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PART A

INSTRUMENT TECHNOLOGY
FOR
REMOTE-SURFACE
EXPLORATION, PROSPECTING AND ASSAYING

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by

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PART A

SECTION I

INTRODUCTION

General

This report is about the instrument/mechanism technology needs for future automated exploration, prospecting and assaying on a remote surface. It is concerned with the scientific instruments that measure geological, geophysical and environmental phenomena, and that map and position for these data. It also is concerned with the support mechanisms that will be required to acquire samples, prepare samples, and in general make it possible for the scientific instruments to do their job. The capability to specify new instrument/mechanism technology needs, for effective remote-surface exploration, prospecting and assaying (EPA), requires first, an understanding of the functions or major elements of such a task, and second an understanding of the scientific instruments and support mechanisms that may be involved. From this kind of information some idea of the new technology that will be required for future remote-surface EPA missions can be derived. The technology needs resulting from a study of particular "driving" missions are not discussed here. Although a study of these missions can influence technology needs, because they may specify the mission objectives, mission profile, time lines, environmental characteristics, etc., such a study represents a slightly different approach than carried out here and one that might be reserved for a subsequent analysis of the results from this study.

In order to more completely understand the remote-surface EPA mission, the concept of such a mission as it might be automated and actually carried out on Earth was reviewed. This resulted in an analog or task model from which the various functions, operational procedures, scientific instruments and support mechanisms for an automated mission could be derived. The task model led to the definition of nine major functions or categories of discrete operational elements that may have to be accomplished on a mission of this type. Each major function may stand alone as an element of an EPA mission, but more probably a major function will require the support of other functions, so they are inter-related. Thus the geochemistry function may require support from sample acquisition, sample preparation, etc., in order to carry out its particular function.

Associated with each major function, in an automated operation, there will be several scientific instruments and/or support mechanisms. The derivation of these instruments and mechanisms, and their technology requirements, represents the piece de resistance of this report. Part A of this report is concerned with the major functions, the scientific instruments and their technology need; while Part B deals with the support mechanisms and their technology needs.

Executive Summary

Our knowledge of the terrestrial planets, the Moon, and perhaps Jupiter is such that our future mission objective for these bodies can be changed from reconnaissance to more in-depth exploration. To accomplish this objective we must take sophisticated instruments right to the planet or body of interest - into its atmosphere and onto its solid surface, if any - if we really want to know what is there and carry out a complex exploration program. For some lines of investigation in situ analysis will not be enough; we must bring samples back into human hands. This is because, in our present or projected state of automation technique, laboratory analytical methods are vastly more powerful, versatile, precise and reliable than any that could be done by remote control. There is also a more fundamental limitation: any machine, even a super-robot, has but a limited repertoire of ideas and skills, while a returned sample, so long as it lasts, in principle can always be examined by new people in new ways that were not thought of when it was collected. However, in situ methods can do far more than they have done to date, and in the following pages some of the scientific instruments and the support mechanisms that may be useful for future remote-surface exploration are reviewed.

In addition to exploration, our subject here includes prospecting and assaying. As elements of the space program these are new. The idea of using extraterrestrial materials and environments as distinct from just finding and studying them for scientific purposes, is an even earlier state of understanding and acceptance than the idea of roving vehicles on Mars. However, it is making headway, and it presents splendid opportunities for the development of new technologies that can be very valuable even if human occupation and use of space is long delayed.

Instrumentation for prospecting and assaying, for example on the Moon or near-Earth asteroids, can have much in common with purely scientific automated rover-borne equipment and Earth-based prospecting equipment. Many of the needs (for example drilling, manipulation, chemical and mineral characterization of rocks and soils) are the same. Therefore in what follows we treat exploration, prospecting and assaying as parts of the same problem; namely to define the instruments and technologies for effective remote-surface EPA.

Section II of this report describes the various functional requirements, operational procedures, instruments and mechanisms that will be part of an EPA mission. These are here classified as nine major functions. It really doesn't matter whether the mission is manned or fully automated, or to be conducted on Earth or on a remote planetary surface, for these are the elements of the EPA task. If the mission is automated then the major functions must be accomplished by mechanisms or sensors that replace what the man could see and do. The major functions described in Section II were derived from a typical Earth-based exploration operation. A summary of the major functions is presented in Table I.

The major functions on an EPA mission will be accomplished by scientific instruments and support mechanisms. A shopping list of some of these instruments and mechanisms is given in Table II. Section III describes the essential scientific instruments for EPA. Along with the technical description, a status review and new technology requirements also are presented. The support instruments are reviewed in Part B, Section V.

Section IV reviews the technology opportunities for the scientific instruments for EPA. These opportunities range from requirements for complete new instruments as with in situ age-dating, to requirements for new sensors and components, to requirements for whole new technologies in sample acquisition, preparation and handling equipment. Table III, entitled Technology Chart, presents a summary of the new technology needs and problems for the scientific instruments. The support instrument technology is reviewed in Part B, Section VI.

TABLE I

SURFACE EPA

Functions & Instruments

MAJOR FUNCTION	DESCRIPTION OF FUNCTION	TYPICAL INSTRUMENTS OR MECHANISMS
IMAGING	Viewing of the remote surface,samples and sky for the field geology functions and photo geology, to assist in the selection, acquisition, and analysis of the samples, to aid in instrument handling and placement, and for navigation, guidance and positioning.	1. Vidicon Camera 2. Facsimile Camera 3. CCD Camera
GEOCHEMISTRY	Determination of the mineralogy/petrology, the elemental/isotopic composition, the mineral phases, the structure and texture, age-dating, and the assaying of remote surface material.	1. X-Ray Diffractometer 2. X-Ray Spectrometer 3. Petrographic Microscope 4. Electron Microprobe 5. Ion Microprobe 6. Pulsed Neutron/Gamma Ray Spectrometer 7. Mass Spectrometer
GEOPHYSICS	Determination of the geophysical parameters [body physics] that are important in ore search and remote surface EPA.	1. Seismometer 2. Gravimeter 3. Magnetometer 4. Electric Methods 5. Electromagnetic Methods 6. Radioactive Methods 7. Well Logging Methods
FIELD GEOLOGY	Provides the geologic context for all measurements, including the instruments and techniques for reconnaissance and surface mapping, preliminary mineral and rock identification, and the site selection for sampling and experimenting.	1. Hand Lens 2. Brunton Compass 3. Sample & Compass Manipulator 4. Record/Map 5. Odometer 6. Spirit Level (Wye Level) 7. Transit

TABLE I (Continued)

MAJOR FUNCTION	DESCRIPTION OF FUNCTION	TYPICAL INSTRUMENTS OR METHOD
SAMPLE ACQUISITION	To acquire surface and subsurface samples of material from remote surfaces. Samples may include oriented cores, chipped sections from outcrops, selected material from the surface, or homogenized regolith material.	1. Core Drill (Diamond Drill) 2. Rotary Drill 3. Cable Drill 4. Auger 5. Drive Tube 6. Surface Sampler 7. Rock Chipper
SAMPLE PREPARATION	To prepare samples by crushing, sieving, slicing, laping encasing, etc. for analysis.	1. Rock Crusher 2. Siever 3. Sample Saw 4. Rock Thin Sectioning 5. Slide Mounting 6. Brush 7. Lapidary Wheel
SAMPLE HANDLING AND STORAGE	Provides precision manipulation of samples to analysis instruments, containers for samples that won't contaminate results, routing from the acquisition and preparation instruments to the analysis instruments and storage with storage recall.	1. Viewing Stage 2. Sample Containers (Various) 3. Storage Box
EXPERIMENT HANDLING	To off-load and retrieve instruments and various equipment as required - i.e., placing charges and sensors for active seismic prospecting.	1. Various For a) Geochem Sensors b) Geophysics Sensors c) Field Geology d) Surveying
NAVIGATION & POSITIONING	Determination of range, latitude/longitude, position on a grid, etc., for mapping and all surface EPA activities.	1. Laser Ranging 2. Radar Ranging 3. Radio Ranging 4. Surveying 5. Land Mark (with imaging) 6. Celestial 7. Dead Reckoning
OTHERS	Special experiments or handling and processing equipment that doesn't fit into the above categories.	

TABLE II

SURFACE EPA INSTRUMENTS

[Shopping List]

Instruments	Application	Remarks
1. Imaging (as a class of instruments)	Viewing of surface, samples, and sky for science navigation and guidance.	Includes TV and facsimile devices, and imaging enhancement devices.
2. X-ray Diffractometer.	Mineral identification (crystal structure).	The standard laboratory instrument for the study and identification of mineral crystal structure.
3. X-ray Spectrometer.	Elemental abundances.	Basically the instrument will require an x-ray gun as the exciter. Elements of low Z ($\leq$ 11) are difficult to detect.
4. Radioactive Survey. (various)	Radioactive elements.	A variety of instruments are available here, including simple electroscopes and Geiger counters, to complex gamma ray spectrometers.
5. Petrographic Microscope. (Polarizing Microscope)	Mineral identification - Rock identification, texture and structure.	Optical microscopy is the most widely used technique for examining rocks. No other technique can so thoroughly characterize a rock.
6. Mass Spectrometer. (Several Devices)	Elemental abundances.	For solid samples some of the sample must be vaporized to produce the gaseous sample. Useful types might include magnetic, quadrupole, and dectrostatic-magnetic mass analyzers.
7. Electron Microprobe.	Elemental abundances.	In this device electrons are accelerated and focused to a small spot on the sample causing secondary electrons and characteristic x-rays to be emitted. The electron microprobe has been used extensively on returned lunar samples.

Instruments	Application	Remarks
8. Ion Microprobe.	Elemental Abundances.	In this device ions are accelerated and focused to a small spot on the sample to generate sputtered secondary ions. Can detect trace elements of concentrations of approximately 1 ppb.
9. Pulsed Neutron/Gamma-Ray Spectrometer.	Elemental Abundances.	Technique provides data on relative abundance for several significant elements/isotopes including hydrogen (water detector), for a large volume of rock.
10. Alpha-Particle Back-Scattering Spectrometer.	Elemental abundances.	An instrument of this type was on Surveyor. An alpha scattering experiment works well on light elements and poorly on heavy elements, so it supplements an x-ray spectrometer.
11. Age-Dating (Several techniques and instruments).	Determination of the absolute ages of rocks,minerals and artifacts.	Several different methods of age-dating are used in terrestrial laboratories. Included are intrinsic methods of U-Th-Pb, Rb-Sr, and K-Ar, and indirect methods such as Fission Track Etching and Cosmic Ray Exposure Ages.
12. Multi-Spectral Imaging	Identify rock units, contacts and structures.	An orbital technique that could have utility in ground surveys and exploration.
13. Infrared Survey (Passive)	Identify heat variations on the surface.	A variety of sensors and techniques are available ranging from thermal imaging devices to bolometers and solid state sensors.
14. U. V. Excitation/ Luminescence.	Identify certain minerals that luminesce during exposure to ultraviolet light.	Minerals that frequently fluoresce are scheelite, willemite, calcite, hyalite, diamond, etc.

SURFACE EPA INSTRUMENTS (Continued)

Instruments	Application	Remarks
15. Seismometer.	Seismicity and ground noise.	Geothermal and volcanic activity are characterized by ground noise.
16. Active Seismic.	Location of structures, beds, contacts, etc. as indicated by changes in the velocity or reflection/refraction of seismic waves.	One of the most used geophysical techniques in oil exploration. Depending on the exploration objectives, the size of the "shot," the number of shot points and detectors, and the geometry of the system are quite variable.
17. Gravimeter. (various)	Delineation of structures contacts and mass accumulations, etc. as indicated by density contrasts in rock units.	Various methods of measurement are well known and some widely used in terrestrial exploration. Basically, one must select either relative gravity measurements or absolute gravity.
18. Magnetometer. (various)	Location of structures, deposits, contacts, etc. resulting from differential polarization of rock units.	There are several designs operating by different scientific principles that can be used for this type of exploration. These are discussed in the text.
19. Electrical Survey. (various)	Provides exploration data as a function of the electrical properties of the ground - i.e., resistivity, etc.	Both telleric and artificially generated electric fields are used here with a variety of instruments and field techniques.
20. Electromagnetic Survey. (various)	Provide exploration data as a function of the electromagnetic properties of the ground.	The induced effect of artificially generated AC currents is the data source. Many techniques and instruments are classified in the text.
21. Radiometric Survey.	Provides exploration data as a function of the effect of the ground on high frequency radio and microwave energy.	Has had limited use in ground exploration but is a valuable spaceborn technique.

SURFACE EPA INSTRUMENTS (Continued)

Instruments	Application	Remarks
22. Sample Acquisition. (various)	Acquisition of surface and near-surface material for analysis instruments.	Includes dental type drills, core drills, augers, trenchers, chippers and various multi-purpose sample arms and acquisition techniques.
23. Sample Preparation. (various)	Sample preparation for various analytical instruments.	Includes crushers, grinders, sieves, lap, etc., and up to something as complicated as thin-section preparation and mounting.
24. Sample Handling. (various)	Transporter for sample material.	Routes material from the appropriate sample preparation instrument to the appropriate analysis instrument, and to storage and retrieval from storage.
25. Storage.	Buffer storage for sample material.	May store material for later retrieval and comparison or later study.
26. Instrument Handling.	Placing and retrieval of sensors.	Placing seismic sensors or charges, placing sensors in desired location, etc.
27. Specimen Handling.	Handling and manipulating material for viewing.	Rotating, rocking, or ranging material for maximum lighting and viewing.
28. Sample Lighting, Lenses, Mirrors and Collimators.	For sample viewing.	To maximize the various types of viewing and optical imaging.

TABLE III

TECHNOLOGY CHART

(Scientific Instruments)

NEW TECHNOLOGY AND PROBLEMS

X = Some
M = Major
1 = Data rate and ground control
2 = Deep drilling

SCIENTIFIC INSTRUMENTS	1. INSTRUMENT GENERAL	New Sensors	Active Cooling	Radiation and Environmental Control	Sensor Sensitivity	Material and Components	2. INSTRUMENT DESIGN	3. SAMPLE ACQUISITION	4. SAMPLE PREPARATION	5. SAMPLE HANDLING	6. EXPERIMENT HANDLING AND MOBILITY	7. OTHER
IMAGING												
1. Vidicon											M	1
2. Facimile											M	1
3. CCD		X	X			X	X				M	1
GEOCHEMISTRY												
4. X-ray Diffractometer		X	X	X	X	X	M	X	X			
5. X-ray Spectrometer		X	X	X	X	X	X	X	X			
6. Radioactive Survey				X	X						X	
7. Petrographic Microscope						X	M	X	M	M		
8. Mass Spectrometer				X		X	M	X	M			
9. Scanning Electron Microscope/Microprobe/Mass						M	M	X	M	X		
10. Ion Microprobe/Mass Analyzer (IMMA)						M	M	X	X	X		
11. Pulsed Neutron Gamma Ray Spectrometer			X	X			X				X	
12. Alpha-Particle Back-Scatter Spectrometer				X			X		X		X	
13. Age-Dating						M	M	M	M	M		
GEOPHYSICS												
14. Seismic							X				M	
15. Gravimetery		X			X	X	X					
16. Magnetometery				X								
17. Electric and Electromagnetic		X				X	X				M	
18. Well Logging						X	X				X	2

Part A
Section II
EPA Major Functions

Before the instruments and new technology for future remote-surface exploration prospecting and assaying can be specified, it is first necessary to understand what is involved in an EPA task - i.e., what operational procedures, instruments, mechanisms, and functional requirements will likely characterize such a mission. In order to accomplish this, and more completely understand the remote-surface mission, the concept of such a mission as it might be automated and actually carried out on Earth was reviewed. (There is considerable precedence for this approach from earlier JPL studies, Ref. 17 and 18.) This resulted in an analog or task model from which the various elements of such an effort were clearly visible. The task model led to the definition of nine, here called, major functions or categories of discrete operation elements that might constitute an EPA mission. Depending on the mission complexity, some or all of the major functions might be involved in a particular EPA mission.

In the following paragraphs some of the major functions that might constitute an automated remote-surface EPA mission are reviewed in sufficient detail to make it clear what the functional operational and instrument requirements will be for this kind of mission. From this kind of information, further mission planning details can be derived, as for example the instruments and mechanisms for accomplishing EPA missions.

Imaging Function

For nearly all phases of an automated remote surface EPA activity the imaging system will represent the most important, complicated and interacting item of equipment on the prospecting vehicle. The imaging system will literally represent the eyes of the entire EPA operation and it will be required for such diverse functions as: (Ref. 14)

1. Geological reconnaissance and photo geology.
2. Site selection for rock and soil samples and for instrument deployment.
3. Observation and direction of sampling operations.
4. Examination of samples (megascopic and microscopic).
5. Terrain assessment for navigation and guidance.
6. Topographic mapping for positioning and attitude control.

In general, for the overall EPA imaging activity, it is probably desirable that the images received be essentially those provided by the eyes of a geologist or "careful observer" as if he were at the site. This requires a camera system, or systems, that can record a panoramic view such that the near and the far field are integrated into a full field with normal perspective. This camera system should be capable of resolving the textural detail of rock or soil fragments in the near field (approx. 1 meter) "surface" that are as small as 0.5 mm in diameter. <u>In addition, it is desirable to supplement this view with a 10X telescopic capability</u>. The hand lens capability would be used for examining the textural properties of selected material while the telescope would permit a higher resolution view of interesting features in the panoramic scan. In the field, a geologist uses his eyes both for panoramic viewing and for examining the near field surface, and in addition, he uses a hand lens for hand specimen textural observations and a field telescope or binoculars for study of distant features.

EPA imaging will require as a minimum:

1. The observing capability equal to that of a human observer using his unaided eye for panoramic viewing, using a hand-held magnifying glass of 10 power for specimen analysis, and finally using a telescope of 10 power for viewing select portions of the panorama.
2. Panoramic (reconnaissance) viewing with widest possible latitude in horizontal field of view and about 70° in vertical field of view.
3. Capability to vary resolution, depth of field, field of view, and frame time.
4. Capability to vary lighting conditions by:
   a. Rotating objects in near field along two perpendicular axes (may be performed by Sample Handling Function).
   b. Changing camera orientation.
   c. Artificial illumination.
5. Capability to reduce selected frames photogrammetrically. This capability requires:
   a. Stereo imagery (0.1 to 1.0 meter based image pairs).
   b. Metric quality imagery or imagery which can be reconstituted on Earth to metric quality.
   c. Position and orientation of camera with respect to coordinates and with respect to local vertical (or horizontal).

6. Camera orientation with respect to vehicle heading and local vertical.

7. Capability to function with a microscope.

In addition, color vision will be required for rock and mineral identification as a Field Geology Function, and for use with certain geochemical instruments.

The scientific instruments that would presently be used for this function are the television vidicon camera, the facsimile camera, and the CCD camera. The diverse imaging requirements to accomplish even a modest EPA mission suggest that several camera systems will be required. Thus a light-weight, low-to medium resolution elevated camera is needed for navigation, guidance, reconnaissance and photo geology, while a medium-resolution camera is needed to support the near-field science activities, and a high-resolution science camera is needed for microscopic work. Sagacious design might reduce the total number of cameras required to accomplish the imaging function; however, the three general ranges of imaging enumerated above will have to be accommodated.

Geochemistry Function

The Geochemistry function will require a capability to determine the age, the mineralogy, and the petrology of work as they are encountered in exploration and prospecting. This includes their elemental and isotopic composition, the mineral phases and the structures and textures. In addition, the capability to determine the elemental composition of bulk samples for assaying is required. Instruments for providing this function are conveniently divided into three categories: The first is elemental/isotopic analysis, which determines the amount of each element and isotope within the sample. The second is crystal structure analysis which unequivocally identifies the mineral species within the sample. The third type is microscopic and petrographic analysis, which determines the specimens' texture and structures and provides mineral identification. The hand lens that a geologist carries is useful for providing some of this type of information; however, the scientific instrument is a petrographic microscope.

The most effective strategy for the geochemical study of a remote surface is to proceed systematically with the mineralogical and chemical characterization of its materials in accordance with geologically determined priorities. It is insufficient merely to chemically analyze the surface rocks. Determination of mineralogy, texture, lithology, and other properties of rock are relevant. Mineralogic composition is particularly important, as the mineral assemblage reflects both the chemical composition and conditions of formation and is far more diagnostic of rock type and formative processes than chemical composition alone. If a choice must be made between a mineralogic and a chemical analysis, the geologist will generally opt for the mineralogic analysis because it contains much chemical information and a great deal more. Such a choice should not be necessary, for mineralogical and chemical experiments can be readily integrated to provide a complete analysis.

The success of any geochemical exploration program depends largely on how intelligently analysis sites are chosen; therefore, meaningful data here will require cooperation between field geology procedures, mapping, imaging, and sampling. A geochemical sensor must have the capability of making measurements on various nearby objects of interest and of visually monitoring the sample selection for such measurements. This requires that a sampling tool or tools be available and that the sampling operation be conducted in close conjunction with an imaging system.

The need for an automated age-dating capability to meet the requirements for this function is quite obvious from a review of the terrestrial analog.

Scientific instruments to carry out some of the aspects of this function, notably elemental analysis, have already been used on space missions, but there is much to be desired here for any future EPA missions. This becomes especially clear from a consideration of the nine instruments discussed for this function in Section III.

Geophysics

Terrestrial geophysical prospecting uses seven different classes of instruments or methods to acquire geologically supportive data for EPA. Table IV presents these methods with some descriptive information. Each method is represented by several specific instruments, or procedures, that may rely on totally different physical principals to measure a given phenomenon. Many of these instruments have already been employed in space measurements, and others will eventually be used.

Most of the geophysical sensors discussed here are easily adaptable to a remote-surface EPA task; however, the complicated procedure whereby a given sensor or an array of sensors may be deployed and retrieved from its operating location will require considerable versatility and coordination between the imaging function, the experiment handling function, and carrier-vehicle mobility.

Field Geology

The Field Geology Function involves the executive responsibility for the field (in situ) aspects of the exploration effort. It provides the geologic context for all measurements, including the instruments and

Table IV
Geophysical Prospecting Methods

	Seismic	Gravity	Magnetic	Electric	Electromagnetic	Radioactivity	Well Logging
Principal Instruments	Geophones or Sensors (Various) -Recording Systems(Various) -Seismic Source	Gravimeter (Various) -Pendulum -Torsion Balance-Accelerometer	Fluxgate - Nuclear Resonance-Field Balance	Detecting Coils (Various) - Electrodes (Various) - Energizing Source (Various) - Recorders (Various)	Detecting Coils (Various - Electrodes (Various) - Energizing Source (Various) - Recorders (Various)	Geiger and Scintillation Counters	Various sensors in a sonde device that can be lowered into the exploritory hole.
Measurement	Time of travel for seismic waves in traverse of direct, reflected or refracted path.	The Earth gravity field its variations and rate of change	The magnetic field of the Earth, its magnetude, direction, and components	Natural earth currents and the effect on the ground of both direct and alternating currents	Various properties of magnetic fields induced in the ground by conductive or electromagnetic means	Detect the high energy particles resulting from natural radioactivity	The electrical, heat, optical, radioactive, accoustical, etc properties of the subsurface in a drill-hole
Results	Depth to reflecting or refracting horizon-Seismic wave speed - Elastic properties of materials-Earth structures	Identification of Earth structures that have a measurable density contrast	Location of magnetic ores ores, bodies, and structures as a result of their susceptibility contrasts	Location of ore deposits, depth to bedrock, bedding and water table, and determination of some of the electrical properties of the ground	Location of ore deposits, depth to bedrock, bedding and water table, and determination of some of the electrical properties of the ground	Location of radioactive minerals of the elements uranium, thorium and potassium	Identification and correlation of stratigraphic sequences

techniques for reconnaissance and surface mapping, preliminary mineral and rock identification, and the site selection for sampling and experimenting. Through this function all the other functions are directed either by preprogramming the in situ operator or by a combination of preprogramming and direct involvement through a data link, data display and control facility and human interpreters. In terrestrial operations the field geologist provides the site manipulations for acquiring samples and implacing instruments, the eyeball imaging system, and the intellect for documenting and control. In a remote surface EPA mission the Field Geology Function will consist of the following elements:

1. Direction of operations relevant to exploration, prospecting and assaying on the remote surface (through a data link and by preprogrammed procedures).
2. Documentation of the field investigation as required for mapping, surveying, experiment and sample site location. recording data, etc.
3. In situ observation through the imaging system for reconnaissance geology and for preliminary rock and mineral identification.

Sample Acquisition

Two extremes of capability for sample acquisition are available and utilized in the terrestrial environment. First there is the human capability as epitomized by the field geologist, where sample selection and acquisition are under the control of a trained intellect with coordinated visual acuity and dexterity of movement. Second there is the drilling and dredging capability where samples are acquired from the subsurface or other inaccessible places. The capability for acquiring oriented cores and samples should be noted.

In order to carry out this EPA function on a remote surface, a diverse manipulator or series of manipulator, variously tipped with drills, chippers, claws, hands, etc., will be required. Also, this function will normally be under the control of the imaging function. The manipulators, suitably tipped, should be able to obtain selected samples as required from exposed rock outcrops and boulders by chipping or drilling, to obtain surface and subsurface soil and rock samples, and to pick up selected individual rock fragments ranging in size from about 0.1 mm to perhaps 10 Cm. The system should be able to mark the orientation on selected samples if required, to dust samples for on the spot viewing, and to fracture rocks to provide a fresh surface for on the spot viewing. In general, for a remote surface EPA mission the sampler should be able to fulfill the following requirements:

(1) Coordination of imaging with sampling activities.

(2) Sampling of particulate material.

(3) Sampling of large rock fragments.

(4) Preliminary assessment of sampled material for texture, mineralogy, and chemistry.

(5) Drilling.

A sampling instrument similar in function and design to the Surveyor sampler and in contrast to a drill or auger-type sampler appears to have the most utility for collection of particulate material. This type of sampler can be directed to any select fragment or area on the surface, scratch at the surface of outcrops, uncover contacts, trench to permit a TV view of the subsurface, and provide data about the vertical distribution of surface material.

It is also necessary to have a device capable of coring, chipping, or breaking fragments from large rocks or outcrops. This type of whole rock sample in which the constituent mineral grains and interstitial material have not been comminuted is desirable for textural-structural study, eyeball viewing during reconnaissance, and for petrographic study. A core or fragment measuring about 2 cm x 4cm x 1 cm is required and its reference orientation at the sample site should be known.

For most of the geochemical instruments a comminuted sample properly sized is required. In many cases a drill tip can be designed to provide the size of fragments required for analysis without additional sample grinding or sorting. A drill-type sampler also provides a low-power rapid technique for subsurface sampling, and it should be designed for use against vertical or sloping outcrops. The limited life of drill bits is a problem.

An auger-type sampler may have some practicability for digging up a pile of sub-surface material that can be subsequently picked over, sorted, and selected by the Surveyor-type sampler. This type of operation must be viewed by the near-field imaging system.

Sample Preparation

In terrestrial operations this function is largely performed in the laboratory, but for remote surface in situ operations it will have to be automated in order to obtain reliable and accurate data for some of the analytical instruments. Fortunately, most of the sample preparation here involves simple operations such as crushing and sieving so automating isn't difficult, but in at least one case, viz preparing rock thin sections for use with a petrographic microscope, the whole process could be quite complex.

To obtain reliable and accurate data from several of the analytical instruments for EPA, it is desirable to prepare the sample before analysis.

The intent in sample preparation is to allow the instrument to generate the best data possible and not to constrain the accuracy or precision of the data by the condition of the sample. It is important to include sample preparation as a factor in the trade-off studies involving expected science return, power, weight, and volume. The preparation, in general, will involve one or more of the operations of comminuting, shaping, and containing the sample. The following is not an exhaustive list of sample conditioning activities, but is representative of the types of procedures necessary:

X-ray diffraction. The sample should be particulate and fine-grained (< 50 μm). It must be presented to the instrument in a fixed form either on an adhesive backing or in a sample tray. The volume required is on the order of 1 cm^3 or less.

X-ray spectrometry. The sample should be particulate, fine-grained, and either less than 20 μm in grain size or less than 59 to 60 μm with no more than a 20% range in particle size. The sample surface must be presented in a fixed form, either in a container or restrained in shape by an instrument-sample interface.

Neutron activation. The sample volume subject to activation must be constant or known.

Microscopic viewing in polarized light. The sample (either particulate or coherent) must have portions less than 50 μm in thickness. It must be embedded in or held by a mount in such a way as to allow transmitted light viewing and positioning in the imaging system.

Sample Handling and Storage

Two separate activities are normally involved in this function. First, there is the need to store samples for subsequent analysis and study. These samples may be screened by the analysis instruments as they are collected, collated and tagged, and then placed in an appropriate storage container. The apollo Astronauts largely accomplished this kind of activity for the returned lunar samples. Second, there is the need to deliver sample material from the acquisition or preparation instruments to the analysis instrument and to manipulate the samples for study by these instruments.

Some of the requirements for this function are as follows:

(1) Store particulate material. The total number of samples will be dictated by the amount of weight allocated to this part of the EPA mission.

(2) Store core samples, selected rocks, chips and grains, and cuttings.

(3) Present collected samples to an array of chemical, mineralogical and texture analysis instruments. Keep or reject any sample after analysis, send any sample directly to storage without analysis, or recall any sample.

(4) Identify samples by storage position and by visual examination of indexed numbers on sample containers.

(5) Package stored samples to minimize intercontamination and loss or transfer of material and to facilitate extraction of sample-containing modules for subsequent off-loading (hermetic sealing is not a requirement during traverse).

(6) Retrieve and dump stored samples, probably included with containers, to prevent contamination of higher priority samples found later.

In addition to a particulate sample handling and storage device, a container should be provided that is accessible from the sample acquisition device for depositing rock fragments that will not fit into the particulate storage mechanism. It is desirable to bag, or at least separate, these fragments to avoid any intercontamination, and also to index them for subsequent identification. The camera system could be used to identify each rock sample on the basis of factors such as size, shape, number of facets, and color.

The sample handling equipment must also include a manipulator device - viz viewing platform or stage - for optical examination of samples, whereby the samples can be positioned, rotated, rocked, translated, etc. in view of the Imaging Function.

Part A
Section III
Description of EPA Scientific Instruments

As indicated in Table I, and also in the previous section of this report, the major functions on an EPA mission will be accomplished by scientific instruments and support mechanisms. In the following pages approximately 30 scientific instruments or methods that may be used for providing a particular type of data for the major functions of imaging, geochemistry, geophysics, and field geology are described. These are the scientific instruments for EPA. The support mechanisms for these instruments are described in Section V.

Along with the technical description, a status review and new technology requirements also are presented.

Imaging Systems

Three imaging systems are discussed here only briefly. Two of these, the facsimile camera and the vidicon camera, are highly developed and have been used on several space missions, while the third, the CCD camera, appears to be advanced and certain in its development cycle and not dependent upon any new instrument technology for its early application.

1. Facsimile Camera

Facsimile camera systems were developed and prototyped by the early 60's for application in the space program. One of the first such devices was developed by Ford Aeroneutronics as an experiment for the Ranger Capsule scientific payload. The device proved to be extremely rugged, light in weight and reliable, and in subsequent field tests by the Astrogeology Branch of U. S. Geological Survey at the Bonita lava flows, it produced high quality, geometrically stable images that were very well suited to stereographic viewing and reduction techniques. Similar cameras were delivered to the lunar surface in 1966 by the Soviet spacecraft Luna 9 and 13 and produced good images. More recently the Soviets used the facsimile principle for imaging from the hostile environment on the surface of Venus (Venera 9 and 10) and on their Lunokhod rovers (Ref. 15). The most recent successful use of facsimile-type cameras on a U. S. planetary mission was on the Viking landers. These cameras were versatile scientific instruments designed for high-and low-resolution imaging in stereo, color, black and white, and infrared (Table V and Ref. 16).

The facsimile camera performs the function of transducing visible energy into electrical energy and establishes the format by which picture information is represented electrically. Several different instrument designs have been used but the typically major element is a top tube which contains the optical viewing subassembly, plus vertical drive, and scanning mechanisms. These elements provide one degree of motion to the optical system by "nods" in the vertical plane. Other elements in the system include an azimuth drive mechanism, which provides the necessary second degree of motion to the optics for rotation in the horizontal plane; motor drive electronics, which provide the power to both the vertical and horizontal drive motors; signal electronics; and synchronization electronics, which provide accurate timing signals to ensure proper playback of the data. The top-tube assembly is housed in an appropriate viewing fixture with ports. The ports in the outside walls of the top-tube housing are sealed with glass windows or other optically transparent material which will pass energy in the region of the electromagnetic spectrum of interest. Inside the housing and behind each window is a flat distortionless mirror which is pivoted so that it may swing in a plane, thereby generating a scan. By this action, each mirror reflects light down the tube onto an image-forming lens, which in turn focuses the light onto the surface of a photosensitive transducer.

2. Television Framing Camera (Vidicon)

This imaging system is highly developed and has been extensively used in the space program, primarily for orbital and flyby missions (Ref. 13), but it has been used on the lunar surface by Surveyor and Apollo. Both the TV and facsimile imaging systems will be needed on most EPA missions. The TV camera is needed to provide images for maneuvering and guidance of the EPA vehicle, but it also provides greater resolution than the facs, thus adding considerably to the geologic work that can be done.

The television camera uses a photo conductive vidicon sensor onto which the optical image is shuttered through a variable focal length lens. Provisions may be made for the insertion of colored or polarized filters into the optical path on command. The vidicon sensor measures approximately 2.5 cm by 17.5 cm.

3. Charge-Coupled Device (CCD)

The charge-coupled device, using line or area array photodiode sensors, is a relatively new imaging technique for space missions. JPL has been involved since FY'74 in a major development effort on CCD's which has been supported by funds from both the NASA Office of Aeronautics and Space Technology and the Office of Space Sciences. Reticon and silicon photodiode CCD line-array cameras have been built at JPL. CCD systems have been proposed as the principal imaging camera for the Lunar Polar Orbiter (Spectro-Stereo Imager), for the Mars '84 Orbiter (Wide-Angle Imager), and for the Mars '84 surface camera (Rover Stereo Imager).

The charge-coupled device as used on EPA missions will be multi-channel line - or area-scan imaging system, providing a capability for high- and low-resolution imaging, stereo imaging, and multispectral imaging. The device will consist of an optical system, sensor drivers, timing logic, system electronics, a photodiode sensor array and spectral filters. The device must be cooled to about - 40°C, and it will require shielding from any onboard RTG.

As indicated earlier, no new technology is urgently required for the design, fabrication or components of these instruments. More responsive sensors, in terms of sensitivity and specific wave-length response, may be required for a particular EPA application, but generally these camera systems have been miniaturized, ruggedized, and utilized to a high degree of perfection. It should be noted that imaging devices are usually more constrained by the communication link that they function through than by their own limitations, so new technology in these will be needed. In the same sense, the operational procedures for imaging and its interrelationship with other major functions on even a simple EPA mission will be complex, resulting in the need to communicate and handle huge quantities of data, which will require new software and ground control technology.

TABLE V

DESIGN CHARACTERISTICS OF VIKING LANDER CAMERA

Characteristics	Survey	Color and Infrared	High Resolution
Instantaneous field of view, deg	0.12	0.12	0.4
Frame width, deg			
Elevation	61.44	61.44	20.48
Azimuth: min	2.5	2.5	2.5
max	342.5	342.5	342.5
Field of view, deg			
Elevation	100; from 40 above^{0} to 60^{0} below horizon, selectable in 10^{0} increments		
Azimuth	342.5; in multiples of 2.5^{0} steps		
Photosensor			
Aperture diameter, mm	0.12	0.12	0.040
Distance from lens, mm	54.5	54.5	55.3, 54.8, 54.4, 53.9
Picture elements per line	512	512	512
Bits per picture element	6	6	6

X-ray Diffractometer

The standard laboratory instrument for the study and analysis of crystal structure is the x-ray diffractometer. This instrument uses essentially monochromatic x-ray radiation and a finely powdered sample spread uniformly over the surface of a glass slide. The instrument is so constructed that the slide, when clamped in place, rotates in the path of a collimated x-ray beam, and a counting sensor, mounted on an arm, is pivoted to rotate about the slide to pick up the reflected x-ray beam. Thus when an x-ray strikes a small crystal grain on the slide it is diffracted back in a preferred direction depending on the crystal structure of the mineral involved. By measuring the diffraction directions relative to the original beam, information regarding the crystal structure may be obtained, and this information may be used to identify the various individual minerals present, and to determine their quantity.

An early study at JPL in 1963 developed the design concept and Bragg-Bentano geometry for a miniature instrument (Ref. 1). An automated prototype of this instrument was built at JPL in the late 60's (Ref. 2). Another instrument design that incorporated an x-ray fluorescence capability was also built (Ref. 3).

Both of the above instruments were successful, i.e., they performed well, providing x-ray diffraction spectra that compared very favorably with laboratory quality spectra. They both had an angular resolution of $2\theta \cong 0.25°$. The diffractometer system contains two major parts: first, the goniometer subsystem which includes the x-ray tube, gas proportional detector, and sample-handling device, and second, the power supplies and data handling mechanisms. The design of the instrument represents a miniaturized version of the standard laboratory counter diffractometer except that it is inverted. X-rays from a small, 25 kv x-ray tube with a copper target are incident on the base of a specimen cup with a basal window of 0.002-inch thick beryllium. The diffracted x-rays will exit through the cup base and will be counted by a gas proportional detector. The potential 2 Θ range is 10 to 80 degrees and scan rates may be from 1/2° to 4°/mm.

A curved position-sensitive solid-state proportional counter has been designed and developed for this instrument, where the curved sensor was used as the direct replacement for a film strip. The expected speed or intensity advantage of the PSPC over a scanning slit is a factor of from 500 to 1000 for identical statistics. This is an extremely important result, since it implies that an isotopic source such as Fe^{55} (5.9 KeV x-ray) can be used in place of the power-consuming x-ray tube. Alternatively, one could use a low power x-ray tube (e.g., 0.1 ma at 10 Kv) to retain versatility. On this basis the PSPC has outstanding promise for lunar or pnaletary analysis, but new technology is required in sensors for this instrument.

X-ray diffractometry may be carried out, as described above, by observing the angle at which diffraction occurs; however, it is also possible to use the diffracted x-ray wavelength to give this same data. An energy resolution of about 0.2 KeV is equivalent to an angular resolution of 0.2°. Since Si(Li) and Ge(Li) easily achieve this energy resolution, an automated instrument may be developed that uses this principle.

Since this sytem requires a broad energy spectrum (2 KeV to 10 KeV), an extremely efficient x-ray generator (W-target), or more appropriately, an isotopic source such as Ni^{63}, may be used. This system would, of course, allow x-ray fluorescence to be carried out simultaneously, and still allow a mass and power reduction over the equivalent traditional x-ray diffractometer. Sensor development would be required for such a diffractometer as an energy resolution of 0.2 KeV isn't practical at the higher energy end of the desired spectrum. On an EPA mission this instrument will require support from sample acquisition preparation and handling mechanisms.

X-ray Spectrometer

X-ray spectroscopy is a widely used technique that appears to be easy to miniaturize and automate. Used by the Soviets in Lunokhod 1 and 2, and on the landers of Viking 1 and 2. Space instruments have used a radioactive source for generating the fluorescing x-rays and this has resulted in less resolution and longer analysis time than for laboratory instruments.

The technique involved for this instrument derives from the fact that any material when bombarded by high-energy particles (electrons, slpha particles or x-rays) will emit x-rays of energy which are characteristic of the elements contained in the sample. This energy increases with the atomic number Z. Elements of low Z (sodium and below, $Z \leq 11$) have low energy x-ray emission, and are difficult to detect above background. Basically the experiment consists of an x-ray sensing head, an electronic control and registration system, a standard sample, and a power supply. The x-ray head comprises an excitation source, fixed dispersive and nondispersive analytical channels, and detector circuitry.

Two different techniques of x-ray energy determination are commonly used. The non-dispersive method involves an energy sensitive detector which converts the absorbed x-ray into an electrical pulse, whose amplitude is proportional to the energy of the incident x-ray. The detectors most frequently used are the semiconductor detector (e.g., Si(Li), the proportional counter, and the scintillatioh counter (e.g., NaI (Tl)). The dispersive method involves a crystal which diffracts a particular wavelength into an x-ray detector, with the diffraction angle determining the energy of the x-rays. In general, the nondispersive-type spectrometer is smaller and lighter than a dispersive-type spectrometer, but is less accurate and requires more data analysis.

The use of Si(Li) detectors has required active cooling to maintain sensitivity; however, this difficulty is being reduced by the appearance of intrinsic germanium and silicon. Intrinsic material is of such high purity that large volume detectors can be fabricated without the necessity of compensation of impurities by the addition of lithium through the diffusion process. Such intrinsic detectors may be stored at room temperature, a procedure that quickly destroys drifted detectors. They still require low temperatures for operation if high resolution is to be obtained but only a modest loss of resolution is incurred at operating temperatures up to 200°K. Since the sinicon detector would have a volume no more than 0.2 cm^3, in-situ cooling to the required 200°K by radiation, or a combination of radiation and thermoelectric cooling, should pose no great difficulty. For EPA missions, depending on the mode and place of operation, support from sample acquisition, preparation, and handling mechanisms may be required.

Petrographic Microscope

Petrographic microscopes have been successfully combined with TV and a compact light-weight prototype system has been built (Ref. 4). Spacial resolutions achieved with cameras on lunar and planetary landers have been limited to about 1 mm, but a proposed microscope design for use with the Viking lander camera would increase its resolution to about 1 μm (Ref. 5).

The petrographic microscope conceived in the late 60's as a Surveyor experiment, was the first and last serious attempt to automate this important geological instrument. It was designed to operate as follows:

A sample of lunar material consisting of sized particles in the range of 10 to 300 μ is delivered to the microscope from the spacecraft sample processor/distributor system. The microscope system separates these particles into fine-grained and coarse-grained fractions. Each fraction is then immersed in a clear isotropic medium of known refractive index. The particles form a monoparticle layer with their tops in a plane. The sample is transported to the field of view of a lens system which displays its magnified image onto the optical sensor of a television system. The immersed sample moves in steps across the field of view of the objective lens. Several images individually focused at different depths in the particle layer are obtained for each field of view. The operation sequence during viewing involves:

(a) Movement of some immersed particles into field of view;

(b) Individual images at several planes of focus taken;

(c) Movement of more immersed particles into field of view and imaging sequence repeated.

Every particle is viewed in both plane-polarized and cross-polarized light. The samples are stored and are available for recovery and review.

The imaging subsystem consists of:

(a) A light source capable of narrow-bandwidth output, and a light condenser;

(b) An objective lens to project a magnified image to a television camera;

(c) Polarizing filters which will allow particles to be viewed in both plane-polarized and cross-polarized light;

(d) A television camera capable of recognizing 10 μ particles at any spot over a field of view of 0.5 x 0.5 mm.

The Surveyor instrument was designed to look only at particulate material; however, the real value of a petrographic microscope is in rock thin-section study. Thin-section examination is the most informative type of microscopy, and the capability to automate thin section preparation must be considered an integral part of the design of a petrographic microscope and needs to be actively supported. The technology to acquire fresh rock samples, cut these to the required thickness for viewing by transmitted light, mount the sample for view and then encase the sample in a material of suitable refractive index represents a series of challenging technological opportunities. A less desirable alternative to a thin section would be examination of a sawed surface that had been coated with a suitable wetting agent.

An automated imaging microscope capable of about 10 μm, and with petrographic attachments, has not been built as a lunar and planetary instrument, but the technology for the design and fabrication of such an instrument appears to be available. However, the technology for automated rock thin-section preparation, including sample acquisition and handling, has never been seriously considered, and this now represents a challenging vista for new ideas in mechanisms, materials, operational procedures, and design for an important EPA instrument. Rock thin-section preparation will be described more completely in a subsequent section of this document (i.e., Description of Support Mechanisms).

Mass Spectrometer

The instrument has been used successfully for atmospheric analysis in the lunar program and in earth applications (Ref. 6). It was also used in combination with gas chromatography to perform an organic analysis on the

Mars Viking landing (Ref. 7). Laboratory instruments of this type for the analysis of solid samples do not exist. For solid samples some of the sample must be vaporized to produce the gaseous sample. If very high energy electrons are used, the solid sample may be vaporized directly by the electron beam; however, the power requirements here are usually high (hundreds of watts), there may be serious thermal problems in the sample or sample holder, and a non-conducting sample must be coated or matrixed with a conducting medium to prevent space charge effects. Primary ion bombardment can sputter out secondary ions from the sample, and some recently devised mass spectrometers do use an ion bombardment source. A laboratory instrument, the CAMECA IMS-3F, that uses primary ions of O_2^+, N^+, A_2^+, or O^-, is available. A laser source might be used for vaporizing and ionizing solids but this technique hasn't been used for a prototype or laboratory instrument.

After being emitted from the sample, the ions must be filtered and focused, magnetically or electrically, in such a manner that ions of a specific mass impinge upon an ion detector. Types of mass analyzers which might be appropriate for EPA on remote surfaces include quadrupole, magnetic, and electrostatic-magnetic (double focusing). The quadrupole analyzer uses a quadrupole electric field, and hence is particularly appropriate when a magnetically clean payload is desired. The magnetic analyzer is most common for ordinary laboratory work, but if the ion source has a significant energy spread (as is the case with an ion bombardment source), the simple magnetic analyzer does not allow a mass resolution comparable to the other two types. The electrostatic-magnetic system adds an energy-focusing electrostatic analyzer to the momentum-focusing magnetic analyzer.

Mass analyzers such as the quadrupole, magnetic, and electrostatic-magnetic instrument can probably be designed for remote surface EPA application; however, the method by which an ionized sample can be prepared from a solid rock sample isn't clear. Options for generating ions from solid samples for an EPA instrument might include a laser ion source or a sputter ion source. In the Ion Microprobe/Mass Analyser, discussed below, and also in the CAMECA instrument, an ion beam is used to sputter of secondary ions so the technique is practical in a laboratory instrument. A pulsed laser to vaporize and ionize samples has been used but an instrument hasn't been built. In summary, the major technology problem for this instrument is the need for an ion source generator that is compatible with the size and environment of an EPA instrument. Instrument design should be straightforward and sample preparation requirements would be negligible, but power requirements may be high, and environmental and thermal problems will have to be considered and accounted for in a remote surface instrument of this type.

One further point that should be noted - a mass spectrometer capable of resolution over the mass range of 1 to at least atomic mass number 238 - may be required as an analysis instrument for automated in-situ age-dating. So the development of such an instrument may have a very high priority.

Scanning Electron Microscope/Microprobe (SEMM)

The Scanning Electron Microscope/Microprobe is a compact laboratory instrument that has been extensively used in the analysis of returned lunar samples. As an analytical instrument it is capable of microscopic measurements of major and minor elements based on electron excitation of characteristic x-rays.

In the laboratory SEMM instrument, electrons are generated in an electron gun, and these are accelerated and focused to a small spot, approximately 1 μm in size on the surface of the sample. This generates secondary electrons and x-rays. The spot may be made to perform a raster scan of the sample surface, and in this process secondary electrons are emitted, and detection of these during scanning yields a topographic "picture" of the sample surface. Characteristic x-rays are also emitted. One x-ray line may be studied as the beam scans, yielding a composition map of the corresponding element; alternatively, the whole range of x-ray energies may be studied while the beam remains fixed, yielding the concentration of all major elements in the spot chosen. The high spatial resolution of this instrument makes it ideal for detailed mineralogical studies.

A major technology problem for any remote-surface automated use of this instrument will be in sample preparation; specifically how to control the effects of sample charging by the electron beam. In the laboratory the sample is usually pre-treated by a rather complicated high power process, with a thin conductive coating to eliminate the surface charging caused by the electron beam. On nonconducting material such as rocks, the effect is most pronounced. Because secondary electrons generated in the surface of the sample are the primary data source in the scanning electron microscope portion of this instrument, techniques to reduce the sample charge effect must not interfere with this process. The laboratory instrument is a high power user so new technology may be required in the design of lower power electron lens and electron source systems.

Ion Microprobe/Mass Analyzer (IMMA)

This is a relatively new geochemical instrument that has now been extensively used in the study of the Apollo samples. The IMMA is similar to the SEMM, discussed above, but uses ions instead of electrons for scanning the sample. In this instrument oxygen ions are generated in an ion source generator (duoplasmatron), and these are accelerated to approximately 10 KeV, and focused to a 10 μm diameter spot on the sample surface. This spot can be used in a scanning mode over a small area of the sample. Secondary ions are generated by sputtering and these are accelerated and their mass spectrum obtained in a mass analyzer.

As with the CAMECA mass spectrometer discussed earlier, the IMMA is capable of isotope analysis, not merely elemental analysis. It is a versatile laboratory instrument that can be used in the scanning mode for determining the topography or the spatial distribution of an element/isotope in the sample. Further with the beam fixed on one spot the instrument can be used to monitor all the different ions sputtered from that spot, thus determining the concentrations of even trace isotopes.

The CAMECA IMS-3F although correctly described as a mass spectrometer is an advanced version of an Ion Microprobe/Mass Analyzer. This significance of this type of instrument for remote-surface EPA missions is very high, expecially for automated in situ age-dating, and so the specification of the CAMECA instrument are presented here:

General

Mass range: 1-300 at full accelerating voltage (can be extended to 500)

Useful sample area: 20 x 20 mm

Secondary ion energy: 5 KeV

Spectrometer maximum energy bandwidth: 150 eV

Mass resolution: Spectrometer Mode: 50 to 5,000

Spectrograph Mode: up to 10,000

Primary Beam

Cold cathode duoplasmatron with adjustable magnetic field

Primary ions: $O_2^+ N^+ A_2 O^-$

Accelerating voltage: 5-20 kV (maximum net energy 15 to 25 KeV)

Beam diameter: < 3 μm to 500 μm

Ion density of the sample: 50 mA/cm^2 (positive), 5 mA/cm^2 (negative)

X Y rastering: 0 to 500 μm

Sample Stage

X and Y displacements by stepping motors. Reproducibility ± 1 μm

X-Y interaction < 1 μm

Fast-acting manual airlock. Direct viewing microscope.

Sample size: 25 mm dia. x 13 mm

Ion Microscope (Direct Imaging)

Spatial resolution: < 1 μm

Imaged field: 25, 150 and 400 μm

Magnification: 60X-100X

Final image: 25 mm dia. (photographic camera outside the vacuum)

Mass Spectrometer

Double focusing design.

Electrostatic analyzer: 86 mm radius, 90° angle

Magnetic analyzer: 127 mm radius, 90° angle

Magnetic field stability: 4×10^{-6}

Detectors

Dynamic range of measurement: 10^9

Faraday cup with D.C. amplifier

Electron multiplier, 18 stages

Channel plate, 10 μm channels, max. gain 10^4

Fluorescent screen, 25 mm dia.

This type of instrument is large - typically 3 meters in length, by 2 meters in width, and about 2 meters in height. It might weigh 1500 kilograms with a vacuum system. Clearly there is a major technology problem involved in the design and miniaturization of this instrument; on the Moon at least vacuum should be no problem. In addition a critical technology concern exists for the ion source generator. The laboratory instrument uses a duoplasmatron for generating ions which requires several amps and 500 watts of power, powerful focusing magnets, and its heat dissipation and environmental impact are high. Other possible ion generators might be the Penning Ion Guage or a radio frequency source, but these seem to present more problems than the duoplasmatron. As a remote-surface EPA instrument, IMMA will require the development of new technology for sample handling and preparation.

Pulsed Neutron/Gamma Ray Spectrometer

A team assembled by NASA in early 1970 worked on the early development of a pulsed neutron experiment but this effort concluded without a prototype design (Ref. 11). The Soviets appear to be working on this concept for lunar and planetary application. Sandia, in the mid '70s built a prototype instrument that is currently being tested at GSFC under a joint NASA-NOAA study. The power supply on this prototype is only about 40 KV-28v, and this is too low. A new breadboard power supply of 50 KV should be operating at GSFC shortly (Jack Trombka, GSFC personal communication).

A typical instrument would consist of a miniaturized neutron source, a NaI(Tl) detector shielded by a beryllium neutron scatterer, a He^3 filled cadmium-covered epithermal neutron detector, and the necessary electronics, logic, and analysis systems.

The general technology to build a satisfactory instrument of this type appears to be in hand. EPA constraints and technology opportunities would concern sensor shielding from any RTG source, shielding from the 14 MeV neutron source, development of the power supply for neutron source and developing a more efficient source, cooling of the Ge x-ray detector, and in general, protection of the instrument from the diverse environments of remote surfaces. Experiment handling will be required to deploy the experiment to the remote surface and retrieve it.

<u>Alpha-Particle Back-Scatter Spectrometer</u>

This was a successful lunar experiment on Surveyor (Ref. 12). Instrument required long counting times - 800 min. - to detect critical rock elements (O, Si, Al, Mg, Na) to an absolute accuracy of 3 percent.

The design and development of this instrument are straightforward and no new technology would likely be required. The instrument would work best in combination with an x-ray fluorescence detector. The instrument will have to be deployed to the surface to function and then retrieved. Since a radioactive source is used, other instruments may have to be shielded and vice versa. The α-experiment will require little sample preparation but the x-ray spectrometer would require particulate material.

<u>Age-Dating</u>

One of the most valuable instruments for future remote-surface EPA missions would be one for automated in situ age-dating. Of the several techniques that are used for age-dating samples in the laboratory, all involve complicated procedures, careful sample collection/selection/processing, and sensitive instruments for analysis. There is no instrument presently in the prototype stage that can do this, nor is the development of such an instrument being seriously pursued. It is generally assumed that automated in situ instruments cannot be developed to perform reliable age-dating, and that sample return is absolutely necessary for this type of analysis. This assumption should be questioned and the prospects for the early development of the automated mechanisms, operational procedures, and instruments for in-situ age-dating should be investigated. The task is formidable but the scientific and dollar value of a practical in-situ method are inestimable.

Age-dating by the U-th-Pb method, etc., as carried out in the laboratory, is a complex experimental procedure consisting of:

(a) Mineral concentration - selection and concentration of single mineral grains from appropriate rock material by first, gentle crushing, and second, microscope/manual/mechanical sorting.

(b) Element concentration-separation and concentration of the elements of interest from the mineral concentrate by wet chemical procedures.

(c) Isotope separation and analysis by mass spectroscopy, etc.

Automated in-situ age-dating will involve duplicating these mineral/element/isotope concentrating processes to provide a material for analysis by an instrument, etc. Thus, in-situ age-dating won't likely be accomplished with a single scientific instrument, but rather may involve a whole series of complicated mechanism and operational procedures to derive a product for final analysis.

There are technology opportunities here in the areas of sample acquisition, sample concentration and preparation, and sensor/instrumentation. Specifically, sample acquisition technology must be able to handle a large quantity of in-situ material to acquire a selected sample. Sample concentration processes may involve manual/microscopic separation and concentration of mineral grains of the desired type, and the further concentration of this material by chemical procedures into the elements of interest. The final stage in age-dating involves isotope separation and counting probably with a mass spectrometer. Some of the technology considerations for in situ mass spectrometry were discussed earlier under that instrument. In any case, for intrinsic age-dating measurements it should detect appropriate isotopes up to mass number 238 at concentrations of about 1 ppm. An EPA instrument of this kind of sensitivity can probably be built. However, the sample concentration/ preparation techniques and technology for this type of remote/surface measurement cannot now be defined. Perhaps the problems here are insurmountable in terms of our present concept for age-dating, and a completely new way of doing this for EPA is needed.

Seismic

Most EPA seismic investigations will involve active not passive techniques, although passive seismology studies, which merely require seismic listening, are of great scientific interest. Passive techniques have recently been used in the study of geothermal sources but they are not normally important in geophysical "exploration." The active seismic methods, as will be needed for future EPA missions, are considered shallow exploration techniques for probing the uppermost kilometer of the remote-surface.

The instrument will consist of a deployable detector or sensors called a seismometer, an auger or drill for preparing a shot-hole, and an explosive charge or surface thumper for providing a seismic energy source. The general concept of an automated active seismic experiment for an EPA mission is described in Ref. 21.

Seismometer. For active seismic prospecting on earth, the detector, together with its associated amplifier and other electronics, is usually tuned to respond to signal energy of 5-150 Hz. Acoustic velocity techniques, and certain so-called "high resolution" reflection techniques used for mapping thin and relatively shallow strata, have used sensors tuned to respond to frequencies up to 300 Hz. In general, reflected seismic energy from a given source will have a slightly higher frequency than refracted or direct waves. The light-weight portable equipment used in terrestrial shallow seismic prospecting is usually tuned to 20-60 Hz. The inertia element of the detector is usually just sensitive enough to begin to detect microseisms, or earth noise.

Considering the above, it is desirable that the sensor/seismometer have the following characteristics:

(1) A single-axis, vertical-instrument configuration.

(2) A 1-150 Hz frequency response.

(3) The ability to detect a minimum surface displacement of 1 nm at 10 Hz.

The frequency response of the instrument down to at least 1 Hz is desirable because the device may be used in a passive mode. In practice, it will be necessary to place the seismometer, or at least its geophone pickup, in hard contact with the surface. The geophone itself can be made quite rugged and will weigh less than 5 oz.

Seismic source. A good seismic detector is able to detect a person stamping on the ground at a distance of 100 ft. Under favorable circumstances, a 1-lb shot can give detectable reflections from a depth of several thousand feet, and refraction signals out to perhaps a mile. Alluvial-covered areas absorb the shot energy and, therefore, require larger charges. Loess-covered areas, which seem to be like the lunar regolith in terms of particle grain size and physical properties, are intermediate in transmission characteristics between consolidated rock and alluvium.

It would seem that a 0.25-lb charge would be sufficient for most shallow prospecting purposes on the remote-surface. This should give reflection data from several hundred feet and horizontal data out to perhaps 1000 ft.

Auger. A 1-m auger is suggested as the third piece of equipment in the active seismic experiment. Seismic charges would be placed in the drill hole through the drill stem. The auger would be both rotated and extended by the drive system through which it passes, similar to a well-drilling rotary or Kelly.

Operating procedures. In terrestrial seismic prospecting, where mobility and backtracking are not problems, the normal procedure is to use one shot point in conjunction with about six detector-seismometers. Energy arrival times for each detector from the one source are plotted as a function of time and distance to portray refraction, reflection, and subsurface structure. On the remote-surface where backtracking and locating emplaced detector-seismometers could be difficult, a suggested procedure is to emplace a series of about five charges during a rover traverse and then, from a selected position with the seismometer on, remotely detonate each charge in turn. A few seconds recovery time must be allowed between detonations to avoid record wipe-out of subsequent events. A shot-point spread of about 50 ft would be used at first to carefully define the average velocity in the soil or regolith, or for precision probing for a suspected contact or structure; however, operating procedures would evolve through experience. Once the velocity function has been determined for the regolith or a particular marker bed, its depth at the other locations and during the traverse could possibly be determined from one shot point and the reflection record. Time anomalies between the regolith and basement rocks could be very high, but between individual sedimentary layers it might be small; therefore, timing accuracy should be controlled to at least 0.005 s and shot-point distance measured to 2%.

No new technology is required in the application of active and passive seismic instruments to EPA. Design and packaging for each application may be challenging and innovating but won't stress available technology. Experiment handling equipment, and remote-surface operational procedures will have to be defined and new technology may be required for this. Experiment handling will require coordination between imaging, mobility, drilling, and experiment handling mechanisms.

Gravimeter

A traverse gravimeter was flown on Apollo 17 (Ref. 22),and on the same mission another type of gravity sensor was used to detect gravity waves, and it also functioned as a seismometer (Ref. 23). Various instrument designs for land, sea and airborne use have been developed for on earth. Doppler tracking has been used on flyby and orbiting spacecraft with great success. A gradiometer instrument has been designed but not flown for orbital applications (see for example Ref. 24). For remote-surface EPA use a stable absolute instrument will be required. A prototype of such an instrument, called a laser gravimeter, was built, and a miniaturized design for remote-surface automated use was proposed (Ref. 25 and 26).

Various methods of measuring gravity are well known and some are widely used. Basically, one may select either relative gravity measurements or absolute gravity measurements. Of the possible choices, the absolute measurement is clearly preferable for EPA.

The most notable of the relative gravity meters are the LaCoste-Romberg/Worden instruments, the vibrating string and the old fashioned "pan balance" principle using more modern instrumentation techniques.

a. LaCoste-Romberg/Worden Gravity Meter

This principle was introduced by LaCoste and Romberg in the mid-thirties and is well known in the literature. Briefly, it is a system of levers and a "zero length" spring which results in a proof mass that has a negligible restoring force (e.g. nearly infinite period). It is extremely sensitive (some models reaching one part in 10^{11} or better). The Worden modification of the

LaCoste-Romberg instrument utilizes an ingenious technique of constructing the important parts of the system out of quartz glass. This requires extreme glass blowing skill, and the net result is an instrument of considerably reduced temperature sensitivity.

b. The Vibrating String Gravity Meter

This instrument was developed by the oil companies in order to overcome the deficiencies and possibly some of the costs of renting gravity meters from the LaCoste-Romberg Company. Shell Oil Company, Esso Oil Company and others are identified with this work.

The principle of operation is quite simple. A proof mass is suspended by a short length of electrically conducting wire at right angles to a magnetic field produced by a permanent magnet. When a current is passed through the wire a force is exerted on the wire. As the proof mass exerts a tension in the wire, the wire has a fundamental resonant frequency and many overtones. By supplying an alternating current which matches a resonant frequency of the wire, the resonant condition of oscillation is acquired. This frequency of resonance is proportional to the tension in the wire, the temperature of the wire, the amplitude of oscillation of the wire and the stiffness (ormodulus of elasticity) of the wire. The system must, of course, be operated in hard vacuum. Gravity is measured by measuring the resonant frequency of the wire.

c. "Pan Balance" Type Instruments

In this type of instrument the proof mass is maintained at a selected equilibrium point (usually) by magnetic forces arising from a flow of electrical current. There are two fundamental problems:

1. The magnet force is very dependent on the geometry.
2. The accurate determination of an electrical current to more than six significant figures is practically impossible.

A recent innovation is associated with Bell Aerosystems and is referred to as a pendulous, force rebalance accelerometer. It appears that the innovation is located primarily in the current measurement area. Instead of using direct current, a pulse forming circuit generates a pulse whose energy is independent of pulse frequency. The balance pan (proof mass) is maintained at the chosen equilibrium point by varying the pulse frequency. The indication of gravitational acceleration is therefore the pulse frequency.

The gravity pendulum has been the standard absolute gravity instrument in geophysics; however, a better instrument for future EPA missions will probably be something like the large prototype laser absolute gravimeter which was first designed and built by Hudson at MSFC.

The Laser Absolute Gravimeter operates as a dynamic Michelson Interferometer to make absolute measurements of gravity accurate to 1 part in 10^7. Basically, momochromatic light from a highly stable helium-neon laser is passed through a beam splitter which directs half of the beam to fixed corner cube reflector A and half to corner cube reflector B (the bird). Both beam halves are reflected back through the beam splitter to a photodetector, producing interference fringes at the detector.

To make the measurement, the bird is released and allowed to fall freely. The bird becomes the moving mirror of a Michelson interferometer. On release of the bird a preset counter is preset with a partial count. As the bird falls, interference fringes move across the photodetector and are detected by the zero crossing detector. When the present counter reaches a full count (n), it generates a start pulse for counter A and starts counting again. When the preset counter reaches n again, it generates a stop pulse for counter A and a start pulse for counter B. When the present counter reaches a count of n again, it generates a stop pulse for counter A and a start pulse for counter B. While the present counter reaches a count of n again, it generates a stop pulse for counter B. The vird is caught by the catch mechanism and is returned to the drop position. The catcher then returns to the bottom of the drop chamber.

No new technology is required for the application of accelerometer and spring-type gravimeters to remote-surface EPA. These instruments can be designed and built using present-day technology. However, there is a need for a stable (drift free) absolute instrument. To build such an instrument would certainly challenge state-of-the-art design and fabrication technology, stress miniaturization and counting circuit electronic technology, and present problems for instrument insulation/isolation and general environmental control for any EPA operation. This type of experiment will not require any support from sample handling, sample preparation or experiment handling functions on the EPA vehicle, but a microcomputer and altimeter will be required for preliminary data reduction.

Magnetometer

On an EPA mission the magnetometer will be used to locate and map magnetic anomalies that relate to geologic structures and ore deposits; thus it may measure values of the magnetic vector field, components of the field, the magnetic gradient or the magnetic susceptibility in order to determine the size distribution, geometry, location, attitude, and nature of rock masses making up the surface and subsurface of the remote surface.

Either a single-or-tri-axis magnetometer, or a gradiometer may be used for EPA. Measurement requirements for this type of mission will be as follows:

a. Values of vector field, or components of this field, to ± 1 gamma.

b. Values of vector gradient field to ± 0.1 gamma.

c. Magnitude of magnetic susceptibility in situ to $\pm 1 \times 10^{-5}$ emu/cc.

Two quite different types of magnetometers are now commonly used in terrestrial magnetic prospecting. They are the nuclear magnetometer and the fluxgate magnetometer. The nuclear magnetometer was developed as an airborne, station, and portable survey instrument in the mid fifties by Varian Associates. It had been known for some time that some atomic nuclei possess a magnetic moment, and these nuclei, when polarized and released by a strong directed field in an ambient field, processed around the later at a frequency directly proportional to the ambient magnetic field. Thus hydrogen atomic nuclei, say as found in water, when polarized and released, processed at approximately 2000 cycles per second in the earth's field.

In the Varian nuclear resonance magnetometer polarization is accomplished by applying a strong magnetic field of approximately 100 gauss to a sample bottle of water. This polarizing field is applied for a period of about three seconds, and then is abruptly removed. During this polarizing time, the magnetic moment of a certain percentage of these nuclei are aligned with the applied magnetic field. Abruptly removing this magnetic field allows the nuclei to precess freely in the earth's magnetic field at a frequency that is directly proportional to the strength of the earth's field. This precession signal is picked up by the same coil which produced the strong polarizing field, and applied to the input terminal of a high gain, band pass amplifier. The output of the amplifier is fed to a frequency counter where a specific number of cycles of the precession frequency form a time gate. As the frequency increases or decreases, the time duration of the gate decreases or increases, respectively. During the gate time a crystal controlled counting frequency of 500 kilocycles per second is counted, thus it is possible to measure the time duration of the time gate very accurately, and a highly accurate determination of the signal period can be obtained. At the end of the time gate counting interval, a voltage proportional to the number of 500 KC pulses is fed to a graphic recorder calibrated to field strength units such as gammas.

The second type of magnetometer is the fluxgate. Although this instrument is used as a single sensor inductor for measuring a component of the earth's magnetic field, it is normally used as a magnetic vector instrument with three orthogonally opposed sensing inductors. Two of these feed signals to a servo system that keeps the third measuring inductor constantly aligned with the earth's field. The winding of the field measuring inductor is energized by a 1000-cycle sinc-wave current. A 1000-cycle band-pass filter follows this and prevents the transmission of harmonic frequencies of 1000-cycles to the inductor.

The second harmonic signal (2000-cycles) generated in the measuring inductor owing to the presence of the earth's field along its axis is separated from the excitation portion of the voltage by a 2000-cycle band-pass filter. This 2000-cycle signal is amplified, phase detected, and fed back to the inductor winding as a direct current. The magnetic field associated with the direct current opposes the axial field in the inductor so that the net field along the axis of the inductor is just sufficient to maintain equilibrium in the feedback-loop. By utilizing a precisely calibrated current feedback to this third inductor, the magnitude of the total magnetic vector can be observed on a dial and recorded on a tape.

The angular components of the magnetic vector, inclination and declination, are obtained from circuits associated with the two aligning inductors.

A triaxial flurgate magnetometer was flown as an ALSEP experiment on Apollos 12, 15 and 16 (Ref. 27),and a portable instrument was used by the Apollo crew on missions 14 and 16 (Ref. 28). Both fluxgate-type and nuclear resonance magnetometers have been flown on deep-space flights. The Soviets used a fluxgate magnetometer on their Lunokhod Rovers. The state-of-the-art for the design and application of magnetometers for EPA is relatively high, and several different designs of the fluxgate instrument have operated for months, even years, on deep space missions.

Some new technology may be required for a new innovative design, or for new methods of magnetic isolation, but overall the design and technology inheritance for any EPA magnetometer is very high. In certain EPA applications a boom might not be a practical way to achieve magnetic isolation from spacecraft and other payload magnetic effects, and technology or techniques will have to be developed for on-board degaussing and the use of strategically placed magnetic compensators.

Electric and Electromagnetic Methods (Various)

A variety of experiments and techniques can be considered here. There are electrical prospecting methods that use naturally occurring ground currents and there are others that rely upon artificial currents. Frequencies from dc to perhaps the MHz range have been used. Sometimes the current or potential difference is applied directly to the ground under investigation while at other times electromagnetic waves are generated from a source above the ground and their change as an effect of the ground is observed. These experiments are powerful tools in terrestrial prospecting and they have been extensively developed. They will have wide application in the future EPA program. Some of the general requirements for this class of measurement are described below.

a. To determine models of subsurface structure, stratification and composition using both natural and artificial energy sources. The scale of the investigation may vary depending upon the energy source, specific type of electrical experiment, and the geological and physical properties of the remote-surface rocks.

b. Measure telluric and other natural currents in the ground in order to understand how they are generated, and to provide a basis for future electrical services.

c. Investigate the in situ electrical properties of rocks to support other EPA investigations.

d. Electrical prospecting for strategic material -- e.g., water.

e. This experiment may measure the electric potential difference or current in the ground between electrodes. From these data, the conductivity or resistivity, which may range from 1 to 10^{12} ohm-cm for lunar rock units, and the dielectric constant, which may range from about 10 electrostatic units for dry lunar rock to perhaps 50 esu for water saturated rocks, can be calculated. This experiment may measure the magnitude and direction of electromagnetic fields induced in lunar material by an external alternating field. The depth penetration of the inducing field is a function of its frequency and the resistivity of the ground. Frequencies in the range of 10 cps to perhaps 500 cps in a resistivity medium of about 10^6 ohm-cm, are probably the most useful, but frequencies in the MHz range may be the easiest to apply on automated missions.

f. The current electrodes or energy sources as well as the potential electrodes must be placed in contact with the surface or arranged in an operating position.

g. The ability to determine the relative positions between any locations occupied by electrodes or energy source within 5% of the distance between them is required. This distance may be as small as a few meters or as great as the entire traverse length.

The many different methods used in terrestrial electric and electromagnetic prospecting have not yet found wide application in the space program; principally because their use requires considerable mobility to disperse source and detectors, and data interpretation requires strict geological control. Apollo 17 conducted a Surface Electric Properties experiment using the LRV and astronauts for dispersing the experiment. An electromagnetic experiment for probing the Moon has been conducted as part of the Explorer 35 and the Apollo Subsatellite magnetometer experiment, where solar plasma was the energizing source and the orbiting magnetometer the detector (Ref. 30 and 31). Electric and electromagnetic prospecting techniques have been highly developed for Earth use resulting in a variety of instruments and field procedures that could have a remote-surface EPA application.

No new technology is required in the application of some of the standard methods of electric and electromagnetic prospecting to remote-surface EPA; however, a great variety of methods are conceivable and some of these may require new technology for detectors and source generation. Certainly, rather involved operational procedures will have to be worked out to conduct some of these experiments, and this will not only place strict demands on mobility and experiment handling mechanism, etc., but it will probably require new technology for software and automation.

Well Logging (various)

A prototype sonde instrument was built for Surveyor that was intended to provide information on the density, magnetic susceptibility, heat flow, and acoustical properties in a prepared hole approximately 2.5 cm in diameter and 50 cm deep (Ref. 32). A sonde-type heat flow experiment was used on Apollos 15, 16 and 17 (Ref. 33). An excellent review of geophysical well logging sondes for lunar application-remote surfaces in general - is given in Ref. 34. Earth-based sonde technology is advanced and sophisticated, and sonde instruments to measure a diverse array of the physical, chemical, optical, electrical, and magnetic properties of the rocks in a prepared hole, to thousands of feet of depth, have been perfected. Some of these that may prove useful for future EPA missions are discussed below.

Thermal Measurements - The combination of surface and borehole thermal measurements can provide two types of information that may be useful for EPA missions. First, the thermal properties of rocks, in particular their thermal conductivity, are of intrinsic interest, are valuable for correlation purposes, and are necessary as input data for heat-flow measurements. The second kind of information, heat flow across the remote surface, is of great importance for formulating planetary thermal models, but it may provide background data for remote-surface EPA missions. This second kind of information may only be derived by borehole measurements.

The temperature sensor to be used will depend upon the type of measurement to be made and will generally be classified according to response time. Probably the most common technique for measuring temperature electrically utilizes the temperature dependence of resistance. Resistance thermometers basically use either metallic resistors or semiconductor resistors (thermistors).

Another common temperature transducer utilizes the variation in contact potential between two dissimilar metals with the temperature of their junction. The potential developed is to a first approximation a linear function of the temperature difference and is independent of the temperature. These transducers are often called thermoelements or thermocouples. In addition to conductive coupling, radiative coupling may be used to sense the borehole temperature. A number of infrared transducers are useful as radiation detectors in this application. Because of the low temperature of the borehole, infrared transducers with long wave-length response are required. A commonly used IR detector for temperature measurement is the bolometer, which is a temperature-dependent resistor blackened to give high emissivity in the infrared region. Still another remote temperature measuring device might be a quartz crystal transducer. It is well known that the resonant frequency of quartz crystals is a function of temperature. For most oscillator crystals this temperature dependence is minimized by properly cutting the crystal. Recently it was recognized that a crystal orientation could be made which exhibits a linear dependence of resonant frequency with temperature and in this mode the crystal could be used as a very accurate temperature transducer. Temperature transducers which utilize this effect are on the market and exhibit very good temperature sensitivity over a wide temperature range and are relatively immune to external noise.

Nuclear Measurements - Various physical, chemical and geological properties of rock can be defined as a result of the natural and induced nuclear radiation they emit or by their reaction to such radiation. In the evaluation of terrestrial subsurface formations, this process is known as nuclear logging. It is widely used to determine such important parameters as formation density, hydrogenous fluid concentration, porosity, lithology, stratigraphy, and correlation. It has proven effective in instances where other types of measurements are either impossible or unreliable.

Measurements of the natural radioactivity of terrestrial rock formations are regularly made in the exploration for mineral and petroleum resources and in the study of the natural radiation environment. The data provided by these measurements have proven to be particularly valuable when interpreted in terms of their geological significance. In many instances the resulting information is quite unique and unattainable by other methods.

Though natural radioactivity is accompanied by distinctive alpha, beta, and gamma radiation, in situ measurements are usually designed to respond only to the gamma component of this radiation. The interaction of alpha and beta radiation with matter is such that they can penetrate no more than a few millimeters of formation. Hence, measurements of these radiations would sample only the immediate surface layer of the formation, which is usually not representative of the associated body of material. The gamma radiation from the natural radionuclides can penetrate some tens of centimeters of formation. This allows measurements to be made which are indicative of the radioactive nature of a significant portion of the formation.

The most frequently used method for the measurement of the natural radioactivity of subsurface formations is gamma ray logging. The total intensity of natural gamma radiation in a drill hole is continuously recorded as a function of depth. This reveals the presence and distribution of radioactive material but does not distinguish between the individual radionuclides. Though total natural gamma activity is not necessarily specific to a given rock type, it usually differs sufficiently between dissimilar formations so as to provide a valuable parameter for distinguishing one from another.

Gamma ray logs are commonly used in defining the vertical extent of, and in determining the interface between, successive rock formations. They also provide a means of correlation in establishing the lateral continuity of particular strata.

If, instead of measuring just the total gamma intensity, the energy spectrum of the gamma radiation is obtained, it is often possible to identify the individual radionuclides and to determine the relative proportions of each.

The principal gamma emitters found in terrestrial rocks are potassium-40 and the members of the uranium and thorium series. Potassium-40 emits a single gamma of 1.46 Mev. The various radionuclides of the uranium and thorium series also emit gammas of specific energies.

Usually such spectral gamma measurements are made on prepared samples under laboratory conditions; however, effective measurements of the uranium-thorium-potassium ratios of various rock formations have been made both on the surface and within drill holes, but the technique has not yet been developed to its full potential.

A factor which limits the application of this method under terrestrial borehole conditions is the excessive time required to obtain adequate spectral definition. Though natural gamma activities are usually quite low, conventional techniques of measuring the variation of total gamma intensity with depth have been developed to the point where logging speeds of several thousand feet per hour are possible. However, the number of gammas within a given energy range is only a small fraction of the total. To obtain a reliable measure of the proportion of gammas occurring in each of a number of separate energy ranges at a given depth requires a prohibitively low logging speed in most practical situations.

Measurements of the bulk density of terrestrial subsurface formations are often made by means of the gamma-gamma technique. This method has been extensively applied in evaluating sedimentary rock formations of interest in petroleum exploration and development. It provides reliable porosity information in known lithologies and is recognized as one of the most accurate quantitative application of current nuclear techniques.

In the gamma-gamma technique a source of gamma radiation is placed next to the formation whose density is to be measured. The gamma radiation is directed into the formation by means of a collimator in the shield surrounding the source. The gammas enter the formation and proceed until they experience an interaction and are either absorbed or scattered. Of those gammas which are scattered, some will be repeatedly scattered and ultimately return toward the borehole wall. A collimated detector placed at the formation interface will respond to those scattered gammas which cross the interface into the detector. The counting rate of the detector depends upon the attenuating properties of the formation. Under common terrestrial conditions, it can be directly related to the formation density. The Soviets used a simple version of this instrument on the Moon and Venus.

Neutrons have been used for borehole studies. This source may be either an encapsulated chemical mixture of a light element and a natural alpha emitter or a miniature accelerator. The associated detector may respond either to neutrons or to induced gammas. Neutron measurements are generally used to examine the hydrogen content of formations.

Most conventional downhole neutron instruments employ a chemical source. Such sources usually produce neutrons of intermediate energy from the interaction of alpha particles on beryllium-9. The alpha particles originate from the radioactive decay of radium, polonium, plutonium or americium. These sources contain an intimate mixture of the alpha emitter and beryllium and are encapsulated to provide structural integrity and to prevent the escape of gaseous decay products. The actual neutron energy spectrum may extend above ten Mev; however, the average neutron energy is only a few Mev. Though chemical sources do not provide the intense flux of high energy neutrons characteristic of accelerator devices, their output is sufficient for most applications. This, together with compactness and reliability, have led to their wide-spread use in standard logging tools.

Electrical Measurements - There are a number of methods which are commonly used for the measurement of the in situ electrical properties of terrestrial subsurface formations. Many of these methods have been developed in response to the exploration, evaluation, and production requirements of the petroleum industry. The relevant parameters have been measured under a wide variety of physical and geological conditions. In fact, subsurface electrical measurements are regularly made in most drill holes and usually provide the basic interpretative information.

Subsurface electrical measurements are commonly made by continuously recording, as a function of depth, some electrical characteristics of the formations adjacent to the borehole. The parameters most often measured are spontaneous potential and electrical resistivity (or its reciprocal, conductivity). The resulting record is then available for interpretation in terms of the known response under varying subsurface conditions.

The single, most indispensible requirement for successfully making conventional borehole electrical measurements is the presence of conductive liquid in the formation pores. For some types of measurements it is essential that the borehole also contain such a liquid.

Measurements of the magnetic properties of subsurface formations are seldom used in terrestrial borehole surveys. This is primarily a result of the nonmagnetic character of most terrestrial sedimentary rocks. However, igneous rocks are known to exhibit a wide range of magnetic susceptibilities. In addition, certain meteoritic materials have been found to be highly magnetic. Hence, there are good reasons to consider magnetic measurements as a possible method for studies of the remote-surface subsurface.

Downhole magnetic measurements could be used to distinguish localized concentrations of magnetic materials, e.g., nickel-iron meteorites, in the vicinity of the borehole. It is possible that sufficient magnetic contrast may occur between successive formations to allow such measurements to be used for bed definition and correlation. Under certain circumstances general rock types might even be identified. These measurements could also provide information valuable in interpreting surface magnetic surveys. However, all of these possibilities must be qualified in terms of the expected EPA environment and related experiences under terrestrial conditions.

Downhole Photography - Downhole photography provides both scientific and engineering information in a form which is readily assimilated. High resolution color photographs of sections of the side wall can be used to study the in situ formation lithology. Such photographs would supplement core analysis and may indicate features in the formation not observable in the core. Indication of induced formation fluorescence may be obtained by photographing the formation under ultraviolet excitation or by photographing fluorescent afterglow following a visible picture. Photographs of sections of the borehole may also provide valuable engineering information on the drill performance.

Sonic Measurements - The subsurface velocity of both compressional and shear waves in remote-surface formations must be known for the best interpretation of the seismic experiments and surveys. A subsurface sonic logging instrument will provide a direct measurement of those quantities in situ. Terrestrial sonic velocity logs were first introduced in oil-well logging as a correlation measurement for seismic surveys, and it appears that they also provide valuable correlation data for the seismic surveys.

Caliper Measurements - The caliper is a device designed to continuously measure the diameter of a bore-hole. It is used quite regularly in terrestrial well logging to provide quantitative definition of the borehole size. This formation is often essential to the accurate interpretation of the various electrical and radiation measurements.

As the caliper is moved along in the hole, the variations in actual borehole diameter are sensed by one or more arms which are maintained in contact with the borehole wall. Any irregularities of this surface of a size comparable to or greater than the contact area of the arms causes a displacement in the position of the arms. This motion is directly coupled to a transducer which provides an electrical signal proportional to the displacement.

The application of Earth-based sonde technology to remote-surfaces EPA isn't expected to seriously challenge present sensor technology. Most of the sensors here are already designed to operate remotely under extremes of temperature and pressure, so except for a modest re-design to prepare a sensor for a particular application no new technology seems to be needed for EPA sonde instruments. However, the drilling requirements for a prepared hole, which in all cases of remote-surfaces EPA needs, will be at least tens if not hundreds of feet deep, and the operation requirements for placing the sonde in the hole, monitoring it, and keeping the hole open, will require new technology.

Part A

Section IV

Technology Opportunities for Scientific Instruments

The scientific instruments and mechanism requirements for automated remote-surface EPA were developed in Section II of this report. Section III presented a description of the essential scientific instruments for EPA along with information on their development status, problems, and technology needs. This information was abstracted in Table III of the Executive Summary. Table VI, following in this section, presents the development status and technology needs for 16 scientific instruments that will be needed for EPA missions.

Three geochemical instruments are seriously in need of attention for future automated EPA missions. These are the x-ray diffractometer, the petrographic microscope, and an instrument/mechanism for age-dating. Of the three, the first appears inevitable with the passage of time, the second is surely possible, and only the third seems very difficult. There doesn't appear to be any new technologies required for the x-ray diffractometer, although suitable sensors are a possible problem; however, design prototyping and testing of this instrument are not progressing at a rate to assure its availability for the EPA-type mission of Mars 86.

To build an automated petrographic microscope with todays state-of-the-art technology is surely possible. Imaging systems with optics to provide resolutions to 10 μm have not been built for lunar and planetary missions, but studies indicate that this shouldn't be a problem (Ref. 5). The design of spectral and polarizing filters to be used with such a high resolution imaging system also shouldn't be a problem. The problems for development of an automated petrographic microscope are in sample preparation, where rock samples must be cut and ground into thin sections for viewing with the microscope. Thin-section examination is the most informative type of microscopy, and the capability to automate thin section preparation must be considered an integral part of the design of a petrographic microscope and needs to be actively supported. The technology to acquire fresh rock samples, cut these to the required thickness for viewing by transmitted light, mount the sample for view and then encase the sample in a material of suitable refractive index represents a series of challenging technological opportunities. The technology for automated rock thin-section preparation, including sample acquisition and handling, has never been seriously considered, and this now represents a challenging vista for new ideas in mechanisms, materials, operational procedures, and design for an important LPA instrument. Rock thin-section preparation will be described more completely in a subsequent section of this document (i.e., Description of Support Mechanisms).

Automated age-dating techniques and instruments for any type of application are not presently being investigated even though this type of analysis represent a valuable tool for future lunar and planetary surface missions. A method for automated in-situ age-dating will probably require a mechanism that can select appropriate rock material, a mechanism for concentrating select minerals from the rock material, a mechanism for elemental concentration of the selected minerals, and finally a geochemical instrument (probably a mass spectrometer) for isotope separation and analysis. Thus, automated in-situ age-dating won't likely be accomplished with a single scientific instrument, but rather may involve a whole series of complicated mechanism and operational procedures to drive a product for final analysis. No wonder the development of an automated age-dating instrument isn't being carried out; however, a serious effort along this line might produce some surprising results.

A functional in-situ age-dating instrument won't compete with sample return missions but rather will supplement them. It is not likely that a developed instrument would provide the precision or varied methodology of a laboratory analysis, and likewise, it is not likely that samples from the diverse sites that could be analyzed by an automated in-situ instrument could be made available for laboratory analysis. Also, each sample return mission may cost in excess of one billion dollars, and many such missions may be desirable. Clearly, NASA can't afford many such missions and new precision, in-situ instrumentation is needed to supplement sample return data.

Everything here requires new technologies and innovative designs, and the development of some method for automated in-situ age-dating is a priority task.

Most Earth-based geophysical sensors are adaptable to EPA missions. A new laser-type absolute gravimeter should be developed, and this would do for gravity measurements what the nuclear resonance magnetometer has done for magnetic measurements. New innovative techniques for electric and electromagnetic prospecting that would conserve mobility are needed. As a matter of fact, probably the paramount problem for easy application of seismic, electric and electromagnetic geophysical methods to EPA missions will involve experiment handling (loading and off-loading of sensors) and the greatly increased vehicle mobility and control required to accomplish this.

Vehicle mobility and control, sample acquisition, experiment handling, and carrying-out the field geology function will all be greatly constrained on an EPA mission by the need to cycle these types of data through a data link for the Space Flight Operations (SFO) analysis and decision process, and then back to the EPA vehicle. On even a very simple EPA mission, the delay times for SFO analysis will be extreme, so new micro-computer and software technology will be needed to relegate many decisions to the EPA vehicle. The need for new technology in this area is already extreme for the Mars 86 rover, and it will get more critical with future EPA missions.

TABLE VI

SCIENTIFIC INSTRUMENTS

Status and Technology Opportunities

Imaging Function

Instrument	Status	Technology Opportunities
Vidicon Imaging (Includes TV, Facsimile and CCD)	Television framing cameras with vidicon sensors are highly developed and have been used on the lunar surface on Surveyor and Apollo, and in numerous planetary flyby and orbiter missions. For a recent description of the Viking Orbiter television system, see Ref. 13. Facsimile cameras have been used in various deep-space missions by both the US and USSR. The most recent use of facsimile-type cameras was on the Viking landers. These cameras were designed for high- and low-resolution imaging in stereo, color, black and white and infrared. The Soviets have used facsimile devices on Lunokhods and on the Venera 9 and 10 flights. The most recent development in imaging systems has been the charge-coupled device (CCD) area array sensor. These have been proposed as the main imaging sensor for the Mars '84 Orbiter as the Wide-Angle Imager, and for the Mars '84 surface camera as the Rover Stereo Imager (2 per rover).	Imaging devices are more constrained by the communications link than by their own capability. They are environmentally sensitive to heat, pressure, vacuum, radiation, etc., so they will need protecting on the various EPA mission options. The CCD requires cooling to -40°C and probably some shielding from any RTG on the spacecraft. No new technology appears to be immediately needed for these instruments per se, and the design and application of optical devices for high resolution imaging should be straightforward. The operational procedures for imaging and its interrelationship with other major functions on even a simple EPA mission will be complex and require new software and ground control technology.

SCIENTIFIC INSTRUMENTS

Status and Technology Opportunities

Geochemistry Function

Instrument	Status	Technology Opportunities
X-ray Diffractometer	An early study at JPL in 1963 developed the design concept and geometry for a miniature instrument (Ref. 1). An automated prototype of this instrument was built at JPL in the late '60s (Ref. 2). Another instrument that incorporated an x-ray fluorescence capability was also built (Ref. 3). Both instruments were highly successful in the laboratory tests; however, development costs and the lunar and planetary exploration requirements to date have not allowed for the continued development of this important EPA instrument. Work beginning this year at JPL is considering design of a combination diffractometer/spectrometer for remote surface use.	Prototype instruments have used a scanning slit-detector that inherently require either very slow scanning time or a very intense x-ray source. The development of a CCD or position-sensitive proportional counter to array along the focusing circle to replace the slit-detector would increase sensitivity. The increased detector sensitivity could allow for replacing the heavy power-consuming x-ray tube with an isotopic x-ray source such as Fe^{55}. It would appear that the technology opportunities for the x-ray diffractometer are limited to design, and it should be relatively straightforward to develop an instrument that can perform in-situ crystal study for EPA. Sensor availability, control of remote surface environmental factors, and in-situ sample preparation are not envisioned as design or operational problems for this instrument. It is possible that active cooling of the detector will be required for certain applications while a high degree of thermal isolation will be required for others. Instrument will require sample preparation and handling.
X-ray Spectrometer	A widely used technique that appears to be easy to miniaturize and automate. Used by the Soviets in Lunokhod 1 and 2, and on the landers of Viking 1 and 2. Space instruments have used a radioactive source for generating the fluorescing x-rays and this has resulted in less resolution and longer analysis time than for laboratory instruments. The	A nondispersive x-ray analysis instrument can provide an EPA technique for rapid and accurate major and minor elemental analyses, especially if incorporated with an alpha-scattering instrument to detect the lighter elements of low z which are not seen by x-ray fluorescence. There doesn't appear to be a major technological problem for the design and development of such an instrument and sample preparation requirements

Instrument	Status	Technology Opportunities
X-ray Spectrometer (Continued)	dispersive system is probably capable of better accuracy than the nondispersive system; however the loss of efficiency caused by the diffraction detector crystal must be overcome by using an active x-ray generator, also the necessity of many accurately positioned x-ray detectors adds to the instrument mass.	are minimal. Present technology would use Si(Li) detectors which require continuous cooling, and this could be a technology problem for some EPA missions. The newer intrinsic germanism and silicon detectors don't completely alleviate the problem so some new sensor technology would be required either for active cooling or more environmentally tolerant detectors. Other problems for EPA application might include shielding from x-ray noise, vibration, and effect on other sensors. Instrument will require sample preparation and handling.
Radioactive Survey (Various)	Geiger counters, electroscopes and scintillation counters have been used extensively in the terrestrial environment for prospecting for radioactive minerals, for both aerial and ground surveys, so several light-weight low power designs are available for general EPA application. In addition, this kind of survey could be accomplished with a gamma ray spectrometer or as part of the function of a pulsed Neutron/gamma ray spectrometer.	No new technology opportunities are apparent here; however, each instrument will have to be designed for the particular EPA environment and it will have to be shielded from radioactive sources on the EPA carrier vehicle and other radioactive instruments. The instrument may require deployment to particular samples or visa versa.
Petrographic Microscope	Petrographic microscopes have been successfully combined with TV and a compact light-weight prototype system has been built (Ref. 4). Spacial resolutions achieved with cameras on lunar and planetary landers have been limited to about 1 mm, but a proposed microscope design for use with the Viking lander camera would increase its resolution to about 10 μm (Ref. 5).	Although an imaging microscope capable of about 10 μm of resolution has not been built as a lunar and planetary instrument, the technology for such an instrument appears to be state-of-the-art. However, the utility of remote petrographic microscopy is likely to depend more on the sample preparation process than on the ability to design flight-qualified instruments. Thin-section examination is the most informative type of microscopy, and the capability to

Instrument	Status	Technology Opportunities
Petrographic Microscope (Continued)		automate thin section preparation must be considered an integral part of the design of a petrographic microscope and needs to be actively supported. The technology to acquire fresh rock samples, cut these to the required thickness for viewing by transmitted light, mount the sample for view and then encase the sample in a material of suitable refractive index represents a series of challenging technological opportunities. A less desirable alternative to a thin section would be examination of a sawed surface that had been coated with a suitable wetting agent.
Mass Spectrometer	The instrument has been used successfully for atmospheric analysis in the lunar program and in Earth applications (Ref. 6). It was also used in combination with gas chromatography to perform an organic analysis on the Mars Viking landing (Ref. 7). Laboratory instruments of this type for the analysis of solid samples do not exist.	Ma analyzers such as the quadrupole, magnetic, and electrostatic-magnetic (double focusing) instruments could probably be designed for remote surface EPA application; however, the method by which an ionized sample can be prepared from a solid sample isn't clear. Where an electron gun is used to vaporize a sample power requirement is high, there may be serious thermal problems, and space charge effects may be difficult to control. Other options for generating ions from solid samples for an EPA instrument might include a laser ion source or a sputter ion source. In the Ion Microprobe/Mass Analyzer, discussed below, an ion beam is used to sputter of secondary ions so the technique is practical in a laboratory instrument. A pulsed laser to vaporize and ionize samples has been used but an instrument hasn't been built. In summary, the major technology problem for this instrument is the need for an ion source generator that is compatible with the size and environment of an EPA instrument. Instrument design should be

Instrument	Status	Technology Opportunities
Mass Spectrometer (Continued)		straightforward and sample preparation requirements would be negligible, but power requirements may be high, and environmental and thermal problems will have to be considered and accounted for in a remote surface instrument of this type.
Scanning Electron Microscope/Microprobe (SEMM)	The Scanning Electron Microscope/Microprobe is a compact laboratory instrument that has been extensively used in the analysis of returned lunar samples. It uses an electron beam for scanning the surface of a sample and x-rays emitted in this process are used for elemental analysis (Ref. 8). Electronics and other critical components for the instrument have already been miniaturized to fit into a volume of only a few cm^3, so development of a flight prototype automated instrument for EPA missions should be straightforward.	A major technology problem for any remote-surface automated use of this instrument will be in sample preparation; specifically how to control the sample charge effect from the electron beam. In the laboratory the sample is usually pretreated by a rather complicated high power process, with a thin conductive coating to eliminate the surface charging caused by the electron beam. On nonconducting material such as rocks, the effect is most pronounced. Because secondary electrons generated in the surface of the sample are the primary data source in the scanning electron microscope portion of this instrument; techniques to reduce the sample charge effect must not interfere with this process. The laboratory instrument is a high power user so new technology may be required in the design of a lower power electron lens and electron source systems.
Ion Microprobe/Mass Analyzer (IMMA)	A relatively new laboratory instrument that has been used for analysis of the Apollo samples. Similar to the SEMM discussed above but uses ions instead of electrons for scanning the sample and sputtered secondary ions, instead of electron generated x-rays, for chemical analysis. GCA Corporation built a prototype automated instrument in 1970 (Ref. 9 and 10) but much design work and new technology are	Aside from the major problems involved in the design and miniaturization of this instrument, a particularly critical technology concern exists for the ion source generator. The laboratory instrument uses a duoplasmatron for generating ions which requires several amps and 500 watts of power, powerful focusing magnets, and its heat dissipation and environmental impact are high. Other possible ion generators might be the Penning Ion Gauge or a radio frequency source, but these seem to present more

Instrument	Status	Technology Opportunities
Ion Microprobe/ Mass Analyzer (IMMA) (Continued)	needed for an EPA instrument. The laboratory IMMA instrument is complicated, massive, has high power requirements, uses a very reactive oxygen ions source, and its function will be difficult to automate and miniaturize.	problems than the duoplasmatron. Instrument will require sample handling and sample preparation.
Pulsed Neutron/ Gamma Ray Spectrometer	A team assembled by NASA in early 1970 worked on the early development of a pulsed neutron experiment but this effort concluded without a prototype design (Ref. 11). The Soviets appear to be working on this concept for lunar and planetary application. Sandia, in the mid '70s built a prototype instrument that is currently being tested at GSFC under a joint NASA-NOAA study. The power supply on this prototype is only about 40 KV-28v, and this is too low. A new breadboard power supply of 50 KV should be operating at GSFC shortly.	The general technology to build a satisfactory instrument of this type appear to be in hand. EPA constraints and technology opportunities would concern sensor shielding from any RTG source, shielding from the 14 MeV neutron source, development of the power supply for neutron source and developing a more efficient source, cooling of the Ge x-ray detector, and in general, protection of the instrument from the diverse environments of remote surfaces. Experiment handling will be required to deploy the experiment to the remote surface and retrieve it.
Alpha-Particle Back-Scatter Spectrometer	A successful lunar experiment on Surveyor (Ref. 12). Instrument required long counting times - 800 min. - to detect critical rock elements (O, Si, Al, Mg, Na) to an absolute accuracy of 3 percent.	The design and development of this instrument are straightforward and no new technology would likely be required. The instrument would work best in combination with an x-ray fluorescence detector. The instrument will have to be deployed to the surface to function and then retrieved. Since a radioactive source is used, other instruments may have to be shielded and visa versa. The α-experiment will require little sample preparation but the x-ray spectrometer would require particulate material.

Instrument	Status	Technology Opportunities
Age-Dating	Of the several techniques that are used for age-dating samples in the laboratory, all involve complicated procedures, careful sample collection, selection and processing, and sensitive instruments for analysis. An automated in situ prototype instrument for age-dating hasn't been built, nor does there appear to be the degree of activity going on here that is warranted. In the view of many, in situ age-dating competes with the sample-return mission, and that isn't so. To accomplish EPA and acquire a fundamental geologic understanding of remote surfaces will require in situ age-dating, or the transport of literally thousands of samples.	There are technology opportunities here in the areas of sample acquisition, sample concentration and preparation, and sensor/instrumentation. Specifically, sample acquisition technology must be able to handle a large quantity of in situ material to acquire a selected sample. Sample concentration processes may involve manual/microscopic separation and concentration of mineral grains of the desired type, and the further concentration of this material by wet chemical procedures into the elements of interest. The final stage in age-dating involves isotope separation and counting probably with a mass spectrometer. Some of the technology considerations for in situ mass spectrometery were discussed earlier under that instrument. In any case, for intrinsic age-dating measurements it should detect appropriate isotopes up to mass number 238 at concentrations of about 1 ppm. An EPA instrument of this kind of sensitivity can probably be built. However, the sample concentration/preparation techniques and technology for this type of remote/surface measurement cannot now be defined. Perhaps the problems here are insurmountable in terms of our present concept for age-dating, and a completely new way of doing this for EPA is needed.

SCIENTIFIC INSTRUMENTS

Status and Technology Opportunities

Geophysics Function

Instrument	Status	Technology Opportunities
Seismic (Various)	A passive seismic experiment was flown on Apollos 11, 12, 14, 15 and 16 (Ref. 19), and also on Viking (Ref. 20). Several different active seismic experiments have been proposed (see for example Ref. 21), and a granade launcher to be used in conjunction with the passive sensor was flown on Apollos 14 and 16. A variety of very small seismic sensors have been developed for terrestrial use. The application of Earth-based technology to EPA seismometers, including sensors, recorders, and seismic source should be relatively straightforward.	No new technology is required in the application of active and passive seismic instruments to EPA. Design and packaging for each application may be challenging and innovating but won't stress available technology. Experiment handling equipment, and remote-surface operational procedures will have to be defined and new technology may be required for this. Experiment handling will require coordination between imaging, mobility, drilling, and experiment handling mechanisms.
Gravimeter (Various)	A traverse gravimeter was flown on Apollo 17 (Ref.22), and on the same mission another type of gravity sensor was used to detect gravity waves, and it also functioned as a seismometer (Ref. 23). Various instrument designs for land, sea and airborne use have been developed for on Earth. Doppler tracking has been used on flyby and orbiting spacecraft with great success. A gradiometer instrument has been designed but not flown for orbital applications (see for example Ref. 24). For remote-surface EPA use a stable absolute instrument will be required. A prototype of such an instrument, called a laser gravimeter, was built, and a mineraturized design for remote-surface automated use was proposed (Ref. 25 and 26).	No new technology is required for the application of accelerometer and spring-type gravimeters to remote-surface EPA. These instruments can be designed and built using present-day technology. However, there is a need for a stable (drift free) absolute instrument. To build such an instrument would certainly challenge state-of-the-art design and fabrication technology, stress miniaturization and counting circuit electronic technology, and present problems for instrument insulation/isolation and general environmental control for any EPA operation. This type of experiment will not require any support from sample handling, sample preparation or experiment handling functions on the EPA vehicle, but a microcomputer and altimeter will be required for preliminary data reduction.

Instrument	Status	Technology Opportunities
Magnetometer (Various)	A triaxial flurgate magnetometer was flown as an ALSEP experiment on Apollos 12, 15 and 16 (Ref.27), and a portable instrument was used by the Apollo crew on missions 14 and 16 (Ref. 28). Both fluxgate-type and optical pumping devices have been flown on deep-space flights. The Soviets used a fluxgate magnetometer on their Lunokhod Rovers. The state-of-the-art for the design and application of magnetometers for EPA is relatively high, and several different designs of the fluxgate instrument have operated for months, even years, on deep space missions.	Some new technology may be required for a new innovative design, or for new methods of magnetic isolation, but overall the design and technology inheritance for any EPA magnetometer is very high. In certain EPA applications a boom might not be a practical way to achieve magnetic isolation from spacecraft and other payload magnetic effects, and technology or techniques will have to be developed for on-board degaussing and the use of strategically placed magnetic compensators.
Electric and Electromagnetic Methods (Various)	The many different methods used in terrestrial electric and electromagnetic prospecting have not yet found wide application in the space program; principally because their use requires considerable mobility to disperse source and detectors, and data interpretation requires strict geological control. Apollo 17 conducted a Surface Electric Properties experiment using the LRV and astronauts for dispersing the experiment (Ref.19). An electromagnetic experiment for probing the Moon has been conducted as part of the Explorer 35 and the Apollo Subsatellite magnetometer experiment, where solar plasma was the energizing source and the orbiting magnetometer the detector (Ref. 30 and 31). Electric and electromagnetic prospecting techniques have been highly developed for Earth use resulting in a variety of instruments and field procedures that could have a remote-surface EPA application.	No new technology is required in the application of some of the standard methods of electric and electromagnetic prospecting to remote-surface EPA; however, a great variety of methods are conceivable and some of these may require new technology for detectors and source generation. Certainly, rather involved operational procedures will have to be worked out to conduct some of these experiments, and this will not only place strict demands on mobility and experiment handling mechanism, etc., but it will probably require new technology for soft wear and automation.

Instrument	Status	Technology Opportunities
Well Logging (Various)	A prototype sonde instrument was built for Surveyor that was intended to provide information on the density magnetic susceptibility, heat flow, and acoustical properties in a prepared hole approximately 2.5 cm in diameter and 50 cm deep (Ref. 32). A sonde-type heat flow experiment was flown on Apollos 15, 16, and 17 (Ref. 33). An excellent review of geophysical well logging sondes for lunar application-remote surfaces in general - is given in Ref. 34. Earth-based sonde technology technology is advanced and sophisticated, and sonde instruments to measure a diverse array of the physical, chemical, optical, electrical, and magnetic properties of the rocks in a prepared hole, to thousands of feet of depth, have been perfected.	The application of Earth-based sonde technology to remote-surfaces EPA isn't expected to seriously challenge present sensor technology. Most of the sensors here are already designed to operate remotely under extremes of temperature and pressure, so except for a modest redesign to prepare a sensor for a particular application no new technology seems to be needed for EPA sonde instruments. However, the drilling requirements for a prepared hole, which in all cases of remote-surfaces EPA needs will be at least tens if not hundreds of feet deep, and the operation requirements for placing the sonde in the hole, monitoring it, and keeping the hole open, will require new technology.

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