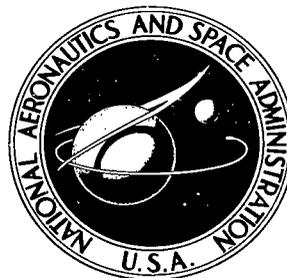


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**APOLLO EXPERIENCE REPORT -
PROCESSING OF LUNAR SAMPLES IN
A STERILE NITROGEN ATMOSPHERE**

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16. Abstract A sterile nitrogen atmosphere processing cabinet line was installed in the Lunar Receiving Laboratory to process returned lunar samples with minimum organic contamination. Design and operation of the cabinet line were complicated by the requirement for biological sterilization and isolation, which necessitated extensive filtration, leak-checking, and system sterilization before use. Industrial techniques were applied to lunar-sample processing to meet requirements for time-critical experiments while handling a large flow of samples.			
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APOLLO EXPERIENCE REPORT
PROCESSING OF LUNAR SAMPLES IN A
STERILE NITROGEN ATMOSPHERE

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SUMMARY

A sterile nitrogen atmosphere processing cabinet line was installed in the Lunar Receiving Laboratory to process sample material returned from Apollo missions. The major problems concerning the installation and operation of the cabinet line were in design and fabrication, leak-checking and sterilization, installation and operation of the environmental monitors, and operational organization and sample control.

Design and fabrication experience showed that welded seams (rather than gasketed), removable parts, careful welding and window-cutting, and unitary construction were important considerations in construction of the class III biological cabinetry. The materials used for cabinet fabrication were found to require lubrication, and the lubricant had to undergo radiation counting. Viton was substituted for Teflon as the material for valve diaphragms, and tempered glass was substituted for Lexan as the material for windows.

Concerning leak-checking and sterilization, it was found important to avoid indiscriminate use of halogens in preliminary leak checks. Therefore, leak-testing always began with a gaseous-nitrogen pressure-decay test before a halogen or helium leak check was made. All cabinets and piping systems were oversterilized to prevent back contamination. Ethylene oxide diluted with Freon was used as the sterilizing agent.

Experience showed that environmental monitoring should be integrated into the design of the cabinet line rather than added after project completion. It was also found advantageous to incorporate certain changeout procedures in equipment design to prevent shutdown or contamination of the cabinet line should a sensor fail. Oxygen-analyzer systems should be final-leak-checked by using bottled oxygen as a tracer gas to detect concentrations of oxygen less than 100 parts per million.

Regarding operational organization and sample controls, an assembly-line type of system was found to be the best method for processing lunar sample material. Two simulations were held to determine the best distribution of duties and the lines of authority among cabinet line operational personnel.

INTRODUCTION

The sterile nitrogen atmosphere processing (SNAP) cabinet line was installed in the Lunar Receiving Laboratory (LRL) after the Apollo 12 mission to process material returned in sealed Apollo lunar-sample return containers (ALSRC) from later Apollo missions. The samples returned to this cabinet line had not been exposed to the environment of the lunar module or command and service module cabin; therefore, every effort was made to design, fabricate, install, and operate the SNAP line in such a way as to minimize the organic materials that could contaminate the samples during processing. In addition, the threat of unknown bacteriological agents in the returned sample material required that the cabinet line and all the auxiliary systems be operated under the requirements of class III bacteriological enclosures. These requirements entailed extensive filtration, leak-checking, and establishing and maintaining complete sterilization of the cabinet line during sample processing and transfer operations. Furthermore, anticipation of a large amount of sample return and a tight schedule for sample processing to support time-critical experiments in other LRL laboratories necessitated an organization and sample controls capable of handling a large flow of samples with no mistakes of identity or confused processing history. This accomplishment is described in the following sections.

CABINET AND EQUIPMENT DESIGN AND FABRICATION

Careful choice of materials and an understanding of special design requirements can assure cabinet lines relatively free of organic materials and facilitate cleaning and sterilization.

The basic materials approved for the construction of the SNAP cabinet line (fig. 1) to minimize organic contamination were stainless steel, aluminum, Teflon, and Viton, in order of acceptability. Theoretically, these materials were ideal; in practice, some compromises had to be made. For example, lubricants were required to prevent galling of metal surfaces in screw threads. Powdered molybdenum disulfide (MDS) mixed with isopropyl alcohol and distilled water was used and applied with an artist's brush. Commercial MDS mixtures were not acceptable because the resin binder in most was highly organic. Because some of the lunar-sample material to be exposed in the cabinets was to be counted for radiation, the batches of MDS used to compound the lubricant also had to be counted. The reason was that, before the SNAP line was designed, it had been discovered during other LRL operations

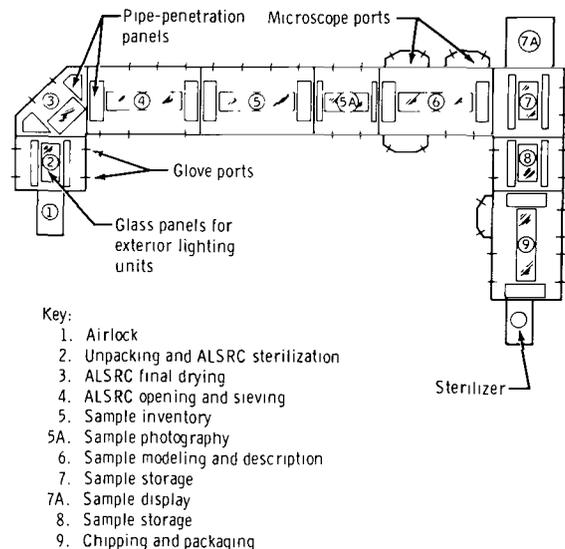


Figure 1. - Functional drawing of SNAP line.

that some lots of MDS contained enough radioactive material to interfere with sensitive measurements of residual radioactivity in the lunar samples.

Cabinet windows also required compromises. Initially, the cabinet windows were made of Lexan, a polycarbonate plastic organically and radiologically inert. Unfortunately, Lexan has an extremely soft surface and is not as transparent as glass. Also, many imperfections (bubbles, etc.) were noted in the large sheets used for windows. The Lexan windows were not satisfactory; after short use, the plastic surfaces were covered with small scratches. Attempts to polish out these scratches were unsuccessful; most polishing materials only scratched the surface more. Those materials that successfully removed the scratches required excessive manpower and expensive materials, and the improvement was only temporary. The grayish haze, or lack of transparency of Lexan, also prevented high-resolution photography of samples through the windows. For this reason, those windows through which the sample photographs were to be taken were exchanged for tempered glass before the first lunar samples were processed in the SNAP line. Another annoying characteristic of Lexan was noted during the processing of fine-grained Apollo 14 lunar samples. The plastic was found to collect a strong static charge; in a short time, the cabinet windows were covered with dust particles, and attempts to wipe the windows clean only caused smudges. Because the tempered glass windows did not exhibit this characteristic, most of the remaining (i. e., nonphotographic) Lexan windows were also exchanged for tempered glass, samples of which were made available for chemical testing and radiation counting.

Less significant compromises were made in the introduction of moisture-monitor sensors (small devices that contain minute quantities of gold and epoxy) and in electrical feedthroughs. The feedthroughs are vacuum-compatible units with a stainless steel body and glass insert, and come closest to meeting the organic requirements as off-the-shelf items.

Compromises were also made in three features external to the cabinets. Most valves in the SNAP line are commercially available diaphragm-type units. Teflon diaphragms were originally specified and installed, but through-leakage resulting from the hardness and cold-flow characteristics of Teflon proved to be a major problem. The valve diaphragms were replaced with Viton, a softer material that was less desirable organically but sealed much better. The flowmeters in the gaseous-nitrogen supply line were acrylic plastic. These units were the only ones available on the tight schedule under which the SNAP line was constructed. These flowmeters proved to be a major source of leaks and were eventually potted with epoxy. Units with stainless steel bodies, Viton O-rings, and Pyrex tubes are commercially available and should be considered in new designs. The exhaust-line back-pressure regulators, which were commercial quality iron/steel items, were another source of leaks. These units were also sealed with epoxy, but, in this case, the problem of organic contamination was not critical because the regulators were on the downstream side of the cabinets.

Several items should be considered in the design of cabinets intended for minimum organic contamination and sterilization. All internal surfaces of the cabinets should be finished to an American Standards Association number 4 satin finish or better. This polished finish was necessary in the LRL because the cabinets were chemically cleaned and sterilized before each mission, and a smooth finish facilitated these operations. To aid cleaning, a 1-inch minimum radius on all corners should be specified. Cracks and crevices should be avoided whenever possible because such openings are traps for

organic and bacteriological contamination during construction and are essentially impossible to clean and sterilize by normal methods afterwards. Also, cracks and crevices are sources of leaks that can be difficult to locate and repair. Generally, welded seams are preferred over gasketed seams. An ideal solution to the problem of cracks and crevices would be to weld together into one unit all the cabinets that comprise a line. Because of limitations imposed by transportation and installation requirements, this unitary construction is extremely difficult to achieve in practice. Nevertheless, every effort should be made to have the manufacturer weld cabinets into units insofar as those limitations will allow. A portion of the SNAP cabinet line welded together as a unit during manufacture is much easier to clean and leak-check than gasketed sections. A removable plate containing piping feedthroughs should also be included in the design of each cabinet. This item is minor, but one that can prevent a major program difficulty if an additional piping feedthrough is required after the cabinet has been installed. It is relatively easy to remove a plate, take it to the shop, cut a hole and weld the new pipe in place, then leak-check, clean, and reinstall the plate in the cabinet. The same task is much more difficult to perform on the cabinet itself while trying to keep the cabinet leaktight, undamaged, and clean. The locations of the pipe-penetration panels on the SNAP line are shown in figure 1.

In contracting to fabricate cabinets or in fabricating cabinets in-house, it should be remembered that manufacturing quality is most important if no sealants such as polysulfide or epoxy are to be used (a requirement for minimum organic contamination). The SNAP cabinets were constructed and assembled with sufficient quality to meet this requirement. In some cases, the piping to and from the cabinets required small amounts of sealants, but experience has shown that sealants in these areas could now be eliminated if further improvements in contamination level were required.

Experience has shown two critical areas in cabinet fabrication in which knowledge and high-quality workmanship are mandatory: in the cutting and forming of the window openings and in welding. Cutting and forming a window opening so that the sides are flat and parallel can be extremely difficult unless the manufacturer has proper equipment and knowledge for working with thin stainless steel sheets. The larger the window, the more difficult the task is. A nonflat, nonparallel window frame is impossible to seal. A Viton gasket cannot be compressed like neoprene; therefore, a flat window frame is mandatory. A nonparallel window frame can easily crack safety glass during torquing and, in some cases, can cause stresses that will eventually shatter tempered glass. It is possible to rework unacceptable window frames by using hydraulic jacks and presses, but this process is a long and tedious operation. The welding operation is critical because heat-induced warpage can affect sealing. A competent manufacturer will avoid this warpage by using proper techniques to prevent heat buildup during welding.

Once the cabinets are installed, the best policy is to minimize modifications requiring welding, particularly near internal cabinet doors. However, if welding is necessary, it should be performed to the same specifications, and the same techniques should be used as those employed by the manufacturer in the original fabrication. Without this control, an inexperienced welder could warp a bulkhead or window frame by overheating while trying to weld in a relatively unimportant hose clip or tool rack.

LEAK-CHECKING AND STERILIZATION TECHNIQUES

The method developed for leak-checking the SNAP line provided maximum leak-tightness with a minimum expenditure of time and effort. The sterilization techniques finally perfected provided complete sterilization with minimum degradation of equipment and few undesirable residues.

The basic philosophy that guided the development of SNAP line leak-checking techniques was to avoid the indiscriminate use of tracer gases containing halogen compounds. This effort was desirable for two reasons. First, the use of halogens early in the leak-check process, when gross leakage is normally encountered, may saturate the immediate area with halogens, which raises the background of the leak detectors, sometimes higher than the maximum acceptable leak rate (0.05 oz Freon/yr). This saturation makes meaningful leak-checking with a halogen detector impossible, because, once an area is saturated, the effects persist for hours and, in some extreme cases, days. Another undesirable effect, particularly in a tightly sealed, multilaboratory building with a carefully controlled environment (like portions of the LRL), is the distribution of halogens by the air-conditioning system to other areas where halogen leak checks may be in progress. The second reason for avoiding halogens early in the leak check is to prevent halogen saturation of gaskets. Once a gasket (e. g. , a window-frame gasket) becomes saturated with halogens during a leak check, it is no longer possible to tell whether or not the leak has been eliminated. The alarm will be triggered by merely bringing the detector close to the window. A saturated gasket may take days to clean up; yet only three to six attempts to leak-check can saturate it. For these reasons, the first step in leak-checking the SNAP line was to use a pressure-decay test. This test is a simple, relatively fast one that can be repeated many times without causing saturation or other problems. The section of the piping or cabinet line under test is pressurized by a small amount (4 inches water gage) of gaseous nitrogen. If the pressure drops rapidly, gross leakage is present, and an external bubble-type leak check can be used to locate the leak. Valve through-leakage cannot be detected with this method but can sometimes be isolated by opening and resealing the block valves, retorquing the block valves, or choosing another block valve in a slightly different location. A slow decrease in pressure (1 to 2 inches water gage over the 1-hour test period) indicates a minor leak that may not be detectable with a bubble solution. In this case, a halogen leak test should be performed. The technique for using halogens (usually Freon-12) is similar to the pressure-decay test. The section under test is pressurized to 2 inches water gage with gaseous nitrogen and then to 4 inches water gage with Freon. A halogen detector gun is used to "sniff" joints and seal areas for leaks. The detector sensitivity is calibrated periodically with a standard leak. Leak areas are marked with strips of yellow tape for repair and retest.

In another leak-checking technique, helium is used as the tracer gas, and a mass spectrometer tuned to the helium peak functions as the leak detector. This technique, which has been used in certain LRL cabinets with good results, has the advantage of high sensitivity, plus rejection of false signals from cleaning chemicals, curing adhesive, and so forth, which sometimes trigger a halogen detector. The vacuum leak detectors normally used with helium require only an atmospheric probe to make them functional at 1 atmosphere.

The necessity that all cabinets and piping between inlet and exhaust biological filters be leaktight cannot be overemphasized, because only with a tight system can biological sterilization be performed successfully using the SNAP-line-perfected techniques. These techniques were developed over a 10-month period to meet the requirements associated with back contamination. The procedures finally developed and certified for use with lunar-contaminated systems required a very high degree of reliability; therefore, it was necessary to oversterilize the system to assure a sufficient margin of safety. The sterilizing agents tested during the developmental period were formaldehyde gas generated by heating powdered paraformaldehyde, ethylene oxide (ETO) gas diluted with Freon (12 percent ETO and 88 percent Freon), and liquid 5 percent sodium hypochlorite. The liquid sodium hypochlorite was used in piping that could not be made leaktight for gaseous sterilization. Various combinations of temperature and relative humidity were tested with the basic goal of minimizing organic contamination and residue introduced by the equipment-sterilization process. The technique finally evolved for effective sterilization with minimum contamination was as follows.

1. The relative humidity of the system was raised to approximately 50 percent by evaporating distilled water. The vapor was circulated through the cabinets and piping for 24 hours by a pumping system that interconnected all components of the system.

2. A liquid mixture of 12 percent ETO and 88 percent Freon was vaporized by passage through stainless steel coils in a 25° C water bath. Between the water tank and the system inlet, two glass vessels were installed to serve as combination sight glasses and traps to prevent particulates or liquid ETO from entering the system. An in-line pressure gage installed between the vessels prevented pressure buildup in the system. The pumping system mentioned previously circulated the ETO-Freon mixture through the cabinets and piping. The cabinet internal doors were open during this operation.

3. During introduction of the ETO and throughout the sterilization period, the relative humidity was kept at approximately 50 percent by evaporating additional distilled water. Temperature was ambient and uncontrolled.

4. The sterilization contact period was 24 hours after introducing the ETO and reaching the desired relative humidity.

5. After the sterilization period, the cabinets were flushed (one and a half gas changes/cabinet/hr) with filtered gaseous nitrogen for 13 hours and exhausted into the contaminated vent to the microbe incinerator. This procedure prevented passage of ETO into the room. The cabinet exhaust valves were then closed and the cabinets vented to the room and fast-flushed (five gas changes/cabinet/hr) for 6 hours, completing the sterilization process. Spore strips were introduced into the cabinet before sterilization and removed afterwards; upon removal, the strips were cultured and examined to determine the effectiveness of the process.

INSTALLATION AND OPERATION OF ENVIRONMENTAL MONITORS

One of the most significant modifications to the SNAP line after installation was the incorporation of an environmental monitoring system. The system was designed, fabricated, and installed to meet increasingly stringent environmental monitoring requirements forwarded by the Lunar Sample Analysis Planning Team (LSAPT) after the Apollo 12 mission. From the standpoint of the technology involved, it was very much a state-of-the-art operation. Integrating the component parts into the system while observing the restrictions of bacteriological contamination was especially challenging. Preliminary studies for future similar tasks should include consideration and, if necessary, design of an integrated environmental monitoring system. At this point, the task can be accomplished efficiently and with a minimum of undesirable effects. Later, the compromises required as a result of insufficient cabinet penetrations, installed piping, and so forth make the task much more difficult.

The primary work cabinets on the SNAP line were equipped to monitor the moisture and oxygen levels of the gaseous nitrogen inside the cabinets in parts per million. The oxygen level of the inlet gaseous nitrogen could also be monitored. A diagram of the moisture and oxygen monitoring system is presented in figure 2. A gas

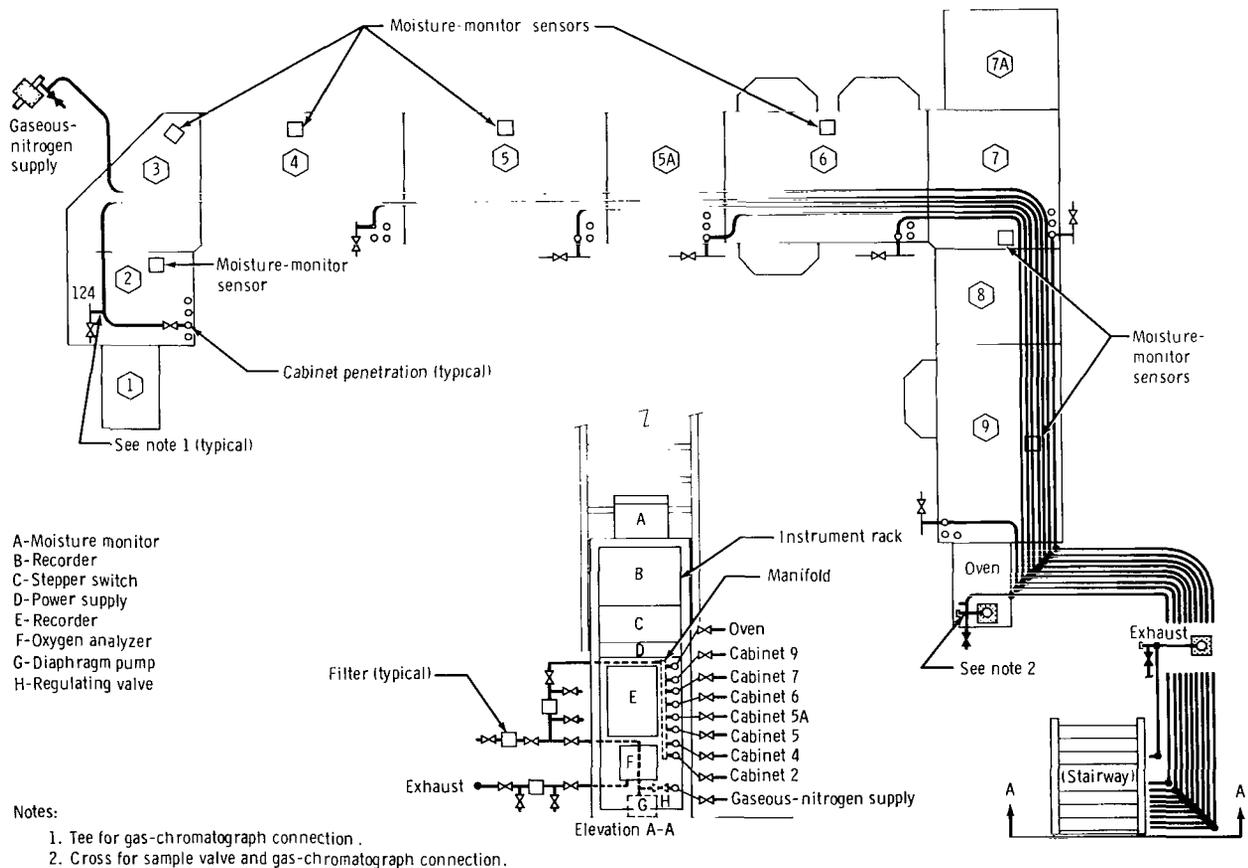


Figure 2. - The SNAP line oxygen-analyzer and moisture-monitor diagram.

chromatograph was used to monitor several of the trace contaminants in the gaseous nitrogen at the inlet and exhaust; the chromatograph was operated by Gas Analysis Laboratory personnel.

The moisture level in the SNAP line was measured using a commercial monitor composed of a control and readout unit and seven remote sensors. In operation, each sensor acted as a capacitor in which electrical capacitance changed as a function of the moisture absorbed. An electronic scanner was fabricated in-house and installed between the sensors and the control and readout unit to allow automatic sequential scanning of the outputs from all sensors. The scanner could be switched out of the circuit for manual selection and monitoring of the sensors. A dual-pen strip-chart recorder was installed to record the output of the cabinet sensors as measured by the control and readout unit. The particular monitor used in the SNAP line was chosen because the sensors were passive, easily installed or removed, and relatively noncontaminating. The sensors, constructed of stainless steel and aluminum, had a small quantity of gold plating and epoxy.

Any design incorporating easily removable sensors should also consider change-out requirements. After cabinet cleaning and before system sterilization, the monitor sensors were installed in the cabinet ceiling with an O-ring and flange. Once installed and sterilized, the sensors could not be removed without requiring reesterilization of the cabinet line. (It was assumed, because all cabinets were interconnected and all exhaust lines were joined in a common manifold upstream of the biological filters, that any component or system problem that could cause a loss of sterility in one cabinet required complete system reesterilization.) This restriction presented problems because of the variable longevity of the sensors. Once installed, some sensors might operate for several days and then become erratic and fail, apparently because of their delicate construction. The majority, however, operated for months without problems. A better design might be to install the sensors in a bypass loop in the cabinet-exhaust line. Should a sensor fail, the loop could be isolated and sterilized; then, the sensor could be replaced and the loop could be reesterilized and returned to service. In fact, a bypass loop was installed on cabinet 3 in the SNAP line where moisture level was critical; but, because this sensor never failed under mission conditions, the replacement feature was never used.

The amount of oxygen in the gaseous nitrogen was monitored by a commercial oxygen analyzer, which gave a direct readout in parts per million of oxygen. A strip-chart recorder provided a permanent record of the instrument readings. Again, basic considerations in purchasing this instrument were the compatibility with cleaning, leak-checking, and sterilizing agents, as well as the passive mode of sensing. The method of sensing was unique, involving the permeation of the oxygen in the gaseous nitrogen through a diaphragm into a "fuel cell," where the oxygen reacted to generate an electrical signal. When expended (after several weeks), the cell could be replaced like a flashlight battery. This approach was significantly different from those used in other types of available units.

During installation and leak-checking, it was discovered that the Freon leak check normally performed on piping and cabinets was not sensitive enough for a unit capable of sensing less than 10 ppm of oxygen. A second leak check was performed using 100 percent bottled oxygen as the tracer gas and the oxygen analyzer as a leak detector. After the leaks detected with this test were repaired, the unit functioned normally.

OPERATIONAL ORGANIZATION AND SAMPLE CONTROLS

Mission operational organization and sample controls for the SNAP line were developed during two simulations and ultimately provided tight control of sample material while remaining adaptable to new situations and requirements.

The initial organization of the Operations Team is shown in figure 3. The Operations Team consisted of LRL (NASA and contractor) and Planetary and Earth Sciences Division personnel. Because the sample-processing operation was the responsibility of the LRL, the NASA LRL Sample Processing Director (SPD) was placed in overall charge of the Operations Team. All contractor personnel working in the cabinet line or with associated equipment were under the direction of a Test Conductor (TC), who was responsible to the SPD. All scientific personnel (curator, LSAPT, and Lunar Sample Preliminary Examination Team (LSPET)) and their activities were directed by a Scientific Advisor (SA), who, though shown in figure 3 as directly responsible to the Processing Director, actually functioned in an independent and equal status except during emergency situations.

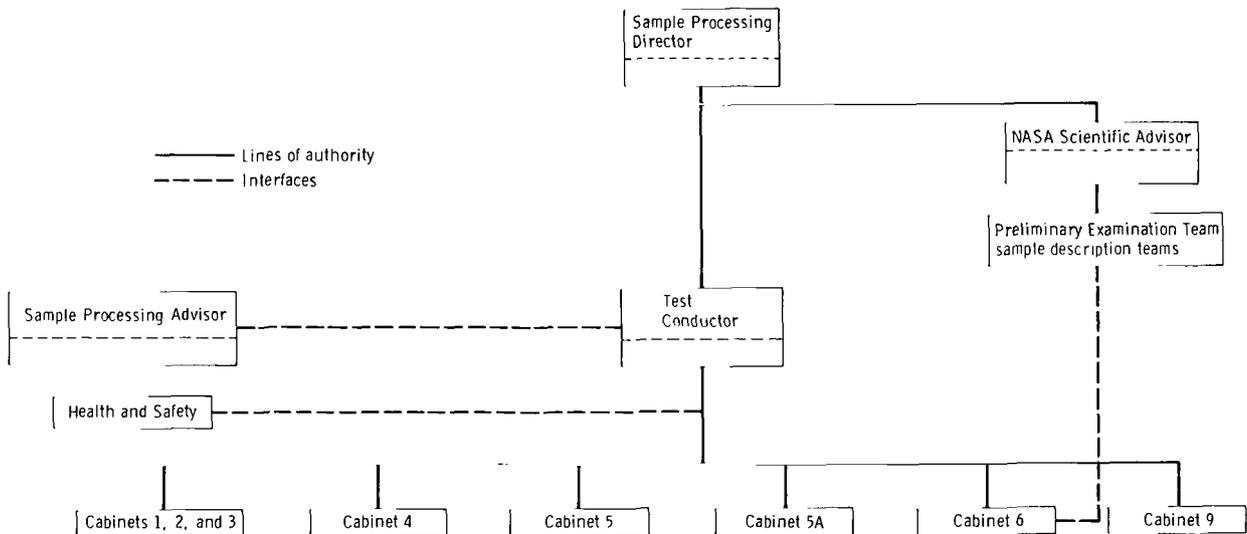


Figure 3. - Original Operations Team organization, used in phase I simulation.

The TC was responsible for the following specific duties.

1. Assuring that procedures and instructions pertaining to the SNAP line were followed
2. Assuring that sample numbers were obtained for all samples
3. Assuring that samples were handled properly to avoid damage or contamination

4. Recording transfers of samples from station to station within the cabinets and from the SNAP line cabinetry to other laboratories

5. Assuring that all samples were stored safely within the cabinets and that storage locations were recorded at the end of the workday

6. Assuring that all sample numbering, transfer, and historical information was entered in the Preliminary Analysis Computation Retrieval and Transmission (PACRAT) computer system

The SA was responsible for the following specific duties.

1. Providing scientific personnel as required to support the LSPET with sample description

2. Providing scientific advice to the SPD on any matters requiring deviation from planned procedures

3. Providing scientific personnel as required to furnish sample-chipping information

The SPD was responsible for the following specific duties.

1. Providing real-time direction to the TC for processing activities occurring in the SNAP line

2. Coordinating scientific requirements with the SA

3. Maintaining the official sample identification and transfer record log for the SNAP line (log entries to be obtained from data gathered by the TC)

The organization shown in figure 3 did not function as well as desired during the phase I simulation. The overall problem was not related to the capabilities of the individuals involved but to the system within which they were trying to work. As processing operations began, it quickly became evident that the TC was not able to monitor and supervise the routine processing operations, maintain the data-package files and status logs, and at the same time manage the overall operations of the line. As the TC became overloaded, he shifted much of his responsibility for routine processing operations to the Sample Processing Advisor (SPA), who formerly was used in a strictly advisory capacity. This arrangement worked well and was used until the completion of the simulation. Data-package review and filing and the status log were still handled by the TC, although the need for change was also recognized in this area.

For the phase II simulation, the contractor portion of the Operations Team was reorganized (fig. 4). The most significant changes were made in the formation of a formal position for the SPA and in the addition of an individual responsible for documentation control. Although the relationships between organizations defined for phase I still applied for the second simulation, the duties of some of the principal team members were slightly changed.

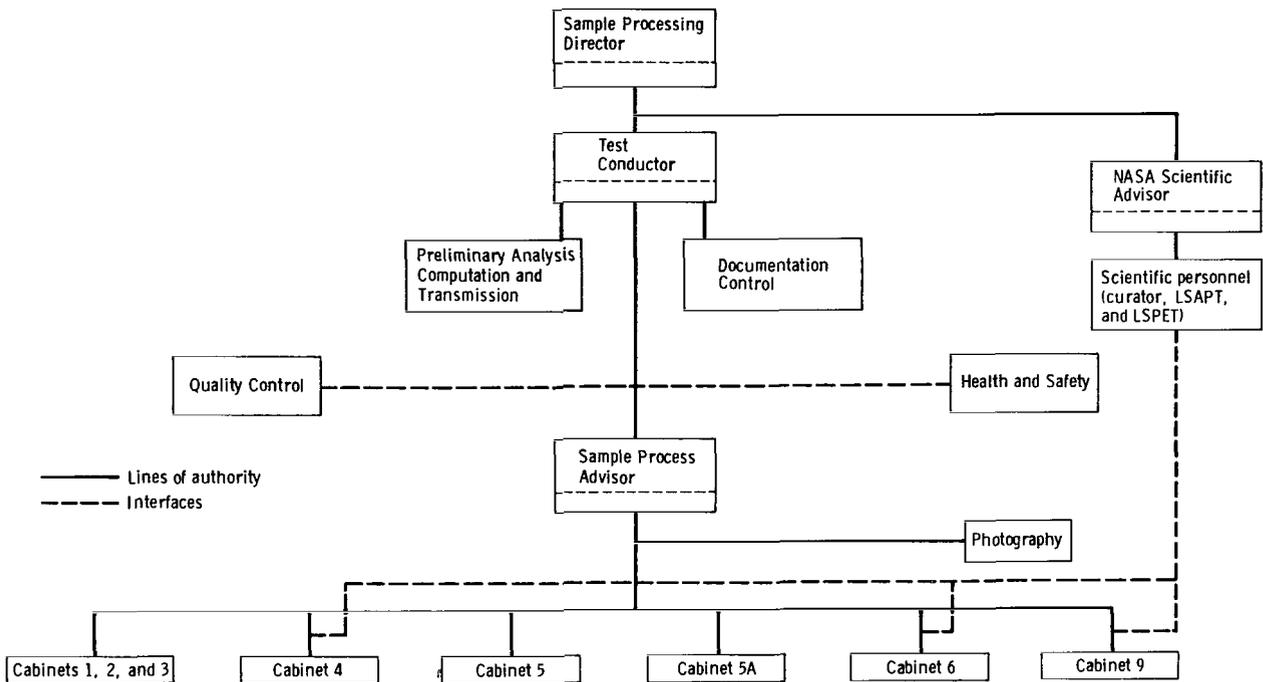


Figure 4. - Revised Operations Team organization, used in phase II simulation.

The duties of the TC were revised as follows.

1. Managing the entire contractor effort on the SNAP line
2. Scheduling inbound and outbound transfers from the cabinet line with Health and Safety Office personnel
3. Assuring that the cabinets and all equipment were operating properly, that the necessary instrument readings and adjustments were made for optimum system performance, and that discrepancies were noted by Quality Control personnel for later resolution

The duties of the SPA were as follows.

1. Assuring that procedures and instructions relative to sample processing were followed
2. Assuring that sample numbers were obtained for all samples
3. Assuring that samples were handled properly to avoid damage or contamination
4. Assuring that all sample historical information was recorded on PACRAT and the written log

5. Assuring safe storage of all samples within the cabinets, and verifying PACRAT location listings at the end of the workday

In addition to his previous duties, the SA was also to provide scientific personnel as required for sieving material from the ALSRC and documented bags.

The phase II organization (fig. 4) operated much better than the phase I organization (fig. 3). The workload was spread more evenly among the people responsible for the various portions of the overall task, and the TC was finally able to obtain an overview of the entire operation instead of being engaged as a full-time recordkeeper. This organization was able to handle the Apollo 14 and 15 lunar-sample processing without difficulty.

Because of the large number of lunar samples the SNAP line was expected to handle and the tight schedule imposed by time-critical experiments, the operational concept developed for the SNAP line was significantly different from that used previously in other areas of the LRL. In establishing the mission organization and its function, lunar-sample processing in the SNAP line was handled as a manufacturing-type operation in which parts (lunar samples) were processed through various operations accompanied by a work order (data package) explaining the work to be performed at each work station. Operating personnel at each work station were trained to perform the specific tasks for which that station was equipped. This technique significantly hastened the flow of samples through the cabinet line and provided a better quality product; that is, more written information on each sample detailing the processing steps performed and the data obtained. This concept was quite different from the type of sample processing previously performed, in which a few highly skilled operators performed all the processing operations with minimum documentation at one or two work stations and moved the necessary equipment into or out of the area to perform the task.

In accordance with this assembly-line concept of sample processing, a data package was generated to follow each sample through the processing operations. Items of descriptive information about each sample were generated, collected, and identified as belonging to that specific sample. A permanent sample number was assigned to each individually identified sample as early as possible, and then all other information about the sample was correlated to this sample number. The collection point for the information generated during sample processing was the data package. A data package containing the step-by-step procedure for processing each sample, as well as spaces for the operators to write in significant information concerning the sample operations performed, was begun on that sample as soon as it was individually identified. The data packages followed the samples through each work station and were turned over to the curator with the samples at the completion of processing operations.

This concept, routine in any manufacturing operation, enabled SNAP line personnel to handle rapidly large numbers of samples with minimum confusion. It also allowed for a complete and rapid review of the status of the operation as necessary. Previous methods used were not necessarily in error; with fewer samples and a more liberal schedule, an investigator could completely process one sample at a time until processing of all samples was completed. For this operation, however, it was more efficient to handle the SNAP line as explained in this report.

CONCLUSIONS

The following conclusions were reached concerning the fabrication and operation of the sterile nitrogen atmosphere processing cabinet line for processing lunar-sample material in the Lunar Receiving Laboratory.

1. Relatively few compromises were required to build the cabinet line in conformity with requirements for minimum organic contamination.
2. A mixture of powdered molybdenum disulfide, isopropyl alcohol, and distilled water was the standard lubricant developed for use in minimum organic-contamination environments. When samples exposed to lubricants are to undergo radiological counting, counting of batches of molybdenum disulfide is also required.
3. The use of Lexan for cabinet windows was attempted because of the organic and radiological characteristics; however, the soft surface, imperfections, lack of transparency, and strong static-charge-collection tendencies rendered this material unsatisfactory.
4. Teflon diaphragms were originally specified and installed in all valves in the cabinet line. Severe through-leakage caused by the hardness and cold-flow characteristics of Teflon dictated replacement of all valve diaphragms with Viton. These Viton diaphragms have performed satisfactorily through Apollo 14 and 15 mission preparations and operations.
5. Cabinets to be used in a minimum organic contamination environment should have an American Standards Association number 4 satin finish or better on all internal surfaces, as well as a 1-inch minimum radius on all corners for ease of cleaning.
6. Cracks and crevices should be kept to a minimum.
7. Welded seams are preferred to gasketed seams, for purposes of cleaning and sterilization. Cabinets should be welded into units consistent with transportation and installation requirements.
8. A removable plate containing piping feedthroughs should be used in each cabinet to simplify later modifications of cabinet piping.
9. Cabinet-fabrication quality is extremely critical if the use of chemical sealants is to be avoided. Two important areas demanding fabrication quality are (1) cutting and forming window openings and (2) welding.
10. Welding operations on installed cabinets should be minimized. For those modifications requiring welding, manufacturer's specifications and techniques should be followed to minimize heat-induced warpage that may adversely affect cabinet sealing.
11. Leak-testing should always begin with a pressure-decay test before a halogen or helium leak check is made.

12. Halogen leak-testing should be performed sparingly to avoid saturation of the work area or gaskets around leaks with halogens.
13. Helium can be used as a tracer gas for leak-checking if a helium leak detector with an atmospheric probe is available. The advantages of using helium are high sensitivity and rejection of false signals from cleaning chemicals, adhesives, and so forth.
14. An ethylene oxide gas-sterilization technique was developed that completely sterilized the cabinet line and all associated piping systems with minimum poststerilization residue in the cabinets.
15. The extent of environmental monitoring should be determined in the design phase of a cabinet-line project; the monitoring equipment should be integrated into the line rather than added after project completion.
16. Changeout of environmental sensors without shutdown or contamination of the cabinet line or contamination of operating personnel should be considered in the design of monitoring equipment.
17. Oxygen-analyzer systems capable of detecting concentrations of oxygen less than 100 parts per million should be final-leak-checked by using bottled oxygen as the tracer gas and the oxygen analyzer as the leak detector. A halogen test does not provide the necessary sensitivity.
18. When numerous samples are to be processed through several operations, it is best to design and man stations in the cabinet line to perform the individual operations and then to pass samples through the stations with documentation showing which operations are required. Each operator should document in writing the work he performs, and the documentation should accompany the sample in all processing phases.

Manned Spacecraft Center

National Aeronautics and Space Administration

Houston, Texas, March 8, 1972

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