN MOVING FROM IDEAS TO CONCEPTUAL APPROACHES, USER RESPONSE STRENGTHENS (30 MAJOR ALTERNATIVE APPROACHES EVALUATED)
- PROJECTING TECHNOLOGY FOR ~ 1980 AND BEYOND IS SHAKY; JUDGEMENT AND "FEEL" VARY

  ∴ USER RESPONSES ARE QUALIFIED, EXPERIMENTS AND TESTS PROLIFERATE, ETC. (E. G. 66 TEST SERIES)
- NON-AEROSPACE USERS NEED EDUCATION AND EXPOSURE TO LOW-COST EXPERIMENT AND TEST METHODS
- 10 YEAR R&D PROGRAM IS "COMFORTABLE" (HINDSIGHT: MAYBE TOO COMFORTABLE?)
- USERS SEEKING EARLIEST INDICATIONS OF PROCESS FEASIBILITY (E. G. REQUIRED GROUND TESTS HEAVY IN '74)
- PROGRAM DECISION DATA (USER AND NASA) ARE INCOMPLETE (E.G., TECHNOLOGY GAPS, TEST OPPORTUNITIES, ETC.)
- LEGAL/FINANCIAL ISSUES ARE MAJOR NODES IN DECISION FLOWS

Figure 16.- Lessons learned in phase II.

- ONE-ON-ONE DIALOGS REMAIN THE WAY TO ACQUIRE SPECIFIC USER DATA
- DEVELOPMENT PLANS, R&D NEEDS, PRODUCTION ANALYSES REQUIRE INTIMATE BLENDING OF COMMERCIAL AND AEROSPACE METHODS – SOME COMPROMISES IN EACH.
- COMMERCIAL USERS CONSIDERATION OF NEW VENTURES IS PRIMARILY INFLUENCED BY ECONOMIC CONSIDERATIONS.
- KEY PROBLEMS IN 1.) ACQUIRING CONSTITUENCY OF USERS,
  2.) POLICY ON USER CHARGES
  - SPACE FACILITY IS ONLY ONE R&D ALTERNATIVE (E.G. TUNGSTEN HAS 18 OTHER PATHS
  - A (PROMISED) BETTER MOUSE TRAP IS NOT SUFFICIENT. IT MUST FIT USER'S ECONOMICS.
  - A BETTER MOUSE TRAP MUST BE SOLD.
  - POLICY MUST NOT DISCRIMINATE AGAINST SMALL ENTREPRENEUR.
- MARKET FORECAST IS MAJOR INFLUENCE ON PROFITABILITY (MARKET SIZE, SHARE, UNITS SOLD, UNIT PRICE, LIFE CYCLE ARE AFFECTED). MORE INTENSE EFFORT REQUIRED HERE.
- SPACE POWER COSTS IS MAJOR INFLUENCE ON UNIT COST. DEVELOPMENT OF LARGE SOLAR CONCENTRATOR FOR HEATING WOULD BE MAJOR BENEFIT.
- 7-30 DAY SHUTTLE/SPACELAB AS COMMERCIAL PROCESSING PLANT LIMITS PROFITABLE PRODUCTS. LONG TERM, IN-ORBIT, AUTOMATED, INTERMITTENTLY MANNED FACILITY IS ANSWER. SHUTTLE FUNCTION IS MAINLY TRANSPORT OF RAW MATERIALS UP, FINISHED PRODUCTS DOWN, ALSO INSTALLATION, MAINTENANCE, REPAIR.
- THE FOUR PRODUCTS STUDIED CALL FOR MINIMUM OF 18 FLIGHTS FOR R&D, 23 FLIGHTS/YR FOR PRODUCTION.
- BASED ON FOUR PRODUCTS SMALL LOW POWER, SPACE-PRODUCED MATERIAL WITH HIGH MULTIPLIER FOR GROUND FINISHING AND HIGH $/LB PRICE IS BEST BET (E.G. ISOENZYMES). NASA SUPPORT OF PROGRAM TO FEASIBILITY STAGE, SHARING R&D COSTS AMONG MANY USERS, LOW COST POWER CAN ADD OTHER BETS (E.G. TUNGSTEN).

Figure 17.- Lessons learned in phase III.