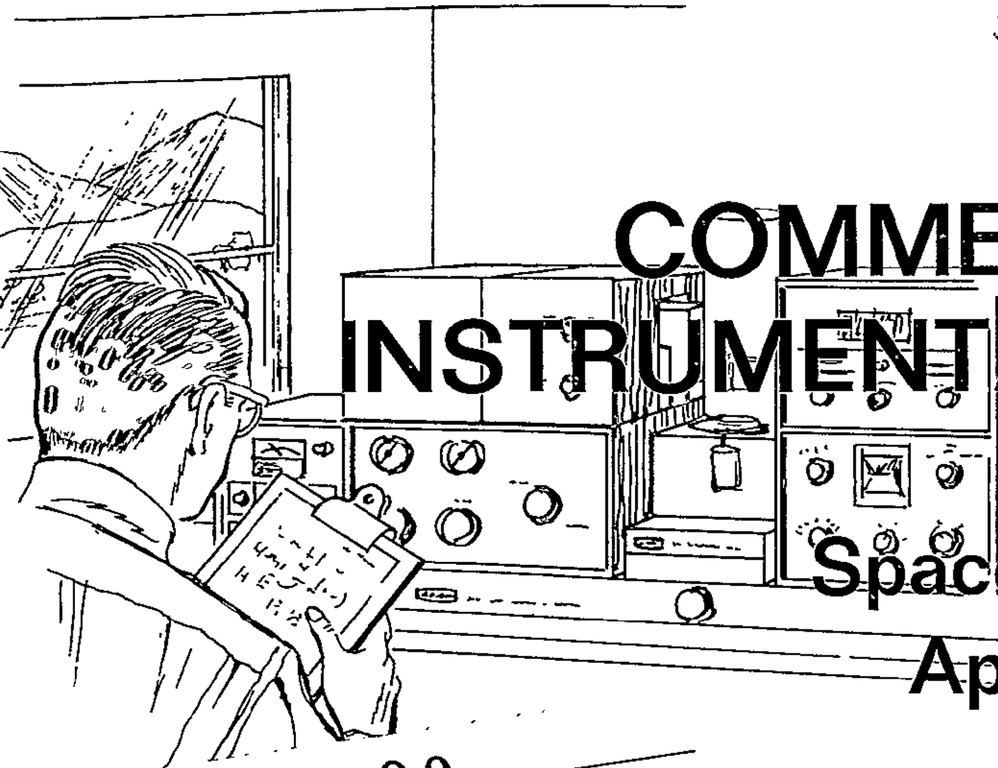
FR-1065-101

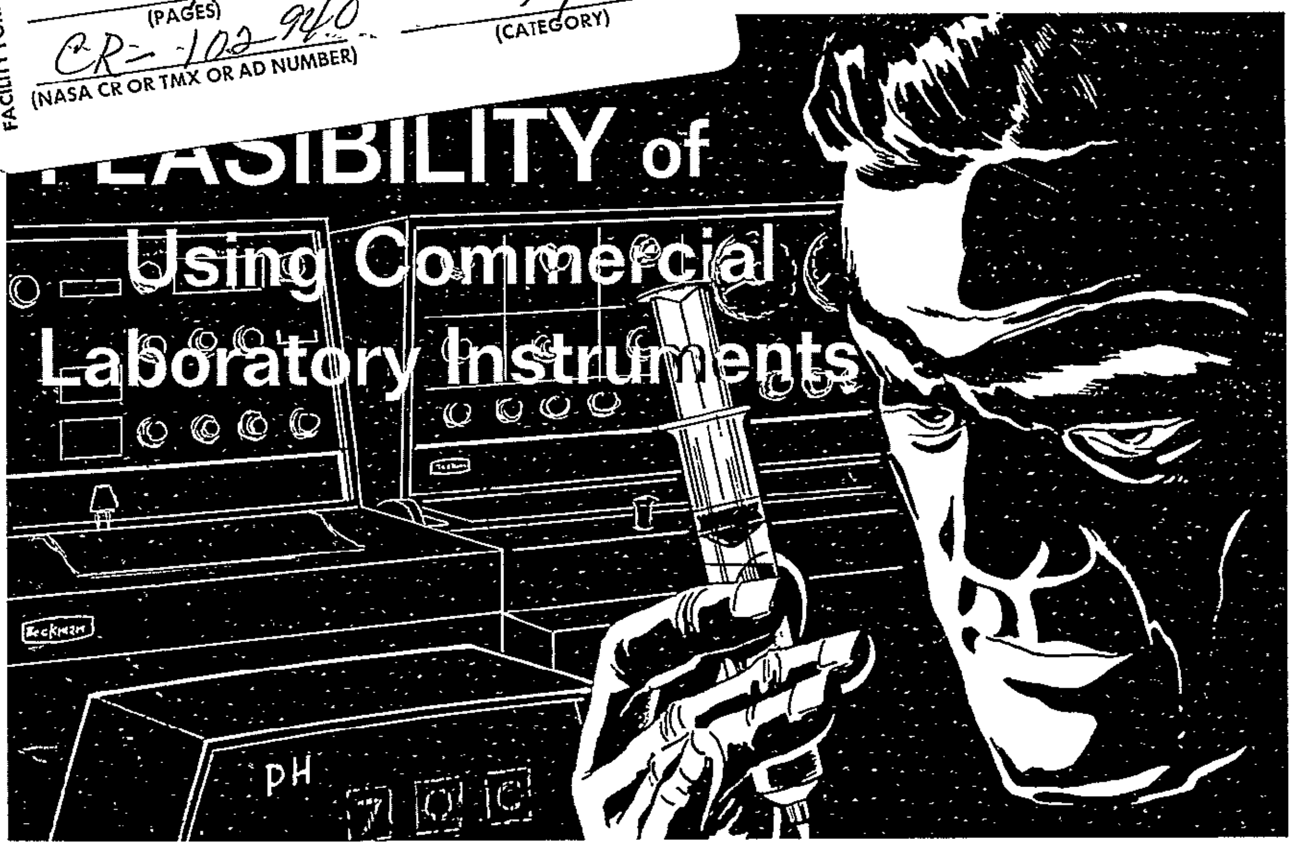
FINAL REPORT

COMMERCIAL INSTRUMENTATION for Space Station Application



October 31, 1970

Contract No. NAS8-26119



FEASIBILITY of Using Commercial Laboratory Instruments

Prepared for:
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER

Beckman® INSTRUMENTS, INC

ADVANCED TECHNOLOGY OPERATIONS
FULLERTON, CALIFORNIA • 92634

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VOLUME 1

FEASIBILITY of Using Commercial Laboratory Instruments

ALLEN C. NORTON, Ph.D.

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ABSTRACT

This report presents the results of a survey of commercial laboratory instruments with respect to possible application of standard scientific instruments in the Space Station laboratories. Twenty-four instrument categories, e.g., spectrophotometers, electronic test equipment, etc., were reviewed in detail with respect to principles of operation, applications, logistics, installation, operation, interface, safety, and modifications needed. A flyability index was developed, and all categories and subcategories of instruments surveyed in detail were rated on 17 dimensions relating to safety, application, logistics, performance, and operation.

The handling of liquid and particulate samples was identified as a major problem for zero-gravity laboratory operation. Several sample-handling devices and techniques were discussed.

It was concluded that it is both feasible and desirable to use commercial instruments in the Space Station laboratories. Modifications are needed on most instruments to circumvent gravity-dependent functions and to improve safety. Final determinations of instrument types required should not be made until actual experiments are committed for flight. To allow review of newly developed instruments, selection of specific instruments should not be made until a later stage of flight preparation. The possibility of making last-minute instrument changes is one of the advantages of using commercial instruments and supports the philosophy of the Space Station program for providing laboratory facilities rather than dictating an experiment program.

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Section 1
INTRODUCTION

The use of off-the-shelf commercial instruments in a space-flight environment is nearly a complete departure from past and present philosophy in the U.S. space program. A switch to commercial, earth-based standards would seem unjustified by viewing the historical development of criteria for high reliability and safety in a hostile environment. While commercial equipment is becoming safer and more reliable, however, space is becoming less hostile. Indeed, the increasing safety and reliability of present commercial instruments is largely attributable to contributions from the space program.

The use of commercial instrumentation is feasible because of four features of the Space Station program. First, commercial instrumentation is being considered only for support of the experimental programs. Failure or malfunction of experimental equipment, while perhaps inconvenient, will not be mission-critical. Second, the vehicle systems will provide shirt-sleeve environment laboratories. Adequate electric power, a recycling EC/LS system, and a two-gas, 14.7 psi atmosphere contribute significantly to the use of standard laboratory equipment. Third, the use of a space shuttle allows for instrument maintenance and supply, trading of one instrument for another if an instrument fails or as needs change. The shuttle also provides a reduction of launch stresses, in comparison to current booster vehicles. Fourth, the presence of repair equipment and trained personnel makes possible on-board assembly, calibration, preventive maintenance, and repair. An instrument need not be shipped in its operating configuration, and when in use its function can be monitored and adjusted by trained scientists.

The use of commercial instrumentation is desirable for three reasons. First, the cost of commercial instruments is approximately two orders of magnitude less than that of comparable space-qualified instruments. The quantity and diversity of instrumentation required to support the Space Station experimental program contribute significantly to its total cost; similarly, the savings can be significant. Second, the flexibility of the experimental program is greatly increased by the use of commercial instrumentation. In contrast to the year or more of development time needed for space-qualified instruments, off-the-shelf commercial instruments can be delivered in a few days and, if needed, can be modified for space use in a few months. As long as suitable commercial instruments are available, changes in instrumentation needs can be implemented with the next shuttle trip. Thus, the Space Station experiment program need be no more instrument-dependent than earth-based programs. Third, the scientist's familiarity with commercial instruments allows him to transfer his existing laboratory skills and scientific expertise into the Space Station. This contrasts with the need for extensive testing, debugging, and operator familiarization with a newly developed space-qualified instrument. This report discusses the needs of the Space Station for laboratory instrumentation to support the experiment programs and the availability of commercial instruments to fulfill those needs. The unique environment of the Space Station laboratories contributes, on one hand, to the possibility of using commercial instruments, and on the other, to the difficulties of actually using these instruments.

Section 2
CURRENT SURVEY

2.1 ASSUMPTIONS OF THIS SURVEY

The present survey considers the use of commercial instruments for equipping the experimental laboratories of the Space Station. Only major items of equipment to be used solely for experimental purposes have been included, although the additional application of a few instruments for environmental monitoring has been noted. The candidate experiments of the Blue Book* have served as a point of departure for identification of specific equipment needs. This survey is not limited, however, to the specific needs indicated in the Blue Book. The guiding principle throughout has been to consider the needs of a scientist coming to the Space Station to perform a group of experiments of which he is in charge (or is, perhaps, the colleague or student of the scientist in charge). He would expect a laboratory equipped with familiar instruments. Instruments unique to his experiments might be available from earth-based storage or specially purchased for the experiment. The use of commercially available equipment is essential to this flexibility of laboratory instrumentation.

Several categories of laboratories were excluded from this study. Mission-critical vehicle systems (communications, navigation, life support) were

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* (See Appendix A). NHB7150.XX (Draft). Candidate Experiment Program for Manned Space Station, September 1969, updated June 1970.

excluded because of the greater need for reliability in these areas. Other categories which were excluded and the reason for exclusion are shown in Table 2-1. Since the instruments surveyed in depth (see Volume 2) form a representative cross section of useful instruments rather than an exhaustive list of instruments possibly needed, many instruments have been excluded on an arbitrary basis. Thus, instruments such as calorimeters, magnetometers, microwave spectrometers, viscometers, and many others are not included.

EQUIPMENT CATEGORIES	REASON FOR EXCLUSION
Astronomy Equipment	Special-order equipment needed for most applications.
Cameras (Film and Video)	Current space-program experience exceeds contribution which could be made by this survey.
Temperature Control (Cryogenic, Freezer, Refrigeration, Water Bath, Dryer, Oven, Furnace)	Highly dependent on support from vehicle systems; interface study needed.
Mass Determination	Special engineering project needed.
Film Processing	Special engineering project needed.
Laboratory Supplies	Special planning study needed.
Mixing and Stirring Devices	Special engineering project needed.
Calculators	Not needed with on-board information management system.
Laboratory Environment Monitor	Special engineering project needed.
Experimental Animal Handling Equipment	Special engineering project needed.

Table 2-1. Equipment Categories Excluded from Study

The availability of a space shuttle has been assumed in considering transport and support of the instruments considered in this survey. The shuttle should provide reduced acceleration and vibration stresses for transport of equipment to the Space Station. A further assumption is that the shuttle will provide a pressurized, but not necessarily breathable, cargo compartment.

Particularly helpful in this respect was the availability of preliminary drafts of the McDonnell Douglas Phase-B (Space Station Definition) reports.

2.2 HOW THIS SURVEY WAS PREPARED

The first three stages of the survey were undertaken concurrently. One was a review of NASA documentation relevant to the Space Station and the needs of the experimental program. (Appendix A lists the documents consulted). Second were informal discussions with laboratory scientists with respect to their instrumentation requirements if they were to pursue their research interests in a remote laboratory such as the Space Station. These were generally casual contacts, rather than formal interviews, with friends and former colleagues. A particularly relevant discussion was with Dr. Walter Garey (University of California, San Diego) concerning instrumentation used on board the *Alpha Helix*, the University of California research ship. Third was a review of literature relevant to available commercial instrumentation. The documents reviewed in this category are listed in Appendix B.

These three lines of effort led to selection of a list of instrument categories which would be considered in this survey (see Table 2-2). The list of instruments was divided into those types manufactured by Beckman Instruments, Inc., and

Audiometers	Infrared Analyzers
Atomic Absorption Spectrophotometer	Mass Spectrometers
Blood Gas Analyzers	Microscopes
Cell Counters	Microtomes
Centrifuges	Optical Test Equipment
Electronic Hematocrit	Osmometers
Electronic Test Equipment (Portable)	Oxygen Analyzers
Electrophysiological Equipment	Radiation Counters
Emission Spectrometer	Radiometers
Flame Photometer	Recorders
Gas Chromatographs	Specific Ion Electrodes
	Spectrophotometers
	X-ray Spectrometers

Table 2-2. Instrument List

those types not. A mailing was prepared to manufacturers of types of instruments not manufactured by Beckman. Appendix C contains an example of the letter which was mailed, a list of the companies to whom inquiry was made, and a few of the more interesting replies to the mailing. The response to our mailing was generally enthusiastic.

For types of instruments manufactured by Beckman, it was considered that competitive companies would be reluctant to provide us with technical information. Thus, for competitive instruments, most of the information for this survey was obtained from files maintained by Beckman's manufacturing and sales divisions.

The next stage of the survey was preparation of the individual instrument reports. These reports were written by a group of scientists within the Advanced Technology Operations of Beckman Instruments, Inc., (a list of contributors appears in Appendix D). All the reports were written to approximately the same format, so that individual instruments can be compared with each other on each of the various categories considered. These individual reports appear in Volume 2, Sections 1 through 25. Section 25 considers sample-handling devices appropriate for a zero-g application. Volume 1, Section 3, summarizes the detailed findings.

An additional stage in this process of information condensation appears in the numerical ratings of the individual instruments. Seventeen dimensions* for evaluation were established--versatility, sampling simplicity, power, etc. A weighting factor was assigned to each rating category as an attempt to account for the relative importance of each. (For example, Safety was weighted 1.0 while Supplies Needed was weighted 0.4). Then each instrument (subtypes were considered where appropriate) was rated on a scale 1 through 5 on each rating category. The sum of the weighted ratings was taken as an index of flyability of the individual instruments. A particular need for an instrument with a low index, however, may completely outweigh the low index rating. The acceptance or rejection of any instrument should include consideration for the need of that instrument in a specific experiment. Also, these instruments have been rated on the basis of general types of instruments commercially available at the time of writing, October 1970. Improved instruments will undoubtedly become available before Space Station hardware must be purchased. The rating method developed herein should provide a basis for the evaluation of instruments being considered for Space Station application.

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* See complete list and definition of terms in Table 4-1.

Perhaps to the dismay of many in the aerospace industry, the present study avoids consideration of military specifications containing standards of safety, reliability, performance, etc. This approach was adopted to emphasize the differences between "space qualified" hardware and commercial instruments and to point out the similarities between the instrument needs of the Space Station laboratories and available commercial instruments.

The awarding of this contract No. NAS8-26119 to prepare a survey and report on commercial laboratory instrumentation confirms the leadership that Beckman has in the field of development and manufacture of scientific instruments. There exists within the corporation a high level of expertise in nearly all areas of scientific instrumentation. The commercial divisions of Beckman manufacture and sell a large variety of scientific, process, electronic, and clinical instruments. The Advanced Technology Operations has had extensive experience in the development and manufacture of custom instrumentation for application in the fields of aerospace, environmental pollution, medicine, bioscience, oceanology, physical and behavioral sciences.

Section 3
COMMERCIAL LABORATORY INSTRUMENTS

3.1 PRINCIPLES OF OPERATION

The operating principle of each type of instrument considered in the survey of the present study is summarized as follows: (Additional details are available in Volume 2.)

Audiometers. Present auditory stimuli to human subjects; vary frequency and intensity to determine absolute threshold at several different frequencies.

Atomic Absorption Spectrophotometer. Determines presence of metallic elements nebulized in a flame by light of specific wavelength absorbed by flame; consists of monochromatic light source (element specific), flame, and monochromator with photomultiplier tube.

Blood Gas Analyzers. Detect dissolved oxygen by current developed as oxygen is reduced at the cathode of a polarographic electrode. Carbon dioxide detects pH change resulting from dissolved CO_2.

Cell Counters. Optical type detects light pulse caused by cell in sample chamber passing a light beam and interrupting it. Impedance type detects change in electrical impedance as cells pass a sensing element. Computer type scans vidicon image and detects cells with image-analysis programs. Firefly type detects light flash of firefly enzymes which occurs in presence of ATP (ATP in a bacteria produces a flash which is counted). Manual type marks colony on culture plate and counts the number or marks made.

Centrifuges. Spins liquid sample to separate components of the sample by centrifugal forces; analytical ultracentrifuges analyze optical changes in sample during the course of centrifugation.

Electronic Hematocrit. Measures the electrical impedance of blood in a thin tube to determine the relative volume of red blood cells in the blood.

Electronic Test Equipment. Oscilloscope displays voltage signal against time on a CRT. Function generator produces periodic electric signals of known shape, frequency, and amplitudes. Multimeter measures voltage, current, or resistance in electrical circuits.

Electrophysiological Equipment. Biopotential devices measure voltage signals from living organisms. Bioimpedance devices measure changes in the electrical impedance of tissue segments resulting from the flow of fluids of different resistivities and reactativities through the segment. Transducer couplers convert mechanical (or other) physiological phenomena into electrical signals for recording. Electrophysiological recordings of all three types are displayed with respect to time.

Emission Spectrometer. Vaporizes a sample in an electric arc and then analyzes the spectral output of the light produced with prism (or grating) and photographic plate.

Flame Photometer. Burn liquid sample in gas flame and then analyze light output at specific wavelengths to determine ionic content.

Gas Chromatographs. Separates chemical compounds by rate at which they pass through a column packed with materials which differentially absorb and release different chemical compounds; samples vaporized and passed through the column with a carrier gas.

Infrared Analyzers. Detect concentration of a specific gas in a gas mixture on the basis of the infrared radiation absorbed; method is made specific by charging comparison cell with the gas for which an analysis is wanted.

Mass Spectrometers. Detect presence of charged particles of different masses by physical separation of the charged particles according to their mass by the action of a magnetic or electric field. (Several different types are discussed in Volume 2, Section 13).

Microscopes. Optical magnification of small specimen for visual observation or photographic recording; selection of illumination and viewing conditions can allow visualization of phase, interference, polarization, or fluorescence.

Microtomes. Sharp knife for cutting thin sections for microscopic observation.

Optical Test Equipment. Optical and mechanical devices for holding, moving, illuminating, viewing, adjusting, and recording the performance of optical elements and components.

Osmometers. Detect changes in freezing point (cryoscopic osmometer), vapor pressure (vapor-pressure osmometer), or osmotic pressure (membrane osmometer) of a solution resulting from the dissolved particles in solution.

Oxygen Analyzers. Detect current resulting from reduction of oxygen at cathode of polarographic electrodes (other oxygen analyzers are discussed in Volume 2, Section 18, but these are markedly inferior to the polarographic method for space application).

Radiation Counters. Liquid scintillation counters use photomultiplier tubes to detect light flashes resulting from the scintillation of a phosphor preparation when a beta particle passes through it; gamma counters use a scintillating crystal to produce light pulses from gamma rays; planchet counters detect the ionization of gas between charged electrodes which occur as particles pass through it.

Radiometers. Measure radiant energy of light or radiation sources as a total of energy over wide spectral bands (pyrheliometer) or the radiant energy in narrow spectral bands (spectroradiometer).

Recorders. Convert a time-varying voltage or current signal to an ink line drawn on paper (strip-chart recorder) or an analog or digital magnetic signal on magnetic tape (tape recorder).

Specific Ion Electrodes. Measure ionic concentration by current flow produced by selective ion exchange.

Spectrophotometers. Measure the absorption or transmission of light (IR, visible, or UV) through the sample at specific wavelengths; spectrophotometers generally scan successive wavelengths while the simpler colorimeters measure intensity at one or a few specified wavelengths.

X-Ray Spectrometers. Analyzes solid samples by their reflection or refraction of a beam of X-rays; the detector is typically a crystal sensitive to the directional orientation of the X-rays.

3.2 APPLICATIONS

The "blue book" (candidate experiment program for manned space stations--see Appendix A) serves as the point of departure for considering the types but not necessarily the specific experiments to be pursued in the Space Station program. Those functional program elements (FPE's) which could be most heavily supported by standard laboratory instruments include:

- 5.3A Solar Astronomy
- 5.9 Small Vertebrates (Bio D)
- 5.10 Plant Specimens (Bio E)
- 5.11 Earth Surveys
- 5.13 Man/System Integration
- 5.17 Contamination Measurements
- 5.18 Exposure Experiments
- 5.20 Fluid Physics in Microgravity
- 5.22 Component Test and Sensor Calibration
- 5.23 Primates (Bio A)
- 5.25 Microbiology (Bio C)
- 5.26 Invertebrates (Bio F)
- 5.27 Physics and Chemistry Laboratory

Table 3-1 presents an application matrix for the instruments considered in Volume 2 with respect to FPE's. Other FPE's or Space Station uses have not

FUNCTIONAL PROGRAM ELEMENTS (FPE's)	1.0 Audiometers	2.0 Atomic Absorption Spectrophotometer	3.0 Blood Gas Analyzers	4.0 Cell Counters	5.0 Centrifuges	6.0 Electronic Hematocrit	7.0 Electronic Test Equipment	8.0 Electrophysiological Equipment	9.0 Emission Spectrometer	10.0 Flame Photometers	11.0 Gas Chromatographs	12.0 Infrared Analyzers	13.0 Mass Spectrometers	14.0 Microscopes	15.0 Microtomes	16.0 Optical Test Equipment	17.0 Osmometers	18.0 Oxygen Analyzers	19.0 Radiation Detector/Counters	20.0 Radiometers	21.0 Recorders	22.0 Specific Ion Electrodes	23.0 Spectrophotometers	24.0 X-Ray Spectrometers
5.3A Solar Astronomy																X				X				
5.9 Small Vertebrates (Bio D)		X	X	X	X	X	X	X		X	X	X	X	X	X		X	X	X		X	X	X	
5.10 Plant Specimens (Bio E)		X			X				X	X	X	X	X	X	X		X	X	X			X	X	X
5.11 Earth Surveys																X				X	X			
5.13 Biomedical and Behavioral Research	X	X	X	X	X	X	X	X		X	X	X	X	X			X	X	X		X	X	X	
5.14 Man/System Integration	X						X	X			X	X	X			X		X			X			
5.17 Contamination Measurements		X			X				X		X	X	X	X				X	X			X	X	X
5.18 Exposure Experiments		X							X		X		X	X		X			X				X	X
5.20 Fluid Physics in Microgravity					X									X		X					X	X		
5.22 Component Test and Sensor Calibration							X				X	X		X		X					X	X	X	
5.23 Primates (Bio A)		X	X	X	X	X	X	X		X	X	X	X	X	X		X	X	X		X	X	X	
5.25 Microbiology (Bio C)		X		X	X					X	X			X			X		X			X	X	
5.26 Invertebrates (Bio F)		X		X	X						X	X		X	X		X	X		X		X	X	X
5.27 Physics and Chemistry Laboratory		X			X		X		X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
General Purpose Laboratory		X			X		X		X		X		X								X			X
Optics Test Facility														X		X					X		X	
Bioscience Laboratory	X		X	X	X	X		X		X	X		X	X	X			X	X		X	X	X	

Table 3-1. Instrument Application Matrix

been excluded as applications of these or other commercial instruments. Indeed, the flexibility of using commercial instruments supports the philosophy intended for the Space Station program.

The specific applications of the instruments surveyed in Volume 2 are summarized below:

Audiometers. Measurement of auditory thresholds.

Atomic Absorption Spectrophotometer. Measurement of presence and concentration of metallic (and some nonmetallic) elements.

Blood Gas Analyzers. Measurement of partial pressure of oxygen and carbon dioxide in blood.

Centrifuges:

General Purpose Centrifuge. Separation of solid components in liquid samples (red blood cells from blood plasma, for example.)

Preparative Ultracentrifuges. Separation of components in liquid sample on the basis of sedimentation coefficients, diffusion coefficients, molecular weights, etc.

Analytical Ultracentrifuge. Determination of sedimentation coefficients, diffusion coefficients, molecular weights.

Cell Counters. Counting the number (concentration) of blood cells, bacteria colonies, or other particles.

Electronic Hematocrit. Determination of the hematocrit, the percentage (volume) of red blood cells in whole blood.

Electronic Test Equipment. Service, test, and calibrate electronic instruments and components.

Electrophysiological Equipment. Record physiological activity or correlates of physiological activity from living subjects in response to experimental or environmental stimulus conditions.

Emission Spectrometer. Rapid (but destructive) determination of presence and concentration of metallic elements in solid sample.

Flame Photometer. Determination of concentration of sodium, potassium, and calcium in blood and urine; can be used for other elements and other fluid samples.

Gas Chromatographs. Separation of mixtures of compounds for identification, quantification, and further analysis.

Infrared Analyzers (Nondispersive). Continuous determination of concentration of IR absorbing gases in gas mixtures.

Mass Spectrometers. Analysis of constituents of gas mixtures.

Microscopes. Examination of small specimens.

Microtomes. Cutting sample into thin slices for microscopic examination.

Optical Test Equipment. Service, test, and calibrate optical instruments and optical parts of instruments.

Osmometers. Determination of osmolality (concentration of dissolved particles) of solutions.

Oxygen Analyzers. Determination of partial pressure of oxygen in a gas mixture.

Radiation Counters. Determination of concentration of radioactive isotopes (often used as tracers) in sample.

Radiometers. Determination of total (or selected spectra) of radiant energy in infrared (IR), visible, and ultraviolet (UV) regions.

Recorders. Recording and storage of analog and digital electrical signals; usually the output of other instruments.

Specific Ion Electrodes. Determination of the concentration of ions (specific to the electrode in use) in solution.

Spectrophotometers. Analysis of organic and inorganic compounds in liquid and gas samples.

X-Ray Spectrometers. Determination (nondestructive) of the presence and concentration of metallic elements in solid samples; determination of molecular structure.

3.3 LOGISTICS

3.3.1 Packing and Installation

The use of commercial instruments for the Space Station experiment program is dependent upon the space shuttle for transport to the station. The vibration and acceleration of the shuttle launch should be greatly reduced, in comparison to a Saturn/Apollo launch, and should be generally consistent with current shipping procedures for scientific instruments. Instruments need not be shipped in their operating configuration but may be disassembled and repacked for maximum protection during shipping. Precision instruments are typically packed for railroad shipment in wooden crates with blocking of critical components and separate packing of delicate parts. Newer techniques involve molded foam shipping containers. Tie-down and perhaps even shock mounting of the packaged instruments will be required in transit. Particularly heavy parts, such as the lead shielding of radiation detectors, requires tie-down to protect nearby items. The radioactive standard for the radiation counters will require shielding during shipping.

The exact nature of the packing materials is not critical to the problem of transport. However, the advantages of useable packing materials should be considered. If reuseable packing material is not feasible, attention should be given to disposal.

Commercial instrument manufacturers typically test their packaged products to meet the standards of the National Safe Transit Committee (NSTC). The packaged product is tested to withstand stresses of a vibration test, a drop test, and an incline impact test as outlined in the National Safe Transit Committee Program document Pre-shipment Test Procedures, January 1968.

Few, if any, instruments are appropriate for shipping in their operating configuration. After unpacking, they must be reassembled for use. With some instruments it may be appropriate to pack the needed tools with the instrument. Calibration and alignment may be needed on some instruments. Manuals will be needed to facilitate assembly and installation of instruments in the Space Station.

3.3.2 Consumable Supplies, Accessories, and Spare Parts

The needs for consumable supplies for laboratory instruments are diverse and, on the whole, specific to each instrument. Typical consumable supplies are gases, reagents, calibration standards, chart paper, etc. There is little commonality of supplies needed among different instruments. The specific needs of each type of instrument surveyed in depth are considered in Volume 2, Sections 1 through 24.

Accessories extend the capabilities or increase the ease-of-operation of many instruments considered in this survey. Just as with planning instrumentation requirements, accessories must be evaluated on the basis of expected needs. An accessory should not be taken merely because it is available. With microscopes, for example, fluorescence attachments need not be taken unless experiments are planned using fluorescent dyes or stains. Accessories, like supplies, are specific to each instrument and are surveyed in depth in Volume 2, Sections 1 through 24.

One type of accessory which has been categorically excluded from consideration in this study is the automated sample changing device. These devices typically move open containers, test tubes for example, on a belt or carrousel through or past the sampling chamber. Such devices are obviously incompatible with zero-g sample handling procedures (see Volume 2, Section 25, and Paragraph 3.4.2). They are also incompatible with the philosophy of making critical observations in Space Station experiments, rather than repeated routine measurements.

Spare parts will be essential for support of commercial instrumentation in the Space Station, since the ability to perform, maintain, and repair operations in flight is a major justification of the use of commercial instruments. The recommended philosophy (see Paragraph 3.3.3) for equipment repair is replacement of defective modules rather than detailed trouble shooting.

Considerable depth is recommended in the stocking of spare modules and parts. Two of the most sensitive parts, present in several different types of instruments, are radiation (light) sources and photomultiplier tubes. At the time of writing (1970), there are not suitable replacements for these. However, trends in the development of solid-state devices should be noted. Improvements in light-emitting diodes, if continued, could allow them to replace radiation sources in some applications. Similar advances are occurring in photo-sensitive solid-state devices: photo FETs and avalanche multiplying photosensitive transistors, for example. These will undoubtedly replace photomultiplier tubes in future instruments. The resulting increase in reliability should be comparable to that of changing from vacuum tubes to transistors.

3.3.3 Maintenance and Repair

The capability for inflight instrument maintenance is a major contributor to the feasibility of using commercial instrumentation for Space Station application. The maintenance capability must be supported by the presence of trained personnel, test equipment, and adequate maintenance manuals. Preflight familiarization with the on-board instrumentation should be provided in an earth-based laboratory. Electronic test equipment is considered in Volume 2, Section 7, and optical test equipment in Volume 2, Section 16. The detail of information needed for maintenance manuals may require microfilm storage and retrieval equipment.

Current trends in the construction of laboratory instruments is toward modularity. Instruments, parts, and accessories will undoubtedly be available in modular form later in the 1970's. This modularity will facilitate maintenance and repair, allowing modular replacement of subassemblies as the major approach to instrument service. Nonetheless, test equipment should be available for identification and replacement of faulty components when necessary for backup service. Modular construction and ease of repair should be considered in the selection of instruments to be used in the Space Station.

3.4 OPERATION

3.4.1 The Operating Environment

The environment of the Space Station laboratories contributes, on one hand, to the possibility of using commercial instruments, and on the other hand, to the difficulty of actually using commercial instrumentation.

The Space Station laboratories in which commercial instrumentation can be used are the integral laboratories and the attached modules. These laboratories include the general-purpose laboratory, the optics test facility, the electronic and electrical laboratory, the experiment and test isolation facility, the mechanical laboratory, the biomedical laboratory, the bioscience laboratory, and the chemistry and physics laboratory. Offering a shirt-sleeve environment with carefully controlled temperature, pressure, humidity, and gas composition, these facilities will be well lit and supplied with electric power and other utilities. In most respects, the Space Station laboratories will be cleaner, better equipped, more livable and workable than the best earth-based laboratories. Their truly unique features, however, will be the unlimited hard vacuum available, the presence of radiation and high energy particles, and existence of continued free-fall conditions (zero-g). The latter two, while obviously essential for the experiment program, present problems in laboratory operation.

The elevated radiation levels make it necessary to protect personnel, experimental animals, and photographic emulsion from unwanted radiation. In addition, the operation of radiation counters is adversely affected by high background radiation. Additional shielding and anti-coincidence circuitry is needed for these counters.

The absence of gravity, while the major independent variable for many experiments, will be the most bothersome aspect of the environment for routine laboratory operation. Objects will tend to float through the laboratory unless restrained. Appropriate restraints will include magnets, Velcro strips, elastic loops, closed containers, and foam packing containers with slightly undersize cut-outs. Many standard laboratory operations are completely impossible in the absence of gravity. These include balance weighing, pouring, measuring pressure against a column of liquid, separating immiscible liquids, etc. All liquid handling wet chemistry operations require special techniques and devices (see Volume 2, Section 25, and Paragraph 3.4.2). Also, convection cooling of laboratory instruments must be replaced by forced-air cooling because of the absence of gravity.

Although a few laboratory tasks may be facilitated by the lack of gravity (cutting parafin ribbons on a rotary microtome, for example), many normally simple tasks will be made far more difficult in a zero-g environment. Some of these can be planned for and alternate methods devised, others will require an adaptation by the crew members, still others may be unexpected until they arise during the course of an experiment. Experience in the Skylab program should help identify and solve some of these problems.

3.4.2 Sample Handling

Sample handling will be a major problem for laboratory operations in the Space Station. Since gaseous samples present the same handling problems in space as they do on earth, earth-based sample handling methods will be generally applicable in space. Solid samples can usually be handled as other small objects are. The major problems arise with liquid and particulate samples. In some cases, particulate samples can be made into solutions or slurries and handled as liquid samples.

Although the behavior of liquids in zero-g is not completely understood, many problems can be anticipated. These anticipated problems include the transfer of fluids from one container to another, mixing liquids, dissolving a gas in a liquid, storing and dispensing liquids, and eliminating bubbles in liquid samples. It is obvious that open containers are unsuitable for liquids in zero-g conditions. Volume 2, Section 25 describes a group of liquid sample-handling devices appropriate for the Space Station laboratory. These devices include tubing, valves, syringes, and collapsible bags. These devices can be assembled in many different configurations to produce a highly flexible sample-handling system. Since it will never be possible to predict all the sample-handling needs of a meaningful experimental program, the potential needs are best anticipated with a flexible and modular system. Nonetheless, some needs can be anticipated and planned for in advance. The use of a spectrophotometer, for example, requires the solution of the problem of filling the sample cell. The solution must provide for filling the cell and removing bubbles from it. This could be done by transferring the sample into an intermediate container, attaching the intermediate container to the sample cell, and then placing both into a modified centrifuge to move the liquid from the intermediate container into the sample cell by centrifugal force, removing bubbles in the same process.

3.5 INTERFACE

3.5.1 Interface with other Laboratory Instruments

Many laboratory instruments provide the input or output for other instruments. For example, preparative ultracentrifuges and gas chromatographs separate different chemical compounds which then may be analyzed by other instruments such as spectrophotometers or radiation counters.

In another example, a nondispersive infrared analyzer may be used as the sensor of a gas chromatograph. Such input/output relations are designated by the letter B in Table 3-2.

KEY:

A. PERFORMS SAME AS SIMILAR MEASUREMENTS.
B. ONE INSTRUMENT PROVIDES INPUT OR HANDLES OUTPUT OF OTHER INSTRUMENT.
C. ONE INSTRUMENT IS USED TO SERVICE OTHER INSTRUMENT.

Section No. / INSTRUMENT	1.0 Audiometers	2.0 Atomic Absorption Spectrophotometer	3.0 Blood Gas Analyzers	4.0 Cell Counters	5.0 Centrifuges	6.0 Electronic Hematocrit	7.0 Electronic Test Equipment	8.0 Electrophysiological Equipment	9.0 Emission Spectrometer	10.0 Flame Photometers	11.0 Gas Chromatograph	12.0 Infrared Analyzers	13.0 Mass Spectrometers	14.0 Microscopes	15.0 Microtomes	16.0 Optical Test Equipment	17.0 Osmometers	18.0 Oxygen Analyzers	19.0 Radiation Counters	20.0 Radiometers	21.0 Recorders	22.0 Specific Ion Electrodes	23.0 Spectrophotometers	24.0 X-Ray Spectrometers
Audiometers																								
Atomic Absorption Spectrophotometers																								
Blood Gas Analyzers																								
Cell Counters																								
Centrifuges																								
Electronic Hematocrit					A																			
Electronic Test Equipment	C	C	C	C	C	C																		
Electrophysiological Equipment			A				C																	
Emission Spectrometer		A																						
Flame Photometer		A					C		A															
Gas Chromatographs					B																			
Infrared Analyzers							C				AB													
Mass Spectrometers							C				AB	AB												
Microscopes																								
Microtomes														B										
Optical Test Equipment		C		C	C				C					C										
Osmometers					BA		C																	
Oxygen Analyzers			A				C				A		A											
Radiation Counters					B		C				B			B										
Radiometers							C									C								
Recorders	B	B	B				B				B		B											
Specific Ion Electrodes		A	A				C			A											B			
Spectrophotometers		A			B		C			A	AB					C			B		B	A		
X-Ray Spectrometers		A					C		A	A											B			

Table 3-2. Interrelation of Laboratory Instrument Operation

Some instruments can make the same or similar measurements, even though greatly different operating principles are involved. Metallic elements, for example, can be detected by an atomic absorption spectrophotometer, an emission spectrometer, a flame photometer, or an X-ray spectrometer. These and other examples in which similar measurements can be made with different instruments are indicated by the letter A in Table 3-2. Such instruments can be used to make cross-checks on each other.

Still other instruments are useful for service and calibration of the analytical instruments. These include the electronic test instruments and optical test instruments (Volume 2, Sections 7 and 16). These instruments and their uses in calibration and maintenance are indicated by letter C in Table 3-2.

3.5.2 Interface with Vehicle Systems

When used in an earth-based laboratory, the instruments surveyed in this study are all capable of independent operation. Although they require laboratory utilities, they are not considered to have system interface with the laboratory. Nontheless, the complexity and needs of the Space Station generally demand that systems planning include the laboratory instrumentation. The need for systems planning is obvious; a closed environment with limited resources cannot be expected to support instruments which occupy space, consume power, generate heat, and produce wastes without planning. Systems planning also provides the opportunity for planning a more efficient laboratory operation than is normally done with earth-based laboratories.

The restraining of laboratory instruments to prevent movement in any direction is not considered in earth-based laboratories. Gravity holds the instruments on the bench or floor, and additional restraint is not required. In the Space Station, all instruments and their movable parts must be positively held in place. The oculars in a microscope and the lead shielding blocks in a liquid scintillation counter are examples of movable parts of instruments which must be restrained from floating freely in the Space Station laboratory.

Rack mounting is an available option for some commercial instruments and is an appropriate solution for restraining some instruments. With other instruments, it may be desirable to store them when not in use, attaching them to the work bench only when needed. This could become very important because of bench-space limitations in the Space Station laboratories. Padded cabinets could store instruments and their accessories while not in use. A somewhat more elegant solution would be swinging mounts operating like a "typewriter desk" which would orient the instrument in working position or swing it away below the bench when not in use. This would be particularly appropriate for a microscope or microtome.

Instrument mounting and storage should also consider the long-range flexibility of the Space Station. The space and mountings used for an instrument during one period may be needed for a different instrument during a later period. Because of the long life span of the Space Station, it will be inevitable that the instrumentation will change as the experiment program matures. Thus, accommodations for one instrument should not, and must not, interfere with future changes in instrumentation. This requirement limits the extent to which it is desirable to integrate instrumentation into vehicle systems. The interfaces provided should reflect the flexibility necessary for future needs.

3.5.2.1 Electric Power

The majority of laboratory instrumentation manufactured domestically is designed to operate on 115 volts rms (nominal), 60 Hz power. A few instruments allow operation on power-line frequencies of 50 to 400 Hz as a standard feature. This added feature is possible only if the instrument is designed without components which are dependent upon the power-line frequency.

The following are examples of instrumentation components which would prevent direct conversion from 60 to 400 Hz operation:

- Transformers with excessive core losses at 400 Hz
- Mechanical systems driven by 60 Hz servo motors
- Blowers and other motor-driven air movers
- Motors in general, including induction, hysteresis synchronous, and servo types designed for 60 Hz only
- Magnetic solenoids
- Flame igniters which may be designed only for 60 Hz operation
- Various circuitry whose timing or operation depends upon the 60 Hz frequency

Power supplies which supply the various regulated and unregulated dc voltages for the instrumentation generally are not limited to 60 Hz operation. The power supplies will function equally well or better on 400 Hz, provided the transformer will operate on 400 Hz or can be replaced by a 400-Hz unit (usually smaller in size and lighter in weight). In some cases, ac ripple voltages will be reduced as a result of the increased frequency and filter attenuation.

In cases where 28-volt dc power would be favored over 400-Hz power, dc-to-dc converters can be used. These converters are typically of a square wave switching design and can generate considerable amounts of interference. The use of feedthrough bypass filtering in addition to LC filtering should prove sufficient to limit interference to acceptable levels. Dc-to-dc converters, operating at frequencies above 5 kHz, prove more efficient and exhibit less output ripple in high-voltage applications such as photomultiplier tube power supplies.

Motors are a major problem in conversion from 60 to 400 Hz, or 28-V dc operation. They are typically used for the following functions in instruments:

- Optical chopper drive
- Recorder chart drive
- Pumps for air and liquid
- Servo loops for autozero or autocal circuits, for recorder pen drives, or for mechanical actuators for optical components

Most are ac induction motors free from commutators and brushes. A large portion are hysteresis synchronous; therefore, their speed is locked to the 60 Hz power line frequency. Many methods can be used to replace synchronous motors.

Solutions to the general problem of elimination of 60 Hz power requirement are as follows:

- Direct replacement by 400 Hz induction motors if speed requirements allow.
- Generation of 60 Hz power for small motors with an oscillator and driver transistors. Low voltage motors, 28-V dc power can be used.
- Use of dc motors with extensive brush interference suppression.
- Use of brushless dc motors. Again, 28-V dc and driver transistors can be used.

Generation of 60 Hz power from 28-volt dc power is the most desirable solution for low-power applications. Precision oscillators with frequency stabilities of better than ±0.5 percent are easily attainable; stabilities better than ±0.05 percent are more difficult. For higher power applications, either 400 Hz single or three-phase or EMI suppressed dc brush-type motors operated from 28-V dc are usable.

Other conversion problems, exclusive of power supplies and motors, are not discussed here and can be handled individually. Required modifications may allow the opportunity for circuit or instrument improvements which enhance operation or effectiveness of the instrument. Addition of EMI filtering and improvement of ground systems as a result of a power supply modification is one example.

3.5.2.2 Temperature Control

Forced-air cooling may be needed to replace the convection cooling which occurs normally in most instruments. In addition, controlled temperature, at temperatures other than ambient, are needed in the operation of some of the instruments and in many of the experiments. Ultracentrifuges, for example, usually operate with the sample kept near freezing to prevent convection currents. Gas chromatographs, on the other hand, operate at elevated temperatures; they often use programmed temperature increases during the course of analysis. Instruments such as a flame-photometer (Volume 2, Section 10) and atomic absorption spectrophotometer (Volume 2, Section 2) will require venting of their flame and isolation of it from the laboratory environment.

Many laboratory operations typically require high, low, or carefully controlled temperatures. Some procedures require cryogenic temperatures, while for others simple freezing is adequate. (Preservation of biological samples, for example). Some biologically active agents are best preserved at refrigerator temperatures (5 to 10°C), and incubators are needed to maintain body temperature (37°C) reactions. Ovens and furnaces are needed for physical and chemical experiments. Water baths are common devices for maintaining temperature in earth-based laboratories, but open-water baths of earth-based laboratories are obviously unsuitable for Space Station applications. Although there is a great variety of commercial instruments available for temperature control, the unique characteristics of the Space Station laboratories make them generally unsuitable for this application. The temperature control apparatus of the Space Station should be completely integrated with the heat exchange economy of the vehicle systems. A separate design definition study would be appropriate for these requirements.

3.5.2.3 Other Utilities

The unlimited vacuum of space is one of the resources which the Space Station will exploit in its experiment program. This vacuum could also be used in the operation of some laboratory instruments. Ultracentrifuges and Mass Spectrometers (Volume 2, Sections 5 and 13) require a vacuum pump in their normal operation. A hard vacuum, supplied as a utility, would eliminate the need for a vacuum pump in both of these instruments, thereby considerably reducing instrument complexity. A vacuum source is also needed for lyophilization. For these applications and others, it is apparent that a vacuum should be provided as a utility in the Space Station laboratories. The vacuum system should also be completely integrated with vehicle systems to provide maximum safety.

Gases are needed for the operation or calibration of several laboratory instruments (Atomic Absorption Spectrophotometer, Blood Gas Analyzers, Flame Photometer, Planchet Counters, Oxygen Analyzers, and Gas Chromatographs). Although gases could be stored centrally and supplied as a laboratory utility, this is not recommended because of the increased possibility for gas-line or connector leakage. Small gas bottles should be used in or near the instrument with which they are associated. Tubing and connectors should be minimized and secure mechanical restraint of the gas bottles provided. Space laboratories should store no more gas and at no higher pressures than needed.

Water must be provided from outlets which mate with the wet chemistry sample-handling devices (see Volume 2, Section 25). Liquid disposal parts must mate with the sample-handling devices and solid disposal facilities must also be provided by vehicle systems.

3.5.2.4 Data Management

Laboratory instruments typically provide their output as an analog voltage signal registered on a meter or a strip-chart recorder. There are present trends toward interfacing laboratory instruments with computers. These trends take the following three directions:

1. Record-keeping for automated routine operations, as in the recording and storage of the results of automated analytical instruments in the clinical laboratory.

2. Signal processing and analysis, as in the pulse-height analysis of signals from liquid scintillation counters or computer analysis of the electrocardiogram.

3. Control of experiments, as in automated electrochemical procedures of control on contingency schedules in behavioral experiments.

The instruments of the Space Station laboratories could be under direct control by the Data Management system with output applied to the system and the system, in turn, directly controlling the operation of the instruments. Alternatively, the instruments could be used by themselves without interface with the Data Management system. Both of these methods are extreme and should be carefully avoided. Data handling and processing capabilities should be used where advantageous, but not when these capabilities interfere with the normal use of the instruments. A reasonable balance between computerized and manual operation will depend upon a large number of factors, including: the actual instruments involved, the range of experiments to be supported, the user interfaces of the data system, the preferences of the principal investigator, the level of personnel running the experiment in the Space Station (principal investigator, co-investigator, technician), the need for complex data analysis, the interactive routines developed for the tasks involved, and many more. The unique feature of the Space Station experiment program is its pursuit of experiments which can only be (or best be) achieved under human control. Experiments which can be completely automated can be accomplished with unmanned satellites. On the other hand, the capabilities of the on-board experimenter should be augmented whenever possible by allowing him to have access to the data-handling and computational facilities of the Data Management system.

A modern data system is capable of accepting, processing, storing, and transmitting vast quantities of data. This can also be a disadvantage because it encourages the uncritical collection, analysis, and storage of massive quantities of data. As the Data Management system interacts with analytical laboratory instruments, the goal of data reduction rather than data proliferation should be kept clearly in mind. While there will be some experiments in which it is necessary to save the large amounts of raw data, others only have limited requirements for data processing and storage. The ideal experiment would return with conclusions and adequate data to support them; far less desirable would be an experiment which returned with only a mass of observations.

The most significant contribution which the Space Station computer can make to laboratory operation is on-line, real-time processing. On-line processing can be used for control of experiments and for interactive analysis. An example of a computer-controlled experiment is the automation of an audiometer. The computer would be interfaced to control the frequency and intensity of an audio oscillator and would sense the positions of a subject's response switch. Earphones would be placed on the subject, and he would be asked to press the response key when he heard a sound. Under software control, the computer would present a tone, record the response or lack of response (with latency, if desired), and then present the next tone at a higher or lower intensity or frequency as determined by the preceding responses. The computer would then prepare an audiogram of auditory threshold as a function of frequency. This audiogram could be compared with previous audiograms and stored for future comparison.

A typical example of interactive routines is from a demonstration of the PDP-12 Computer (4K memory, AD converters, CRT screen, and magnetic tape). This example illustrates the capabilities of a high-speed counter interfaced with a laboratory instrument which gives an analog voltage signal output. The input signal is sampled and digitized, starting either from a trigger or as controlled by the experimenter. The sampling rate determines the time base of the sample and is chosen by the experimenter. After 256* points have been sampled, the points are displayed as a waveform on the

*Other sample lengths can be used; they are usually powers of two.

CRT screen. The experimenter can then move a cursor on the screen to display the coordinates of any point on the curve. He can move the curve up or down with respect to a base line. By digital filtering, he can smooth the curve or remove high or low frequencies. He can also scale the signal to increase or decrease the gain or can reverse the polarity. He can integrate or differentiate the signal. All of these operations (corresponding to many hours of plotting and calculation) can be done repeatedly, reversibly, almost instantly, and under keyboard control. The original signal, the manipulated signal, and any intermediate form can be stored on magnetic tape or retrieved from tape for viewing or additional analysis.. Capabilities such as these are applicable to the output of many instruments and in many disciplines.

The preceding example of interactive (between experimenter, his data, and the computer) data analysis is not truly a real-time operation with respect to the data generation. Examples of true real-time operations include pulse-height analysis and signal averaging. Pulse-height analyzers are typically used to analyze the output of radiation counters. They separate pulses on the basis of amplitude--keeping separate counts for different amplitude ranges. This allows simultaneous determination of the concentration of different isotopes. Signal averaging functions allow separation of signal from noise in triggerable or time-locked signals. The output of a spectrometer or the evoked response of the electrophalogram are examples. Another application of real-time analysis is Beckman's Metabolic Gas Analyzer which uses a small, digital computer to analyze the output of a mass spectrometer and gives readings of O_2 consumed, CO_2 produced, and respiratory index for each breath.

On-line and interactive processing makes three major contributions to the Space Station experiment program. First, it makes major reductions in the time needed for calculations and data manipulations. Second, it makes a significant contribution to the process of data reduction. Third, and perhaps most important, it allows the experimenter to assess an experiment while the experiment is being run, and to make changes in the conduct of the experiment predicated on actual as well as anticipated experimental results. A feedback loop is established with the experimenter in the loop.

The onboard computer can also be used for off-line processing from a variety of input sources. The capabilities required for these applications are considerably less stringent than those for on-line processing.

Still another application for the Space Station computer would be to provide desk calculator capabilities for laboratory use. This would include basic arithmetic operations and a few simple functions (sine, log, exponential, etc.) which could be operated from a simple keyboard input and provide a convenient output. These functions could be replaced completely by some of the currently available electronic desk calculators. Careful attention should be paid to the developmental costs of a desk calculator capability in comparison to commercially available calculators.

There is currently an unresolved controversy concerning computer processing of analytical instrument output data. The question is whether to time-share a large computer or use a small local computer to satisfy the required operations. This controversy is not pursued in the present study. However, we must point out that the use of small computers (2 to 8K memory) for on-line analysis of the output of analytic instruments is currently a widely used laboratory technique. An intermediate solution would be to interface small computers with the on-board data management system.

3.5.3 Electromagnetic Interference

3.5.3.1 Sources of Interference

Interference is generated by fast-rising current waveforms or by high-frequency RF energy. Sources of interference include the following:

- Power supply, heater, or motor speed-control regulators which use silicon-controlled rectifiers, triacs, magamps, and pulse-width modulators.
- Digital logic and counting circuits, digital data transmission lines, and other digital control circuits.
- RF oscillators.
- Switching type dc-to-dc converters.
- Brush-type motors.
- Power switches, thermal cutout switches, rotary stepping switches, and other switching devices which interrupt power.
- Arc lamp or flame igniters.

3.5.3.2 Control of Interference

Conduction or radiation of the interference generated can usually be controlled by application of filtering and/or shielding. Some sources are easy to control, others are more difficult and require extensive suppression. Much depends upon the power level involved and the frequencies generated. It is generally far better to eliminate the source than to attempt suppression.

3.5.3.3 Sensitivity to Interference

Electronic circuits are susceptible to radiated RF energy. In general, high-impedance circuits such as those associated with a photomultiplier tube and potentiometric electrochemical sensors are more susceptible to interference. RF or transient energy on input power lines, if allowed to pass through power supplies or radiate inside enclosures, can cause problems especially in digital circuitry.

Conversion of instruments from 60 Hz to either 400 Hz or 28 V dc operation requires modification of both power supplies and other circuitry. This gives the designer an opportunity to implement modification and sufficient suppression to allow conformance to reasonable EMI requirements.

3.5.3.4 Requirements and Standards

The electromagnetic interference requirements specification to which Space Station equipment will be tested must be reasonable and realistic. Many of the existing specifications (MIL-STD-461A, MIL-STD-826A) require interference and susceptibility testing levels which far exceed the actual levels that instruments will be subjected to in space. Some safety margin is certainly necessary, but not to the extent of completely excluding a majority of laboratory equipment without major modifications or complete redesign.

Two factors must be kept in mind in establishing EMI standards for the Space Station. First, the autonomy of the Space Station permits it to be occasionally, even frequently, out of radio contact with the ground operations. Thus, instruments which produce interference so severe as to block radio reception completely are not necessarily unusable in the Space Station. Second, commercial laboratory instruments, even though they may both produce and be sensitive to interference, operate satisfactorily in a ground-based laboratory. A commercial spectrophotometer, for example, contains an electric motor producing EMI and a photomultiplier tube sensitive to EMI; yet this instrument operates without interfering with itself. Also, instruments which produce EMI do not transfer with instruments sensitive to EMI if they are not operated at the same time--this is often the case in established laboratory procedure. Thus, Space Station EMI standards must be based more on actual requirements than on past experience with space vehicles which did not have the capabilities or requirements of the Space Station.

3.6 SAFETY

Safety is of highest importance in planning Space Station instrumentation, and must not be compromised. There are many risks associated both with spaceflight and with laboratory operation. Laboratory instruments must not contribute to these risks. Inherently safe instruments should be chosen, carefully maintained, and operated in strict conformance with the stringent safety standards. The importance of safe operation cannot be overemphasized. Many instruments, if misused, can be extremely dangerous in an earth or space laboratory.

3.6.1 Flamability and Toxicity

The atomic absorption spectrophotometer and the flame photometer (Volume 2, Sections 2 and 10) require a flame for their operation. Although a flame is impossible to use in a pure oxygen atmosphere and an unacceptable risk in an enriched oxygen atmosphere, the sea-level-like atmosphere planned for the Space Station eliminates many of the flamability hazards and allows consideration of these instruments in the Space Station. This should not imply the complete lack of risk associated with open flames in the Space Station. The flame should very definitely be vented and isolated from the laboratory environment. Also, isolation should be provided for the sample vaporization electrodes of the emission spectrometer (Volume 2, Section 9).

The presence or absence of approved nonmetallic materials in commercial instruments has not been treated in depth in this study. There are, to be sure, some nonmetallic materials in commercial instruments which are not approved. Table 3-3 shows some typical (approved and not approved) nonmetallic materials used in commercial laboratory instruments. The materials used differ from model-to-model and even from one manufacturing run to the next. In the next few years, before final selection of Space Station instrumentation must be made, there are certain to be many changes in and additions to the nonmetallic materials used in commercial instruments. It is easy to make a comparison check of a specific instrument manufactured at a specific time with an approved nonmetallic parts list. Materials which are not approved are generally found in knobs, gears, insulation, circuit boards, etc. Most of these items are not critical and can be replaced by an approved material. At worst, this will cause a slight increase in cost. Also, some custom casting or

Application	
Rigid plastics for knobs, gears, plugs, cams, fittings, and miscellaneous mechanical parts	Typically PVC, ABS, Polyethylene, Polypropylene, Teflon, Nylon, Delrin, Penton, and many epoxy formulations, some of them filled. To a much lesser degree, polycarbonates, polyimides, polysulfores, Kel F and Vinylidene fluorides may also be used. Many of these compounds have not been approved for space applications.
Adhesive, Sealant, and Patching Compounds	Silicone rubbers, Eastman 510, and Toktite. Epoxy materials, ortho cresol novalac, p-aminophenol, and cycloalyphatris phenol novalar
Insulation	Vinyl and PVC insulation and sleeving often used versus Teflon for wiring

Table 3-3. Typical Nonmetallic Materials Used in Commercial Laboratory Instruments

machining of critical parts could be required. Obviously, such modifications need be considered only after a specific instrument is selected for use in the Space Station.

3.6.2 Microbiological Hazards

Laboratory instruments do not, themselves, introduce microbiological hazards. As biological samples are analyzed, contamination can occur. In the Space Station laboratories this will be largely controlled by use of closed sample handling devices (Volume 2, Section 25). Since samples are not allowed free access to the laboratory environment, microorganisms in the samples cannot spread contamination beyond the closed sample-handling devices. Single-use disposable sample-handling devices will help reduce contamination, and flushing with bactericidal solutions can sterilize nondisposable items.

Microbiological cultures should be maintained inside closed glove boxes.* For observation, inverted microscopes are easily adapted to be used inside glove boxes.

The mere presence of human experimenters and animal subjects in the laboratory contribute to the microbiological population. There is no need or justification to attempt to maintain "germ-free" laboratories. Indeed, the development and stabilization of microbiological populations in the Space Station is the subject of some of the experiments. (Functional program elements 5.25, Microbiology (Bio C)).

3.6.3 Ionizing Radiation

In the Space Station laboratories, the necessarily high radiation levels will be added to by some of the experimental instruments and materials. The major contributor will be the X-ray Spectrometer (Volume 2, Section 24) and the various radioisotopes used in biomedical experiments. The highest standards of radiation safety must be maintained in the Space Station. This should include radiation safety training and qualification by at least one crew member, as well as on-board facilities for shielding, monitoring, and decontamination.

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*A clear plastic box with gloves protruding inside, allowing an experimenter to manipulate the contents.

The following documents are particularly relevant to radiation safety:

Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure. U.S. Dept. of Commerce, National Bureau of Standards Handbook 1969.

Principles of Radiation and Radiological Safety, Philip Ting (Radiation Safety Officer): Beckman Instruments, Inc., 1970.

The harmful consequences of ionizing radiations to a living organisms are due to the energy absorbed by cells and tissues. This absorbed energy (or dose) produce chemical decomposition of the molecules present in the living cells, related to ionization of atoms within the tissue. The amount of ionization or number of ion pairs produced by ionizing radiation in the cells or tissues provides some measure of the amount of decomposition or physiological damage that might be expected from a given quantity or dose.

A dose of one Radiation Absorbed Dose (RAD) means the absorption of 100 ergs of radiation energy per gram of absorbing material. The RBE (Relative Biological Effectiveness) is a factor which is used to compare the biological effectiveness of absorbed radiation doses (i.e., RADS) due to different types of ionizing radiation. The value of the RBE for a particular type of nuclear radiation depends upon several factors, such as the energy of the radiation, the kind and degree of the biological damage, and the nature of the organisms or tissue under consideration. Typical values of the RBE for radiations of several types are given in Table 3-4.

Type of Radiation	RBE Factor
Gamma and X-Rays	1
Beta	1
Proton	10
Alpha	10
Fast Neutron	10
Slow Neutron	5

Table 3-4. Values of RBE for Radiation

The REM (Roentgen Equivalent Man) reflects not only the amount of energy dissipated but also the amount of biological damage derived from such energy dissipation. It is defined as equal to the product of the RAD and RBE factor. Currently, statements of permissible exposure of humans to ionizing radiation are expressed in REM. For example, if an individual received 10 r (roentgens) of cobalt gamma rays, 1 RAD of beta to the whole body from an internal emitter, 5 RAD of slow neutrons, and 1 RAD of fast neutrons, the whole body dose equivalent would be as shown in Table 3-5.

Exposure	RBE Factor	Dosage
10 roentgens cobalt gamma	1	10 x 1 = 10
1 RAD beta	1	1 x 1 = 1
5 RAD slow neutrons	5	5 x 5 = 25
1 RAD fast neutrons	10	1 x 10= 10
Total REM		46

Table 3-5. Bodily Dose Equivalent

Some biological changes caused by radiation appear in a short time (may be minutes, days, or months) while others may not be seen for several years.

When a massive dose of radiation to the whole body is received instantaneously, the effects may be seen as early as the first day and will follow a course dependent upon the size of the dose received. Only minor injury would occur at doses less than 100 roentgens, but about 50 percent fatalities occur in the range of 400 to 500 r. As the whole body dose approaches 1000 r, the fatalities reach 100 percent. The physiological effects of increasing radiation doses is shown in Table 3-6.

In addition to the effects of heavy irradiation, some of the consequences may not appear for many years. While changes in the texture or pigmentation of the hair may be seen relatively soon, other effects, such as cataract and leukemia, may not appear for 5 or more years. Some delayed effects result from acute exposure, whereas others are of significance where the dose is delivered in repeated small exposure over a long period of time.

Radiation safety standards of the FRC (Federal Radiation Council) and the ICRP (International Commission on Radiological Protection) are the most widely used criteria in radiological health. The Radiation Protection Guides, recommended for normal peace-time operation by FRC, are summarized in Table 3-7. The Radiation Protection Guides provide different limits for the radiation worker (5 REMS per year or 100 M REMS per week), and the general population (0.5 REMS per year or 10 M REMS per year).

0-25 r*	25-100 r	100-200 r	200-300 r	300-600 r	600 or more
No detectable clinical effects.	Slight transient reductions in lymphocytes and neutrophils.	Nausea and fatigue with possible vomiting above 125 r.	Nausea and vomiting on first day.	Nausea, vomiting, and diarrhea in first few hours.	Nausea, vomiting, and diarrhea in first few hours.
Delayed effects may occur.	Disabling sickness not common, exposed individuals should be able to proceed with usual duties.	Reduction in lymphocytes and neutrophils with delayed recovery.	Latent period up to two weeks or perhaps longer.	Latent period with no definite symptoms, perhaps as long as one week.	Short latent period with no definite symptoms in some cases during first week.
	Delayed effects possible, but serious effects on average individual very improbably.	Delayed effects may shorten life expectancy in the order of one percent.	Following latent period, symptoms appear but are not severe; loss of appetite and general malaise, sore throat pallor, petecheae, diarrhea, moderate emaciation.	Epilation, loss of appetite, general malaise, and fever during second week, followed by hemorrhage, purpura, petecheae, inflammation of mouth and throat, diarrhea, and emaciation in the third week.	Diarrhea, hemorrhage, purpura, inflammation of mouth and throat, fever toward end of first week.
NOTE: Adapted from "The Effects of Nuclear Weapons", U. S. Government Printing Office, (1957). *Roentgens			Recovery likely in about 3 months unless complicated by poor previous health, superimposed injuries, or infections.	Some deaths in 2 to 6 weeks. Possible eventual death to 50% of the exposed individuals for about 450 roentgens.	Rapid emaciation and death as early as the second week with possible eventual death of up to 100% of exposed

Table 3-6. Summary of Effects Resulting from Acute Whole Body External Exposure of Radiation to Man

Type of Exposure	Condition	Dose (REM)
Radiation worker:		
(a) Whole body, head and trunk, active blood forming organs, gonads, or lens of eye	Accumulated dose 13 weeks	5 times number of years beyond age 18 3
(b) Skin of whole body and thyroid	Year 13 weeks	30 10
(c) Hands and Forearms,	Year 13 weeks	75 25
(d) Bone	Body burden	0.1 microgram of radium-226 or its biological equivalent
(e) Other organs	Year 13 weeks	15 5
Population		
(a) Individual	Year	0.5 (whole body)
(b) Average	30 years	5 (gonads)

Table 3-7. Radiation Protection Guides
Federal Radiation Council

3.6.4 Electroshock

Electrical equipment in Space Station laboratories (or any laboratory) should not allow electric current to flow through personnel using the equipment or being measured by the equipment. Table 3-8 shows the effects of electroshock.

The need for electroshock safety is particularly applicable to electrophysiological measuring equipment. The shock pathways to the human body generally

Current Levels (RMS)	Effects of Current
Microshock* (Microamperes)	
0 - 20	Safe for a Normal Heart
20 - 800	Ventricular Fibrillation Threshold
Macroshock (Milliamperes)	
0 - .5	No Sensation
.5 - 2.	Threshold of Sensation
2. - 10.	Muscular Contractions (Mild to Strong)
5. - 25.	Painful Shock (Unable to Let Go)
Over 25.	Violent Muscular Contraction
Over 100.	Paralysis of Breathing
20. - 200.	Ventricular Fibrillation
Over 200.	Paralysis of Breathing Without Fibrillation

*Note: Microshock refers to electroshock which is presented directly to the heart through a cardiac catheter. Very small currents are adequate to induce fibrillation under these conditions. Although cardiac catheterization in Space Station laboratories is not anticipated at the time of writing, it cannot be excluded. In uncatherized patients, considerably higher currents can be tolerated.

Table 3-8. Effects of Shock Currents

involve grounding of the body. Human subjects have traditionally been grounded to a local powerline or earth ground to minimize power-frequency, common-mode signals. Without grounding, common-mode signals will usually produce unacceptable interference in monitoring systems having low common-mode-rejection. The typical electrocardiograph in use today directly grounds the right leg of the human subject. With the subject grounded, the possibilities for electroshock are enhanced.

Consider the typical case of two electromedical instruments connected to one person, and providing separate ground connections. Three types of shock paths are then possible.

- A shock from either instrument, through the person, to ground.
- A shock, due to a difference in ground potentials from one ground connection, through the person, to the other ground connection.
- A direct shock from an accidental contact with a source of potential, producing a current through the person, to ground.

The first hazard is a leakage or ejection current from the instrument input (sensor or electrodes) through the human subject, to ground. This is present to a suprising degree in many instruments, and numerous cases of this shock have been reported. The possibility of the occurrence of leakage current shocks can be greatly reduced by use of isolated system inputs and by use of a grounded faraday shield in instrument power transformers.

The second type of hazard is quite common, even with equipment that is, in itself, safe. Large (hundreds of millivolts) ground potential differences may exist between several outlets in the same laboratory. Since some humans may have an impedance as low as 1000 ohms, a potential difference of only several hundred millivolts between two grounds can result in currents of hundreds of microamperes.

The third type of hazard occurs only when an appliance or instrument has grossly failed. In this case, a relatively high potential produces a shock through the ground provided by an unoffending instrument. If the ground were not present, the shock would be minimal, even with direct powerline contact.

Since the beginnings of medical electronics, electromedical apparatus has been designed to provide what amounts to a "copper strap" ground connection to the patient. The national standards now proposed, or under discussion, would all require that this practice be ended. Of course, it is impossible to completely "float" the patient above ground potential, but values of common-mode input impedances as high as 10. to 50. megohms, at 60 Hz. are possible today for individual instruments. As the patient-to-ground impedance is increased, pickup of interfering 60 Hz signals increases and very high values of common-mode rejection are required (over 100 dB) for monitoring low-level signals.

At the time of writing, national standards are being developed for safety of medical astronauts. It is likely that some instruments now being sold will not meet the standards adopted. The electrophysiological instruments selected for the Space Station should comply with high safety standards.

Safety standards for protection of the instrument operator (grounding of panel cases, etc.) are more firmly established (see, for example, the National Electrical Code) and complied to by all major manufacturers. This electrical safety must not be compromised when making instrument modifications for Space Station application.

3.6.5 Physical Personnel Hazards

Physical personnel hazards presented by laboratory instruments are things such as protruding knobs, sharp corners, or hot parts or assemblies of instruments. These are not usually considered hazards in earth-based laboratories because the experimenter is not faced with the problems of a zero-g environment. Space Station scientists are not restrained to the laboratory floor, but will be able to float with ease through the laboratories. This increases the chances of accidental collision with the instruments, causing possible injuries.

A simple solution to several of these hazards is a metallic cage surrounding each instrument with appropriate access to the operating controls. These cages might be installed when a new crew of scientists arrived, and left on until the new men had become used to maneuvering in a zero-g environment. Then the cages could be removed.

3.7 MODIFICATIONS

In the course of this study, it has become apparent that many instruments, while not suitable for direct, off-the-shelf-to Space Station application would, however, be suitable if modified. There are generally two types of needed modifications: those to improve safety, and those to correct a gravity-dependent operation. Other modifications may be considered optional: those which aid interface with the Space Station, and those which aid maintenance or operation. Although modifications will add to the price of commercial instruments, the increases will be small in comparison to the costs of developing a new space-qualified instrument.

Some types of modifications are common to several of the instruments surveyed. Restraints are needed to hold many of the instruments on the workbench and to hold parts of the instrument together. In the liquid scintillation counter, for example, not only must the instrument be held firmly on the bench or floor, but its lead shielding, normally held securely by gravity, must be held securely to the rest of the instrument to avoid damage to the delicate photomultiplier tube. Mercury, used for switches, pressure columns, or electric contacts must be eliminated. Fumes and gases, normally vented to the laboratory, must be externally vented. Modifications to eliminate protruding knobs and sharp corners are needed on most instruments. Some instruments could be adapted to make use of the external vacuum of space to replace a normally internal vacuum pump, and others could make use of the on-board data management or temperature control systems. The output of many analytical instruments can be recorded, stored, and analyzed by the Space Station computer following slight modification of instrument output. Other instruments can be simplified by adapting them to make use of the Space Station temperature control facilities--cooling of centrifuges or heating of the gas chromatograph columns, for example.

Some modifications can easily be made on completed instruments, replacing knobs, for example. Other modifications are best implemented during assembly. This is particularly appropriate where gears, bearings, adhesives, insulation, potting materials, etc., may be involved. If, as in the latter case, otherwise standard instruments are built to order, with specified components, this opportunity could be taken to replace many commercial components with high reliability parts. This would be particularly appropriate for mechanical parts and electronic components. The improved instrument reliability should more than justify the moderate cost increases.

Slight-to-moderate modification is required of most laboratory instruments to allow their safe and successful use in a space laboratory. In most cases, the cost increases of the needed modifications would be trivial in comparison to the time and costs of developing new "space-qualified" instruments.

Some modification is also required for almost every instrument considered to adapt the equipment for zero-gravity operation. All modifications should be made by the original equipment manufacturer to reduce the possibility of degrading performance as the result of the modifications. Most large instrument companies have a custom products department or a contracts division which routinely modifies their standard instruments for specific customer applications. Many instrument manufacturers, conversely, do not maintain the rigorous quality control to which NASA is accustomed. Although it is the purpose of this survey to consider the modifications of standard equipment and reduce the need for qualification test programs in lieu of flight hardware development, it should be obvious that any equipment which will be used in the Space Station laboratory must meet certain quality assurance, safety, and reliability criteria. For this reason, it is best to consider that modifications be performed by an instrument manufacturer who has either military or NASA experience, so that if modifications are needed, they can be achieved within minimum quality assurance and reliability constraints.

3.8 AVAILABLE INSTRUMENTS

Analytical instruments can be divided into two general categories, scientific instruments for laboratory use and process instruments. The laboratory instruments are designed for use as bench-top equipment and utilize batch-type sampling. Process instruments are usually designed for plant installation where operation is required 24 hours per day and the sample is normally continuously flowing or automatically injected.

For Space Station laboratory applications, both categories of instruments should be considered. For example, the process instruments are generally more rugged than laboratory versions. This may be desirable for specific applications in the space laboratory such as the continuous monitoring of a specific component. The additional rigidity and reliability necessary, however, is generally accompanied by an increase in size and weight and decrease in flexibility.

Sampling techniques and requirements are probably the most difficult parameters to be considered in the modification of existing instrumentation for space applications. This point has been discussed in some detail for most of the instrument categories reviewed in this study. The decision of whether a process or laboratory instrument should be considered for a specific application will often be dependent upon the specific sampling requirements for the desired application.

Scientific instruments are produced by a large number of manufacturers throughout the world. In general, the simpler the instrument, the greater the number of available models and manufacturers. There are several companies in the United States which produce a wide variety of instrumentation for chemical analysis. These companies also produce ancillary equipment such as data handling, recording, and sampling accessories. The following is a list of the largest instrumentation companies which produce both optical and electrochemical instrumentation and provide a wide variety of readout equipment options.

Beckman Instruments, Inc.	Fullerton, California
Consolidated Electrodynamics Corp.	Pasadena, California
Hewlett-Packard	Palo Alto, California
Leeds and Northrup	Philadelphia, Pennsylvania
Mini Safety Appliances	Pittsburgh, Pennsylvania
Minneapolis Honeywell	Minneapolia, Minnesota
Perkin-Elmer Corp.	Norwalk, Connecticut

In addition to these corporations whose principal emphasis is in the area of scientific instrumentation, there are several major corporations which manufacture scientific instruments in one of their divisions. There are also tens, perhaps hundreds, of smaller companies manufacturing limited lines of instruments. Although limited in diversity, these small companies must not be dismissed as producing instruments of inferior quality. This survey has considered principally U. S. manufacturers; there are many foreign instrument manufacturers (principally in Western Europe and Japan) who produce a wide diversity and high quality of scientific instruments. Indeed, providing scientific instrumentation could well prove an appropriate venture for international cooperation on Space Station programs.

Section 4
INSTRUMENT RATINGS

The instruments considered in the present survey were rated on the basis of the 17 rating categories (Table 4-1). Individual instruments were rated for each category on a five-point scale from 1 (inferior) to 5 (superior). A relative-importance weighting factor was given to each rated category. The rating category "Versatility", considered to be highly important, was given a weighting factor of 1.0; while the rating category of "Ease of Packing/ Installation", not as important, was given a factor of only 0.3. The product of the rating and the weighting factor gives the weighted rating. The sum of the weighted ratings for each instrument type or subtype yields the Flyability Index.

While the Flyability Index for each instrument is one of the major products of the current survey, and is certainly responsive to current and future needs of the Space Station Program, it should not be considered as a final determiner of which instruments should be used in the Space Station. The need for specific instruments to accomplish specific experiments is still a major factor in final selection of instrumentation for spaceborne applications. The current study provides a valuable framework for evaluating instruments for Space Station application and points out advantages, disadvantages, and possible difficulties in using commercial instruments. Instruments not considered by this survey can and should be evaluated by the same method as presented here. This is especially useful for instruments developed between the time that this report was published

Relative Weighting Factor	Category	Definition
1.0	Safety	Presence of hazards such as flame, toxocity, radiation, microorganisms, etc. High rating for safe types of instruments.
1.0	Versatility	The number of different types of measurements and experiments in which the instrument can be used.
0.9	Ease of Modification	Number and complexity of modifications of commercial instruments necessary for space-station use. High rating for easy modification.
0.8	Spacecraft Interface	Need or recommendation for interface with spacecraft systems. High rating for low interface requirements.
0.8	Sampling Simplicity	Ease with which samples are prepared, handled, or introduced.
0.7	Power	Electric power used (115 V ac, 60 Hz assumed). High ratings for low power consumption.
0.7	Other Utilities	Need for other service (vacuum, gas, water, etc.). High ratings for low need.
0.6	Maintainability	Simplicity or lack of needed maintenance, calibration, alignment, etc.
0.6	Ease of Operation	Simplicity of operation and skills needed. High rating for low skills needed.
0.6	Environmental Sensitivity	Sensitivity to environmental conditions--temperature, pressure, radiation, shock, etc. High rating for low sensitivity.
0.6	Heat Generated	Heat which needs to be dissipated during warm-up, standby, and operation. High rating for low heat-producing equipments.
0.5	Electromagnetic Interference	Radiation of EMI during warm-up or normal operation. High rating for lack of interference.
0.5	Warm-up and Speed of Operation	Time needed for warm-up or preparation of instrument for use. High rating for short time.
0.4	Size	Includes both volume and mass. High rating for small, light instruments.
0.4	Power Conversion	Ease of conversion to operate on 28 V dc or 400 Hz ac power.
0.4	Supplies Needed	Need for supplies such as ink, paper, reagents, etc. High rating for low need.
0.3	Ease of Packing/ Installation	Lack of special packing and installation procedures.

Table 4-1. Instrument Rating Categories

and the time when the Space Station becomes a reality. Of importance is the fact that the ratings and weighting factors, although derived after considerable study and experience, are arbitrary, and should certainly be re-evaluated as more modern instruments become available. As priorities in the Space Station change, the weighting factors should certainly reflect these new priorities.

The instrument types are listed in order of decreasing flyability indexes in Table 4-26. The rank order of instruments in this table confirms many expectations of the suitability of particular commercial instruments for Space Station application. Those most suitable are instruments which themselves are products of space-age technology adapted for commercial use: digital multimeters, portable magnetic tape recorders, and function generators. Beckman has developed a space qualified colorimeter and specific ion electrodes for the IMBLMS program. Also, electrochemical oxygen sensors, developed for Gemini and Apollo programs, have been manufactured for clinical use by Beckman. Audiometers and optical test equipment, although not specifically space age instruments, appear as highly suitable categories for using commercial instruments to fill Space Station needs.

The end of Table 4-26 lists instruments which are the least suitable for application in the Space Station. These are the ultracentrifuges and mass spectrometers. These instruments are large, heavy, power hungry, complex, difficult to operate, perhaps even dangerous. They have low flyability indexes not merely because they are commercial instruments; instead, their character is determined by the functions they perform. Further, if the Space Station is to provide instrumentation to meet the needs of many diverse disciplines, experiments, and scientists, the full instrumentation capabilities must be available, if needed. We suggest <u>need</u> as the primary determination for flying an instrument in Space Station.

None of the many instruments surveyed in this study was found to be completely unflyable. Even an analytical ultracentrifuge can be flown, if it is needed. This instrument will, however, cost power, weight, and space; must be modified (if a commercial unit is chosen) and complexly integrated with the vehicle systems; and must be used with the most stringent safety routines.

The analytical ultracentrifuge was surveyed in this study as an extreme in size, weight, and complexity. There is not at present an identified need for such an instrument in any of the functional program elements in the current version of the Blue Book. But, the ultracentrifuge is an instrument of considerable analytical value without alternative instruments for substitution. The only alternative to flying an ultracentrifuge would be returning samples to an earth based laboratory for analysis.

Other instruments with relatively low flyability indexes will be essential to the Space Station experiment program: spectrophotometers, mass spectrometers, and radiation counting equipment. These instruments, for example, are powerful analytical tools which the Space Station must include if it is truly to provide well equipped laboratory facilities.

Category	Weighting Factor	MANUAL Rating	MANUAL Weighted Rating	AUTOMATIC Rating	AUTOMATIC Weighted Rating
SAFETY	1.0	5	5.0	5	5.0
VERSATILITY	1.0	2	2.0	2	2.0
EASE OF MODIFICATION	0.9	5	4.5	4	3.6
SPACECRAFT INTERFACE	0.8	5	4.0	5	4.0
SAMPLING SIMPLICITY	0.8	4	3.2	5	4.0
POWER	0.7	4	2.8	4	2.8
OTHER UTILITIES	0.7	5	3.5	5	3.5
MAINTAINABILITY	0.6	4	2.4	4	2.4
EASE OF OPERATION	0.6	4	2.4	5	3.0
ENVIRONMENTAL SENSITIVITY	0.6	5	3.0	4	2.4
HEAT GENERATED	0.6	4	2.4	4	2.4
ELECTROMAGNETIC INTERFERENCE	0.5	4	2.0	4	2.0
WARM-UP AND OPERATING SPEED	0.5	4	2.0	4	2.0
SIZE	0.4	5	2.0	4	1.6
POWER CONVERSION	0.4	3	1.2	3	1.2
SUPPLIES NEEDED	0.4	5	2.0	4	1.6
EASE OF PACKING/INSTALLATION	0.3	4	1.2	4	1.2
TOTAL (FLYABILITY INDEX)			45.6		44.7

RATINGS:
1. Inferior
2. Below Average
3. Average
4. Above Average
5. Superior

	MANUAL	AUTOMATIC
Advantages:	Independent Operation Little Logistic Support Portability	Ease of Operation Independent Operation
Disadvantages:	Single Use Only	Single Use Only

Table 4-2. Audiometers--Flyability Index Rating

Category	Weighting Factor	Rating	Weighted Rating
SAFETY	1.0	2	2.0
VERSATILITY	1.0	4	4.0
EASE OF MODIFICATION	0.9	3	2.7
SPACECRAFT INTERFACE	0.8	2	1.6
SAMPLING SIMPLICITY	0.8	4	3.2
POWER	0.7	3	2.1
OTHER UTILITIES	0.7	2	1.4
MAINTAINABILITY	0.6	3	1.8
EASE OF OPERATION	0.6	4	2.4
ENVIRONMENTAL SENSITIVITY	0.6	3	1.8
HEAT GENERATED	0.6	2	1.2
ELECTROMAGNETIC INTERFERENCE	0.5	3	1.5
WARM-UP AND OPERATING SPEED	0.5	2	1.0
SIZE	0.4	3	1.2
POWER CONVERSION	0.4	2	0.8
SUPPLIES NEEDED	0.4	3	1.2
EASE OF PACKING/INSTALLATION	0.3	3	0.9
TOTAL (FLYABILITY INDEX)			30.8

RATINGS:
1. Inferior
2. Below Average
3. Average
4. Above Average
5. Superior

Advantages:
Versatility
Ease of Operation
Sampling Simplicity

Disadvantages:
Warm-up
Heat Generated
Safety

Table 4-3. Atomic Absorption Spectrometer--Flyability Index Rating

		DISSOLVED O_2 SENSOR		DISSOLVED CO_2 SENSOR		AMPLIFIER/READOUT	
Category	**Weighting Factor**	**Rating**	**Weighted Rating**	**Rating**	**Weighted Rating**	**Rating**	**Weighted Rating**
SAFETY	1.0	5	5.0	4	4.0	4	4.0
VERSATILITY	1.0	2	2.0	2	2.0	3	3.0
EASE OF MODIFICATION	0.9	3	2.7	3	2.7	4	3.6
SPACECRAFT INTERFACE	0.8	5	4.0	5	4.0	5	4.0
SAMPLING SIMPLICITY	0.8	3	2.4	3	2.4	4	3.2
POWER	0.7	5	3.5	5	3.5	4	2.8
OTHER UTILITIES	0.7	5	3.5	5	3.5	5	3.5
MAINTAINABILITY	0.6	2	1.2	2	1.2	4	2.4
EASE OF OPERATION	0.6	3	1.8	3	1.8	4	2.4
ENVIRONMENTAL SENSITIVITY	0.6	2	1.2	2	1.2	4	2.4
HEAT GENERATED	0.6	5	3.0	5	3.0	3	1.8
ELECTROMAGNETIC INTERFERENCE	0.5	5	2.5	5	2.5	4	2.0
WARM-UP AND OPERATING SPEED	0.5	4	2.0	4	2.0	5	2.5
SIZE	0.4	5	2.0	5	2.0	4	1.6
POWER CONVERSION	0.4	4	1.6	4	1.6	3	1.2
SUPPLIES NEEDED	0.4	4	1.6	4	1.6	5	2.0
EASE OF PACKING/INSTALLATION	0.3	3	0.9	3	0.9	3	0.9
TOTAL (FLYABILITY INDEX)			**40.9**		**39.9**		**43.3**
RATINGS: 1. Inferior 2. Below Average 3. Average 4. Above Average 5. Superior	**Advantages:**	Size and Power Independent Operation		Size and Power Independent Operation		Size and Power Independent Operation	
	Disadvantages:	Sample Handling Problem Calibration Maintenance		Sample Handling Problem Calibration Maintenance		Sample Handling Problem Calibration Maintenance	

Table 4-4. Blood Gas Analyzers--Flyability Index Rating

Category	Weighting Factor	IMPEDANCE TYPE		LIGHT SCATTERING TYPE		FIREFLY ENZYME TYPE		MANUAL COUNTING TYPE	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
SAFETY	1.0	3	3.0	3	3.0	3	3.0	2	2.0
VERSATILITY	1.0	3	3.0	3	3.0	2	2.0	3	3.0
EASE OF MODIFICATION	0.9	2	1.8	3	2.7	3	2.7	3	2.7
SPACECRAFT INTERFACE	0.8	3	2.4	3	2.4	3	2.4	3	2.4
SAMPLING SIMPLICITY	0.8	4	3.2	4	3.2	3	2.4	4	3.2
POWER	0.7	3	2.1	3	2.1	3	2.1	4	2.8
OTHER UTILITIES	0.7	4	2.8	4	2.8	2	1.4	4	2.8
MAINTAINABILITY	0.6	2	1.2	2	1.2	3	1.8	4	2.4
EASE OF OPERATION	0.6	2	1.2	2	1.2	2	1.2	3	1.8
ENVIRONMENTAL SENSITIVITY	0.6	3	1.8	3	1.8	3	1.8	3	1.8
HEAT GENERATED	0.6	3	1.8	3	1.8	3	1.8	3	1.8
ELECTROMAGNETIC INTERFERENCE	0.5	3	1.5	3	1.5	3	1.5	2	1.0
WARM-UP AND OPERATING SPEED	0.5	3	1.5	3	1.5	3	1.5	4	2.0
SIZE	0.4	3	1.2	3	1.2	4	1.6	4	1.6
POWER CONVERSION	0.4	3	1.2	3	1.2	3	1.2	4	1.6
SUPPLIES NEEDED	0.4	3	1.2	3	1.2	2	0.8	3	1.2
EASE OF PACKING/INSTALLATION	0.3	3	0.9	3	0.9	3	0.9	3	0.9
TOTAL (FLYABILITY INDEX)			31.8		32.7		30.1		35.0
RATINGS: 1. Inferior 2. Below Average 3. Average 4. Above Average 5. Superior	Advantages:	Easy Connection with Sample Handling Tubes		Easy Connection with Sample Handling Tubes		Same Tests can be Made with a Liquid Scintillation Counter		None	
	Disadvantages:	Modification Needed		Modification Needed		Applicable only to Bacteria		Requires Use on Open Culture Plates Counts only Bacteria Colonies	

Table 4-5. Cell Counters--Flyability Index

		GENERAL PURPOSE ULTRACENTRIFUGE		PREPARATIVE ULTRACENTRIFUGE		ANALYTICAL ULTRACENTRIFUGE		HEMATOCRIT CENTRIFUGE	
Category	Weighting Factor	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
SAFETY	1.0	3	3.0	1	1.0	1	1.0	3	3.0
VERSATILITY	1.0	5	5.0	3	3.0	1	1.0	1	1.0
EASE OF MODIFICATION	0.9	3	2.7	2	1.8	1	0.9	4	3.6
SPACECRAFT INTERFACE	0.8	4	3.2	2	1.6	1	0.8	4	3.2
SAMPLING SIMPLICITY	0.8	4	3.2	2	1.6	1	0.8	3	2.4
POWER	0.7	4	2.8	1	0.7	1	0.7	3	2.1
OTHER UTILITIES	0.7	5	3.5	2	1.4	2	1.4	5	3.5
MAINTAINABILITY	0.6	3	1.8	2	1.2	2	1.2	3	1.8
EASE OF OPERATION	0.6	4	2.4	2	1.2	1	0.6	4	2.4
ENVIRONMENTAL SENSITIVITY	0.6	3	1.8	2	1.2	2	1.2	3	1.8
HEAT GENERATED	0.6	3	1.8	1	0.6	1	0.6	4	2.4
ELECTROMAGNETIC INTERFERENCE	0.5	2	1.0	2	1.0	2	1.0	2	1.0
WARM-UP AND OPERATING SPEED	0.5	4	2.0	1	0.5	1	0.5	4	2.0
SIZE	0.4	3	1.2	1	0.4	1	0.4	5	2.0
POWER CONVERSION	0.4	3	1.2	2	0.8	2	0.8	3	1.2
SUPPLIES NEEDED	0.4	5	2.0	3	1.2	3	1.2	4	1.6
EASE OF PACKING/INSTALLATION	0.3	3	0.9	2	0.6	2	0.6	3	0.9
TOTAL (FLYABILITY INDEX)			39.5		19.8		14.7		35.9

RATINGS: 1. Inferior 2. Below Average 3. Average 4. Above Average 5. Superior		GENERAL PURPOSE ULTRACENTRIFUGE	PREPARATIVE ULTRACENTRIFUGE	ANALYTICAL ULTRACENTRIFUGE	HEMATOCRIT CENTRIFUGE
	Advantages:	Versatility Sampling Simplicity	None (unless instrument is needed)	None (unless instrument is needed)	Size Sampling Simplicity
	Disadvantages:	Electromagnetic Interference	Power Used Heat Generated Safety	Power Needed Heat Generated Safety	None

Table 4-6. Centrifuges--Flyability Index Rating

Category	Weighting Factor	Rating	Weighted Rating
SAFETY	1.0	3	3.0
VERSATILITY	1.0	1	1.0
EASE OF MODIFICATION	0.9	4	3.6
SPACECRAFT INTERFACE	0.8	5	4.0
SAMPLING SIMPLICITY	0.8	5	4.0
POWER	0.7	4	2.8
OTHER UTILITIES	0.7	5	3.5
MAINTAINABILITY	0.6	4	2.4
EASE OF OPERATION	0.6	5	3.0
ENVIRONMENTAL SENSITIVITY	0.6	4	2.4
HEAT GENERATED	0.6	4	2.4
ELECTROMAGNETIC INTERFERENCE	0.5	5	2.5
WARM-UP AND OPERATING SPEED	0.5	4	2.0
SIZE	0.4	5	2.0
POWER CONVERSION	0.4	5	2.0
SUPPLIES NEEDED	0.4	4	1.6
EASE OF PACKING/INSTALLATION	0.3	4	1.2
TOTAL (FLYABILITY INDEX)			43.4

RATINGS:

1. Inferior
2. Below Average
3. Average
4. Above Average
5. Superior

Advantages:

Size and Power
Independent Operation
Operating Simplicity

Disadvantages:

Usable for only one measurement
Breakable glass capillary needed

Table 4-7. Electronic Hematocrit--Flyability Index Rating

		OSCILLOSCOPE		DIGITAL MULTIMETER		FUNCTION GENERATOR		
Category	Weighting Factor	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	
SAFETY	1.0	4	4.0	5	5.0	5	5.0	
VERSATILITY	1.0	4	4.0	4	4.0	4	4.0	
EASE OF MODIFICATION	0.9	5	4.5	5	4.5	5	4.5	
SPACECRAFT INTERFACE	0.8	5	4.0	5	4.0	5	4.0	
SAMPLING SIMPLICITY	0.8	5	4.0	5	4.0	5	4.0	
POWER	0.7	5	3.5	5	3.5	5	3.5	
OTHER UTILITIES	0.7	5	3.5	5	3.5	5	3.5	
MAINTAINABILITY	0.6	2	1.2	3	1.8	3	1.8	
EASE OF OPERATION	0.6	3	1.8	5	3.0	4	2.4	
ENVIRONMENTAL SENSITIVITY	0.6	4	2.4	4	2.4	4	2.4	
HEAT GENERATED	0.6	5	3.0	5	3.0	5	3.0	
ELECTROMAGNETIC INTERFERENCE	0.5	4	2.0	4	2.0	4	2.0	
WARM-UP AND OPERATING SPEED	0.5	4	2.0	5	2.5	5	2.5	
SIZE	0.4	5	2.0	5	2.0	5	2.0	
POWER CONVERSION	0.4	5	2.0	5	2.0	5	2.0	
SUPPLIES NEEDED	0.4	5	2.0	5	2.0	5	2.0	
EASE OF PACKING/INSTALLATION	0.3	4	1.2	5	1.5	5	1.5	
TOTAL (FLYABILITY INDEX)			47.1		50.7		50.1	

RATINGS:
1. Inferior
2. Below Average
3. Average
4. Above Average
5. Superior

Advantages: None

Disadvantages: None

Table 4-8. Electronic Test Equipment--Flyability Index Rating

Category	Weighting Factor	Rating	Weighted Rating
SAFETY	1.0	5	5.0
VERSATILITY	1.0	5	5.0
EASE OF MODIFICATION	0.9	4	3.6
SPACECRAFT INTERFACE	0.8	3	2.4
SAMPLING SIMPLICITY	0.8	4	3.2
POWER	0.7	4	2.8
OTHER UTILITIES	0.7	4	2.8
MAINTAINABILITY	0.6	3	1.8
EASE OF OPERATION	0.6	3	1.8
ENVIRONMENTAL SENSITIVITY	0.6	2	1.2
HEAT GENERATED	0.6	3	1.8
ELECTROMAGNETIC INTERFERENCE	0.5	2	1.0
WARM-UP AND OPERATING SPEED	0.5	4	2.0
SIZE	0.4	4	2.0
POWER CONVERSION	0.4	4	2.0
SUPPLIES NEEDED	0.4	3	1.2
EASE OF PACKING/INSTALLATION	0.3	3	0.9
TOTAL (FLYABILITY INDEX)			40.5

RATINGS:
1. Inferior
2. Below Average
3. Average
4. Above Average
5. Superior

Advantages: Versatility, Safety

Disadvantages: Sensitive to EMI

Table 4-9. Electrophysiological Equipment--Flyability Index Rating

Category	Weighting Factor	Rating	Weighted Rating
SAFETY	1.0	2	2.0
VERSATILITY	1.0	5	5.0
EASE OF MODIFICATION	0.9	4	3.6
SPACECRAFT INTERFACE	0.8	3	2.4
SAMPLING SIMPLICITY	0.8	3	2.4
POWER	0.7	1	0.7
OTHER UTILITIES	0.7	3	2.1
MAINTAINABILITY	0.6	4	2.4
EASE OF OPERATION	0.6	4	2.4
ENVIRONMENTAL SENSITIVITY	0.6	3	1.8
HEAT GENERATED	0.6	4	2.4
ELECTROMAGNETIC INTERFERENCE	0.5	2	1.0
WARM-UP AND OPERATING SPEED	0.5	4	2.0
SIZE	0.4	2	0.8
POWER CONVERSION	0.4	1	0.4
SUPPLIES NEEDED	0.4	2	0.8
EASE OF PACKING/INSTALLATION	0.3	2	0.6
TOTAL (FLYABILITY INDEX)			32.8

RATINGS:
1. Inferior
2. Below Average
3. Average
4. Above Average
5. Superior

Advantages:

Pwr Reqd only during Anal.
Versatile--analyzes many elements & materials.

Disadvantages:

Large size.
Pwr reqmts during analysis can be large
Safety problems during sample ignition

Table 4-10, Emission Spectrometer--Flyability Index Rating

Category	Weighting Factor	Rating	Weighted Rating
SAFETY	1.0	1	1.0
VERSATILITY	1.0	2	2.0
EASE OF MODIFICATION	0.9	3	2.7
SPACECRAFT INTERFACE	0.8	2	1.6
SAMPLING SIMPLICITY	0.8	4	3.2
POWER	0.7	3	2.1
OTHER UTILITIES	0.7	2	1.4
MAINTAINABILITY	0.6	3	1.8
EASE OF OPERATION	0.6	4	2.4
ENVIRONMENTAL SENSITIVITY	0.6	3	1.8
HEAT GENERATED	0.6	2	1.2
ELECTROMAGNETIC INTERFERENCE	0.5	3	1.5
WARM-UP AND OPERATING SPEED	0.5	3	1.5
SIZE	0.4	3	1.2
POWER CONVERSION	0.4	3	1.2
SUPPLIES NEEDED	0.4	3	1.2
EASE OF PACKING/INSTALLATION	0.3	3	0.9
TOTAL (FLYABILITY INDEX)			28.6

RATINGS:

1. Inferior
2. Below Average
3. Average
4. Above Average
5. Superior

Advantages:

Sampling Simplicity
Ease of Operation

Disadvantages:

Flame Needed
Gas Needed
Venting Needed

Table 4-11. Flame Photometer--Flyability Index Rating

		SINGLE OR DUAL COLUMN TC DETECTOR		HIGH SENSITIVITY DETECTOR TYPE		PREPARATIVE	
Category	**Weighting Factor**	**Rating**	**Weighted Rating**	**Rating**	**Weighted Rating**	**Rating**	**Weighted Rating**
SAFETY	1.0	3	3.0	3	3.0	3	3.0
VERSATILITY	1.0	5	5.0	5	5.0	3	3.0
EASE OF MODIFICATION	0.9	4	3.6	4	3.6	4	3.6
SPACECRAFT INTERFACE	0.8	3	2.4	3	2.4	3	2.4
SAMPLING SIMPLICITY	0.8	4	3.2	4	3.2	4	3.2
POWER	0.7	2	1.4	2	1.4	2	1.4
OTHER UTILITIES	0.7	2	1.4	2	1.4	2	1.4
MAINTAINABILITY	0.6	3	1.8	3	1.8	3	1.8
EASE OF OPERATION	0.6	3	1.8	3	1.8	3	1.8
ENVIRONMENTAL SENSITIVITY	0.6	4	2.4	3	1.8	4	2.4
HEAT GENERATED	0.6	2	1.2	2	1.2	2	1.2
ELECTROMAGNETIC INTERFERENCE	0.5	4	2.0	4	2.0	4	2.0
WARM-UP AND OPERATING SPEED	0.5	2	1.0	2	1.0	2	1.0
SIZE	0.4	3	1.2	3	1.2	2	0.8
POWER CONVERSION	0.4	3	1.2	2	0.8	2	0.8
SUPPLIES NEEDED	0.4	2	0.8	2	0.8	1	0.4
EASE OF PACKING/INSTALLATION	0.3	3	0.9	3	0.9	2	0.6
TOTAL (FLYABILITY INDEX)			**34.3**		**33.3**		**30.8**
RATINGS: 1. Inferior 2. Below Average 3. Average 4. Above Average 5. Superior	**Advantages:**	Versatility Sampling Simplicity Ease of Modification		Versatility Sampling Simplicity Ease of Modification		Sampling Simplicity Ease of Modification	
	Disadvantages:	Warm-up and Operating Speed Heat Generated Supplies Needed		Warm-up and Operating Speed Heat Generated Supplies Needed		Supplies Needed Warm-up and Operating Speed Size	

Table 4-12. Gas Chromatographs--Flyability Index Rating

		NONDISPERSIVE TYPE (LABORATORY)		NONDISPERSIVE TYPE (PROCESS)		BREATH ANALYZER (LABORATORY)	
Category	Weighting Factor	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
SAFETY	1.0	5	5.0	5	5.0	5	5.0
VERSATILITY	1.0	3	3.0	3	3.0	2	2.0
EASE OF MODIFICATION	0.9	4	3.6	4	3.6	4	3.6
SPACECRAFT INTERFACE	0.8	4	3.2	4	3.2	4	3.2
SAMPLING SIMPLICITY	0.8	4	3.2	4	3.2	4	3.2
POWER	0.7	3	2.1	3	2.1	3	2.1
OTHER UTILITIES	0.7	4	2.8	4	2.8	4	2.8
MAINTAINABILITY	0.6	3	1.8	3	1.8	3	1.8
EASE OF OPERATION	0.6	5	3.0	5	3.0	4	2.4
ENVIRONMENTAL SENSITIVITY	0.6	2	1.2	2	1.2	2	1.2
HEAT GENERATED	0.6	3	1.8	3	1.8	3	1.8
ELECTROMAGNETIC INTERFERENCE	0.5	3	1.5	3	1.5	3	1.5
WARM-UP AND OPERATING SPEED	0.5	4	2.0	4	2.0	4	2.0
SIZE	0.4	3	1.2	3	1.2	3	1.2
POWER CONVERSION	0.4	3	1.2	3	1.2	3	1.2
SUPPLIES NEEDED	0.4	4	1.6	4	1.6	4	1.6
EASE OF PACKING/INSTALLATION	0.3	3	0.9	3	0.9	3	0.9
TOTAL (FLYABILITY INDEX)			39.1		39.1		37.5

RATINGS: 1. Inferior 2. Below Average 3. Average 4. Above Average 5. Superior		Nondispersive Type (Laboratory)	Nondispersive Type (Process)	Breath Analyzer (Laboratory)
	Advantages:	Ease of Operation Sampling Simplicity Safety	Ease of Operation Sampling Simplicity Safety	Ease of Operation Safety Sampling Simplicity
	Disadvantages:	Environmental Sensitivity Power Conversion Maintainability	Environmental Sensitivity Power Conversion Maintainability	Environmental Sensitivity Versatility Maintainability

Table 4-13. Infrared Analyzers--Flyability Index Rating

		MAGNETIC SECTOR		QUADRUPOLE		DOUBLE FOCUSING	
Category	Weighting Factor	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
SAFETY	1.0	3	3.0	3	3.0	3	3.0
VERSATILITY	1.0	4	4.0	4	4.0	4	4.0
EASE OF MODIFICATION	0.9	2	1.8	3	2.7	1	0.9
SPACECRAFT INTERFACE	0.8	2	1.6	2	1.6	2	1.6
SAMPLING SIMPLICITY	0.8	3	2.4	3	2.4	3	2.4
POWER	0.7	2	1.4	2	1.4	1	0.7
OTHER UTILITIES	0.7	3	2.1	3	2.1	3	2.1
MAINTAINABILITY	0.6	1	0.6	1	0.6	1	0.6
EASE OF OPERATION	0.6	2	1.2	2	1.2	1	0.6
ENVIRONMENTAL SENSITIVITY	0.6	2	1.2	3	1.8	2	1.2
HEAT GENERATED	0.6	3	1.8	3	1.8	3	1.8
ELECTROMAGNETIC INTERFERENCE	0.5	3	1.5	2	1.0	2	1.0
WARM-UP AND OPERATING SPEED	0.5	2	1.0	2	1.0	2	1.0
SIZE	0.4	2	0.8	2	0.8	1	0.4
POWER CONVERSION	0.4	1	0.4	1	0.4	1	0.4
SUPPLIES NEEDED	0.4	3	1.2	3	1.2	3	1.2
EASE OF PACKING/INSTALLATION	0.3	2	0.6	2	0.6	2	0.6
TOTAL (FLYABILITY INDEX)			**26.6**		**27.6**		**23.5**
RATINGS: 1. Inferior 2. Below Average 3. Average 4. Above Average 5. Superior	**Advantages:**	Versatility Sampling Simplicity		Versatility Environmental Sensitivity		Versatility Sampling Simplicity	
	Disadvantages:	Maintainability Power Conversion Difficulty of Installation		Maintainability Power Conversion Power		Maintainability Power Conversion Size	

Table 4-14. Mas Spectrometers--Flyability Index Rating

Category	Weighting Factor	LABORATORY Rating	LABORATORY Weighted Rating	METALOGRAPHIC Rating	METALOGRAPHIC Weighted Rating	STEREO Rating	STEREO Weighted Rating
SAFETY	1.0	4	4.0	4	4.0	4	4.0
VERSATILITY	1.0	5	5.0	3	3.0	4	4.0
EASE OF MODIFICATION	0.9	5	4.5	5	4.5	5	4.5
SPACECRAFT INTERFACE	0.8	4	3.2	4	3.2	4	3.2
SAMPLING SIMPLICITY	0.8	4	3.2	3	2.4	3	2.4
POWER	0.7	4	2.8	4	2.8	4	2.8
OTHER UTILITIES	0.7	5	3.5	5	3.5	5	3.5
MAINTAINABILITY	0.6	4	2.4	4	2.4	4	2.4
EASE OF OPERATION	0.6	3	1.8	3	1.8	3	1.8
ENVIRONMENTAL SENSITIVITY	0.6	4	2.4	4	2.4	4	2.4
HEAT GENERATED	0.6	3	1.8	3	1.8	3	1.8
ELECTROMAGNETIC INTERFERENCE	0.5	4	2.0	4	2.0	4	2.0
WARM-UP AND OPERATING SPEED	0.5	3	1.5	3	1.5	3	1.5
SIZE	0.4	4	1.6	4	1.6	4	1.6
POWER CONVERSION	0.4	5	2.0	5	2.0	5	2.0
SUPPLIES NEEDED	0.4	3	1.2	4	1.6	4	1.6
EASE OF PACKING/INSTALLATION	0.3	3	0.9	3	0.9	3	0.9
TOTAL (FLYABILITY INDEX)			43.8		41.4		42.4

RATINGS:
1. Inferior
2. Below Average
3. Average
4. Above Average
5. Superior

	LABORATORY	METALOGRAPHIC	STEREO
Advantages:	Versatility Few Utilities Needed Independent operation	Versatility Few Utilities Needed Independent operation	Versatility Few Utilities Needed Independent operation
Disadvantages:	Operator skill needed	Operator skill needed	Operator skill needed

Table 4-15. Microscopes--Flyability Index Rating

Category	Weighting Factor	ROTARY Rating	ROTARY Weighted Rating	SLIDING Rating	SLIDING Weighted Rating	VIBRATING Rating	VIBRATING Weighted Rating
SAFETY	1.0	2	2.0	2	2.0	3	3.0
VERSATILITY	1.0	3	3.0	3	3.0	2	2.0
EASE OF MODIFICATION	0.9	4	3.6	5	4.5	3	2.7
SPACECRAFT INTERFACE	0.8	5	4.0	5	4.0	4	3.2
SAMPLING SIMPLICITY	0.8	3	2.4	3	2.4	3	2.4
POWER	0.7	4	2.8	4	2.8	3	2.1
OTHER UTILITIES	0.7	5	3.5	5	3.5	4	2.8
MAINTAINABILITY	0.6	4	2.4	4	2.4	3	1.8
EASE OF OPERATION	0.6	2	1.2	2	1.2	2	1.2
ENVIRONMENTAL SENSITIVITY	0.6	3	1.8	3	1.8	3	1.8
HEAT GENERATED	0.6	5	3.0	5	3.0	4	2.4
ELECTROMAGNETIC INTERFERENCE	0.5	5	2.5	5	2.5	2	1.0
WARM-UP AND OPERATING SPEED	0.5	3	1.5	3	1.5	3	1.5
SIZE	0.4	3	1.2	3	1.2	4	1.6
POWER CONVERSION	0.4	4	1.6	4	1.6	3	1.2
SUPPLIES NEEDED	0.4	3	1.2	3	1.2	3	1.2
EASE OF PACKING/INSTALLATION	0.3	3	0.9	3	0.9	3	0.9
TOTAL (FLYABILITY INDEX)			38.6		39.5		32.8
RATINGS: 1. Inferior 2. Below Average 3. Average 4. Above Average 5. Superior	Advantages:	Independent Operation No Utilities Needed No Heat Generated		Independent Operation No Utilities Needed No Heat Generated		Size No Utilities Needed	
	Disadvantages:	Safety Difficult to Operate		Safety Difficult to Operate		Safety Difficult to Modify	

Table 4-16. Microtomes--Flyability Index Rating

		OPTICAL BENCH SURFACE PLATE CIRCULAR TABLE		AUTOCOLLIMATOR ALIGNMENT TELESCOPE REFLEX MICROSCOPE		INTERFEROMETER		MODULATION TRANSFER FUNCTION EQUIPMENT	
Category	Weighting Factor	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
SAFETY	1.0	4	4.0	5	5.0	4	4.0	4	4.0
VERSATILITY	1.0	5	5.0	5	5.0	5	5.0	3	3.0
EASE OF MODIFICATION	0.9	5	4.5	4	3.6	5	4.5	4	3.6
SPACECRAFT INTERFACE	0.8	3	2.4	4	3.2	4	3.2	3	2.4
SAMPLING SIMPLICITY	0.8	2	1.6	4	3.2	3	2.4	2	1.6
POWER	0.7	5	3.5	3	2.1	3	2.1	2	1.4
OTHER UTILITIES	0.7	5	3.5	5	3.5	5	3.5	5	3.5
MAINTAINABILITY	0.6	3	1.8	4	2.4	3	1.8	3	1.8
EASE OF OPERATION	0.6	3	1.8	5	3.0	4	2.4	2	1.2
ENVIRONMENTAL SENSITIVITY	0.6	4	2.4	4	2.4	5	3.0	3	1.8
HEAT GENERATED	0.6	5	3.0	4	2.4	4	2.4	2	1.2
ELECTROMAGNETIC INTERFERENCE	0.5	5	2.5	5	2.5	5	2.5	3	1.5
WARM-UP AND OPERATING SPEED	0.5	5	2.5	4	2.0	4	2.0	3	1.5
SIZE	0.4	2	0.8	3	1.2	2	0.8	2	0.8
POWER CONVERSION	0.4	5	2.0	4	1.6	4	1.6	4	1.6
SUPPLIES NEEDED	0.4	3	1.2	4	1.6	3	1.2	2	0.8
EASE OF PACKING/INSTALLATION	0.3	1	0.3	2	0.6	2	0.6	1	0.3
TOTAL (FLYABILITY INDEX)			38.0		45.3		43.0		32.0
Advantages:		Simplicity		Versatility		None		None	
Disadvantages:		Size Weight		Fragility		None		Fragility	

RATINGS:
1. Inferior
2. Below Average
3. Average
4. Above Average
5. Superior

Table 4-17. Optical Test Equipment--Flyability Index Rating

Category	Weighting Factor	MEMBRANE Rating	MEMBRANE Weighted Rating	VAPOR PRESSURE Rating	VAPOR PRESSURE Weighted Rating	CYROSCOPIC Rating	CYROSCOPIC Weighted Rating
SAFETY	1.0	3	3.0	3	3.0	3	3.0
VERSATILITY	1.0	3	3.0	3	3.0	3	3.0
EASE OF MODIFICATION	0.9	2	1.8	2	1.8	3	2.7
SPACECRAFT INTERFACE	0.8	3	2.4	3	2.4	3	2.4
SAMPLING SIMPLICITY	0.8	1	0.8	2	1.6	3	2.4
POWER	0.7	3	2.1	3	2.1	3	2.1
OTHER UTILITIES	0.7	3	2.1	3	2.1	3	2.1
MAINTAINABILITY	0.6	3	1.8	3	1.8	3	1.8
EASE OF OPERATION	0.6	2	1.2	2	1.2	3	1.8
ENVIRONMENTAL SENSITIVITY	0.6	2	1.2	2	1.2	3	1.8
HEAT GENERATED	0.6	3	1.8	3	1.8	3	1.8
ELECTROMAGNETIC INTERFERENCE	0.5	3	1.5	3	1.5	3	1.5
WARM-UP AND OPERATING SPEED	0.5	3	1.5	3	1.5	3	1.5
SIZE	0.4	3	1.2	3	1.2	3	1.2
POWER CONVERSION	0.4	3	1.2	3	1.2	3	1.2
SUPPLIES NEEDED	0.4	2	0.8	2	0.8	2	0.8
EASE OF PACKING/INSTALLATION	0.3	3	0.9	3	0.9	3	0.9
TOTAL (FLYABILITY INDEX)			38.3		29.1		32.0
RATINGS: 1. Inferior 2. Below Average 3. Average 4. Above Average 5. Superior	Advantages:	None		None		Ease of Operation	
	Disadvantages:	Sample Handling		Difficulty of Operation		None	

Table 4-18. Osmometers--Flyability Index Rating

		PARAMAGNETIC		CATALYTIC COMBUSTION		THERMAL CONDUCTIVITY		ELECTROCHEMICAL	
Category	Weighting Factor	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
SAFETY	1.0	4	4.0	1	1.0	2	2.0	5	5.0
VERSATILITY	1.0	3	3.0	3	3.0	3	3.0	3	3.0
EASE OF MODIFICATION	0.9	4	3.6	5	4.5	5	4.5	5	4.5
SPACECRAFT INTERFACE	0.8	5	4.0	5	4.0	5	4.0	5	4.0
SAMPLING SIMPLICITY	0.8	3	2.4	3	2.4	5	4.0	5	4.0
POWER	0.7	4	2.8	3	2.1	4	2.8	5	3.5
OTHER UTILITIES	0.7	5	3.5	5	3.5	5	3.5	5	3.5
MAINTAINABILITY	0.6	4	2.4	4	2.4	4	2.4	4	2.4
EASE OF OPERATION	0.6	5	3.0	5	3.0	5	3.0	5	3.0
ENVIRONMENTAL SENSITIVITY	0.6	2	1.2	4	2.4	4	2.4	5	3.0
HEAT GENERATED	0.6	4	2.4	3	1.8	4	2.4	5	3.0
ELECTROMAGNETIC INTERFERENCE	0.5	4	2.0	4	2.0	4	2.0	4	2.0
WARM-UP AND OPERATING SPEED	0.5	3	1.5	3	1.5	4	2.0	3	1.5
SIZE	0.4	3	1.2	4	1.6	4	1.6	5	2.0
POWER CONVERSION	0.4	3	1.2	2	0.8	2	0.8	4	1.6
SUPPLIES NEEDED	0.4	5	2.0	4	1.6	4	1.6	4	1.6
EASE OF PACKING/INSTALLATION	0.3	2	0.6	4	1.2	4	1.2	5	1.5
TOTAL (FLYABILITY INDEX)			40.8		38.8		43.2		49.1

RATINGS: 1. Inferior 2. Below Average 3. Average 4. Above Average 5. Superior		Paramagnetic	Catalytic Combustion	Thermal Conductivity	Electrochemical
	Advantages:	Measures O_2 Partial Pressure	None	Relatively Simple	Excellent Long-Term Stability Very Safe Rugged & shock resistant Measures O_2 Partial Pressure
	Disadvantages:	Shock & Vibration Sensitive	Combustion Requires High Temperature--Poses Safety Questions	Nonspecific for O_2 Use of Hydrogen Gas is Dangerous	Limited Life Sensor

Table 4-19. Oxygen Analyzers--Flyability Index Rating

Category	Weighting Factor	LIQUID SCINTILLATION		PLANCHET		GAMMA	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
SAFETY	1.0	3	3.0	3	3.0	3	3.0
VERSATILITY	1.0	4	4.0	3	3.0	2	2.0
EASE OF MODIFICATION	0.9	3	2.7	2	1.8	4	3.6
SPACECRAFT INTERFACE	0.8	3	2.4	3	2.4	3	2.4
SAMPLING SIMPLICITY	0.8	3	2.4	2	1.6	3	2.4
POWER	0.7	3	2.1	3	2.1	3	2.1
OTHER UTILITIES	0.7	3	2.1	3	2.1	3	2.1
MAINTAINABILITY	0.6	3	1.8	3	1.8	3	1.8
EASE OF OPERATION	0.6	3	1.8	2	1.2	3	1.8
ENVIRONMENTAL SENSITIVITY	0.6	2	1.2	2	1.2	2	1.2
HEAT GENERATED	0.6	3	1.8	3	1.8	3	1.8
ELECTROMAGNETIC INTERFERENCE	0.5	4	2.0	4	2.0	4	2.0
WARM-UP AND OPERATING SPEED	0.5	3	1.5	3	1.5	3	1.5
SIZE	0.4	2	0.8	2	0.8	3	1.2
POWER CONVERSION	0.4	3	1.2	3	1.2	3	1.2
SUPPLIES NEEDED	0.4	2	0.8	3	1.2	3	1.2
EASE OF PACKING/INSTALLATION	0.3	2	0.6	2	0.6	2	0.6
TOTAL (FLYABILITY INDEX)			32.2		29.3		31.9

RATINGS:		LIQUID SCINTILLATION	PLANCHET	GAMMA
1. Inferior 2. Below Average 3. Average	Advantages:	Versatility	None	Ease of Modification
4. Above Average 5. Superior	Disadvantages:	Installation Size Radiation Sensitivity	Difficult to Operate Radiation Sensitivity	Radiation Sensitivity

Table 4-20. Radiation Counters--Flyability Index Rating

		PYHELIOMETER		SPECTRORADIOMETER	
Category	Weighting Factor	Rating	Weighted Rating	Rating	Weighted Rating
SAFETY	1.0	5	5.0	3	3.0
VERSATILITY	1.0	2	2.0	5	5.0
EASE OF MODIFICATION	0.9	1	0.9	3	2.7
SPACECRAFT INTERFACE	0.8	4	3.2	3	2.4
SAMPLING SIMPLICITY	0.8	5	4.0	4	3.2
POWER	0.7	5	3.5	3	2.1
OTHER UTILITIES	0.7	5	3.5	5	3.5
MAINTAINABILITY	0.6	4	2.4	3	1.8
EASE OF OPERATION	0.6	5	3.0	3	1.8
ENVIRONMENTAL SENSITIVITY	0.6	4	2.4	5	3.0
HEAT GENERATED	0.6	5	3.0	3	1.8
ELECTROMAGNETIC INTERFERENCE	0.5	4	2.0	4	2.0
WARM-UP AND OPERATING SPEED	0.5	4	2.0	3	1.5
SIZE	0.4	5	2.0	2	0.8
POWER CONVERSION	0.4	5	2.0	3	1.2
SUPPLIES NEEDED	0.4	5	2.0	4	1.6
EASE OF PACKING/INSTALLATION	0.3	4	1.2	3	0.9
TOTAL (FLYABILITY INDEX)			44.1		38.3

	PYHELIOMETER	SPECTRORADIOMETER
Advantages:	Small and generally rugged	Versatile Many accessories available
Disadvantages:	Single Purpose Not a versatile research tool	Generally calibrated with high power lamp Fairly bulky

RATINGS:
1. Inferior
2. Below Average
3. Average
4. Above Average
5. Superior

Table 4-21. Radiometers--Flyability Index Rating

		STRIP CHART		MAGNETIC TAPE ANALOG OR DIGITAL		MAGNETIC TAPE AUDIO	
Category	Weighting Factor	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
SAFETY	1.0	4	4.0	5	5.0	5	5.0
VERSATILITY	1.0	4	4.0	3	3.0	3	3.0
EASE OF MODIFICATION	0.9	4	3.6	4	3.6	5	4.5
SPACECRAFT INTERFACE	0.8	5	4.0	5	4.0	5	4.0
SAMPLING SIMPLICITY	0.8	5	4.0	5	4.0	5	4.0
POWER	0.7	5	3.5	3	2.1	5	3.5
OTHER UTILITIES	0.7	5	3.5	5	3.5	5	3.5
MAINTAINABILITY	0.6	4	2.4	5	3.0	5	3.0
EASE OF OPERATION	0.6	4	2.4	4	2.4	5	3.0
ENVIRONMENTAL SENSITIVITY	0.6	4	2.4	4	2.4	4	2.4
HEAT GENERATED	0.6	5	3.0	4	2.4	5	3.0
ELECTROMAGNETIC INTERFERENCE	0.5	4	2.0	4	2.0	4	2.0
WARM-UP AND OPERATING SPEED	0.5	5	2.5	5	2.5	5	2.5
SIZE	0.4	4	1.6	3	1.2	5	2.0
POWER CONVERSION	0.4	4	1.6	2	0.8	5	2.0
SUPPLIES NEEDED	0.4	4	1.6	3	1.2	4	1.6
EASE OF PACKING/INSTALLATION	0.3	5	1.5	5	1.5	5	1.5
TOTAL (FLYABILITY INDEX)			47.7		44.6		50.5

RATINGS:		STRIP CHART	MAGNETIC TAPE ANALOG OR DIGITAL	MAGNETIC TAPE AUDIO
1. Inferior	Advantages:	None	None	Size Portability
2. Below Average				
3. Average				
4. Above Average				
5. Superior	Disadvantages:	None	Power Conversion	None

Table 4-22. Recorders--Flyability Index Rating

		GLASS ELECTRODES		MEMBRANE ELECTRODES	
Category	Weighting Factor	Rating	Weighted Rating	Rating	Weighted Rating
SAFETY	1.0	3	3.0	3	3.0
VERSATILITY	1.0	4	4.0	3	3.0
EASE OF MODIFICATION	0.9	5	4.5	5	4.5
SPACECRAFT INTERFACE	0.8	5	4.0	5	4.0
SAMPLING SIMPLICITY	0.8	4	3.2	4	3.2
POWER	0.7	5	3.5	5	3.5
OTHER UTILITIES	0.7	4	2.8	4	2.8
MAINTAINABILITY	0.6	3	1.8	3	1.8
EASE OF OPERATION	0.6	4	2.4	4	2.4
ENVIRONMENTAL SENSITIVITY	0.6	4	2.4	4	2.4
HEAT GENERATED	0.6	5	3.0	5	3.0
ELECTROMAGNETIC INTERFERENCE	0.5	5	2.5	5	2.5
WARM-UP AND OPERATING SPEED	0.5	4	2.0	4	2.0
SIZE	0.4	5	2.0	5	2.0
POWER CONVERSION	0.4	5	2.0	5	2.0
SUPPLIES NEEDED	0.4	3	1.2	3	1.2
EASE OF PACKING/INSTALLATION	0.3	5	1.5	5	1.5
TOTAL (FLYABILITY INDEX)			45.8		44.8
RATINGS: 1. Inferior 2. Below Average 3. Average 4. Above Average 5. Superior	Advantages:	Low Power, Few Modifications Needed		Low Power, Few Modifications Needed	
	Disadvantages:	Maintenance, Safety		Maintenance, Safety	

Table 4-23. Specific Ion Electrodes--Flyability Index Rating

		ULTRAVIOLET SPECTROPHOTOMETER		INFRARED SPECTROPHOTOMETER		COLORIMETER	
Category	**Weighting Factor**	**Rating**	**Weighted Rating**	**Rating**	**Weighted Rating**	**Rating**	**Weighted Rating**
SAFETY	1.0	3	3.0	2	2.0	5	5.0
VERSATILITY	1.0	4	4.0	4	4.0	5	5.0
EASE OF MODIFICATION	0.9	2	1.8	2	1.8	5	4.5
SPACECRAFT INTERFACE	0.8	3	2.4	3	2.4	5	4.0
SAMPLING SIMPLICITY	0.8	3	2.4	2	1.6	3	2.4
POWER	0.7	3	2.1	2	1.4	5	3.5
OTHER UTILITIES.	0.7	3	2.1	2	1.4	4	2.8
MAINTAINABILITY	0.6	3	1.8	2	1.2	4	2.4
EASE OF OPERATION	0.6	3	1.8	2	1.2	5	3.0
ENVIRONMENTAL SENSITIVITY	0.6	3	1.8	2	1.2	5	3.0
HEAT GENERATED	0.6	3	1.8	2	1.2	5	3.0
ELECTROMAGNETIC INTERFERENCE	0.5	3	1.5	3	1.5	4	2.0
WARM-UP AND OPERATING SPEED	0.5	3	1.5	3	1.5	4	2.0
SIZE	0.4	2	0.8	2	0.8	5	2.0
POWER CONVERSION	0.4	2	0.8	2	0.8	5	2.0
SUPPLIES NEEDED	0.4	3	1.2	2	0.8	4	1.6
EASE OF PACKING/INSTALLATION	0.3	3	0.9	2	0.6	5	1.5
TOTAL (FLY-BILITY INDEX)			**31.7**		**25.4**		**49.7**

RATINGS:

1. Inferior
2. Below Average
3. Average
4. Above Average
5. Superior

	ULTRAVIOLET SPECTROPHOTOMETER	INFRARED SPECTROPHOTOMETER	COLORIMETER
Advantages:	Versatility Sampling Simplicity Ease of Operation	Versatility Warm-up & Operating Speed	Versatility Power Conversion Size
Disadvantages:	Modification Power Conversion Size	Packing/Installation Power Conversion Maintainability	Supplies Needed Sampling Maintainability

Table 4-24. Spectrophotometers--Flability Index Rating

Category	Weighting Factor	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
SAFETY	1.0	3	3.0						
VERSATILITY	1.0	5	5.0						
EASE OF MODIFICATION	0.9	2	1.8						
SPACECRAFT INTERFACE	0.8	4	3.2						
SAMPLING SIMPLICITY	0.8	3	2.4						
POWER	0.7	4	2.8						
OTHER UTILITIES	0.7	2	1.4						
MAINTAINABILITY	0.6	4	2.4						
EASE OF OPERATION	0.6	3	1.8						
ENVIRONMENTAL SENSITIVITY	0.6	5	3.0						
HEAT GENERATED	0.6	4	2.4						
ELECTROMAGNETIC INTERFERENCE	0.5	3	1.5						
WARM-UP AND OPERATING SPEED	0.5	3	1.5						
SIZE	0.4	3	1.2						
POWER CONVERSION	0.4	3	1.2						
SUPPLIES NEEDED	0.4	2	0.8						
EASE OF PACKING/INSTALLATION	0.3	3	0.9						
TOTAL (FLYABILITY INDEX)			36.3						

RATINGS:
1. Inferior
2. Below Average
3. Average
4. Above Average
5. Superior

Advantages: Very Versatile Anal.Inst. Pulse height or single channel analyzer can have other usage.

Disadvantages: Probably requires liquid N_2 or He coolant for detector.

Table 4-25. X-Ray Spectrometers--Flyability Index Rating

Instrument Group	Instrument	Flyability Index Rating
Electronic Test Equipment	Digital Multimeter	50.7
Recorders	Portable Magnetic Tape	50.5
Electronic Test Equipment	Function Generator	50.1
Spectrophotometers	Colorimeter	49.7
Oxygen Analyzers	Electrochemical	49.1
Recorders	Strip Chart	47.6
Electronic Test Equipment	Oscilloscope	47.1
Specific Ion Electrodes	Glass Electrodes	45.8
Audiometers	Manual	45.6
Optical Test Equipment	Autocollimator, Alignment Telescope, Reflex Microscope	45.3
Specific Ion Electrodes	Membrane Electrodes	44.8
Audiometers	Automatic	44.7
Recorders	Analog or Digital Magnetic Tape	44.6
Radiometers	Pyrheliometers	44.1
Microscopes	Laboratory Microscope	43.8
Electronic Hematocrit	Electronic Hematocrit	43.4
Blood Gas Analyzers	Amplifier/Readout	43.3
Oxygen Analyzers	Thermal Conductivity	43.2
Optical Test Equipment	Interferometers	43.0
Microscopes	Stereo Microscope	42.4
Microscopes	Metalographic Microscope	41.4
Blood Gas Analyzers	Dissolved Oxygen Sensor	40.9
Oxygen Analyzers	Paramagnetic	40.8
Electrophysiological Equipment	Electrophysiological Equipment	40.5
Blood Gas Analyzers	Dissolved Carbon Dioxide Sensor	39.9
Microtomes	Sliding Microtome	39.5
Centrifuges	General Purpose Ultracentrifuge	39.5
Infrared Analyzers	Nondispersive Type (Laboratory)	39.1
Infrared Analyzers	Nondispersive Type (Process)	39.1
Oxygen Analyzers	Catalytic Combustion	38.8
Microtomes	Rotary Microtome	38.6
Osmometers	Membrane Osmometer	38.3
Radiometers	Spectroradiometer	38.3
Optical Test Equipment	Optical Bench, Surface Plate, Circular Table	38.0
Cell Counters	Light Scattering Type	37.7
Infrared Analyzers	Breath Analyzer (Laboratory)	37.5
X-ray Spectrometers	X-ray Spectrometers	36.3
Centrifuges	Hematocrit	35.9
Cell Counters	Manual Counting Type	35.0
Gas Chromatographs	Single or Dual Column, TC Detector	34.3
Gas Chromatographs	High Sensitivity Detector Type	33.3

Table 4-26. (Sheet 1 of 2). Instrument Flyability Index

Instrument Group	Instrument	Flyability Index Rating
Microtomes	Vibrating Microtome	32.8
Emission Spectrometers	Emission Spectrometers	32.8
Cell Counters	Light Scattering Type	32.7
Radiation Counters	Liquid Scintillation	32.2
Osmometers	Cryoscopic. Osmometer	32.0
Optical Test Equipment	Modulation Transfer Function Equip.	32.0
Radiation Counters	Gamma	31.9
Cell Counters	Impedance Type	31.8
Spectrophotometers	Ultraviolet Spectrophotometer	31.7
Atomic Absorption Spectrophotometer	Atomic Absorption Spectrophotometer	30.8
Gas Chromatographs	Preparative-Gas Chromatograph	30.8
Cell Counters	Fire Fly Enzyme Type	30.1
Radiation Counters	Planchet	29.3
Osmometers	Vapor Pressure Osmometer	29.1
Flame Photometer	Flame Photometer	28.6
Mass Spectrometers	Quadrupole Mass Spectrometer	27.6
Mass Spectrometers	Magnetic Sector Mass Spectrometer	26.6
Spectrophotometers	Infrared Spectrophotometer	25.4
Mass Spectrometers	Double Focusing Mass Spectrometer	23.5
Centrifuge	Preparative Ultracentrifuge	19.8
Centrifuges	Analytical Ultracentrifuge	14.7

Table 4-26 (Sheet 2 of 2). Instrument Flyability Index

Section 5
CONCLUSIONS

The following are conclusions reached as a result of the study and instrument survey:

- It is feasible to use commercial scientific instruments in the experiment program of the Space Station.
- Slight-to-moderate modifications will be needed for most instruments. The needed modifications will improve safety and eliminate gravity-dependent instrument functions.
- One of the major departures from earth-based laboratory procedures in the Space Station will be the handling of liquid and particulate samples.
- The qualification criteria for laboratory instruments must be realistically oriented to actual needs of the Space Station laboratories and experiment program. The perpetuation of historical requirements which are inappropriate for the Space Station must be discouraged.
- Instrument manufacturers are capable of providing off-the-shelf, modified, or made-to-order laboratory instruments for Space Station Application.
- The recommendation of specific instruments and specific modifications thereto should not be made at this time. The actual experiments to

fly (and to need instrumentation support) are yet to be determined. Many new and even more flyable instruments will be available when the Space Station is operational than are available now.

- The use of commercial instruments is not only feasible, but it provided positive support for the flexible philosophy of the Space Station program. As the needs of an experiment change, commercial instruments can be sent, via shuttle, for use within a few days or weeks. As new instruments are developed for earth-based laboratories, they can also be used for Space Station experiments.

Appendix A

NASA SPACE STATION DOCUMENTS

The following Space-Station Documentation was consulted in preparing this study and instrument survey:

Space Station Program Definition (Phase B), Statement of Work. April 14, 1969.

Space Station Program Phase B Definition Study, 7th Technical Review, McDonnell Douglas Astronautics Company--West. (MDC G0502). June 1970.

Space Station Task Team, PD-SS, Guidelines and Constraints Document, Space Station Program Definition Phase B. June 12, 1970.

Experiment Module Concepts Study, Interim Detailed Progress Report: Vol. I, Management Summary; Vol. II, Experiments and Mission Operations; Vol. III, Module and Subsystem Design; Vol. IV, Resource Requirements; Vol. V, Appendices. Advanced Space Systems, Research and Engineering, Convair Division of General Dynamics. May 1970.

E&D In-house Study of a Space Base, Progress Review, Manned Spacecraft Center. September 3, 1969.

Space Station Program Definition, DRL 8, Vol. I, Experiment Support Requirement Analysis. McDonnell Douglas Astronautics Company. January 13, 1970.

Space Station Definition, MSFC-DRL-160 Line Item 8, Vol. III. Analysis of Operations, McDonnell Douglas Astronautics Company--West. July 1970.

Space Station Definition, DRL 8, Vol. V, Book 3, Information Management Study, Preliminary Draft. McDonnell Douglas Astronautics Co. April 28, 1970.

Space Station Definition, MSFC-DRL-160 Line Item 8, Vol. VI, Payload Accommodation and Integration. McDonnell Douglas Astronautics Company--West. July 1970.

Space Station Definition, DRL 8, Vol. VII, Appendix B, Preliminary Definition of Experiment Modules. Martin Marietta Company. March 1970.

Generation and Evaluation of Microscopy/Biochemistry System for AES, Vol. I. Beckman Instruments, Inc. January 5, 1966.

Biological Specimens Storage for Extended Space Missions. Spacelabs, Inc. October 1, 1967.

Study to Define Microbiological Test Requirements for Manned Space Flight, Federal Systems Division. International Business Machine Corp. July 20, 1967.

A Study to Determine the Feasibility of Using Physical Methods for Biochemical Analysis under Space Flight Conditions. Hayes International Corporation. September 16, 1967.

A Biomedical Program for Extended Space Missions. NASA/MSC. May 1969.

Biomedical Instrumentation Requirements for a Manned Orbiting Laboratory. Beckman Instruments, Inc.

Candidate Experiment Program for Manned Space Stations, "The Blue Book".* NASA. September 15, 1969--updated July 15, 1970.

Integrated Medical and Behavioral Laboratory Measurement System, Definition Report--Task I, April 14, 1969; Design Report--Task II, June 27, 1969. Lockheed Missils & Space Company.

Physical Methods for Biochemical Analysis in Spaceflight. Spacelabs, Inc. October 1, 1967.

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*This document considers possible experiments to be conducted in the Space Station, and groups individual experiments with similar subject matter into functional program elements (FPE's). There are 27 FPE's in the current version of the "Blue Book." These are referred to in the current survey with respect to applications of the instruments considered.

Appendix B

LITERATURE RELEVANT TO COMMERCIAL INSTRUMENTATION

The following commercial instrumentation literature was consulted during the development of the study and instrument survey:

1970 Instruments Specifier Annual, Industrial Research, Nov. 20, 1969.

1968 Yearbook & Buyers' Guide, Industrial Research, May 15, 1967.

The 100 Most Significant New Technical Products of 1969, Industrial Research, December 1969.

Analytical Reviews 1970 Fundamentals, Analytical Chemistry, April 1970.

Guide to Scientific Instruments, 1969-1970, Science, November 1969.

Recchione, P.A. (Ed.), ISA Transducer Compendium, Plenum Press, N.Y. 1963.

Laboratory Guide, Analytical Chemistry, July 1969.

Appendix C

SURVEY CORRESPONDENCE

To obtain technical information for types of instruments not manufactured by Beckman Instruments, Inc., letters were sent to 212 instrument manufacturing companies. A sample of the inquiry letter is shown in Figure C-1, and some of the interesting and helpful replies are shown in Figure C-2. Responses were received from 136 different companies. The exact percentage of responses cannot be calculated from these figures since multiple replies (from different divisions, or with regard to different products) were received from some companies who are listed only once. It is our pleasure to acknowledge and thank the following companies for their responses:

Advanced Instruments	David W. Mann
Aero Vac	Davidson Optronics
Allied Impex	Digi-Data
American Optical	Dohrmann
Ames	EG&G
Ampex	E.I. DuPont Instrument
Amprobe Instrument	E. Leitz
Anacon	Ealing
Astro-Science	Edmund Scientific
AST/Servo Systems	Electronic Associates
Baird-Atomic	Electro-Nucleonics
Barnes Engineering	Electro Optics
Bausch & Lomb	Electro Powerpacs
Belfort Instrument Co.	Engis Equipment
Bell & Howell	Eppley Laboratory
BIF	Ercona
Biotronex Lab	Esterline Angus
Bissett-Berman	Extranuclear Labs
BLH Electronics	Ferson Optics
Bristol	Fischer Scientific
Canoga Electronics	Fiske Associates
Chadwick-Helmuth	Flight Research
Coleman Engineering	Gaertner Scientific

Galileo Corp. of America	Paillard
Gamma Scientific	Pemco
General Electric	Perkin-Elmer
GeoSpace	Photo Kinetics
Granville-Phillips	Photo Research
Grason-Stadler	Photovolt
Gulton Industries	Precision Instrument Co.
Hallikainen Instruments	Precision Scientific
Harry Ross	Red Lake Labs
Harshaw Chemical	Robertshaw Controls
Heat Technology	Rudolph Instruments
Hewlett-Packard	Rustrak Instrument
High Accuracy Products	Santa Barbara Research Center
Honeywell	Schleicher & Schuell
Houston Instrument Co.	Schoeffel Instruments
Hughes Aircraft	Schultz Instruments
Hydro Products	Science Associates
Information International	Siemens America
International Sales	Simpson Electric
ITT	Sloan Instruments
Jarrell-Ash	Southern Precision
Johnston Laboratories	Spectrex
Kahl Scientific Instrument Co.	Stromberg Datagraphics
Karl Heitz	Taylor Instruments
Kinelogic	Techni-Rite Electronic
Klett Manufacturing	Teledyne Analytical
Kollmorgen Color Systems	Tensitron
Killsman Instruments	Tiyoda Optical--Technical Instruments
Korad	Tracor
Lab-Line Instruments	Traid
Lafayette Instrument	Tropel
Lehigh Valley Electronics	UNeCO
Lipshaw Manufacturing	Unitron
LKB Instruments	Varian
Los Angeles Scientific Instrument	Veeco Instrument
Magna	Vickers Instrument
Materials Research	W. & L.E. Gurley
Mechanics for Electronics	W.F. Sprengnether Instruments
Melabs	Warner & Swasey
Midwestern Instruments	Westinghouse Electric
MSE-London	West Instrument
National Instrument	Wild Heerbrugg
New Brunswick Scientific	William J. Hacker
Nikon	Yellow Springs Instrument Co.
Olympus Corporation of America	Oxford Labs
	Carl Zeiss

Beckman® INSTRUMENTS, INC.

ADVANCED TECHNOLOGY OPERATIONS
2500 HARBOR BOULEVARD FULLERTON CALIFORNIA 92634 TELEPHONE: (714) 871-4848 · TWX 910 592 1260 · TELEX 06 78413

July 20, 1970

Nikon Inc., Instrument Division
623 Stewart Avenue
Garden City, New York 11530

Attention: Sales Manager

Dear Sir:

Beckman Instruments, Advanced Technology Operations, under contract from the National Aeronautics and Space Administration, Marshall Space Flight Center, is preparing a survey of instrumentation relative to the experiments being planned for the orbiting Space Station Program (late 1970's). This survey explores the possibility that off-the-shelf commercial instruments may be adequate to support several of the experiments being planned. The relaxed space, weight, and power requirements of the larger Space Station together with frequent shuttle service between the Station and earth make feasible the use of standard instruments (modified as necessary) for non-critical experiments. The savings of this approach in contrast to developing "space qualified" instrumentation is obvious, and considerable.

I am requesting, herewith, your cooperation in providing technical information on Microscopes. I would appreciate receiving, as a minimum, some of your advertising and sales materials; additional material on specifications, operation, supplies and support, and applications would also be welcome. If this notion of using available instruments in a zero-g environment intrigues you, I would be delighted to hear and discuss with you any problems or solutions which come to mind.

Sincerely,

BECKMAN INSTRUMENTS, INC.

Allen C. Norton

Allen C. Norton, Ph.D.
Senior Research Physiologist
Advanced Technology Operations

Figure C-1. Typical Letter of Inquiry

CABLE - "UNITRON" NEWTON

TELEPHONE - WOodward 9 8600

UNITRON INSTRUMENT COMPANY
66 NEEDHAM STREET • NEWTON HIGHLANDS, MASS 0216

July 28, 1970

Dr. Allen C. Norton
Advanced Technology Operations
BECKMAN INSTRUMENTS INC.
2500 Harbor Boulevard
Fullerton, CA 92634

Dear Dr. Norton:

Thank you for your interesting letter explaining the reasons for using standard instruments on an orbiting space platform.

Being somewhat of a "bug" on the subject of space travel and space stations, I am quite interested in your program. If you need any particular information about any one of the microscopes in our enclosed catalog, please feel free to call or write me.

Cordially yours,

Harold Zeltsar

UNITRON INSTRUMENT COMPANY
Harold Zeltsar/mm

Encl.

THE TREND IS TO UNITRON

Figure C-2. Letter of Response

AMERICAN OPTICAL
CORPORATION

SCIENTIFIC INSTRUMENT DIVISION
Eggert and Sugar Roads, Buffalo, N. Y., U.S.A. 14215
Area Code 716—895-4000

July 30, 1970

Allen C. Norton, Ph.D.
Senior Research Physiologist
Advanced Technology Operations
Beckman Instruments, Inc.
25 Harbor Boulevard
Fullerton, California 92634

Dear Dr. Norton:

Even if I were not interested in the sale of instrumentation, as a tax payer I would enthusiastically support a survey which would consider commercial instrumentation in favor of developing "space qualified" instrumentation. I think that many government funded programs would benefit by this kind of a practical approach. It did seem rather unusual to me that after progressing from the caveman's club on down through modern hand tools that it was necessary to spend so many hundreds of thousands of dollars to develop something as basic as a hammer for the space program.

I'm enclosing copies of brochures describing our microtomes and also a reference manual. Clamping these microtomes to a fixed base would seem to solve at least one problem in a zero-g environment and I would imagine that some rather unique methods would have to be devised for handling the fluids which are going to be necessary for processing of tissue specimens.

If any further information is required, please don't hesitate to contact me.

Sincerely,

R S Morris

Product Manager

R. S. Morris/pe

Enc: SB820, SB815, 820-301, OmU2

TWX 710-522-1731 • Cable Amoptico • Telex 91-285

Figure C-2. Letter of Response (continued)

YELLOW SPRINGS INSTRUMENT CO., INC.

YELLOW SPRINGS, OHIO, 45387

PHONE 767-7242 (AREA CODE 513)
TELEX 20-5437

July 28, 1970

Allen C. Norton, Ph. D.
Senior Research Physiologist
Advanced Technology Operations
Beckman Instruments Inc.
2500 Harbor Boulevard
Fullerton, California 92634

Dear Dr. Norton:

Thank you for your letter of July 20th requesting information on the YSI Model 30 Electronic Hematocrit. Enclosed for your reference is a sales bulletin and instruction manual describing the instrument. Obviously, we have no experience with this unit in a zero-g environment, but, at first thought, we can see no particular reason why the instrument would not work. The only possible difficulty we can see is possible problems that zero-g might cause in keeping the blood in the cell. If zero-g would not cause the blood to leave the cell, or something of that nature, then we can see no reason why this instrument would not be qualified for your experiment.

If you have any questions after reading the enclosed data, please feel free to contact us for clarification.

Sincerely,

YELLOW SPRINGS INSTRUMENT CO., INC.

Richard M. Horn
Assistant to the Sales Manager

RMH:nr

enclosures

Measurement and Control for Science and Industry

Figure C-2. Letter of Response (continued)

SCHOEFFEL
LIGHT AND LIGHT MEASUREMENT

24 Booker Street, Westwood, New Jersey 07675 (201) 664-7263

July 28, 1970

Beckman Instruments, Inc.
Advanced Technology Operations
2500 Harbor Boulevard
Fullerton, California 92634

Attention: Allen C. Norton, Ph.D.

Dear Dr. Norton:

We appreciate your interest in the Schoeffel Instrument Corporation, and we are enclosing advertising literature on some of the instrumentation which we offer. I might add that the thought of a Schoeffel instrument "in orbit" is fascinating.

Currently, only one optical bench, the BA 607, is available, although there have been tentative plans to offer the triangular type, which has more universal appeal. Regarding collimators, such applications are handled on an "as come" basis, since the only collimating lenses and mirrors which we handle are for use in our own lamp housings and monochromators.

A brief corporation "resume" is also included. It was used in a recently completed mailing, the purpose of which was to make our technological capabilities known to others who might be searching for subcontractors to assist them in the areas of operations, supplies and support.

Please contact us for further details. We look forward to being of service

Very truly yours,

SCHOEFFEL INSTRUMENT CORP.

R W Bardell

R. W. Bardell

RWB/led

Enclosures: Instrumentation Brochure
Subcontractor Mailing Sample

EUROPE: Schoeffel Instrument GMBH, 2351 Trappenkamp, C Strasse 2, Deutschland

Figure C-2. Letter of Response (continued)

Red Lake Laboratories, Inc.

HIGH SPEED MOTION PICTURE CAMERAS

2971 CORVIN DRIVE
CABLE: REDLAKE — SANTA CLARA

SANTA CLARA, CALIFORNIA 95051

PHONE: (408) 739-3034
TWX: 910-339-9241

24 July 1970

In reply refer to:

Allen C. Norton, Ph.D.
Senior Research Physiologist
Advanced Technology Operations
Beckman Instruments, Inc.
2500 Harbor Boulevard
Fullerton, California 92634

Dear Dr. Norton:

Red Lake Laboratories is very interested in the program you outlined in your letter of July 20, and we are enclosing for your information a complete packet of our advertising and sales material, including our specifications and price lists on our current line of equipment.

In addition, you have been placed on our mailing list as new products are available. We do have some new products that very well could be utilized in the zero-g environment for the orbiting space station program. Please keep us advised on this program as we would be interested in working in any way possible.

Sincerely,

RED LAKE LABORATORIES, INC.

Joe Y. Saunders
Sales and Service

JYS.js
Enclosures

cc: R. C. Kiteley

Figure C-2. Letter of Response (continued)

COLEMAN
ENGINEERING COMPANY, INC.

3121 WEST CENTRAL AVENUE
P.O. BOX 1974
SANTA ANA, CALIF. 92702
TELEPHONE (714) 546-1600

July 29, 1970

Dr. Allen C. Norton
Senior Research Physiologist
Advanced Technology Operations
Beckman Instruments, Inc.
2500 Harbor Boulevard
Fullerton, California 92634

Dear Dr. Norton:

Coleman Engineering Company, Inc., is pleased to accept your invitation to participate in the survey of photographic instrumentation for possible use in space station applications. Enclosed please find our current sales literature covering those photographic systems we feel would be of interest.

Currently, we are in the process of up-dating our product brochures to more adequately describe our products and their associated areas of application. We will ensure that copies of these new materials are made available to you at the earliest possible time. Should you have any questions concerning the attached, please feel free to contact me, direct.

The idea of using commercially available instrumentation in a "zero-g" environment does intrigue us, and we would be most happy to meet with you at a mutually agreeable time to discuss the potential and limitations of a program of this nature. I would very much like to have our Chief Optical Engineer and National Sales Manager in attendance at any meeting which might be arranged, so as much advance notice as possible would be helpful.

Thank you for considering Coleman Engineering Company, Inc., in the scope of your survey.

Sincerely,

Coleman Engineering Company, Inc.

R. Lynn Livingston

R. Lynn Livingston
Director of Marketing

RLL:bg
Enclosures

Figure C-2. Letter of Response (continued)

E. LEITZ, INC.

ROCKLEIGH · NEW JERSEY 07647 · TELEPHONE (201) 767-1100

Leica

Leitz

July 29, 1970

Beckman Instruments, Inc.
2500 Harbor Blvd.
Fullerton, California 92634

Attention: Dr. Allen C. Norton, Ph. D.
Senior Research Physiologist
Advanced Technology Operations

Dear Dr. Norton:

We are writing in reply to your letter of July 20th and we are frankly not at all certain as to where our equipment might be useful in your advanced technology planning. Generally speaking, our microtomes are very heavy and our microscopes are not necessarily heavy but take a fair amount of space. Therefore, at the moment, I think it best for us to provide you with a catalog on our equipment and then you would be in a better position to determine its use in your planning. We have an excellent 35mm camera both range finder and single lens reflex and from the standpoint of photomicrography, our LEITZ line of LEICA cameras may well be considered. We have motorized versions and other special purpose designs which may fit into your photographic requirements.

After you have received the literature, if you care to see some of our equipment, you may wish to contact our California office (3848 Campus Drive, Newport Beach, California 92660) and one of our representatives could either show you the equipment or discuss this possibility with you.

Very truly yours,

E. LEITZ, INC.
Scientific Instruments Division

W. F. Butler

William F. Butler
Sales Manager

WFB/aeb

Figure C-2. Letter of Response (continued)

DAVID W. MANN COMPANY

174 Middlesex Turnpike, Burlington, Massachusetts 01803. Telephone: 617-272-5600 Telex 94-0283

August 27, 1970

Dr. Allen C. Norton
Senior Research Physiologist
Beckman Instruments, Inc.
2500 Harbor Boulevard
Fullerton, California 92634

Dear Dr. Norton:

Referencing your letter in which you requested technical information on optical benches, scientific and special purpose cameras, we are pleased to enclose literature descriptive of our product line. You will note that none of the systems described are space qualified but have been developed for very high precision and highly accurate photographic data analysis in the earth environment.

It should be noted that our microdensitometers and comparators are being used for the reduction of photographic data from orbiting satellites and observatories for extraterrestrial exploration and also for the earth resources program. We have yet to apply our capabilities to "space use". The major problems we see are those related to maintaining tolerances so necessary to adequate data reduction. The performance of our systems is dependent on being in a gravity field, being properly lubricated and constrained such that position of the photographic plates relative to an optical axis is known to a high degree of precision.

We are certainly interested in the possibility of providing equipment for a manned orbiting laboratory or other satellites. We would appreciate receiving information as a result of your study. If we can be of further assistance please write or call at your convenience.

Sincerely,

Aubrey C. Tobey
Director of Marketing

ACT/bl
Encls.

DIVISION OF GCA CORPORATION

Figure C-2. Letter of Response (continued)

HEWLETT PACKARD

AVONDALE DIVISION · Route 41, Avondale, Pennsylvania 19311, Telephone 215-268-2281

July 27, 1970

Allen C. Norton, Ph.D
Senior Research Physiologist
Advance Technology Operations
Beckman Instruments, Inc.
2500 Harbor Boulevard
Fullerton, California 92634

Dear Dr. Norton:

Current literature on the Model 302B Vapor Pressure Osmometer and the Series 500 Membrane Osmometer is enclosed.

As to zero-g operation, I am intrigued but neither of these instruments would operate in such an environment without extensive modification. In the vapor pressure instrument some arrangement could probably be made to maintain saturation of the chamber atmosphere without using an open-cup reservoir. However, the samples are held in the reading position by a combination of gravity and surface tension and with the former absent I am afraid that quite a mess would result. I do not know of any competitive vapor pressure osmometer which would not have the same problems, but might I suggest a competitive technique? Freezing point depression yields similar information in the same molecular weight range. The sample and temperature sensor might be enclosed in a flexible container, such as a plastic bag, and then frozen in a suitable refrigerator.

The membrane osmometers balance the osmotic pressure developed in the cell against a column of liquid whose height is then measured. This instrument, obviously, needs gravity. I think your best bet would be the CSM-1 or CSM-2 made by Melabs of Palo Alto. In these instruments the pressure developed in a sealed chamber is measured by a strain gage attached to a diaphragm which forms one of the chamber walls. However, the calibration procedure involves the use of a liquid column of known height; perhaps some alternate method can be worked out.

Figure C-2. Letter of Response (continued)

I am sorry that I cannot provide a simple answer to your request. As partial compensation I am including a data sheet on our Model 2801A Quartz Thermometer, which might well be an adjunct to many of the experiments contemplated. The electronics of this instrument are force-cooled by a fan rather than depending on convertion, and it should take zero-g in its stride.

Very truly yours,

Fred W Rowland

Fred Rowland
Regional Sales Engineer

FR:gy
Enc.
302B, 500, 2801A - data sheets

EG&G

EG&G, INC, CROSBY DRIVE, BEDFORD, MASSACHUSETTS 01730 · TEL. 617 271-5000
CUSTOM EQUIPMENT DIVISION

August 10, 1970

Dr. Allen C. Norton
Advanced Technology Operations
Beckman Instruments, Inc.
2500 Harbor Boulevard
Fullerton, California 92634

Reference: Letter of July 20, 1970 to EG&G Sales Manager

Dear Dr. Norton:

We are indeed interested in the possibility of using commercial instruments for non-critical experiments in the Orbiting Space Station Program. EG&G is, we believe, particularly well qualified to supply special purpose cameras and photometers, as the development of such devices have represented a substantial part of our operations for many years. As a result, we have both commercial products and a considerable file of designs for cameras and instruments produced in single or small quantities for special applications, some of which may be of interest to you.

As examples of our capabilities, I am enclosing material describing our light instrumentation, which includes photometers, and our LC-4 Oscilloscope Camera. The light instrumentation is a commercial product line, while the LC-4 is a special camera development.

The EG&G Model 580 Radiometer system may be of particular interest. It is a very adaptable modular, portable, calibrated group of instruments which can cover a very wide range of photometric and radiometric measurements with high absolute accuracy. It is designed around the concept that suitable instrumentation can remove such measurements from the laboratory and permit them to be made by other than highly trained personnel.

ALBUQUERQUE BEDFORD — BOSTON — SALEM LAS VEGAS SANTA BARBARA SAN RAMON WASHINGTON

Figure C-2. Letter of Response (continued)

Dr. Allen C. Norton

August 10, 1970
Page 2

The EG&G Model LC-4 Camera, by contrast, is a highly specialized precision instrument designed for one particular application. It is highly corrected to provide a photographic record of an oscilloscope CRT screen with maximum fidelity at high writing speeds. It permits quantitative analysis of oscillograms with minimum error introduced in the recording process.

If these examples indicate that we might fit into the scheme of things, we certainly would like to discuss further the instrument needs for the Orbiting Space Station. We shall hope to hear from you again soon.

Very truly yours,

EG&G, INC.

Allyn B. White

Allyn B. White
Manager, Engineering Sciences

ABW:mlm
Enc.

Appendix D

BECKMAN EMPLOYES CONTRIBUTING TO THE WRITING OF THIS REPORT

John Brady	- Advanced Technology Operations
Willis Cash	- Scientific Instruments Division
C. H. Cherrenka	- Spinco
Richard Cramer	- Advanced Technology Operations
Ron Dayton	- Scientific Instruments Division
Walt Donner	- Advanced Technology Operations
Mo Galaso	- Spinco
Jerry Hawthorne	- Scientific Instruments Division
August Hell	- Scientific Instruments Division
Bill Henderson	- Advanced Technology Operations
Victor Huebner	- Advanced Technology Operations
Ken Jacobson	- Spinco
Allan Pacela	- Corporate Research Activity
Arne Peterson	- Clinical Instruments Operations
Con Rader	- Corporate Research Activity
Dick Rholeder	- Scientific Instruments Division
Mert Robinson	- Advanced Technology Operations
Jerry Rost	- Advanced Technology Operations
Martin Roth	- Scientific Instruments Division
Gerry Stillman	- Advanced Technology Operations
Philip Ting	- Scientific Instruments Division
Tom Underwood	- Advanced Technology Operations
Jack Walsh	- Advanced Technology Operations

Cover and art work by Herb Abraham - Advanced Technology Operations

CR-102940

Beckman® INSTRUMENTS, INC.

ADVANCED TECHNOLOGY OPERATIONS
2500 HARBOR BOULEVARD, FULLERTON CALIFORNIA 92634 • TELEPHONE (714) 871-4848 • TWX 910-592-1260 • TELEX 06-78413

CUSTOMER: National Aeronautics & Space Admin.
ADDRESS: George C.Marshall Space Flight Ctr.
Marshall Space Flight Center, Ala.

DATE: October 30, 1970
CUSTOMER CONTRACT/ORDER NO. NAS8-26119

BECKMAN ORDER/JOB NO.1363-1065-800

TECHNICAL REPORT: D--2

ATTENTION: A&TS-MS-IP

The enclosed documentation as required by the referenced contract/order is being transmitted herewith:

Qty.	Code	Dwg. Number	Description
2 ea	D-2	N/A	FR-1065-101 FINAL REPORT - Vols. 1 and 2

Code: A - Drawings
B - Financial Status Reports
C - Progress Reports
D - Final Report
E - Other

Please direct questions regarding the above to the attention of the undersigned.

Very truly yours,

BECKMAN INSTRUMENTS, INC.

J. L. MORGAN
Contract Administrator

JLM:L

Enc.

Beckman® INSTRUMENTS, INC.
ADVANCED TECHNOLOGY OPERATIONS
FULLERTON, CALIFORNIA • 92634