PRELIMINARY ANALYSIS FOR LUNAR ROVING VEHICLE STUDY GROUND DATA SYSTEMS AND OPERATIONS

JPL CONTRACT NO. 952668

VOLUME II OF III

ROVING VEHICLE PAYLOAD

(SCIENCE MODE TIME LINE ANALYSES)

HUGHES

HUGHES AIRCRAFT COMPANY
SPACE SYSTEMS DIVISION

30 JUNE 1970

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This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

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SUMMARY

The study contract for preliminary analysis for Lunar Roving Vehicle (LRV) Ground Data Systems (GDS) and Operations was initiated in September 1969, and was originally intended as a six-month task. During February 1970, Hughes was directed to stretch out the existing program with a Final Report delivery scheduled for 30 June 1970.

The content of the Final Report (Volumes I, II, and III) constitutes only part of the final product by the Hughes Aircraft Company in response to Contract No. 952668. The total response is listed below and it should be noted that material printed in Jet Propulsion Laboratory documents was supplied under the terms of the contract in final draft form.

- Preliminary Analysis for Lunar Roving Vehicle Study — Ground Data Systems and Operations, Hughes Reference No. C0077, dated 30 June 1970: Volume I, Roving Vehicle Guidance (Remote Driving Study); Volume II, Roving Vehicle Payload (Science Mode Time Analyses); Volume III, Roving Vehicle Navigation (Evaluation Determination Analyses).

- LRV Navigation and Guidance System Phase A Study Report, JPL Document No. 760-42, dated 15 October 1969: Section V, Mission Operations; Section VI, Navigation and Guidance Operations; Section VII, Problem Areas; Section X, Plan for Phase B Study.

- Science Ground Data System and Science Operations Organization for Remotely Controlled Lunar Traverses — Phase A Study Report, JPL Document No. 760-39, dated 10 October 1969: Section VI, Science Operations; Section VII, Problem Areas, Section X, Phase B Study Plan.

- Operations Profiles for Lunar Roving Missions, JPL Document No. 760-46, dated May 1970.

Originally, it was not planned for Hughes to participate in Phase A Report preparation. The basic responsibility of Hughes in the early part of this contract had been to assist JPL in defining all mission-dependent Earth activities and resources (hereinafter referred to as the "Mission Operations Complex" — MOC) required to support the remote-controlled phase of the

LRV Mission. Since this constituted a variable which is dependent upon mission requirements, the total plan which implemented these requirements was first established.

Mission requirements also dictate a general LRV design. Such a design is not necessary in defining a general MOC but becomes necessary in establishing its details (commensurate to the extent of available LRV design detail). No sole LRV design existed throughout the contract period. Bendix and Grumman each had several designs in the early part of the period and JPL therefore postulated a single design to act as a baseline for the Hughes effort of MOC definition. Considerable time was spent coordinating with JPL sources regarding establishing and periodically up-dating a postulated LRV design without incompatibilities and with a level of detail useful toward MOC definition. Continuing assistance to JPL was provided in assessing the effect on the GDS baseline design of the LRV mission, vehicle, and science payload changes during the study, and design change recommendations were made as appropriate.

It was originally intended to deliver to JPL detailed definition of the Ground Data System in the areas of display, operations profile, operations organization, navigation programs and computer applications, hazard prediction programs, and avoidance maneuver techniques. During January and February of 1970, it was determined by JPL that the study should concentrate more in the areas of 1) remote driving problems, 2) Navigational analyses for operations use (concentrating on elevation determinations), and 3) time line analyses. In particular, it was decided to develop the above definitions to only the intermediate level and not initiate work on a general command and control computer program, or identify a single operations organization. It has also been intended to expand the detail of the MOC to a level of detail attainable within the remainder of the contract period. However, this effort was also suspended at JPL's request. Thus, during January and February of 1970, a report entitled "MOC Definition for Synthesized LRV Design" was submitted. This report consisted of five basic sections plus an appendix; and included an Introduction, Synthesized LRV Description, Operations Profile, and MOC Profiles. This material was used by JPL in preparing the Phase B Report.

The MOC profile charts in the Phase B Report show the direct correlation of all the particular Earth-based activities and equipment used to implement each specific operational activity identified by numerical subdivision of a basic operation "mode"(the first divisional level within the remote controlled phase of the mission). The estimated Delta time to accomplish each row of the MOC charts was also calculated. An iteration with specific operational activities and general mission plans is required to establish total mission time lines. This was not pursued further in the areas of Guidance and Navigation by Hughes at JPL's request.

Paralleling the above in time was an effort by Hughes to identify (for operational use) the subtle aspects of perhaps the most demanding of the LRV mission requirements--Navigation and Guidance. A review was made of all available documentation produced by Bendix, General Motors, and Grumman regarding the subject. Preliminary investigation in Navigation by landmark showed that accuracy versus number of visual landmarks, and accuracy versus number of navigation updates for a given course, was not a simple relationship. Subsequent investigations established appreciably reliable criteria for operational decisions when navigating by landmark.

Volume I details considerations applicable to aid remote driving by superimposing driving aids on the TV panorama. These aids are used by the Remote Driver at the Remote Controller Position while the vehicle is in motion. The vehicle general design baseline is first established.

Volume II contains four detailed time line studies of portions of the Stationary Science Mode. These studies provide an additional link in the continuing iterative process of defining the LRV mission operations procedure, ground equipment, and administrative organization.

Volume III is mainly concerned with elevation determination. Some early unfinished work on Rover Navigation is also presented. Preliminary error curves of Rover position as affected by landmark orientation with respect to LRV path are shown; also, a table representing a partial comparison of various navigation schemes is included. The elevation determination methods considered are 1) use of the basic LRV instruments, 2) addition of a ranging Laser and precision inclinometer, 3) tracking an orbiter from the Rover, and 4) miscellaneous techniques including a stable platform, on e or more star trackers, a sun seeker, gyrocompassing, Foucauld pendulum, and differential ranging. The intent of the volume is to provide sufficient information concerning a variety of navigation and elevation determination methods to permit filtering out of less attractive schemes.

ROVING VEHICLE PAYLOAD

GENERAL

Preliminary functional requirements for LRV Payload Control and Payload Data Analysis were reviewed, and Hughes-recommended ground data system functional payload requirements were included in the formal issue of Jet Propulsion Laboratory Document Number 760-39, entitled "Science Ground Data System and Science Operations Organization for Remotely Controlled Lunar Traverses Phase A Study Report," dated 10 October 1969. The critical GDS functions and the basic operations organization were identified as a part of this effort. The problem areas, Section VII, and the Phase B plan contained in Section X were also provided.

An integrated GDS functional science baseline design was jointly established by Jet Propulsion Laboratory and Hughes Aircraft Company personnel (Table 1). Lunar mode definitions, selection, and interrelation were confirmed and flow diagrams prepared. Major sequence diagrams were also completed including detail to the mission functional level. Science GDS requirements were analyzed on a continuing basis.

During January and February 1970, the above material was detailed and submitted in near final form for inclusion in the Jet Propulsion Laboratory Report 760-46, Operations Profiles for Lunar Roving Missions, dated May 1970. Also, during January 1970, the payload task was directed into a Time Line Analysis Study.

Prior to January 1920, certain other work was initiated under the overall task of "Science Payload Control and Data Analysis." This work, not yet completed, is identified in Appendix A.

SCIENCE MODE TIME LINE STUDY

I. SUMMARY

1. Introduction

It was found, from the Phase A studies, that scientific investigations along the traverse route ("background" measurements) required that the vehicle be essentially stationary. Further study also indicated that scientific investigations and operations at these background sites were identical with operations at the primary science sites (which also require a stationary vehicle and may or may not require a chain of stationary measurements within a site). Since these operations are identical, a single science mode was identified to group these operations into a single unified task description.

Operations associated with the Stationary Science Mode have been further subgrouped into major and minor sequences. The major sequences have been grouped into experiment related activities and, at the present time, include the following:

Reconnoiter	(1.1)
Magnetometry Operations	(1.2)
Neutron Gamma-Ray Analysis (NGRA)	(1.3)
Gravimetry	(1.4)
Visual Terrain Assessment	(1.5)
Laser Scanning	(1.6)
Earth Distance Ranging	(1.7)
Sample Acquisition Operations	(1.8)
Visual Examination of Sample	(1.9)
Soil Mechanics	(1.10)
Gas Analysis	(1.11)
Sample Disposition	(1.12)
Mineral Phase Analysis	(1.13)
Chemical Element Analysis	(1.14)

The numbers in brackets refer to the sequence numbers utilized in Jet Propulsion Laboratory Report 760-46, Operations Profiles for Lunar Roving Missions. Further details of the Science Mode may be found in this document.

The following report provides detailed analyses of times required for accomplishment of four of the Science Mode major sequences. These sequences are Magnetometry (1. 2), Gravimetry (1. 4), Sample Visual Examination (1. 9), and Mineral Phase Analysis (1. 13). The time line figures developed for these sequences are shown in Table 1. The objective, in each case, is to assure that the vehicle and MOC designs are molded to operational considerations to prevent the mission time line from becoming exorbitantly large with little hope of meeting overall mission objectives.

Conclusions have been developed which indicate that the execution of the baseline science operations is possible within a two-hour time frame. Also, a Stationary Science Mode of two hours is commensurate with accomplishing a 1000 km automated lunar traverse within one calendar year.

2. Discussion

Previous time line studies had utilized two basic assumptions in order to establish the basis for the time line. These assumptions were:

a. Communications bandwidths and powers would be limited so that, for example, engineering and video data could not be transmitted simultaneously. Also, surface sampler/television operations would be cumbersome, requiring frequency reconfiguring and switching.

b. Exploration would be conducted through unfamiliar (unreconnoitered) terrain and many real time decisions would be required involving identification of science sites, etc.

c. All LRV commanding would be closely supervised (with permission to proceed required for each minor sequence) and conducted from a single command console within the operations facility.

As a result of these assumptions, the first cut at a science mode time line showed some 20 to 24 hours being required for execution of the mode. These extensive hours were caused primarily by the inability of the LRV and MOC to accommodate parallel operations and the imposition of extensive administrative command control procedures. A 24-hour Stationary Science Operations Mode would jeopardize the success of any LRV mission since the number of 24-hour science modes which could be accommodated within the mission would be sharply curtailed.

The latest time line study has reversed each of the three previous assumptions as follows:

a. No limitation on communications bandwidths or spacecraft and ground equipment configurations. This assumption permits the paralleling of several of the science mode major sequences, which alone could save considerable mission time.

b. Orbital reconnaissance photographs will be available of the entire traverse route which will enable detailed route planning and eliminate the need for many real time decisions regarding placement of science sites, etc.

c. Maximum flexibility will be given to the individual command operators so that their commanding tasks can be executed with maximum commanding efficiency.

As mentioned previously, a Stationary Science Mode of two hours duration has been developed utilizing these assumptions. Table 1 shows the extrapolation of times from the four sequences that have been studied to include the entire science mode. The accrual of the two-hour calculation can be seen in the mode time column.

Figure 1 illustrates the paralleling of major sequences which has been utilized for the science mode. Here it is seen that the magnetometer and NGRA once deployed are operated continuously until retrieved. Also, gravimeter, terrain assessment, laser ranging, earth distance ranging, and gas analysis operations all parallel each other.

The time requirements for each sequence have been identified in terms of series time, parallel time, and total time. Series time is that time devoted to a sequence in which no other sequence may be in progress (magnetometer deployment). Parallel time is devoted to those operations of the mode which can occur in parallel with other sequences (magnetometer data monitoring). Total time is the summation of the two and yields an indication of the time required for that sequence if it were performed by itself. The final column, Mode Time, is an ordered summation of the series time, and it indicates, again, some two hours required at each Stationary Science Site.

For a mission of 1000 km traverse and 13 lunar days with no lunar night driving,* and a mean traverse velocity of 1 km/hr, the traverse time will be 1000 hours. The number of hours in 13 lunar days, assuming 12 effective earth days for the mission per lunar day, is 3744 hours. Subtracting traverse hours, we obtain 2744 hours available for modes of science, navigation updates, active seismic, battery charging, RGM placement, and periodic major checkout. Optimistically assuming that science will be able to requisition two-thirds of this available time, approximately 1830 hours would be available for science. At two hours per site, it is clear that approximately 915 science sites could be included in the mission plan. Attainment of a generally accepted figure of 1000 science sites per mission (utilizing roughly 1.75 hours per science site) is entirely possible; since, it is not clear that each execution of the Stationary Science Mode will require execution of each major sequence in the mode. In particular, if the Magnetometer (1.2) or NGRA (1.3) sequences were not always executed, the 1000 Stationary Science Sites could easily be included in the mission plan.

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*Incorporation of this capability will increase the time which may be allocated to the science mode; however, the dynamics of the night driving problem are not well enough understood, as yet, to permit incorporation of this capability in the Time Line Study.

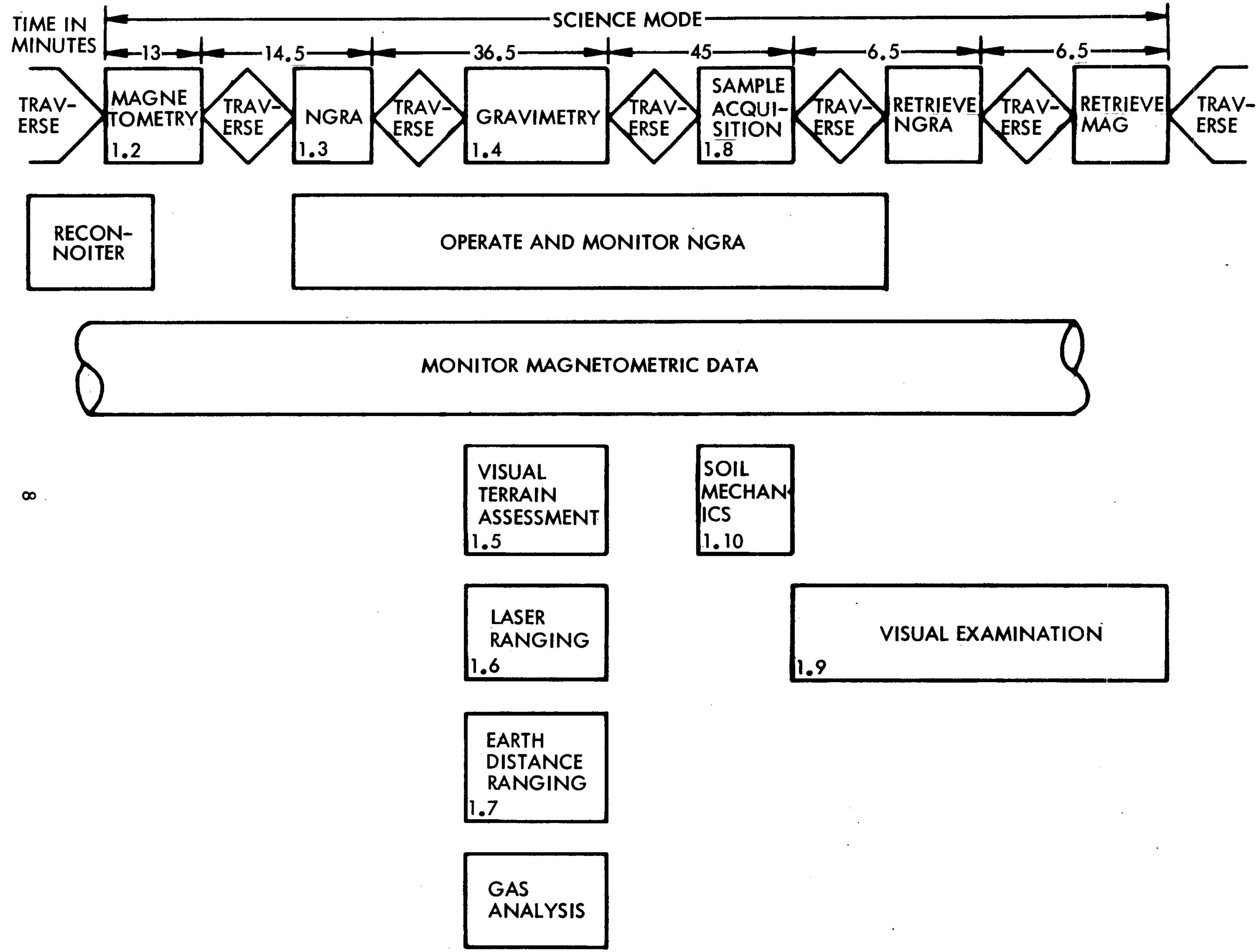

FIGURE 1 SCIENCE MODE MAJOR SEQUENCE

TABLE 1. TIME LINE EXTRAPOLATION TO ENTIRE SCIENCE MODE

(All Time in Minutes)

Sequence+	Series Time	Parallel Time	Total Time	Mode Time
1.1	0	0	0	0
*1.2	18.5	30.0	48.5	18.5
1.3	20.0	30.0	50.0	38.5
*1.4	↑		↑	│
1.5	****36.5		36.5	│
1.6	│		│	↓
1.7	↓		↓	75.0
**1.8	45.0	0	45.0	│
***1.9	0	30.0	30.0	│
1.10	0	45.0	45.0	↓
1.11	0	2.0	2.0	120.0
1.12	2.0	0	2.0	│
*1.13	0	30.0	30.0	↓
1.14	0	30.0	30.0	122.0

*Time lines for these sequences have been studied in detail.

**Three samples acquired.

***Three samples examined.

****Assumes Sequences 1.4, 1.5, 1.6, and 1.7 can be performed in parallel and will not exceed the studied time line estimate for Gravimetry (1.4) of 36.5.

+Numbers refer to Science Mode sequences from JPL Document 760-46, Operations Profiles for Lunar Roving Missions.

Nearly all of the basic science mode assumptions can be questioned. For example, Sequences 1.13 and 1.14 have been shown as parallel operations. In the final analysis, it may be required that these sequences be performed in series in the mission as great amounts of power are consumed during operation of the instruments which may preclude operation of other devices on the vehicle. Also, the equipments for Sequences 1.5 and 1.6 (Visual Lurain Assessment and Laser Scanning) are presently undefined, and it is a bold assumption to include operation of these devices in parallel to the 36.5 minute Gravimetry Sequence.

Mechanization of the MOC requires careful attention. The assumptions utilized in this study require sophisticated software in support of many sequences (particularly the device deployment/retrieval operations). Also, communication of information such as: station coordinates, vehicle constraints, objectives, etc., are presumed accomplished with supreme efficiency and high degree of automation.

The role of scientific support during the science mode also requires examination. This was highlighted in the Visual Examination Sequence where significant savings in time could be achieved by decisions to photograph only salient features of each sample rather than extensive photograph imaging of all facets. In general, it seems that execution of the science mode should result in data for delayed time evaluation rather than extensive real time evaluation. It is recognized that some real time evaluations will be required in order not to overlook valuable data. It is felt that consultations should be conducted with each responsible scientific area in order to develop a more perfect operating plan and to assure optimum operations design of the experiment hardware.

II. MAGNETOMETRY SEQUENCE

1. Introduction

The purpose of this paper is to investigate the time line associated with operation of the magnetometer on an automated lunar roving vehicle mission. Assumptions and discussion of operations and conclusions about the time line effect on the mission make up the major portion of this section.

A best case approach was utilized in developing the Magnetometry Sequence time line; that is, normal traverse pictures (taken while traversing to the magnetometry station) were assumed suitable for deployment spot selection and automation for operation of deployment/retrieval manipulator was provided. It is concluded that the Magnetometry Sequence will consume approximately 13 minutes of mission time.

In the following discussion the above conclusion is developed more fully. The operations profile for the Magnetometry Sequence is first discussed. Then the time line associated with each step of the operations profile is developed to form the time line for the entire sequence.

This is one of a series of studies conducted on the automated roving vehicle time line under Jet Propulsion Laboratory Contract No. 952668, "Lunar Roving Vehicle Ground Data System Design Study."

2. Discussion

The magnetometer will be the first instrument deployed at a Science Site and will provide the prime data for the magnetometry experiment. The objective is to measure the time-varying intensity and vector direction of the magnetic field at each Science Site. To have minimal electromagnetic interference, the magnetometer must be at least 75 feet away from the LRV and all other deployed science-instrument packages. The magnetometer will be continuously sending data to the LRV. Therefore, the data processed when the LRV is moving 75 feet away from the magnetometer will show a decaying of effects upon the magnetic field. This data can be used to calibrate the magnetometer.

There are a series of operations necessary for the implementation of the magnetometry experiment:

- Selection of magnetometry station (possibly during traverse). (Mode 5. 0, Sequence 1. 1)
- Traverse to station. (Mode 5. 0)
- Select spot for instrument placement. (Sequence 1. 2. 1)
- Deploy instrument. (Sequence 1. 2. 1)
- Traverse to an area at least 75 feet away from instrument. (Mode 5. 0)
- Data collection and transmission (deploy other instruments). (Sequence 1. 2. 2)
- Traverse back to instrument. (Mode 5. 0)
- Instrument retrieval and storage. (Sequence 1. 2. 3)

2. 1 Selection of Magnetometry Station and Spot (Estimated Duration: 2. 0 minutes)

Best use of time can be made by using the "traverse" mode for selection of the magnetometry station. From a best case analysis standpoint, it is assumed that as the camera is viewing ahead of the LRV during traverse, the entire Science Site and, specifically, a magnetometry station that satisfies the following constraints can be determined. The station must appear to:

a) Be stable enough to support the instrument.

b) Have a topography which would allow a deployment that is stationary and allows simple retrieval of the instrument.

c) Allow accurate communication with the LRV.

d) Give the LRV easy traverse to isolate and then retrieve the magnetometer.

Coordinates of this station must be submitted to the navigation/guidance function for subsequent traverse operations. This submittal should be automated and could be implemented with touch pen contact on a video display. As the Operations Profile Flow Chart, Figure 2, shows this traverse to the magnetometry site will be part of the Traverse Mode. Further detailed operations profile diagrams for the Magnetometry Sequence are provided as Figures 3 and 4.

The Magnetometry Sequence (1. 2) will begin when the LRV arrives at the magnetometry station. Selection of a magnetometry "spot" will follow and a time allocation will depend on the care taken in its selection. This "spot" selection can possibly be done during traverse to the station. If not, the time is additive to the mission and should be minimized. If spot selection is required at the station, a foreground survey will be conducted and the spot selected from the pictures taken. Two minutes will be required for this activity.

2. 2 Magnetometer Deployment (Estimated Duration: 5. 0 minutes)

The deployment of the magnetometer will be done after the "spot" is selected. This deployment should be done either automatically or semi-automatically (examples of possible automatic deployments are mentioned in Section 2. 3) to minimize both time and energy requirements. It is advisable during this period to simultaneously deploy the magnetometer, perform the Reconnoiter (major) Sequence, if required, and select the NGRA and gravimetry sites.

Since the time needed for the reconnoiter will be about 10 minutes, the time for deployment can be increased to 10 minutes if desired, when done simultaneously with reconnoiter. If the traverse pictures were adequate for reconnoiter, the deployment should be done as rapidly as possible using, again, an automatic process as described below. Approximately 5. 0 minutes will be required for instrument deployment.

2. 3 Possible Deployment Techniques

It has been assumed that all instrument deployment techniques will utilize a "Surveyor type" multipurpose manipulator arm which is commandable in azimuth, extension, elevation, and through all articulations of the manipulator head. All manipulator positions can be referenced to a common vehicle origin of coordinates through Euler transformations and translations as may be required; therefore, it is conceivable that a computer program could be developed which would be capable of generating a command program which would reposition the manipulator automatically from one spot on the vehicle to another (say from stowed manipulator to the stowed magnetometer spot). These spots would all be referenced to the common vehicle coordinates. Also, spots outboard of the vehicle could be referenced to the vehicle coordinates through video imaging and TV pointing angles; therefore, the computer program could be capable of repositioning the manipulator to outboard deployment spots.

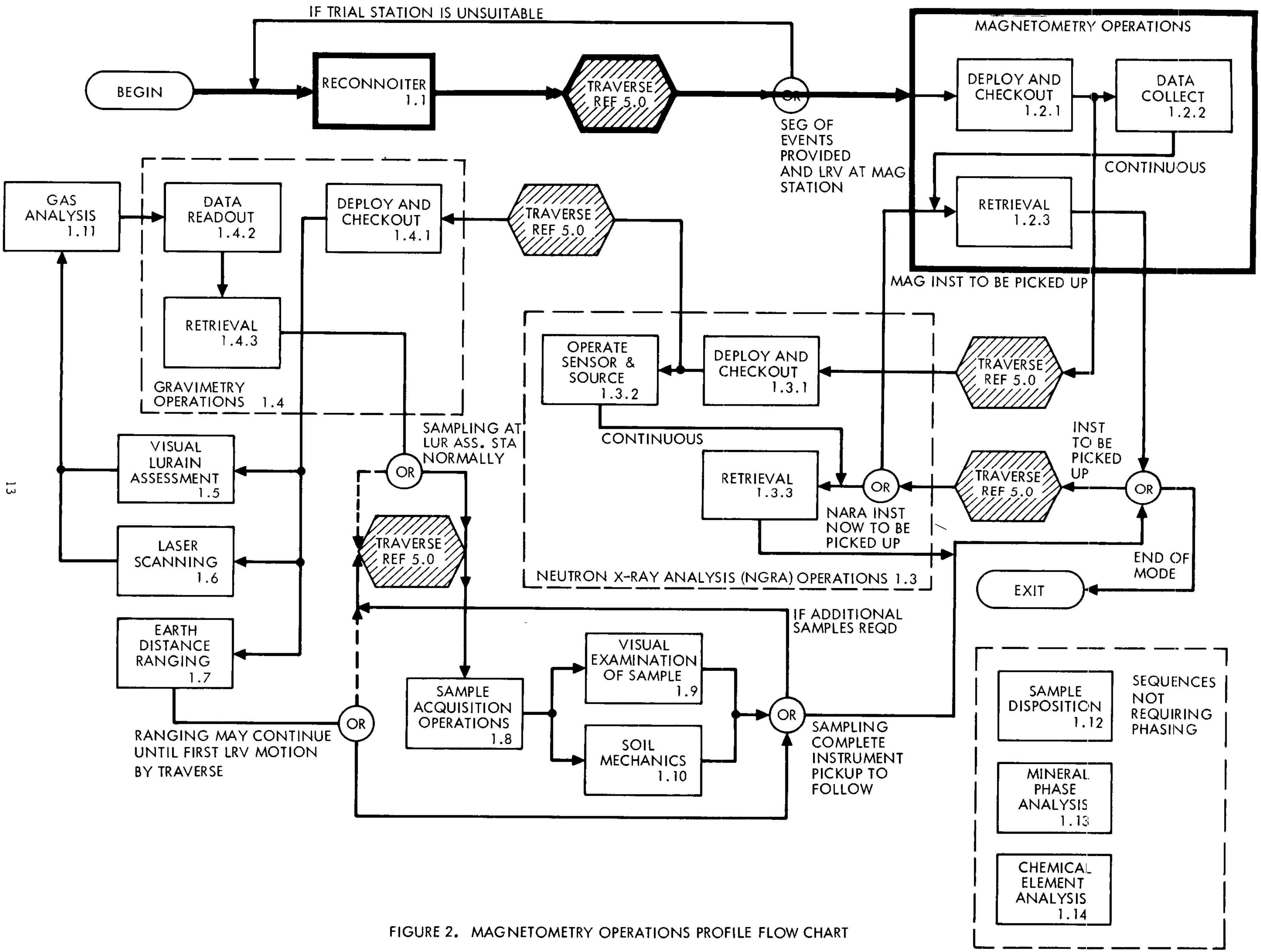

FIGURE 2. MAGNETOMETRY OPERATIONS PROFILE FLOW CHART

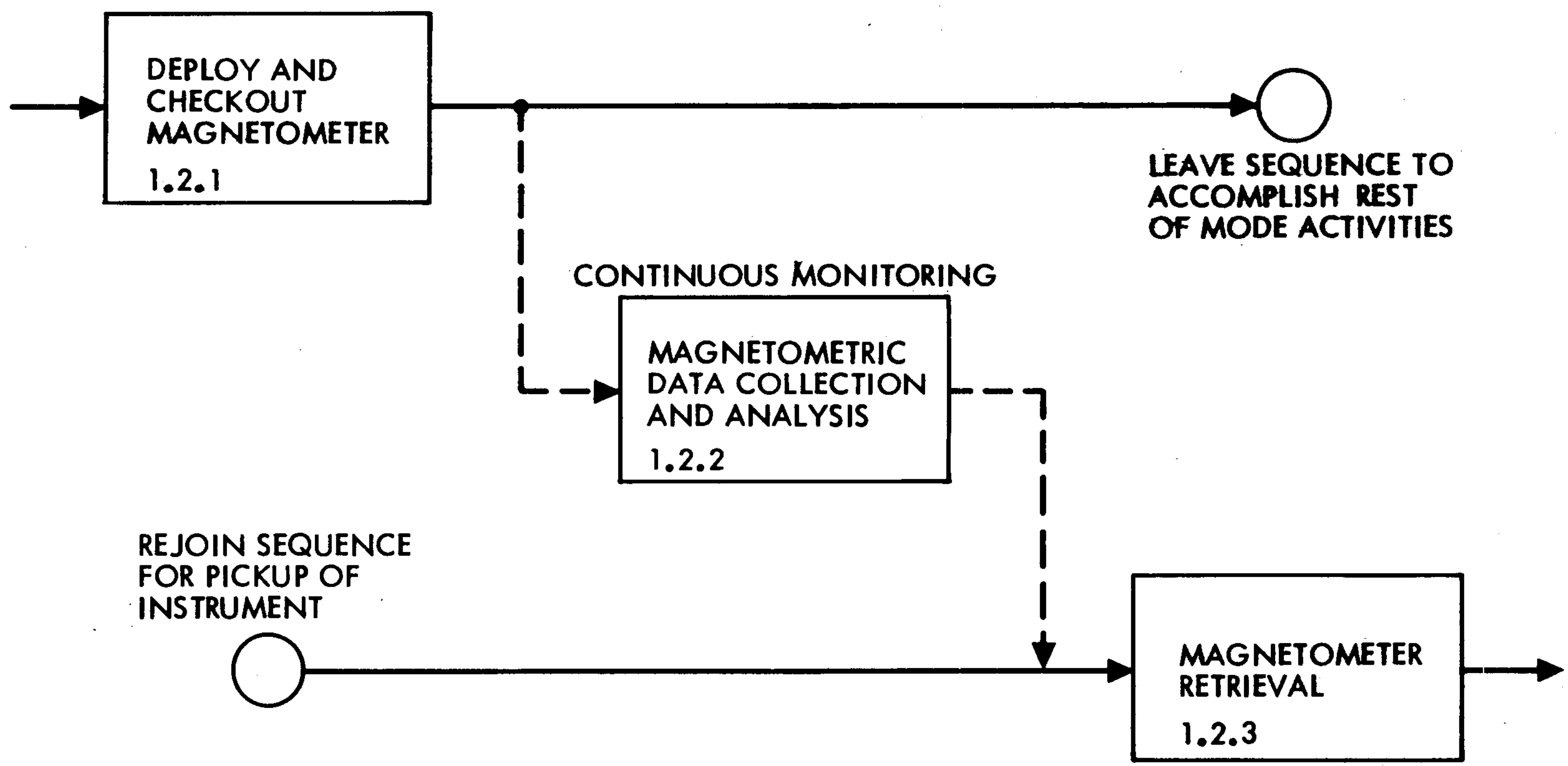

FIGURE 3 MAGNETOMETRY OPERATIONS MAJOR SEQUENCE 1.2

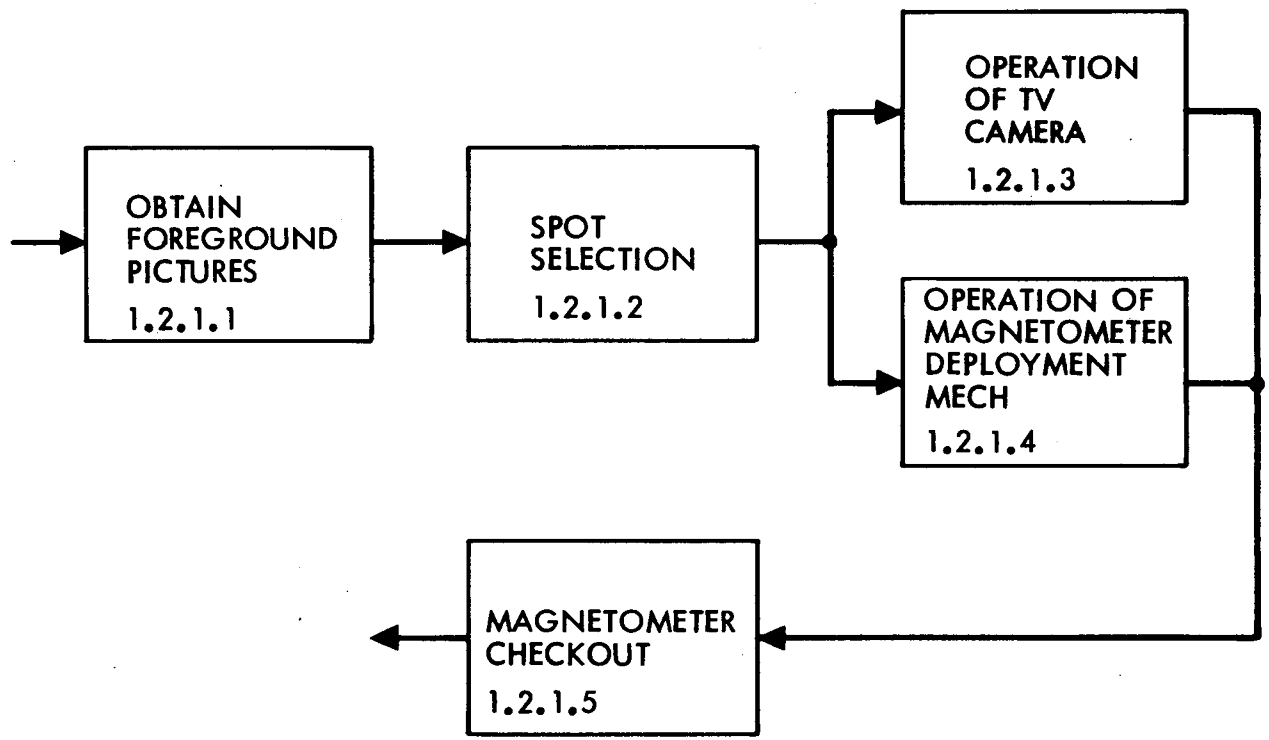

FIGURE 4 MAGNETOMETER DEPLOYMENT AND CHECKOUT MAJOR SEQUENCE 1.2.1

This computer program and vehicle mechanization capability has been assumed as a baseline design feature. The sequence of event for any deployment activity would be as follows:

a) Identify and mark deployment spot. Through video foreground imaging (obtained for most part during traverse without need for additional foreground surveys) spot is selected and coordinates calculated by computer from touch pen contact on video presentation and TV pointing angles.

b) Pick up device — Manipulator commanded automatically from stowed position to device. Manipulator will be commanded to stop just short of device. Manually generated command sequences with video monitoring will be employed for vernier positioning of the manipulator to grasp the device and lift it from the stowed position.

c) Deploy device to spot — Computer generated command sequence will be utilized to reposition the manipulator with device to a position just short and above the outboard deployment spot. Again, manually generated command sequences with video monitoring will be utilized for vernier positioning and release of the device on the lunar surface.

Device retrieval activities would be the reverse of the above sequence with computer generated commands utilized for gross manipulator repositionings and manual command sequences utilized for vernier control.

It has been estimated that 5.0 minutes should be alloted for any device deployment/retrieval activities. Any allotment greater than 5.0 minutes could seriously impact the success of the LRV mission due to the many deployment/retrieval activities required during the mission. With 1000 Science Sites and magnetometry NGRA, and 3 sampling operations required of the manipulator at each site, it can be seen that as many as 10,000 deployment/retrieval operations may be required during the mission.

Deployment of GDS hardware (including study of 2 versus 3 dimensional display requirements) computer programs and operating procedures should be undertaken to optimize manipulator use.

2.4 Magnetometer Isolation (Expected Duration: 1.5 minutes)

The isolation of the magnetometer from the LRV will be accomplished by LRV traversal to the NGRA site (which will be approximately 75 feet away from the magnetometry site). Assuming a LRV traverse speed of 1.0 km/hr, 1.5 minutes will be required.

2.5 Magnetometer Retrieval (Return and Retrieve) (Expected Duration: 5.0 minutes)

The LRV will be assumed to be approximately 75 feet away from the magnetometry experiment as determined during Reconnoiter/Site Selection.

Therefore, the time needed to traverse that distance at a speed of 1.0 km/hr is 1.5 minutes. This traverse should be done with camera coverage and real time computer analysis to ensure that the LRV returns to the correct location for retrieval.

The retrieval of the magnetometer should, again, be a semiautomatic procedure using the Surface Sampler. As previously discussed a 5.0 minute retrieval period has been allocated.

3. Conclusions

The magnetometry events and their associated mission time allocations are shown below. It was found that by selecting the magnetometry site during traverse and then simultaneously doing the deployment, reconnoiter and other site selections, the total stationary science time could be lowered.

MAGNETOMETRY EXPERIMENT

Event			Remarks
1. Spot selection	2.0		May be done during traverse
2. Deployment, reconnoiter	-	(5.0)	Deployment only
Sites selection	10.0	-	Deployment and reconnoiter time
3. Isolate instrument	1.5	(1.5)	Assuming LRV speed is 1.0 km/hr
4. Return to instrument	1.5	(1.5)	Assuming LRV speed is 1.0 km/hr
5. Retrieve instrument	5.0	(5.0)	Semiautomatic procedure
		(13.0)	Magnetometry implementation
	2.0		Magnetometry and reconnoiter implementation
(Best case totals)			

There is a requirement of 30 minutes for data collection when the magnetometer is remote (isolated). This time, in general, will not be additive to the mission because the time needed at the subsequent NGRA and gravimetry sites is greater than the 30-minute requirement.

III. GRAVIMETRY SEQUENCE

1. Introduction

The purpose of this paper is to investigate the time line associated with operation of the gravimetry instrument in an automated roving vehicle mission. Discussion of the operational aspects is given, and conclusions are reached regarding time line impact and functions of the instrument deployment device.

A best case approach was utilized for deployment activities, normal traverse pictures (taken while traversing to the gravimetry station) were assumed suitable for deployment spot selection, and the paralleling sequences of visual terrain assessment, laser scanning, and earth distance ranging could be conducted without mutual interference. It is concluded that the Gravimetry Sequence (and any paralleling activities) will consume approximately 33. 5 minutes of mission time.

In the following discussion the above conclusion is developed more fully. The operations profile for the Gravimetry Sequence is first discussed. The gravimeter baseline and the time line associated with each step of the operations profile are developed to form the time line for the entire sequence.

This is one of a series of studies conducted on the automated roving vehicle time line under Jet Propulsion Laboratory Contract 952668, Lunar Roving Vehicle Ground Data System Design Study.

2. Discussion

The gravimeter will be utilized to provide the prime data for the gravimetry experiment. This data consists of absolute measurements of the acceleration of lunar gravity in order to determine gravimetric anomolies. Operation of the instrument itself appears to be mechanistic. Alignment of the verticle axis, through horizontal leveling, is the only operation requiring close tolerances. It seems that an automatic device could provide vernier alignment (leveling) once commanding had brought it within range of the automatic device.

The Science Mode Operations Profile is shown in Figure 5. Sequences that have some association with the Gravimetry Sequence, and which are discussed to some extent in this report are highlighted. Figures 6 and 7 depict the operations profile of some of the minor sequences of the Gravimetry Sequence.

Prime operations functions associated with the instrument include:

a) Station selection for vehicle placement at instrument deployment. (Would normally be same sequence as selection of panoramic station since both would be done simultaneously. This selection operation would be conducted during Reconnoiter Sequence or during the traverse prior to reaching the Science Site.)

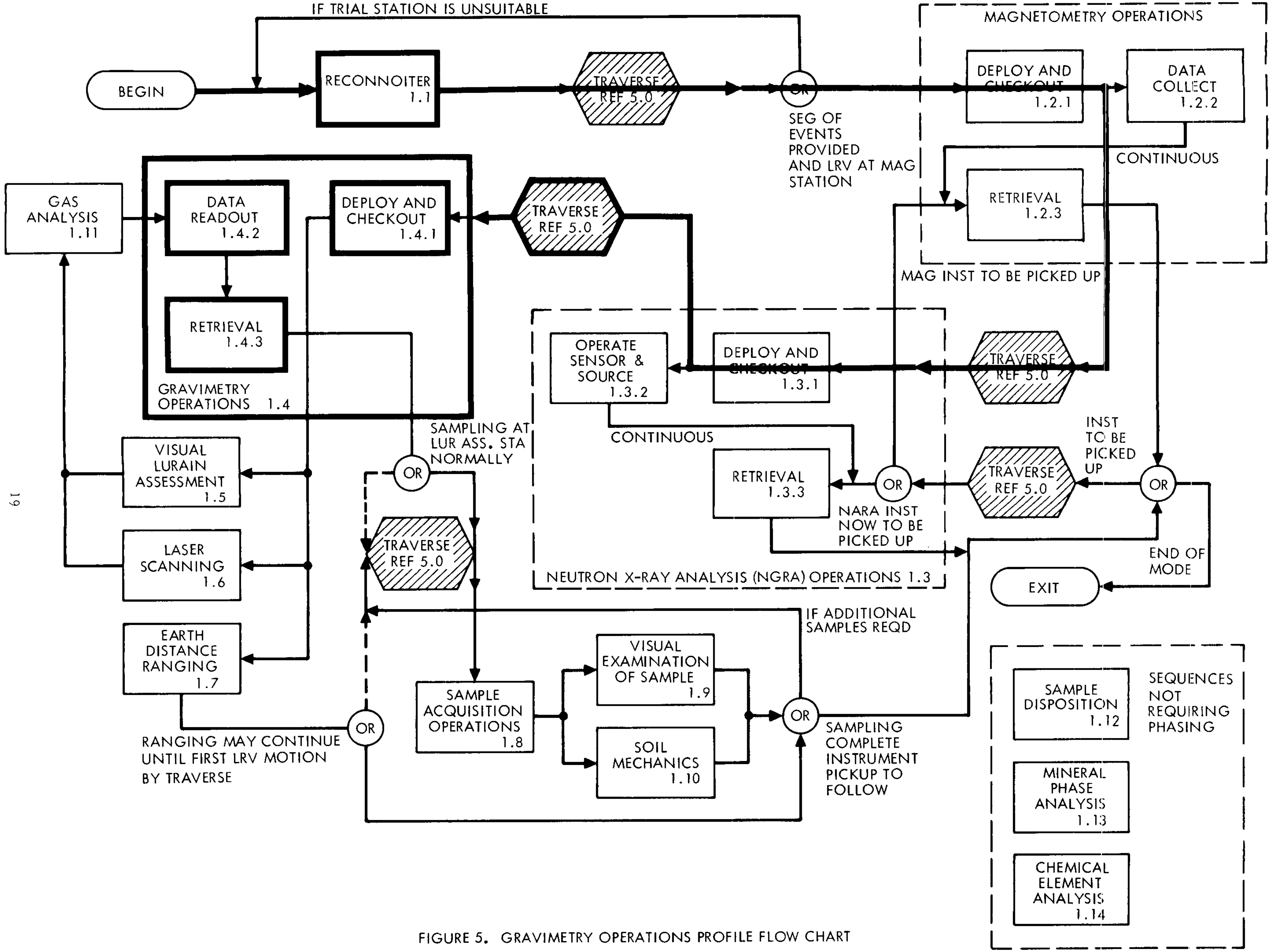

FIGURE 5. GRAVIMETRY OPERATIONS PROFILE FLOW CHART

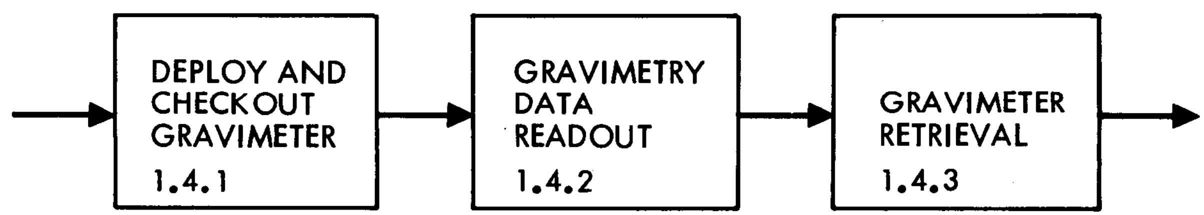

FIGURE 6 GRAVIMETRY OPERATIONS MAJOR SEQUENCE 1.4

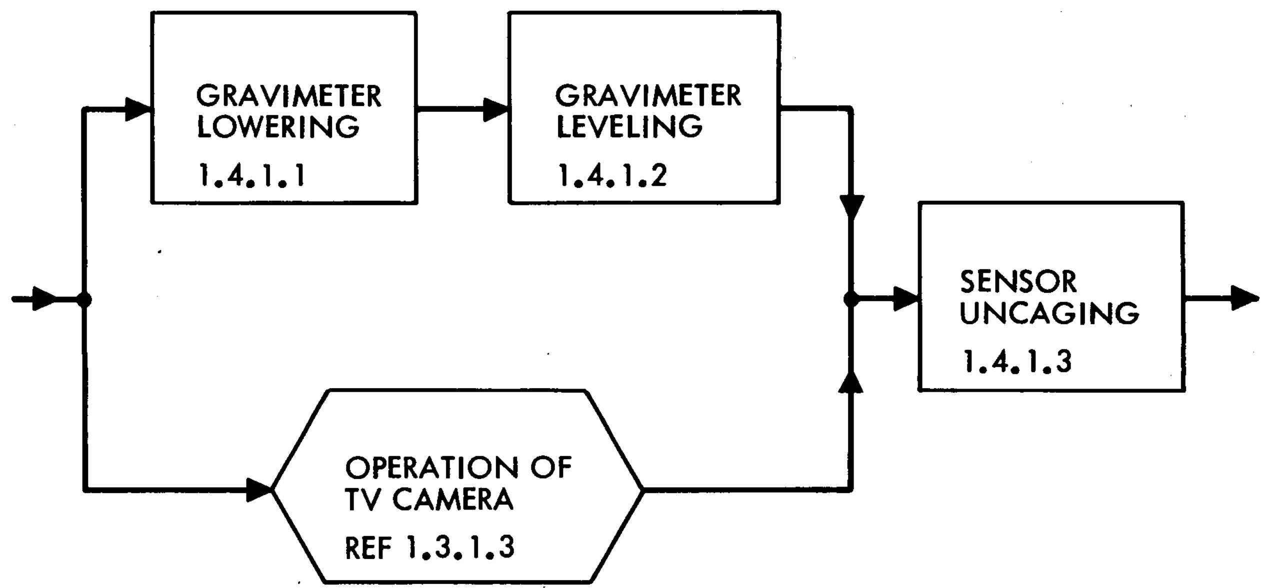

FIGURE 7 GRAVIMETER DEPLOYMENT AND CHECKOUT MINOR SEQUENCE 1.4

b) Traverse to station, select "spot" for instrument placement, and position vehicle over spot. (Would be conducted as portion of Traverse Mode 5. 0.)

c) Lower, level, uncage, and allow settling of instrument. (This is a most time consuming operation as current data indicates thirty minutes are required for damping out of mechanical vibrations.) (Minor Sequences 1. 4. 1. 1, 1. 4. 1. 2, 1. 4. 1. 3, 1. 3. 1. 3).

d) Activities, activation of electronics, and accumulation of readings. (Rather straight forward. Three separate readings taken and averages for measurement calculation.) (Minor Sequence 1. 4. 2)

e) Instrument retrieval and storage. (Minor Sequence 1. 4. 3)

2. 1 <u>Instrument Baseline</u>

The instrument baseline includes use of a Michelson Interferometer with internal laser light source to measure the absolute acceleration of gravity at selected locations. The computation involves simple equations of linear motion under constant acceleration. Readings are obtained from two internal counters within the device. These readings are obtained from an individual drop sequence which utilizes a falling mirror as the moving mirror portion of the Michelson Interferometer. No active data processing is required during the drop sequence. The mirror is simply raised, counters zeroed, mirror dropped, counters read, mirror raised, etc., until three separate readings have been obtained.

2. 2 <u>Station Selection Events (Estimated Duration: 2 minutes)</u>

Selection of the gravimetry station will, in general, occur during the Reconnoiter Sequence (1. 1). Characteristics will include those required by Terrain Assessment (1. 5) and Laser Ranging (1. 6) in order that these sequences may be accomplished simultaneously. Gravimetry constraints upon selection of this station include level, stable ground for instrument placement and data available so that terrain effect corrections can be computed. These corrections consist of the following:

a) Free air corrections — required due to varying distance from center of mass. Amountes to 0. 187 milligals/m (Reference 2).

b) Bouguer corrections — associated with varying distance from center of mass but adds correction for increased mass under instrument. Amounts to 0. 112 milligals/m (Reference 2), but of opposite sign from free air correction.

c) Topographic correction — required only in hilly areas as a supplemental correction to the Bouger plane (Reference 2).

Details of these corrections are given in the literature and will not be discussed further here except to say that vertical control will be required to an accuracy of ± 10 m in order to control the terrain error to approximately one-fourth of the desired survey accuracy (Reference 2).

Station selection activity would consist of reviewing a panoramic survey (or pictures taken during traverse) for a suitable gravimetry station. Coordinates of this station must be submitted to the navigation/guidance function for subsequent traverse operations. This submittal should be automated and could be implemented with touch pen contact on a video display.

Allocation of time to the station selection activity is somewhat subjective. As this time may be directly additive to the mission, it should be minimized as far as practicable and a figure of 2 minutes has been selected as being representative. This time would not be additive to the mission if accomplished during the travers e prior to reaching the Science Site.

2.3 <u>Vehicle Placement Events (Estimated Duration: 3.0 minutes)</u>

The vehicle placement activity would occur entirely within the Traverse Mode (5.0) and would be comprised of traversing to the deployment station, conducting a foreground survey (if necessary), selecting the deployment spot, and positioning of the vehicle over this spot for dropping of the gravimetry instrument. From definition of the Science Site, the gravimetry station would be within 50 meters of the vehicle. Assuming a vehicle traverse speed of 1.0 km/hr, the vehicle would require approximately 3.0 minutes to cover this 50 meters of the vehicle. Assuming a vehicle traverse speed of 1.0 km/hr, the vehicle would require approximately 3.0 minutes to cover this 50 meters. The 1.0 km/hr velocity represents the arithmetic mean of velocities postulated by Ulrich (Reference 3) for various terrain types.

Once on station, a "spot" for instrument deployment must be selected. Normally this would occur directly in the path of the vehicle as the instrument is merely lowered through the vehicle to the ground. In this case, the traverse pictures taken should provide satisfactory foreground information for the spot selection decision. In lieu of this, a foreground survey may be required in the vicinity of the vehicle to locate a satisfactory spot.

Again, since the spot would normally be in the vehicle's path, the vehicle positioning task would involve stepping the vehicle forward until the spot had been located beneath the lowering hole. If the spot were not directly in front of the vehicle, some vehicle maneuvering would, of course, be required in order to occupy the spot.

It would be most unusual if the deployment spot were not selected from the area directly in front of the vehicle; therefore, this possibility will be ignored as best case analysis of events are to be studied. It can be assumed, therefore, that the final spot selection and vehicle positioning will not add appreciable time to the sequence of events.

2.4 Instrument Placement Events (Estimated Duration: Manual 8 minutes, Automatic 30 seconds)

The lowering, leveling, and uncaging operation will, for the most part, require automated sequences for their timely and safe accomplishment. Specifically, a single command should initiate the lowering sequence which would self terminate. If manual control with video monitoring were utilized, the time required for lowering would intuitively seem to be excessive. This can be shown as follows:

a) Manual Lowering Sequence

Time required for TV picture	10 secs
Number of pictures required 7 to 10	x 10
	100 secs
Reposition TV camera	30 secs
Number of repositioning required 1 to 2	x 2
	60 secs
Lowering CMD time	0.5 sec
Number of lowering commands 30 to 50	x 50
	25 secs
Operator evaluation total	≈ 5 min
Total Time	≈ 8 min.

b) Automatic Lowering Sequence

Single lowering command	0.5 sec
Lowering time (automatic lowering and self terminating)	≈ 20.0
	10.0
Total Time	≈ 30.0 secs

Leveling of the gravimeter will be required to within approximately 20 arcsec (Reference 1). This would probably be most easily accomplished, from a technical standpoint, with manual commanding/automatic techniques. A manual commanding sequence would position the instrument within the range of the automatic levelers which could be enables with a single command.

To permit timely execution of the leveling command sequence, telemetry should be provided which would indicate the degree of instrument offset from which corrective command requirements could be calculated. It is estimated that the leveling command sequence would be executed within a one-minute period.

The range of automatic leveling cannot be estimated at this point; however, its execution should also be rapid and consume not more than one minute.

Uncaging consists of a single command to release the detent mechanism. At this point a long wait would be programmed into the sequence as current information indicates that thirty minutes would be required for damping of the release transient.

2.5 Instrument Operation Events (Estimated Duration: 3 minutes)

Activation of the electronics and accumulation of readings would seem to be a rather straight forward sequence which would utilize the instrument's remote control features. Operation of the instrument has been covered previously and in the literature (Reference 1) and will not be covered further here. It is estimated that approximately one minute would be required for each reading sequence--requiring a total three minutes.

2.6 Instrument Retrieval Events (Estimated Duration: 60 seconds)

Instrument retrieval could again be a semiautomatic sequence with only a firm requirement for caging and retrieval commands. This seequence should not require more than a minute for its accomplishment.

3. Conclusions

Gravimetry events and their association with explicit mission time are summarized as follows:

	Event	Time (Min.)	Remarks
a)	Station Selection	2.0	Assumes photos available either from panorama or traverse pictures.
b)	Traverse, Spot Selection, and Vehicle Positioning	(3)	Does not take mission time as these events can be performed during traverse.
c)	Lower, Level, Uncage, and Allow to Settle	32.5	Parallel events to Terrain Assessment (1.5) and Laser Ranging (1.6) activities.
d)	Activation and Accumulation of Readings		
e)	Retrieval and Storage	1.0	

These events, therefore, consume approximately 38.5 minutes of mission time.

Conclusions concerning time wise impact to the mission are as follows:

1) The gravimeter cannot be used unless the vehicle is stationary. A stationary vehicle is required for 33.5 minutes.

2) Use of the gravimeter may or may not require significant mission time depending upon: it is coincident with the Terrain Assessment/Laser Ranging activities. These two activities require approximately 33.5 minutes for their accomplishment and their time lines are yet to be detailed.

It has been concluded that the deployment/retrieval events should be automated as the savings in time is significant and is directly associated with savings in mission resources.

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IV. SAMPLE VISUAL EXAMINATION SEQUENCE

1. Introduction

The purpose of this paper is to investigate the time line associated with operation of the sample visual examination equipment in an automated roving vehicle mission. Assumptions and discussions of operations and conclusions about the time line effect make up the major portion of this section.

A worst case approach was utilized in developing the visual examination sequence time line; that is, it was assumed that no scientific help was available to examine the sample pictures in real time, and no automation was provided to expedite the operation. It was quickly seen that, due to the many pictures required for a survey of the samples in three dimensions, extensive time would be consumed by the sequence unless real time analysis would reduce the number of pictures to those required for salient characteristics of the sample and unless some automation was provided.

In the following discussion, the above conclusion is developed more fully. The operations profile for the examination sequence is first discussed. The time line associated with each step of the operations profile and the number of pictures required for each sample are developed to form the time line for the entire sequence.

This is one of a series of studies conducted on the automated roving vehicle time line under Jet Propulsion Laboratory Contract Number 952668, Lunar Roving Vehicle Ground Data System Design Study.

2. Discussion

The sample imaging system will be utilized to provide prime data for the visual examination of samples experiment. An imaging system baseline design has not yet been established; therefore, several cases have been assumed to examine the various associated time lines. In most cases, it appears that a single operations profile with common minor sequences will apply to the baseline assumptions, and it is upon this basis that the time estimates have been provided.

The science mode operations profile is shown in Figure 8. Sequences that have some association with the sample visual examination sequence, and which are discussed to some extent in this report, are highlighted.

The operations profile for the sample examination sequence is shown in Figure 9. This profile assumes that the sample has been acquired and is positioned on the viewing stage (as performed by the sampling sequence) for examination or is located in situ, outboard of the vehicle. Operations tasks include:

a) Positioning of the camera for sample viewing (1. 9. 1): A step that will only be required when the sample imaging system employs a

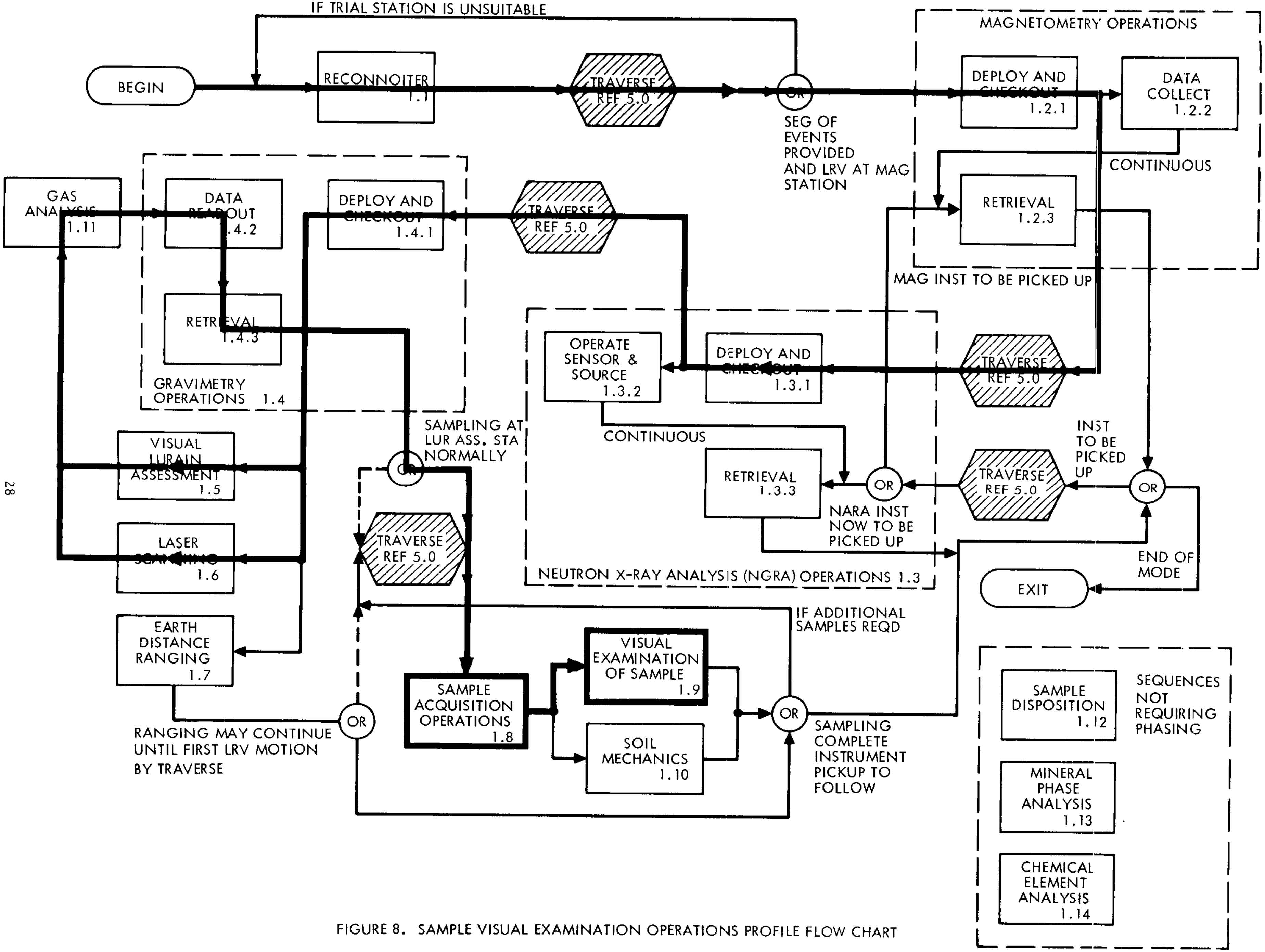


FIGURE 8. SAMPLE VISUAL EXAMINATION OPERATIONS PROFILE FLOW CHART

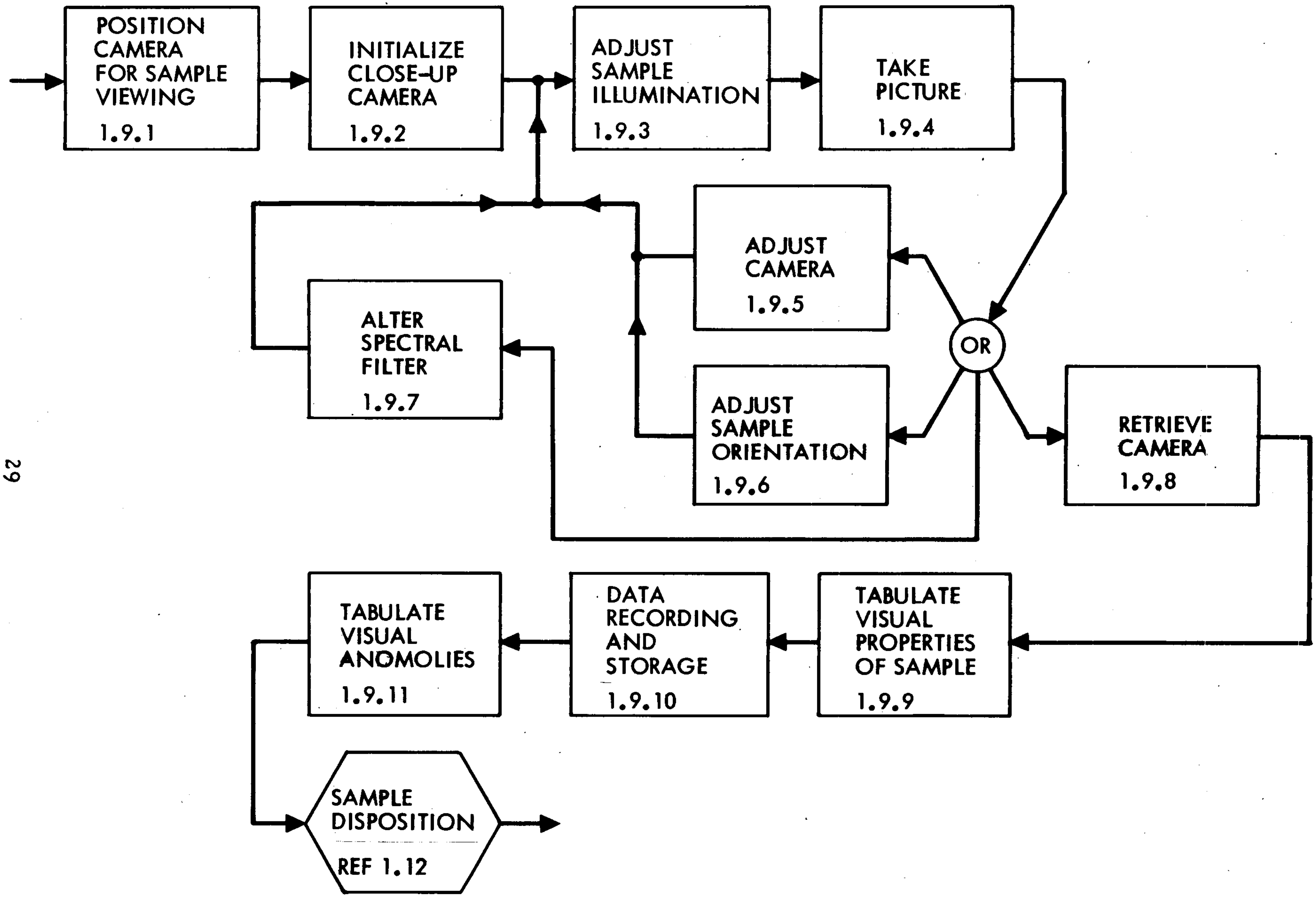


FIGURE 9 SAMPLE VISUAL EXAMINATION MAJOR SEQUENCE 1.9

multipurpose camera which will require specific positioning for either onboard or in situ sample examination.

b) Camera initialization (1.9.2): Camera will be energized, dust cover removed, etc.

c) Illumination adjustment (1.9.3): Adjustment of the illumination angle is a desirable operation. Illumination of the sample will be achieved by either artificial light or by sunlight directable by mirrors or adjusting vehicle position.

d) Taking picture (1.9.4): The process of obtaining video and video hard copy data and performing analysis of this data to determine subsequent command and picture requirements.

e) Adjust camera (1.9.5): The process of optimizing or altering video presentation by changing camera focus and/or iris.

f) Adjust sample orientation (1.9.6): The process of rotating the sample on the viewing stage. Assumes an onboard sample. For an in situ examination, there would be no rotation possible.

g) Alter spectral filter (1.9.7): The process of altering the video system spectral response by changing the colored filter in front of the camera.

h) Retrieve camera (1.9.8): Will be required only to retrieve multipurpose camera that has been deployed for sample investigations either onboard or in situ on the lunar surface.

2.1 Instrument Baseline

At the present time, it is evident that surface heterogeneity, texture, and color are the primary sample characteristics which must be defined during the visual sample examination process. Surface heterogeneity and texture will be examined by rotation of the sample and illumination angles to cause changes in the viewing aspect and shadow formation. Surface color will be examined by reconstruction of spectral filtered images. Color reconstruction may assist in establishing sample heterogeneity. It is assumed that focal distance and iris settings are commandable to vary the focal point and depth of field of the camera systems and that the camera optics provide a X10 magnification of the sample.

The two modes of image capture and transmission were initially considered. The first assumed a shuttered camera with discrete video pictures transmitted upon command. The second assumed continuous video imaging and transmission. As the study progressed, it did not seem to make any significant difference whether discrete or continuous imaging hardware/procedures were visualized. This is due to the fact that the detailed analysis of the sample will require the equivalent of individual pictures at some point in time; and, therefore, the operations procedures will be very similar for either discrete or continuous imaging techniques.

For the worst case analysis approach, it was assumed that picture requirements could be implemented by a camera operator untrained in geological observation. To implement this technique, a picture taking sequence would be provided which would capture the visual properties of any sample through iris, focal, and illumination ranging surveys. In this fashion, a set of photographs would be available for delayed time analysis by responsible scientists. It would be of no particular advantage of provide real time scientific analysis, except to perhaps reduce the picture taking requirements due to real time decisions to reduce the scope of picture taking.

Additional instrument configurations include: (1) use of a repositionable multipurpose camera and (2) a mechanically fixed dedicated camera for sample imaging. The first configuration would permit onboard and in situ sample examination procedures by repositioning the camera utilizing a manipulator device. The second configuration would permit imaging only of samples presented to a viewing stage.

The first configuration may preclude other operations during the sample examination activity, as the camera may be required for traverals, etc.

Implementation of the first configuration would require more operational steps (sequences 1.9.1 and 1.9.2, above) than the second and, thus, more mission time line.

It is assumed that the camera deployment activity can be simultaneously monitored from a foreground TV camera to assure safety of the instrument and proper progress of the deployment procedure. The deployment procedure will closely parallel that discussed for magnetometer deployment (sequence 1.2).

2.2 Positioning of the Camera for Sample Viewing (estimated duration: 10 minutes for in situ, 5 minutes for onboard examination)

This minor sequence will be required only if the sampling camera is a multipurpose, repositionable device. Two types of repositionings will be required. The first includes repositioning of the camera outboard of the vehicle for in situ sample examination. The second includes positioning of the camera in a receptacle for onboard examination.

Positioning of the camera, in any case, will involve utilization of a manipulator device in a fashion discussed for deployment of the magnetometer (sequence 1.2). The total series of operations necessary for deployment of the camera to in situ examination includes:

- Selection of the sample investigation station: Assumed accomplished during sequence 1.1 (Reconnoiter) or 1.5 (Visual Lurain Assessment).

- Traverse to station: Assumed accomplished by mode 5.0 (Traverse). Maximum duration of traverse would be on the order of 3.0 minutes, if it is assumed (as in the gravimetry sequence) that the maximum traverse would be 50 meters, and the traverse speed would be 1 km/hr.

- Select sample spot for camera placement: Will be accomplished with a foreground survey similar to that utilized in sequence 1.2 (Magnetometry). Time required would be on the order of 2 minutes.

- Deploy camera to sample spot: Will be accomplished utilizing a manipulator device in a fashion similar to the magnetometry deployment. Time required for the deployment activity should be approximately 5 minutes (see magnetometry discussion).

The only operation needed for positioning of the camera for onboard sample examination is deployment to the viewing receptable. This activity should be similar to the outboard, in situ deployment step and should require approximately 5 minutes.

2.3 Camera Initialization (estimated duration: 2 minutes)

The camera will be energized; initial iris, shutter, and focus settings made; dust covers removed; and an initial picture taken to evaluate setup. This minor sequence should require approximately 2 minutes, including the time required to evaluate the initial picture for further command requirements.

2.4 Illumination Adjustment (estimated duration: 2.25 minutes for sunlight, 0.25 minute for artificial light)

In order to highlight the surface characteristics of the sample, it will be necessary to vary the angle of incident illumination. At this point in time, the baseline design includes use of either artificial light or mirror directed sunlight. It is felt that the use of sunlight could require approximately 2 additional minutes (per step) over artificial light use due to vehicle repositioning requirements to obtain the proper sun angle. Use of sunlight would require only a stepping of the light source position and a verification of same over the telemetry link. Time required would be approximately 0.25 minute.

2.5 Take Picture (estimated duration: 1 minute)

In all baseline design approaches, it is assumed that TV video data will be obtainable at the control facility in near real time (a nominal 10 seconds delay has been utilized for guidance and control studies). Additionally, it is assumed that video hard copy is also available without appreciable delay.

This operation consists of getting the video hard copy and analyzing subsequent command and picture requirements. It is estimated that

2 minutes maximum would be required for this operation and 1 minute required on the average.

2.6 Adjust Camera (estimated duration: 0.25 minute)

This operation consists of commanding the proper iris, shutter and/or focal setting and obtaining proper verification of commands via telemetry. It is expected that this sequence would require no more than 0.25 minute.

2.7 Adjust Sample Orientation (expected duration: 0.25 minute)

This operation consists of commanding rotation of the viewing platforms or sample holding mechanism and obtaining proper verification of commands via telemetry. It is expected that this sequence would require no more than 0.25 minute.

2.8 Alter Spectral Filter (expected duration: 0.25 minute)

Similar to two preceding sequences where, here, commanding and telemetry verification is required of the filter wheel position.

2.9 Retrieve Camera (expected duration: 5 minutes for in situ or onboard camera configurations)

The operation required here includes removal of the camera from its sampling position (in situ or onboard) and insertion into its other use receptacle.

2.10 Number of Pictures

At the present time, no empirical data has been developed which could be utilized to formulate the method of picture taking. Also, it is not yet known what the scientist's requirements will be in terms of minimal data; therefore, it is difficult to conceptually evaluate the number of sample pictures that might be required to provide adequate coverage. This number is critical, however, to providing an overall visual examination time line, as it indicates the number of iterations required of the operations profile (how many focus steps, how many illumination adjustments, etc.). Therefore, the following sequence is postulated without any particular justification as a means of providing a nominal time line analysis and initiating further study in the sample examination area:

a) Samples will be examined from six aspect angles (top, bottom, and four sides).

b) For each aspect angle, illumination will be varied over 10 to 90 degree incident angles in 20 degree steps (5 steps).

c) For each aspect angle and a single illumination angle (50 degrees), a focal ranging survey will be conducted (5 steps).

d) Therefore, a single sample examination sequence will require sixty pictures.

3. Conclusions

Table 2 contains a summation of the time line. It can be seen from the total that, without real time scientific or equipment automation help, approximately 1.5 hours will be required for conduct of the sequence. If natural sunlight were utilized, an additional approximately 2.5 hours would be required. In addition, the vehicle would have to be stationary. If it is assumed that three samples will be visually examined at each science site, as much as 7.5 hours could be consumed in sample examination of samples from a single science site. Intuitively, allocation of this much time to this sequence seems excessive and would probably compromise the mission; therefore, the following operational considerations are postulated in an attempt to expedite the sequence:

a) Provide real time scientific help to determine the picture taking requirements. The purpose of this help will be to determine what pictures would be most helpful in classifying the sample in order to expedite the sequence.

b) Provide means to automate the sequence, either onboard or through ground command and control. It is conceivable that a command program could be executed which would execute prestored commands without pauses for operator evaluation of video or additional command requirements. The time required for such an automated sequence would consist of the command message time plus some mechanism repositioning time. This automated sequence would represent the other extreme of the time line analysis and could require as little as 5 to 15 minutes for execution, depending whether the camera was dedicated or not.

Ideally, the final operations approach to the sample examination sequence will utilize a combination of scientific help and automation to obtain a more reasonable time line.

V. MINERAL PHASE ANALYSIS SEQUENCE

1. Introduction

The purpose of this paper is to investigate the time line associated with operation of the X-ray diffractometer in support of the mineral phase analysis experiment on an automated lunar roving vehicle mission. Assumptions and discussion of operations and conclusions about the time line effect make up the major portion of this section.

A best case approach was, again, utilized in developing the mineral phase analysis sequence (1.13) time line; that is, feeding of sample specimens to the device is mechanized with little commanding required, and operation

TABLE 2. Sample Visual Examination Time Line

Number of Executions	Sequence Number	Multipurpose Repositionable Camera		Dedicated Fixed Camera
		In Situ	Onboard	
1	1.9.1	10	5	0
1	1.9.2	2	2	2
30	1.9.3	0.25/7.5	0.25/7.5	0.25/7.5
60	1.9.4	1/60	1/60	1/60
30	1.9.5	0.25/7.5	0.25/7.5	0.25/7.5
6	1.9.6		0.25/1.5	0.25/1.5
30	1.9.7	0.25/7.5	0.25/7.5	0.25/7.5
1	1.9.8	5	5	5
	Totals	99.5	96.0	86.0
If Using Natural Sunlight				
30	1.9.3	2/159.5	2/156.5	2/146.0

of the X-ray diffractometer can be accommodated in parallel to any vehicle activity, and, therefore, time consumed in operation of the device will not be additive to the mission. It is concluded that X-ray analysis (spectrometry assumed similar to diffractometry) of any specimen will require 21 minutes for quick look and 36 minutes for more detailed statistical examination. Neither of these times are additive to the mission.

In the following discussion, the above conclusion is developed more fully. The operations profile for the mineral phase analysis sequence is first discussed. The X-ray diffractometer baseline, precedent events, and the time line associated with each step of the operations profile are developed to form this time line for the entire sequence.

This is one of a series of studies conducted on the automated roving vehicle time line under Jet Propulsion Laboratory Contract Number 952668, Lunar Roving Vehicle Ground Data System Design Study.

2. <u>Discussions</u>

The X-ray diffractometer will be utilized to provide the prime data for the mineral phase analysis experiment. This data consists of X-ray intensity versus diffraction scan angle measurements. From this data, information regarding the rock-forming phases and estimation of their abundances and compositions may be developed. Operation of the instrument itself appears to be mechanistic. Two scan rates are to be provided. The first, faster, permits quick look analysis of the specimen. The second, slower, provides a more detailed statistical accumulation of diffraction data.

Once initiated, the scanning continues automatically to the end unless commands to terminate or retrace are given.

Preparation of the sample appears to be a critical problem, in that powdered specimens will be required. Two forms of obtaining the required, prepared sample have been proposed:

a) Use of an onboard pulverizer for positive control of the pulverized specimen.

b) Use of a sample drill which will provide the proper degree of sample pulverization during the sample acquisition sequence (1.8).

Only method (a) would add time to the mineral phase analysis sequence.

Apparently, the X-ray diffractometer requires great amounts of power. It is assumed that the LRV is capable of handling this large amount of power in parallel with other LRV activities. In this way, the mineral phase analysis sequence will not require specific time allotments from the mission sequence but will be capable of fitting in where required. This assumption may be "soft," in that the power demand may be so great as to preclude video transmissions or traverse operations and may require X-ray operations only in the lunar day when solar energy could be utilized to supplement the normal LRV energy sources.

At this point in the study, however, it will be assumed that operation of the X-ray instrument is nonconstraining. This assumption parallels the best case approach which is being implemented.

The science mode operations profile is shown in Figure 10. Sequences that have some association with the mineral phase analysis sequence, and which are discussed to some extent in this report, are highlighted. Figure 11 depicts the operations profile of some of the minor sequences of the mineral phase analysis sequence.

Prime operations functions associated with this instrument include:

- Sample selection (sequence 1.5)
- Sample acquisition (sequence 1.8)
- Sample preparation (minor sequence 1.13.1)
- Instrument calibration (minor sequence 1.13.2)
- Irradiation of sample (minor sequence 1.13.3)
- Disposal of sample (minor sequence 1.13.4)

2.1 Sample Selection (estimated duration: unstudied)

The selection of samples will be implemented in the visual terrain assessment sequence; therefore, time allocation for this selection will be given in that segment.

2.2 Sample Acquisition (estimated duration: unstudied)

The samples will be temporarily stored in buffer storage cups until they are needed. This sequence of events will be discussed, and time will be allocated in the sample acquisition sequence.

2.3 Sample Preparation (estimated duration: 1.0 minute)

The X-ray diffractometry will require that the samples be in the form of very small particles. The two proposed methods are to (1) have a pulverizer onboard the LRV or (2) pick up small particles created by drilling into the lunar surface.

If a pulverizer is designed for the LRV, a nominal time allocation of 1 minute can be used for transferring and crushing. This is based upon a mechanized sequence for pulverization. If the drill is used, the time will occur as part of sample acquisition sequence.

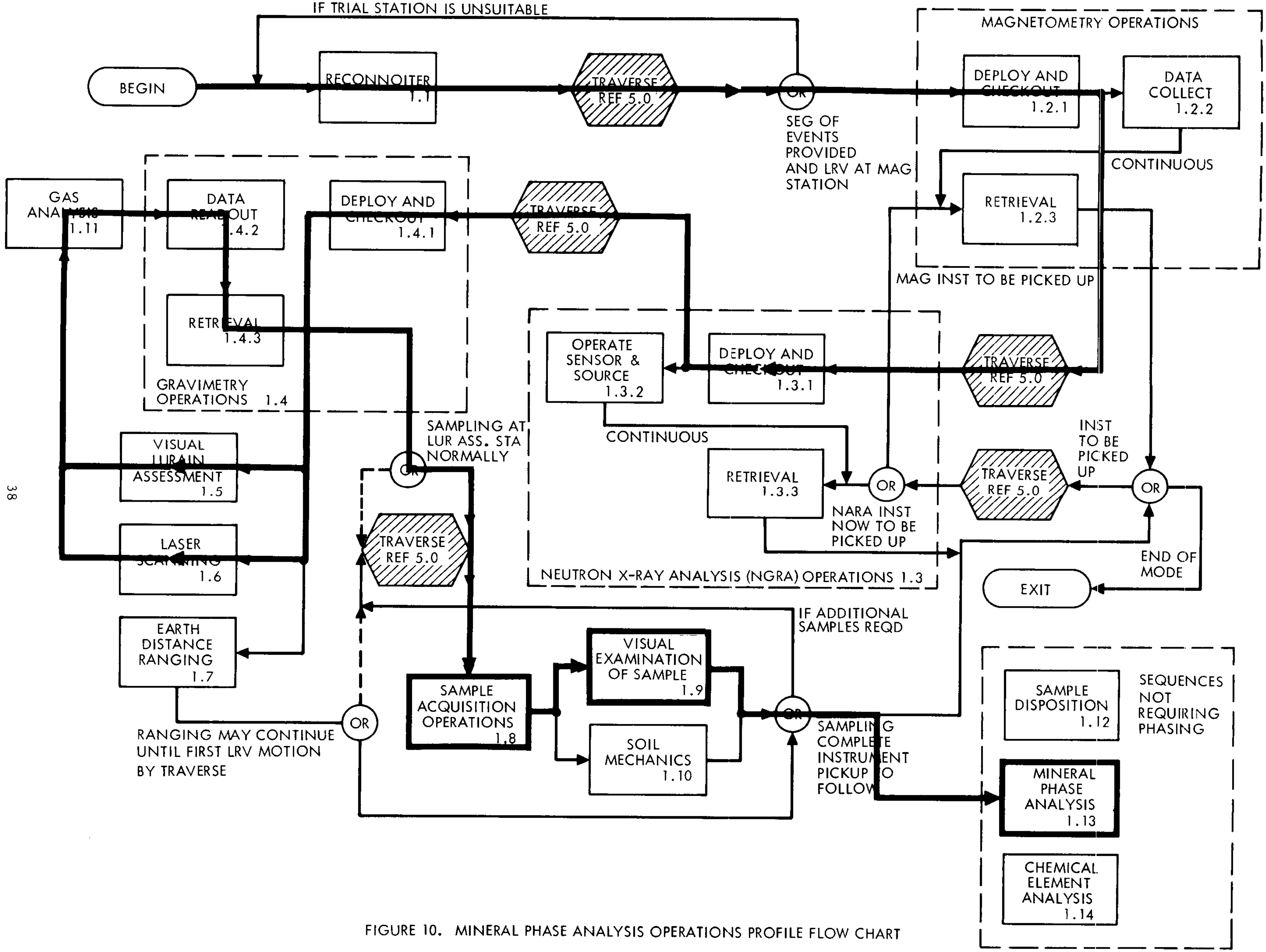


FIGURE 10. MINERAL PHASE ANALYSIS OPERATIONS PROFILE FLOW CHART

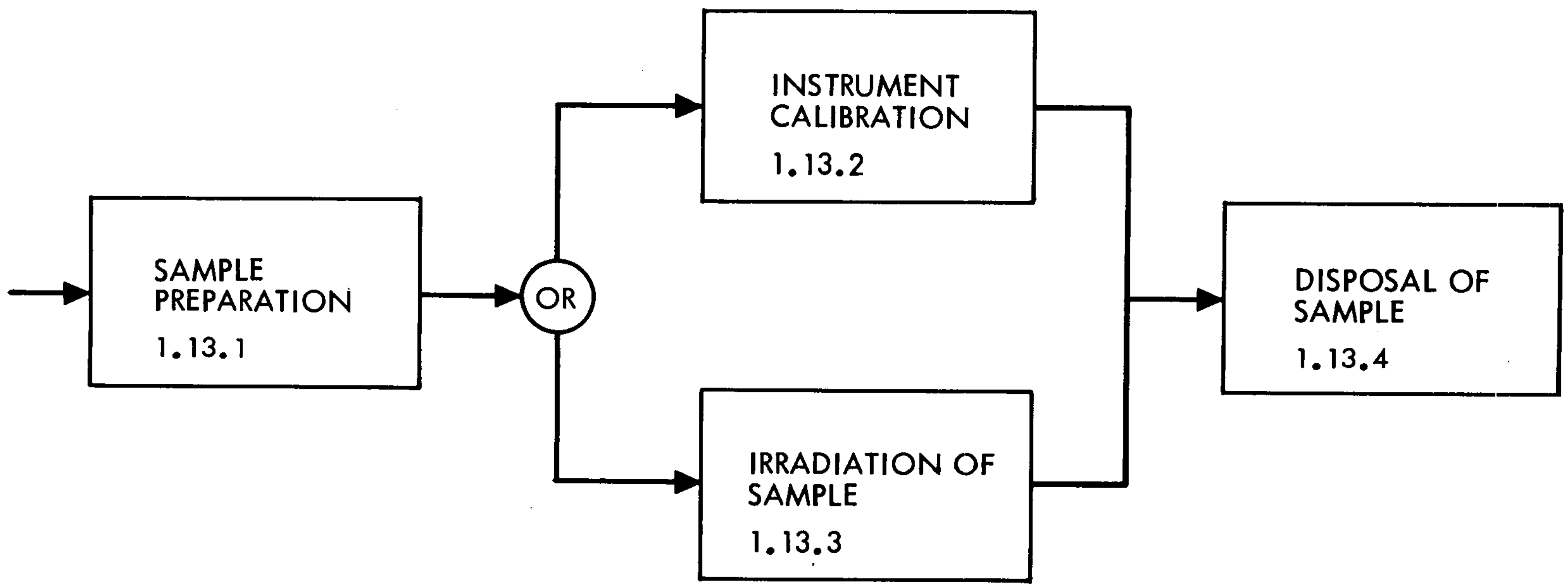


FIGURE 11 MINERAL PHASE ANALYSIS MAJOR SEQUENCE 1.13

2.4 Instrument Calibration (estimated duration: 34 minutes)

A standard specimen, nominally quartz, will be utilized to provide calibration of instrument operation at many scattering angles. In this way, nonlinearity in specimen and/or slit rotation rate may be determined. The sequence of events includes:

a) Non-X-ray background count (2 minutes)

b) High resolution scanning (30 minutes)

c) Non-X-ray background count (2 minutes)

2.5 Irradiation of Sample (estimated duration: 19 minutes — quick look, 34 minutes — high resolution)

Two modes of scanning operation are possible. The first, quick look, is accomplished at a scan rate twice that of the second. The second, high resolution, requires longer time due to the slower scan rate. Operational considerations and scientific objectives will dictate the scanning rate required. It is conceivable that the quick look at a specimen might be immediately followed by a high resolution scan.

The sequence of events is identical to the instrument calibration minor sequence, the high resolution and quick look scanning periods being 30 and 15 minutes, respectively, and total time being 19 and 34 minutes, respectively.

2.6 Disposal of Samples (expected duration: 1 minute)

After the diffractometry experiment is completed, mechanical operation will dispose of the samples. Camera coverage will be provided to give a visual check that the sample cups are clean. This operation should require approximately 1 minute.

3. Conclusions

The following table summarizes the mineral phase analysis sequence:

Event	Time (min) Quick Look	Time (min) High Resolution
Sample Preparation	1.0	1.0
Instrument Calibration*	(34.0)	(34.0)
Irradiation of Sample	19.0	34.0
Disposal of Sample	1.0	1.0
	21.0	36.0
	(55.0)	(70.0)

*Instrument calibration may not be a requirement for each analysis operation.

APPENDIX A

SUSPENDED SCIENCE PAYLOAD CONTROL AND DATA ANALYSIS TASKS

PREFACE

During December 1969, a number of tasks were initiated by Hughes under the general category of "Science Payload Control." Due to re-direction by JPL in early 1970, many of these tasks were suspended and remain incomplete. The material included herein is presented to indicate some of the preliminary thinking done in those areas where future contributions can be made. Further study is required in all cases, and the material is not to be considered in final form.

Scientific sample analysis, selection/rejection, storage, indexing, and recall for subsequent comparison based on the LRV sample analysis and acquisition and storage systems.

Scientific sample analysis will be accomplished within the framework of three major sequences of the Science Mode. These sequences are:

- Sample Visual Examination (1.9) - This sequence will utilize a medium magnification (X10) video imaging system to provide information on surface, heterogeneity, texture, and color. A detailed time line analysis of this sequence has been performed and is included in the Time Line Analysis Section of this report.

- Mineral Phase Analysis (1.13) - This sequence will utilize an X-ray diffractometer to provide diffractograms of selected samples. A time line analysis of the sequence is also included in the Time Line Analysis Section of this report.

- Chemical Element Analysis (1.14) - This sequence will utilize an X-ray spectrometer to provide X-ray spectrograms of selected samples. Time line analysis of this sequence has not been performed; however, it should be similar to the time line of Sequence 1.13.

Operations Profile and MOC diagrams have been prepared for each of these sequences; however, detailed MOC design tradeoffs have not been accomplished due to the lack of LRV hardware definition and the desire to complete a time line analysis of the Science Mode.

Sample acquisition concepts were briefly analyzed and three basic sampling schemes have been proposed. These schemes are summarized as follows:

1) Provide random sampling of the lunar surface by sampling at discrete intervals along the traverse. The interval length being determined by the sample storage capacity and the intended length of the lunar traverse.

2) Provide selected sampling by choosing the "most valuable" samples at each Science Site.

3) Provide a combination of schemes 1 and 2 whereby specific portions of the sample storage capacity would be devoted to each technique.

Intuitively, one would think that as the number of samples over the traverse increases, the corresponding distribution of sample characteristics approaches that of the area being traversed. This would be the motive of the "random" sampling process. This sampling process would have to be carefully regulated to assure randomness by eliminating possible human decisions to move over a little to scoop soil rather than chip or core a rock specimen. It must be recognized, however, that the distribution of sample characteristics will be biased by the possible heterogeneity of the lunar surface and the necessity of avoiding unnegotiable terrain.

The "selected" sampling scheme would utilize high sampling rates to rapidly fill the available storage. Subsequent samples, once the storage was filled, would require a decision process whereby new or previously stored samples would be jettisoned. This technique would most certainly acquire the most valuable set of samples possible to acquire, according to whatever might be established as sampling criteria. The drawbacks for method two would come from using human preconception to develop sampling criteria over a traverse which may have no terrestrial analog.

Lack of LRV design details in the area of the sample acquisition and storage systems prevents further, in-depth, study of the selection/ rejection, storage, indexing and recall for subsequent comparison concepts of sample handling.

Additional study efforts in this area could include an analysis of the statistics of random sampling in regard to population size, terrestrial analogs, lunar models, etc. Also, scientific help could be sought to establish relative values for sample types and video (TV) recognition of same. A computer program could be developed which would rate every sample in storage, develop current scientific values of samples, and provide accept/reject recommendations.

A general command and control program which is required for effective integrated control of the science payload.

A general Command and Control Program is required for effective integrated control of the LRV. That portion of the program which will interface with the scientific payload and operations team is briefly described herein.

Functional requirements for this subprogram include:

1) Providing a check of logical (not format) command errors. This would check for commands out of sequence and for configuration problems where lock-out of certain commands is desirable.

2) Providing single or multiple commands in proper format for the LRV (LRV command format).

3) Providing queuing of command messages.

4) Providing executions and timing as required.

From an operator's standpoint, commanding will be accomplished in two steps, formatting and execution. The formatting sequence will consist of activating simple operator controls associated with the desired command transmission. These controls might be push button arrangements, with a single push button associated with the command(s) required. In this fashion maximum use can be made of command consoles functionally designed for the particular operation required (for example operation of the manipulator). Command inputs will be stacked in queues associated with each console. Reset of these queues will be possible through manual control.

Execution will be accomplished on a first-in, first-out (FIFO) basis with a single level of priority for more urgent commands. The execution sequence will first execute the priority queue then the straight FIFO queue until all command requests have been executed.

Adequate displays of queues, status, etc. will be required at all command consoles so that affected operators will know the status of their command programs.

An emergency command capability will be provided which will allow inputting of LRV command messages directly into the command message formatter without requiring supervision by the Command Control Program.

Specialized displays, programs, and operational techniques which provide for a high degree of efficiency in accomplishing the total complex of Science/Operations functions in support of the LRV mission.

GDS Baseline

The GDS baseline will have to promote a smooth flow of LRV commands and telemetry and video data between the LRV and Mission Control Center. The following concepts were formulated as the result of initial studies into the GDS:

Commanding Concepts

1) Multiple command consoles (one for each responsible engineering activity) should be provided. This will enable the individual, who is charged with the responsibility of accomplishing a task, to operate the vehicle directly under his control in the fashion he requires. He will not, therefore, have to communicate his requirements to others.

2) A command monitor computer program should be provided which will check all commands for logical (not format) errors prior to execution. Prestored command routines could be activated by a single request. This would be useful for often repeated command sequences.

3) Commands will be self checking and error rejecting at the spacecraft.

Data Display Concepts

Science operations displays were grouped into consoles associated with a particular sequence, i.e. gravimeter, magnetometer, etc. No attempt has been made to consider multiple use of these consoles in order to define operator positions. In particular, it would seem possible to merge the deployment/retrieval of the magnetometer, NGRA, and gravimeter and operation of the multipurpose manipulator arm into a single operator position due to similarity and non-overlapping nature of these activities. Other groupings of operator positions should be examined prior to recommending a final configuration of a science GDS. Pertinent data display concepts are:

1) All incoming data should be converted to engineering units for display by a computer program.

2) A data edit computer program should monitor all incoming data and identify alarmed, etc. data at all display consoles.

3) Multiple data display consoles should be provided which will permit call up of data display configurations as required.

4) Data display consoles should have a means of holding existing data without update as configured by the operator. Simultaneous updates should also be provided. In this fashion data changes would be readily available.

During the course of the study the need for a specialized display technique was evidenced for control of the multipurpose manipulator. Certain key functional design requirements have been developed. These include:

- Video display and commanding functions should be closely integrated. Means postulated included use of a scaled video display device from which coordinate information could be developed; use of 3-dimensional/holographic techniques; use of touch button controls for command functions; use of a "joy-stick" type of controller for command generation.

- Means should be provided for predicting the effect of commands upon manipulator motion prior to execution. This could be accomplished by a computer trace which would overlay the video presentation.

- Means should be provided to compare the effect of currently executed commands with prior status. This would be valuable during sampling and shipping operations where it may be necessary to locate dropped or chipped samples. It would be provided by a blink comparator device which could take two video scenes and "blink" sequentially between them.

The following charts portray some of the approaches considered for mechanization of the science GDS.

FIGURE 12 1.1 RECONNOITER AND 1.5 VISUAL LURAIN ASSESSMENT

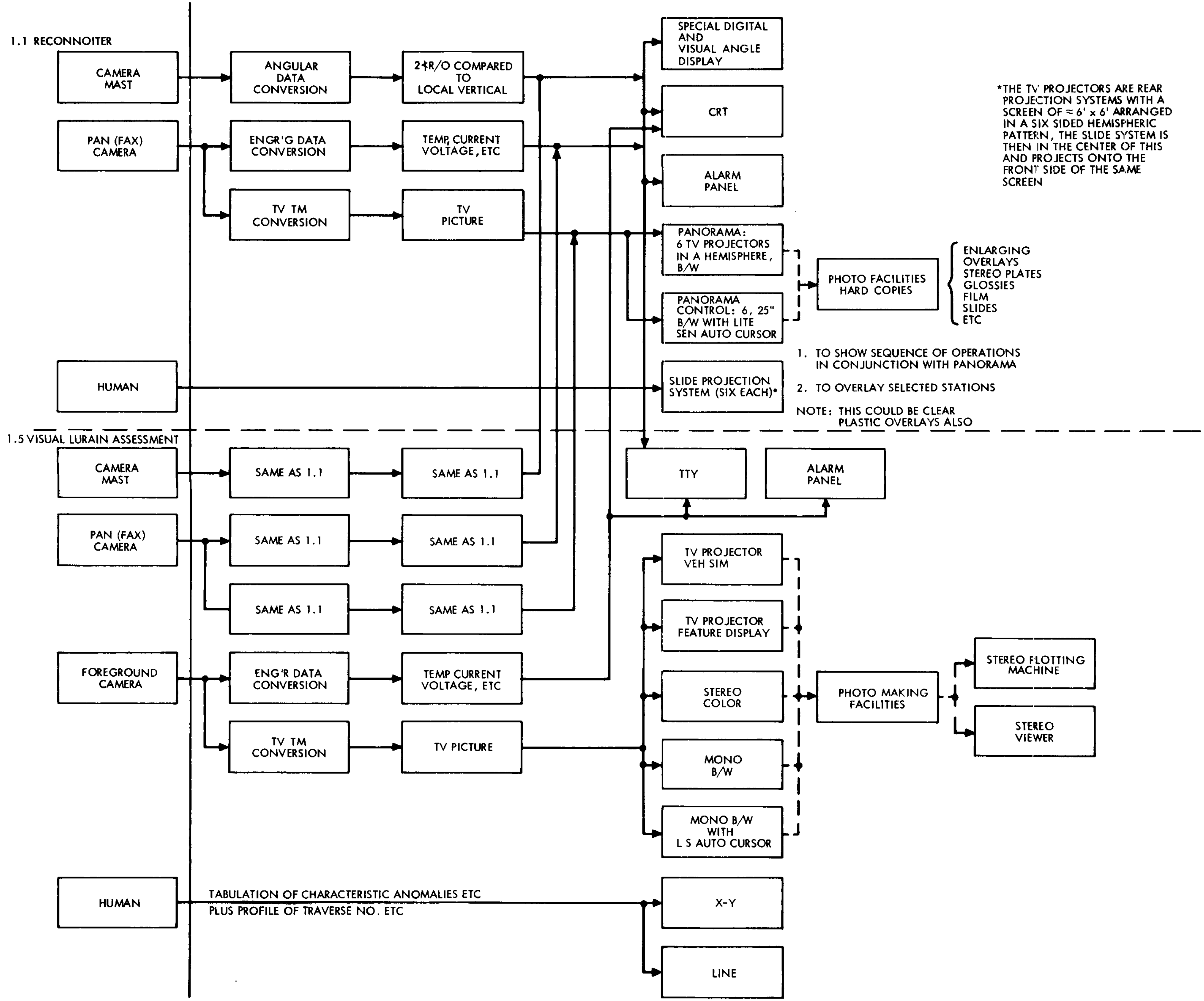


FIGURE 13 1.2 MAGNETOMETER OPERATIONS
1.4 GRAVIMETER OPERATIONS
1.3 NGRA (BULK DENSITY)

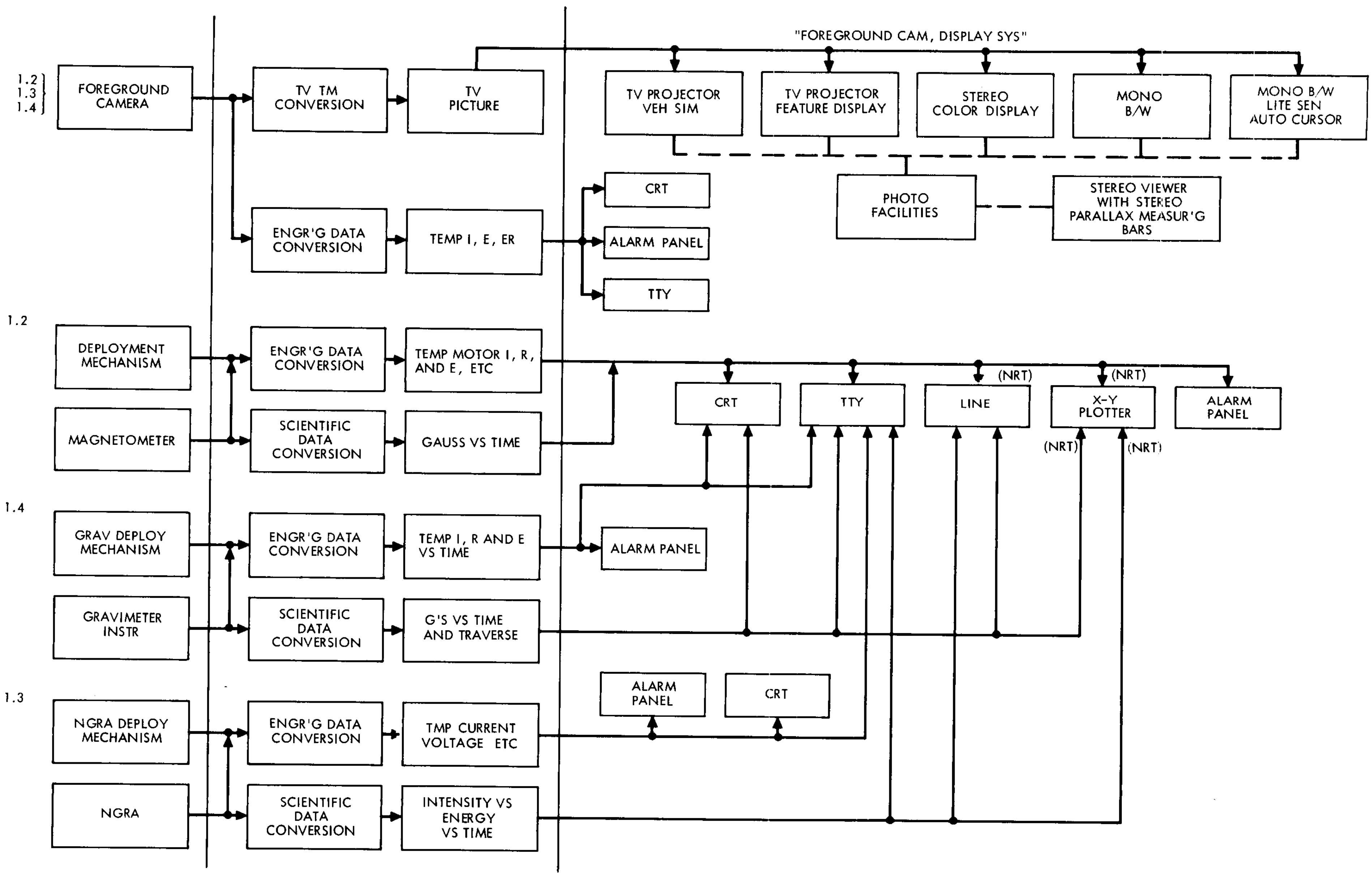


FIGURE 14 1.6 LASER SCANNING (DISTANCE AND HEIGHT ETC. PLUS ALBEDO)

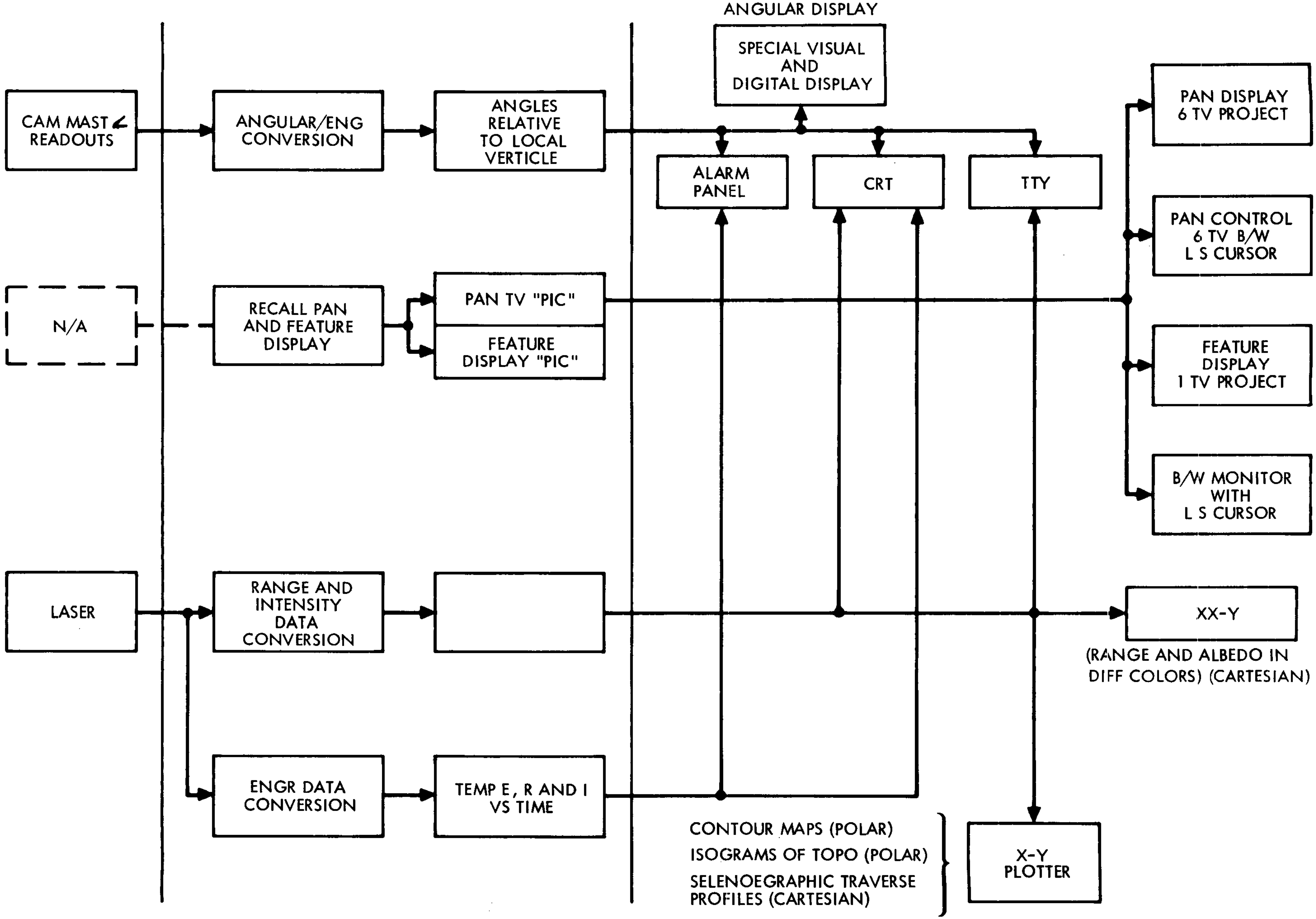


FIGURE 15 1.11 GAS ANALYSIS MASS SPECTROMETER (ATMS)
1. VEHICLE STOPPED AND MECH INACTIVE
2. LUNAR SUNRISE
1.7 EARTH DISTANCE RANGING (RETRO-REFLECTOR)
(VEHICLE STOPPED)

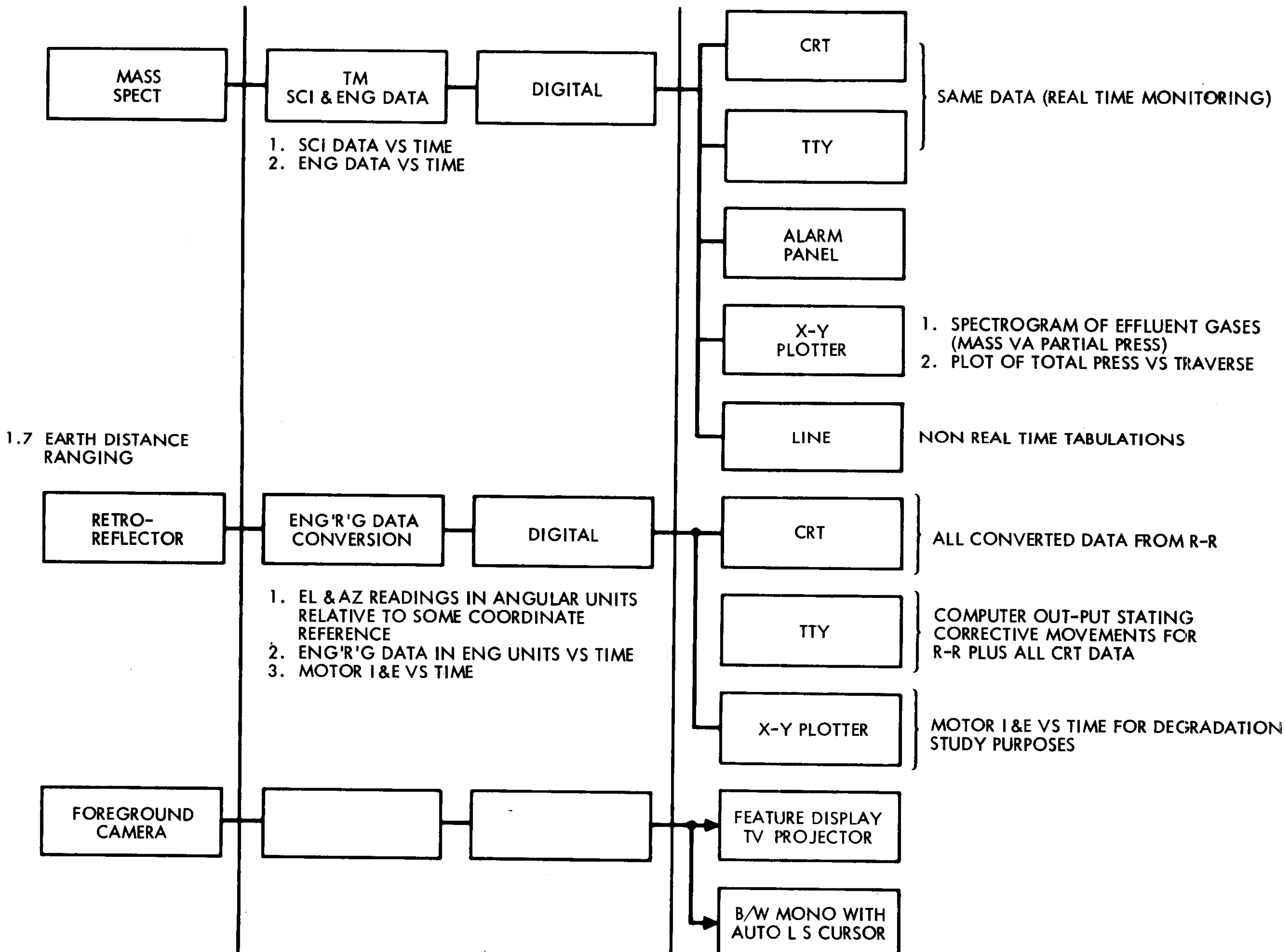


FIGURE 16 1.10 SOIL MECHANICS EXPERIMENT
1. FOREGROUND TV
2. MANIPULATOR WITH SCOOP
3. VEHICLE WHEELS (MOVING)

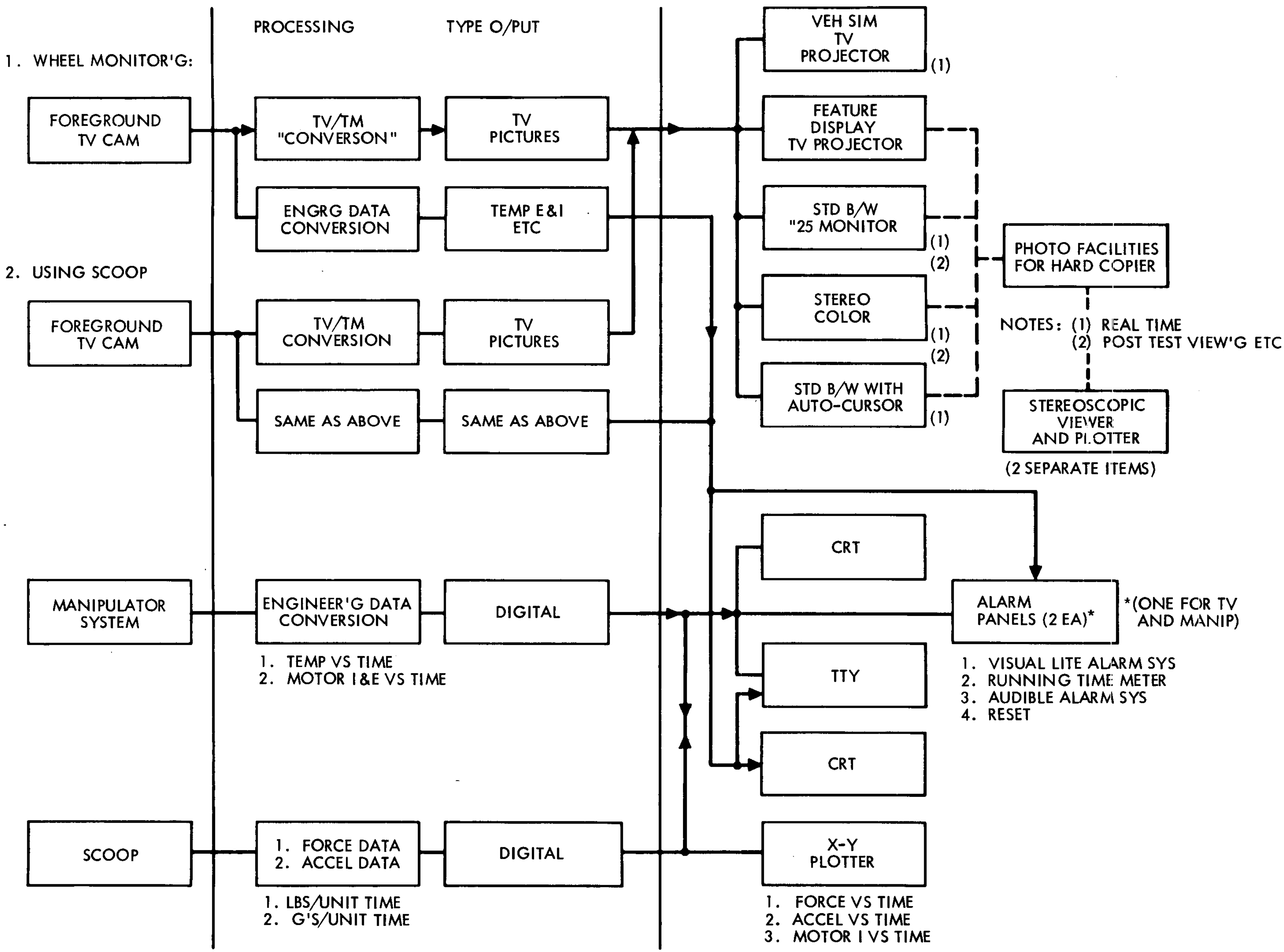
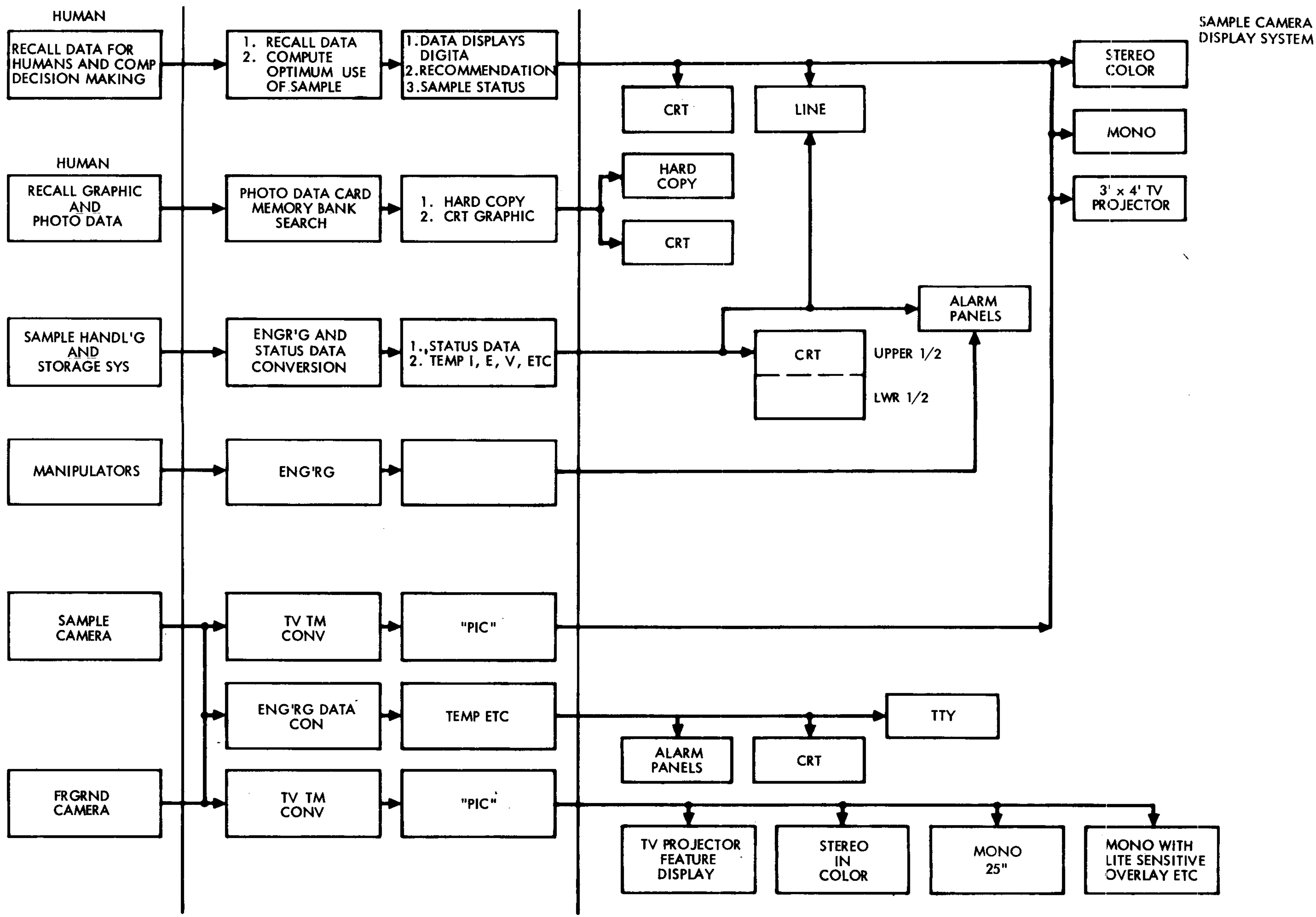


FIGURE 17 1.12 SAMPLE DISPOSITION



The following diagrams relate the flow of data between the MOC computer programs and elements of the LRV for individual operations sequences. This data has been generated from the Operations Profile diagrams and MOC charts which were published in JPL document 760-46.

FIGURE 18 LASER POINTING SEQUENCE

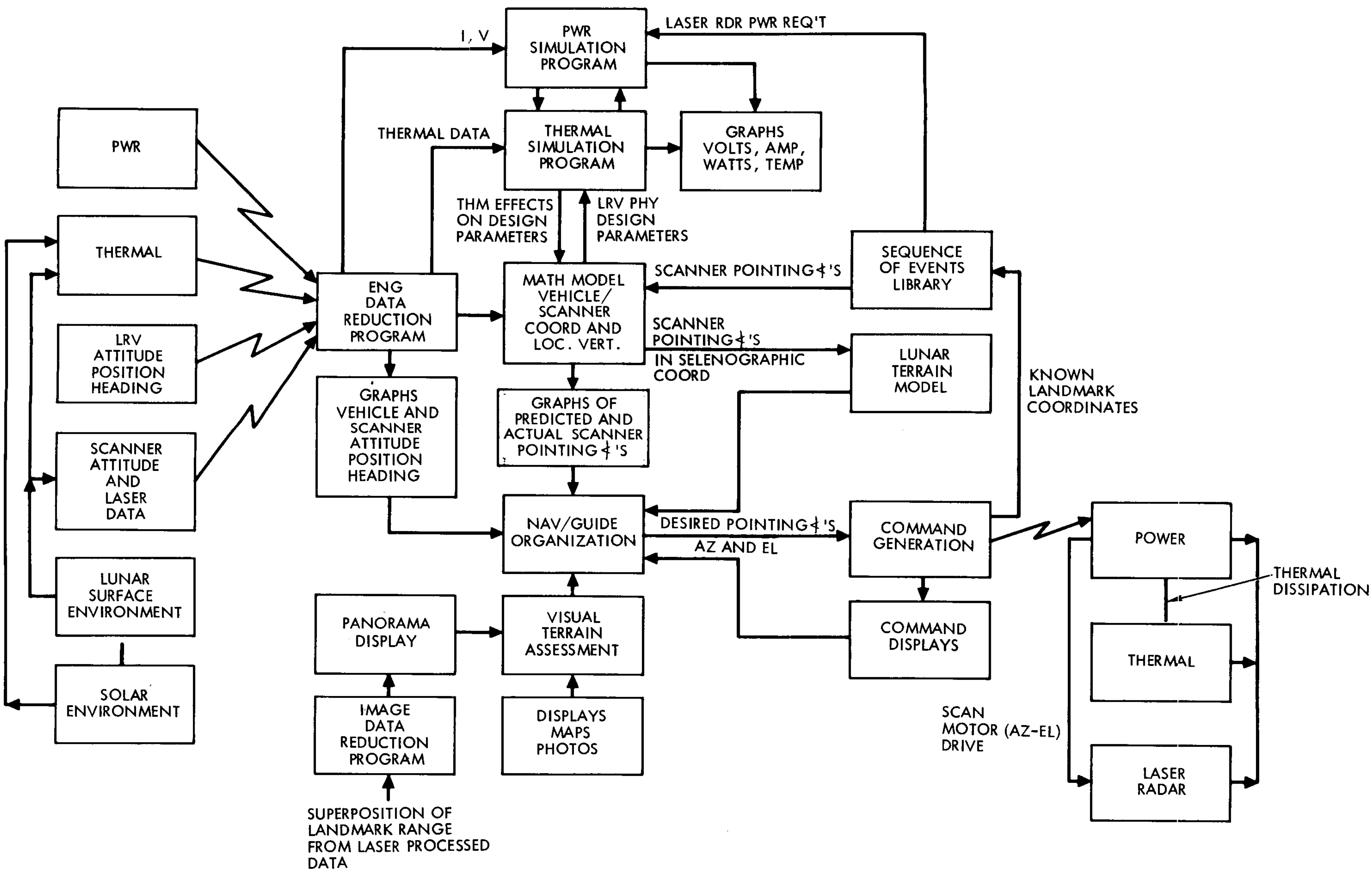


FIGURE 19 RECONNITER SITE SELECTION

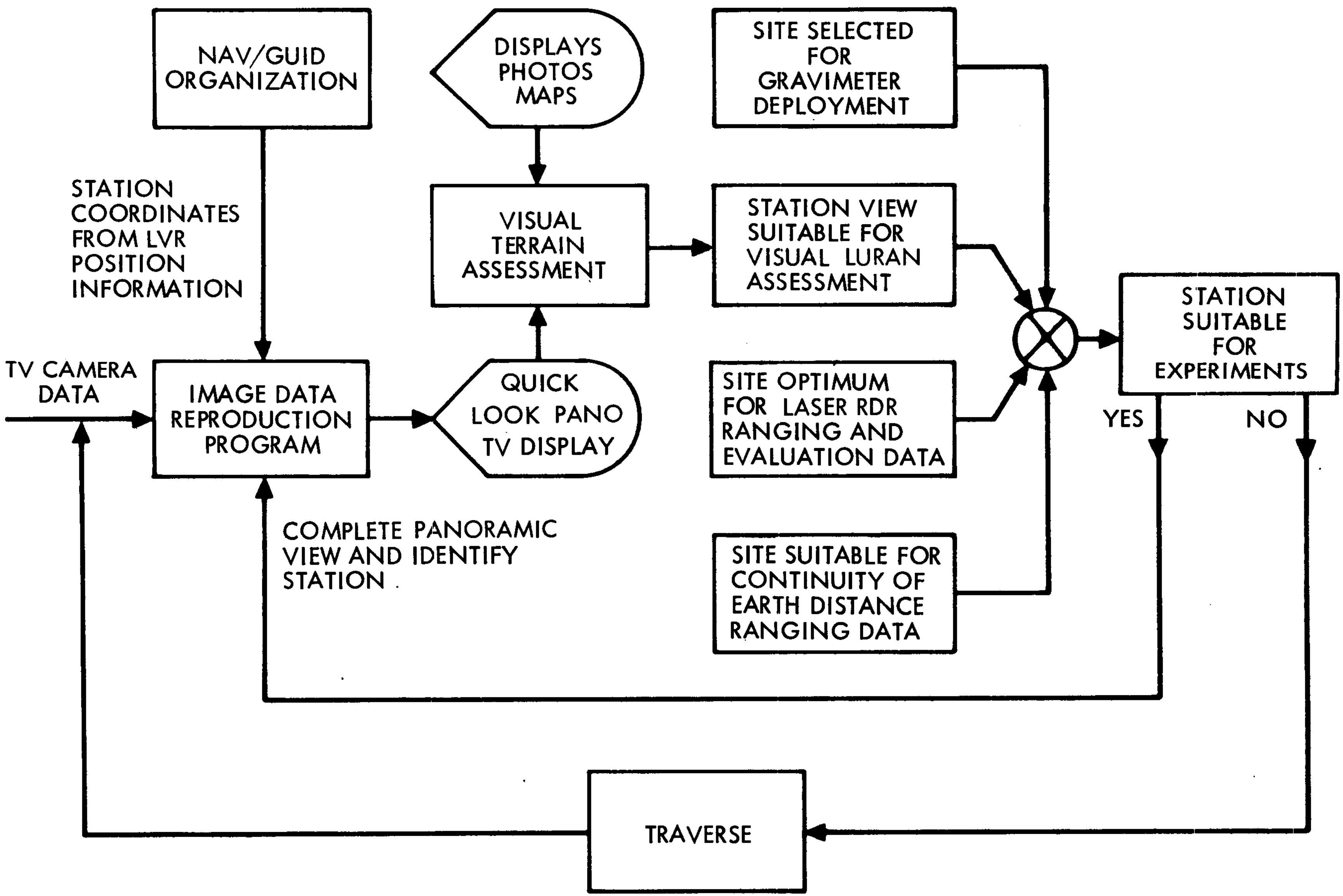


FIGURE 20 EXPERIMENT SITE SELECTIONS

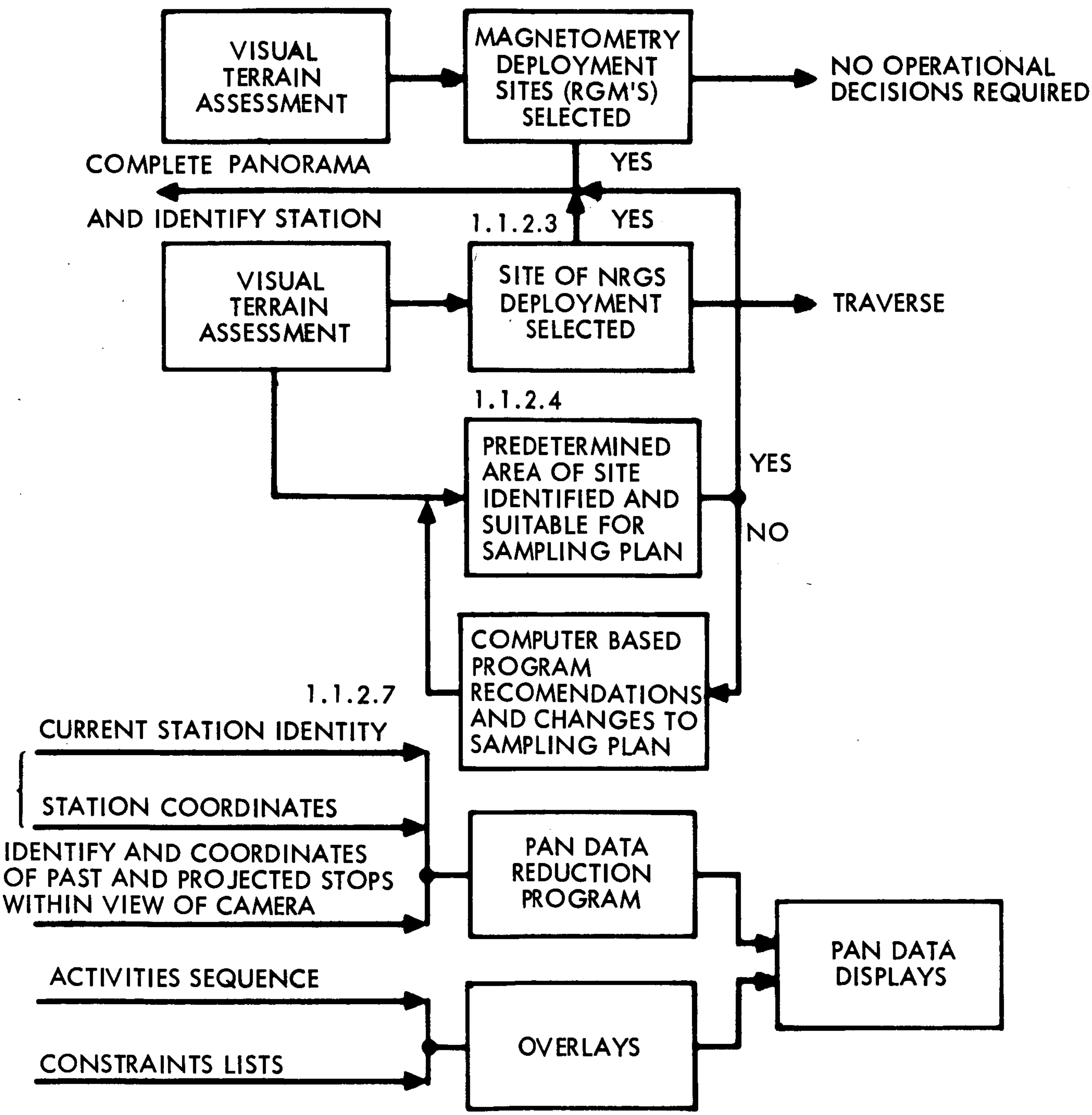
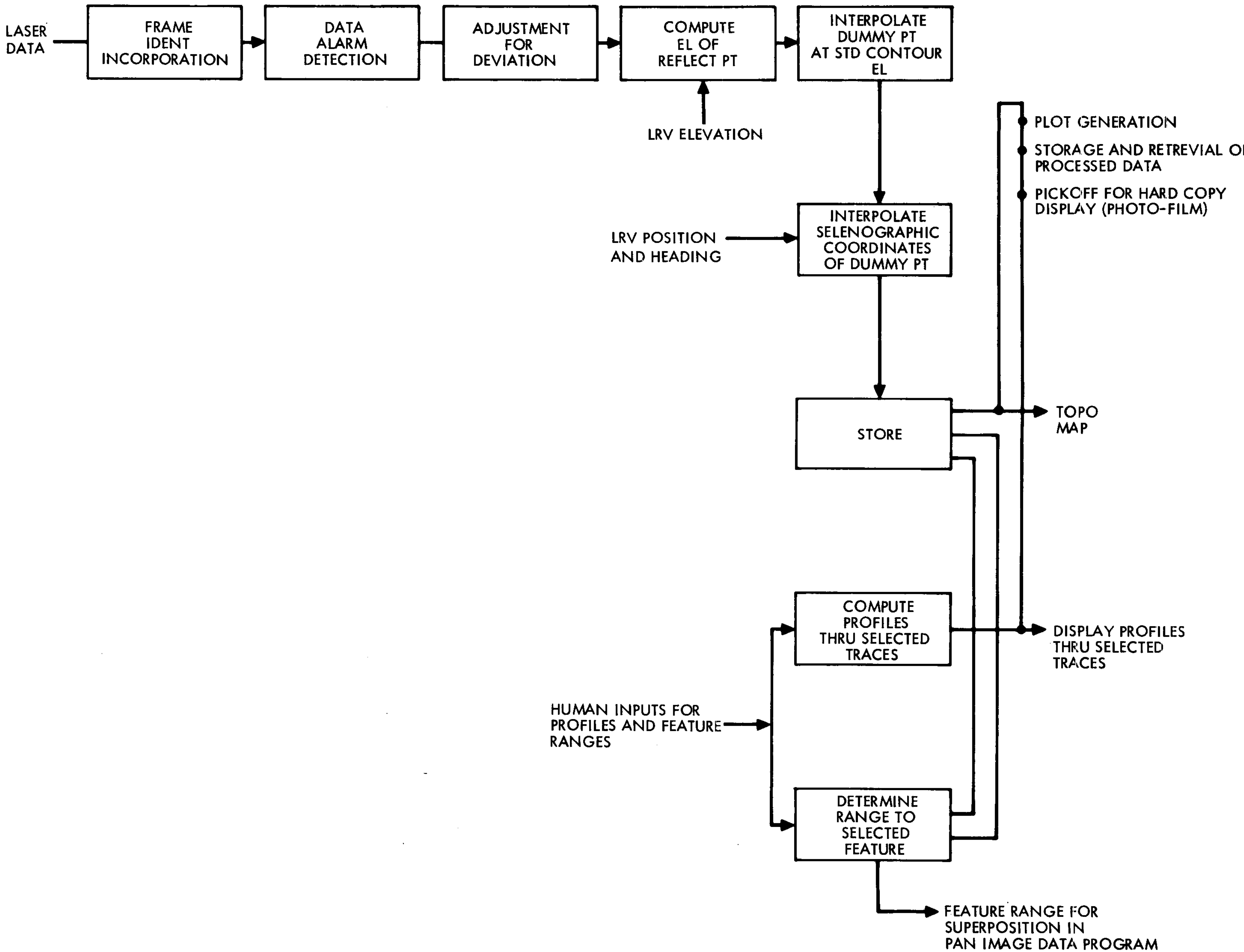


FIGURE 21 LASER SCANNING OPERATION



Administrative Control

It is fairly obvious that the LRV mission time line could get rapidly out of hand if the Administrative and MOC designs do not promote smooth flow of command procedures without extensive delays for permission to proceed, etc. Top level administrative control should be executed with the Mission Director who gets into the administrative loop at mode change time. His function at this time would be to: (1) evaluate accomplishments and expenditure of resources of present mode against objectives and mission profile; (2) determine activities to follow; and (3) allocate objectives and resources for next mode.

The value of the mode as a building block is readily apparent as mission objectives and, therefore, resources can be generally allocated to a single responsible organization. With this allocation the responsible organization can execute control of the functions until the objectives specified are met or until it is evident that insufficient resources have been allocated.

Performance of the specific sequences will be performed with great individual freedom by responsible engineers. Execution of the sequences and expenditure of resources will be monitored by the responsible organization. In this fashion great individual freedom is given to the performing individual to expedite performance of his task. Yet, close supervision is guaranteed so that proper progress of the mission is assured and performance of the sequences is kept in context of mission objectives.

The following figure summarizes the flow of activities and information through the LRV organization.

It has been assumed that the mission objectives, vehicle and MOC constraints and resources are adequately defined at all times so that exploration decisions (ignoring non-standard operations) can be rapidly and accurately made in real-time without delay in conduct of the sequence.

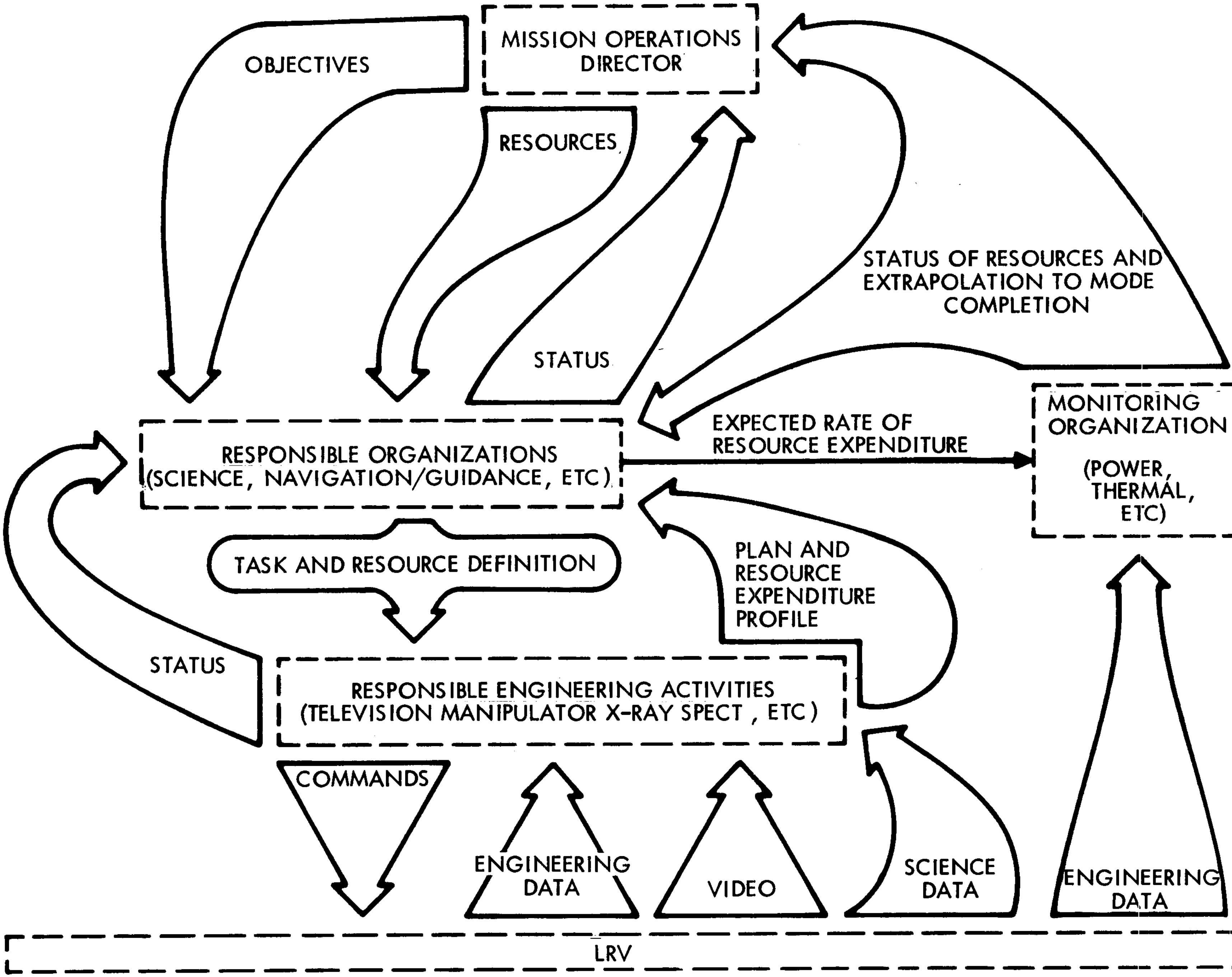


FIGURE 22 INFORMATION FLOW AND LRV ORGANIZATIONAL CONTROL