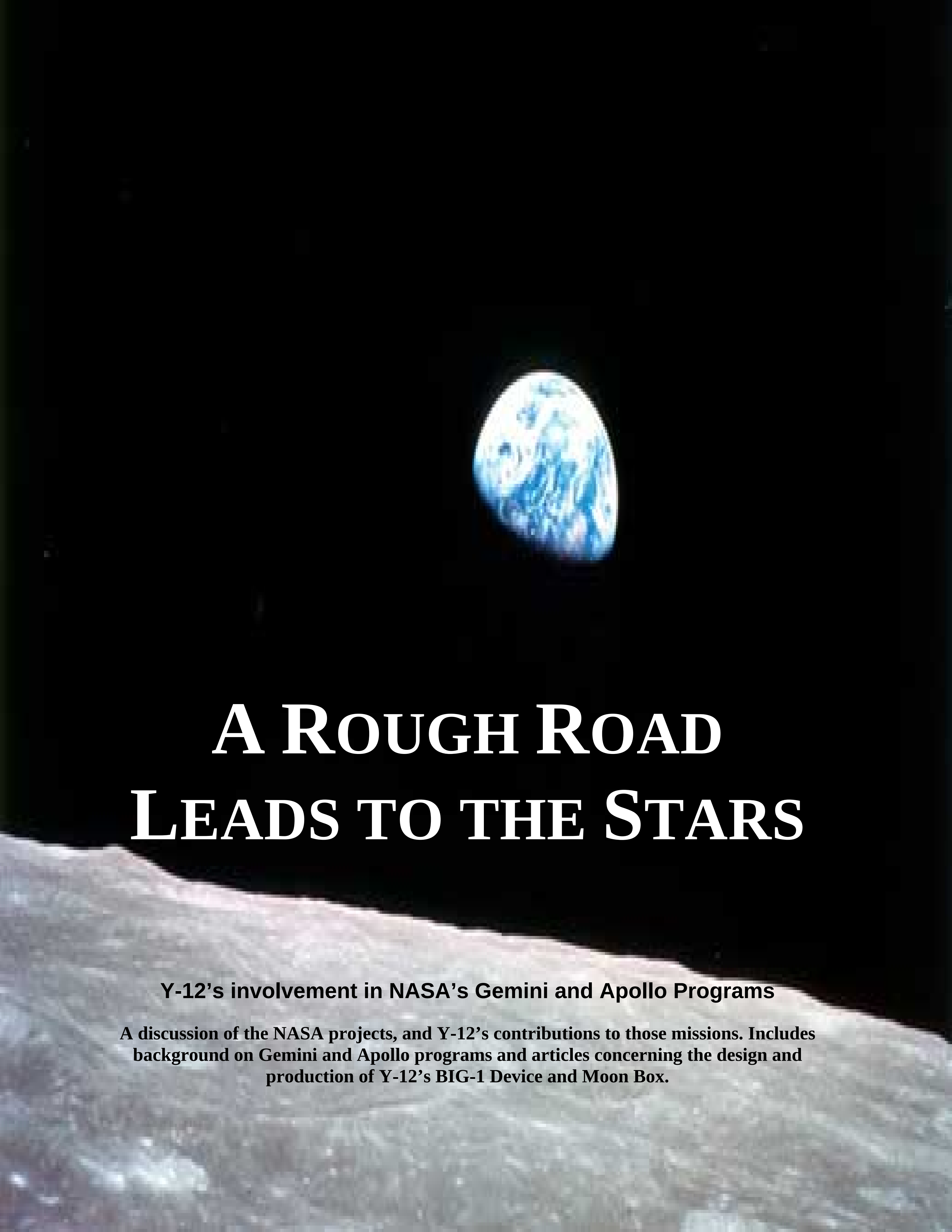


A Rough Road Leads to the Stars

Y-12's involvement in NASA's Gemini and Apollo Programs

A discussion of the NASA projects, and Y-12's contributions to those missions. Includes background on Gemini and Apollo programs and articles concerning the design and production of Y-12's BIG-1 Device and Moon Box.

Booklet Introduction

On May 25, 1961 President John F. Kennedy addressed the House of Representatives on a matter of Urgent National Needs. Not knowing what to expect, Congress was shocked to hear Kennedy propose "…before this decade is out…landing a man on the Moon."[1] The National Aeronautics and Space Administration (NASA) was almost as

President Kennedy challenges Congress.

surprised. While they were aware of Kennedy's intention of putting man on the moon, many NASA scientists declared such a feat to be impossible.[2] In his speech, Kennedy quoted British explorer George Mallory saying that America would go the Moon "because it's there." Knowing the risk involved in his request, Kennedy soberly said that "as we set sail we ask God's blessing on the most hazardous and dangerous and greatest adventure on which man has ever embarked."

At this point in America's space program, only one man had successfully been sent into Earth's lower orbit, and developing a shuttle capable of a lunar journey was far from complete. NASA's federal funding was nowhere near where it needed to be for such a program and Kennedy, despite the lunar landing being his suggestion, was still reluctant to grant a funding increase. Although, NASA was confident America could beat the Soviet Union to the Moon, a draft proposition was written for an American-Soviet agreement for a joint moon landing.[3] This was never officially proposed, and by the mid-1960s, the United States was making tremendous strides in the Apollo Program.

In this booklet are articles about both the Gemini III BIG-1 Device and the Apollo Lunar Sample Containers, or "moon boxes," both of which were designed and created here at Y-12.

[1] John F. Kennedy, *Special Message to the Congress on Urgent National Needs*. (accessed July 14, 2011).

[2] Charles Murray and Catherine Bly Cox, *Apollo*. (New York: Simon & Schuster, 2004), 16-17.

[3] Frank Sietzen, "Soviets Planned to Accept JFK's Joint Lunar Mission Offer," *SpaceCast News Service*, October 2, 1997 (accessed July 14, 2011).

Gemini Program

The 12 Gemini missions began as a bridge between the previous Mercury missions and America's dream of lunar exploration, the Apollo program. Gemini was devised to test spacecraft equipment and mission procedures, as well as to train astronauts and ground crews for Apollo. All three Apollo 11 crew members, "Buzz" Aldrin, Neil Armstrong, and Michael Collins were members of the Gemini missions which ranged from five hours to 14 hours each. These missions served as tests for equipment and training for the future Apollo missions.

The Mercury missions began in August of 1959 with several tests of shuttle equipment including the launch escapes and the shuttles' heat shield. In December of 1959, finding that their equipment was adequate for launch, NASA successfully sent Sam the monkey into space; Sam would be followed by Miss Sam in January of 1960, Ham the Chimpanzee in February of 1961 and Enos the Chimpanzee in November of 1961.

Mercury also saw the first American in space: Alan Shepard. Shepard piloted his shuttle *Freedom 7* in May of 1961 shortly after the Soviets' Yuri Alekseyevich Gagarin led a space mission making him the first man to reach outer-space. Shepard was cured of Ménière's disease, an inner ear disorder affecting balance and hearing. Shepard had contracted the disease while working on the Mercury project in the late 1950s and early 60s. Shepard was also the first astronaut to hit a golf ball "for miles and miles and miles"[4] on the lunar surface. Shepard was commander of the Apollo 14 mission, America's third successful lunar mission, which was the first to successfully broadcasted color video of the moon. The final Mercury mission was piloted by Gordon Cooper on May 16, 1963.

The Gemini Program preparations as early as October 1961 with its first launch nearly three years later in April 1964. The first two missions were equipment tests, much like in Mercury, therefore they were unmanned. However, in March of 1965, Virgil "Gus" Grissom and John Young manned a mission lasting more than five hours in Earth orbit.

Young (left) and Grissom (right).

Gemini III was the first space mission that would judge how long man could survive and function in space. Such matters had long been the concern of NASA scientists, and with Gemini III, perhaps the eventual lunar astronauts could be prepared and protected from space's severity. Grissom and Young would go beyond the gravitational pull and air protection in which mankind had evolved and that had protected the Earth from the harshness of outer-space.

[4] "EVA-2 Closeout and the Golf Shots". NASA. NASA. Retrieved May 29, 2007.

The objectives of the Gemini program included successful demonstrations of Extra-Vehicular Activity, or spacewalks, outside of the spacecraft and the evaluation of the astronaut's ability to perform exterior tasks; the perfection of atmospheric re-entry and landing at a preselected location; demonstrations that humans and equipment could withstand eight to 14 days outside Earth's atmosphere; and to provide astronauts with zero-gravity rendezvous and docking experience for future Apollo missions.

The first spacewalk was performed by Ed White during the Gemini IV mission in 1965. White used an oxygen propelled gun to push himself out of the spacecraft while passing over the Hawaiian Islands and returned to the craft 23 minutes later while traveling over the Gulf of Mexico. While Gemini III saw the manual reentry and landing in the Atlantic Ocean, the craft landed nearly 60 miles away from the recovery site, and Grissom and Young had to wait two hours for helicopters to find them. The first rendezvous was performed during Gemini VIa. Gemini VI came within one foot of its sister-craft, Gemini VII, and, had they borne the proper equipment, VI would have docked with VII. The endurance of men and equipment was demonstrated through the success of all missions, including Gemini VI and Gemini IX, which were unable to complete their missions due to technical problems, but succeeded with their second attempts, Gemini VIa and Gemini IXa. The Gemini program cost NASA nearly $1.3 billion.

The Y-12 facility provided a very important piece of equipment for the Gemini III flight: the *Blood In Gemini Device*, or BIG-1. Gemini III was responsible for an experiment that was important for scientists to understand how energy in space would affect cells in zero-gravity. In previous missions, astronauts returned with cell damage that scientists attributed to prolonged exposure to small amounts of radiation during missions. Upon this discovery, NASA formed an experiment that would expose human blood samples to set amounts of radiation for a limited period of time; these samples would then be compared to samples with no radiation exposure to determine the effects. The experiment would be done aboard the Gemini III *Molly Brown* so the device in which the experiment would be done had to be resistant to numerous environmental challenges. NASA turned to Y-12, whose engineers were famed for their precision machining, and the BIG-1 Device was proclaimed excellent by NASA scientists and astronauts.

AEC 30001 (BIG-1) DEVICE

Used for the GT-3 Manned Spaceflight for the S-4 Experiment on the Synergistic effect of Zero-G and Radiation on White Blood Cells.

MARCH 23, 1965.

PICTURES & INFORMATION FROM NASA: HTTP://WWW.NASA.GOV/

Design, fabrication, and testing of the hardware for this experiment was done at Y-12.
Identical material was placed in a laboratory at Cape Kennedy and was used as a control.

The Gemini III Mission took place on March 23, 1965.
It had a crew of two men, Virgil "Gus" Grissom and John Young.

Why Was This Important?

The effect of radiation on cells during flight was a concern in light of plans for long-duration manned space flight. Unknown biological effects produced by the "heavy primaries" component of radiation, blocked from Earth's surface by the atmosphere and hence inaccessible to terrestrial laboratories, or the interaction of radiation with some aspect of the space flight environment such as prolonged weightlessness, might be the cause of damage to the cells. Experiment S-4 was designed to furnish a basis for weighing these alternatives.

John Young (left) and Virgil "Gus" Grissom (right).

How Was It Done?

Human blood samples were to be exposed to a known quantity and quality of radiation, (both in the spacecraft and on the ground) during the zero gravity phase of the mission. The frequency of various chromosomal aberrations in both sampled could be compared.

Production of chromosomal aberrations is one of the best known effects of radiation, so it was selected as the parameter to measure for this study; Human leukocytes were chosen as the cell to be studied, since the cells would all be in a uniformly sensitive stage in the cell cycle.

Because induction of chromosome aberrations is a non-linear function of Radiation dose, a graded series of four different radiation exposures was used. Two complete sets of blood samples were flown to protect against loss of data; each sample set was from a different blood donor. In total, ten 3 ml blood samples were flown;

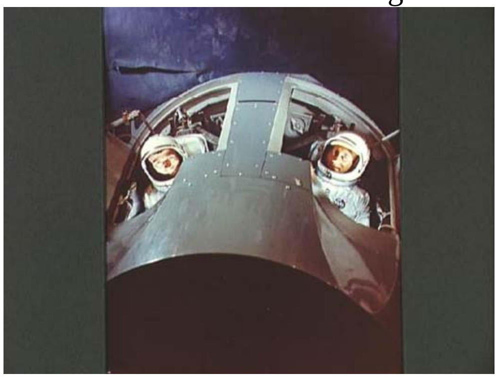
eight were irradiated with each of the four doses, and two were not irradiated and served as the in-flight controls. The simultaneous ground control experiment consisted of ten 3 ml samples drawn from the same donors at the same time as the in-flight samples. As an additional control, blood samples were obtained from the flight crew before and after the flight, and short-term leukocyte cultures were prepared. Preflight the samples were obtained as close to the mission as possible (2 days prior to launch) from both the flight and backup crews, so that the sample would remain viable.

Irradiation was accomplished by identical devices, on the ground at the launch Site, and the other on the right hand hatch of the Gemini spacecraft, each device contained 22 Fluoroglass dosimeters. Approximately 9 hours before launch the two identical experiment devices were assembled and tested, then at 210 minutes before launch the flight unit was mounted into the spacecraft. The ground control unit was placed inside a temperature controlled cabinet, in which the temperature was periodically adjusted to correspond to the temperature readout from the spacecraft.

The experiment used a radiation source, Phosphorus - 32.
The team wanted to use X or Gamma rays to irradiate the blood samples, but could not for two reasons: (1) the small mass allotted to them for the experiment excluded and (2) too much shielding would have been required to protect the flight crew. Therefore, beta radiation was chosen. Radioactive Phosphorus - 32 was chosen as the radiation source for three reasons (1) it emits only a single beta-particle, (2) the particle energy was suitable and (3) it had been used extensively in radiobiology studies to date.

To be mounted on the right-hand hatch, the experiment was wholly self-contained in a half-kilogram (one pound) hermetically sealed aluminum box that held the blood samples, a radiation source, and instrumentation. The copilot had only to twist the handle and push it in to start the irradiation of the blood samples. Twenty minutes later he would twist the handle in the opposite direction and pull it out to stop the experiment. Word of these actions relayed to ground would allow them to be duplicated.

From one end of the box an operating handle protrudes. Each of the five epoxy-resin and fiberglass holders contains two sterile, heparinized, 3-ml blood samples in the form of discs 3 mm thick. The four blood sample holders which are to be irradiated are inserted in the aluminum housing in tracks

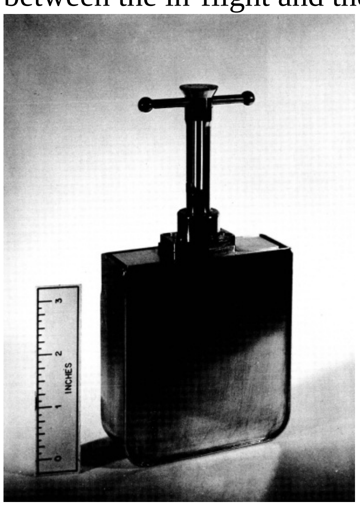


Young (left) and Grissom (right) sitting in Gemini III spacecraft

running between the paired aluminum and platinum P-32 source plate holders. When the operating handle is pushed in these four blood sample holders are moved into position between the pairs of P-32 source plates, thus starting irradiation of the blood samples through the thin blood-chamber "window." When the operating handle is pulled out, the blood-sample holders are withdrawn, thus stopping the irradiation. The non-irradiated control blood sample holder is located behind, and shielded from, the P-32 source plate array. The space above the control holder is occupied by an instrument package assembly. The P-32 source plate pairs arranged in a graded series of total activities in a ratio of 1:2:3:4, so as the yield the required series of irradiation doses during the simultaneous exposure of the blood samples.

To provide cooling of the experimental device, a thermoelectric Cooler was incorporated into the mounting bracket for the S-4 experimental device. This refrigerator-bracket used spacecraft power to transfer heat from the experimental device to the spacecraft hatch structure and also provided a telemetry signal for readout of the device temperature during the mission.

A number of measuring devices were included within the experimental device in order to help confirm correspondence between the in-flight and the ground portions of the experiment. Two silver-metaphosphate fluoroglass-dosimeter rods were located within the stems of the blood sample chamber sealing screws, where they would record the dose received by each blood sample. The instrument package was designed to provide records of the temperature within each device during the experiment, and particularly records of excessively high or low temperatures, with a record of the time of irradiation. These records were written by means of spots of colored light moving slowly across strips of color film. The time is then read across the strips resulting on the developed film while the color at any given point indicates the temperature at that time.



The device before final sealing. The operating handle is in the "non-irradiate" position.

The times at which an irradiation is begun and ended are recorded by still another colored spot. The instrument package contains also a pair of large volume silver-metaphosphate fluoroglass dosimeter blocks. These measure the ambient radiation within the experimental device.

The second phase of the experiment was designed to explore the possibility that cells might be directly affected by low gravity. Because the effects were easier to detect in simple cells systems than in a complex organism and because theory argued that effects would appear only in cells upward of one micron across, the eggs of a sea urchin were selected as the experimental material. The eggs were to be fertilized at the start of the experiment, and the possible changes brought about by low gravity observed at several stages of the development.

Results

Grissom's attempt to run the cell-growth failed, perhaps, as he remarked later, because he had "too much adrenalin pumping" and twisted the handle too hard.

The radiation experiment gave Young some trouble, but he was able to complete the task.

Results showed that the occurrence of single break aberrations was much higher in the flight samples. There was no significant difference between the yields of multiple break aberrations in the flight and ground control samples. The flight crew chromosome aberration analyses showed no increase in aberration frequency due to space flight. It appeared that some space flight factor did interact synergistically with radiation to affect the chromosome rejoining system (the cell's ability to repair damage), thus producing the single breaks.

Results of the Experiments were analyzed by M.A. Bender, P.C. Gooch, and S. Kondo of ORNL.

These people were acknowledged as having been instrumental in the S-4 Experiment:

From Y-12: H. F. Smith, Jr.; E. N. Rogers; W. T Smith, Jr.

From ORNL: F. N. Case; F. M. Faulcon; W. L. Lee; F. J. Pearson; K. P. Jones; J. L. Hosszu; J. R. Azzi

The BIG Project

By: Walker Smith

Purpose of Project

Early scientific reports from the Soviet Space Program reported a possible radiation effect on human blood in space that was greater than that expected from the same amount of radiation here on earth. NASA wished to explore this more fully and requested the support of the Department of Energy. Oak Ridge National Laboratory was tasked to design a confirming experiment and y-12 was tasked to provide engineering and logistical support to this effort.

The ORNL Biology Division assigned Dr. Michael A. Bender to head up the project and design and carry out the experiment with the support of other ORNL divisions and the Y-12 Plant facilities.

Description of the Experiment

A device was required which could be placed in the Gemini spacecraft and operated by the astronauts while in weightless orbit of the earth. Weight limits for the device were very stringent and the operation had to be simple enough to be done while wearing heavy gloves and while also performing many other experiments. Samples of human

Figure 2

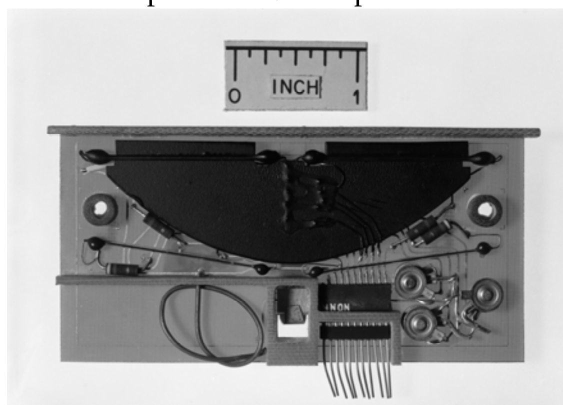


Figure 1

blood were to be situated such that they could be moved into an area where they could be exposed to a known amount of radiation for a known amount of time, then removed and protected from the source for the remainder of the flight. The device had to be compact enough to fit into some unoccupied niche in the spacecraft that was readily accessible to the astronaut. The completed, flight ready, device was to be delivered to the space craft approximately 2 hours before launch from Cape Canaveral, Florida. A ground control device, identical in every way was to be maintained at Cape Canaveral during the flight. The flight device had to be recovered from the spacecraft upon touchdown in mid-Atlantic and the necessary blood cultures carried out to determine the effects of the radiation. This required a biologist to be aboard the recovery vessel and one to be at the cape to perform the necessary work simultaneously. Thus any difference in the effect on the blood cells would indicate that there was a synergism between weightlessness and radiation.

This project was named the "Blood in Gemini" or BIG project.

Y-12 Participation

Y-12 Plant designed the flight device to NASA standards, fabricated it, performed all tests necessary for flight qualification, and provided all necessary supporting equipment and field support at the launch site.

Personnel Involved

Harwell F. Smith was overall Y-12 Project Manager.

Merle B. Hilton, Tool Engineering, designed the experimental device.

Stan E. Groothuis, Instrument Engineering, designed the instrumentation and coordinated its fabrication.

William W. Lee, Development Division, coordinated all testing.

Walker T. Smith, Process Engineering, coordinated the fabrication of the flight devices, designed the support equipment and facilities, assembled the flight and the ground control devices, and provided field support at Cape Canaveral.

Experimental Devices

Two different experimental devices were designed and constructed for submission to NASA. They were identical in function, differing only in geometry. BIG-1 operated through linear motion, while BIG-2 operated through a rotary motion. Either would have been satisfactory but BIG-1 was chosen because of earlier flight qualification. At NASA's request slight modification of the operating handle was made to better accommodate the operation of the device by the gloved hand of the astronaut.

The housing was machined from a single piece of type 6061 aluminum. A side plate and top of the same material completed the assembly. The operating handle was made from stainless steel. The blood sample holders were made of epoxy resin with "windows" reinforced with fiberglass. The radiation sources were aluminum sheet stock with platinum discs coated with Phosphorus ^{32} glued to the substrate. The unit was completed by an instrumentation package which recorded time, temperature, and apposition of the samples at all times during the flight. ***Figure 1*** and ***Figure 2*** show the configuration and layout of this

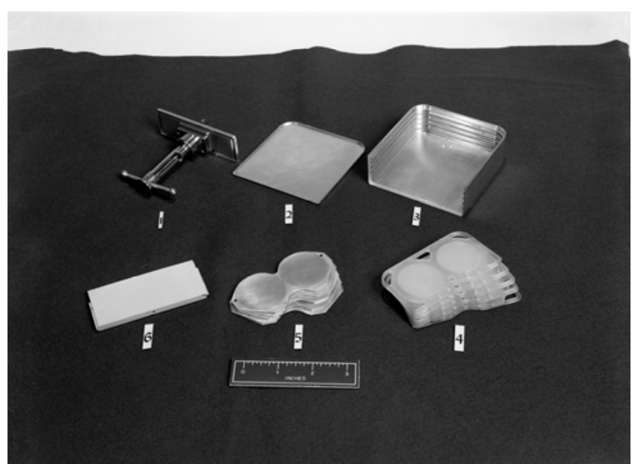


Figure 3

package. These components are shown in ***Figure 3*** and their position within the housing is shown in ***Figure 4***. The final configuration is shown in ***Figure 5*** in which the side plate has been left off to

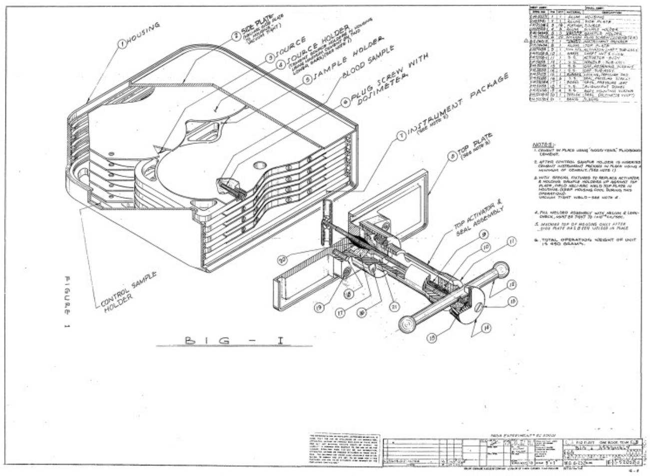


Figure 4

show sample holders and source plates.

Operation of this device required only that the astronaut rotate the operating handle crossbar 45 degrees counterclockwise, push it down, and rotate 45 degrees clockwise at the beginning of the exposure and to reverse these actions at the end. This would place the blood samples between the source plates for the required period of time to accomplish the radiation desired. The times for these actions was to be controlled by NASA ground control station and would be recorded on the internal instrument package.

Support Equipment

In order to support the final preparation of the experimental package just prior to launch, a mobile laboratory and welding and testing facility was provided. This consisted of a 40 foot semitrailer equipped with heat, air conditioning, and self-contained electrical supply and basic biological laboratory equipment. This unit was further furnished by Y-12 with welding facilities, vacuum leak testing facilities, work benches with basic mechanical tools and sleeping facilities for the personnel on duty during flight. ***Figure 6*** shows this unit which was taken by Y-12 personnel to Cape Canaveral ten days prior to scheduled launch.

Additional support equipment necessary to open the flight unit after recovery including a special saw, a radiation shield, and other necessary tools and radiation measuring instruments were designed, fabricated or procured, and placed in specially designed portable cases to be used by the biologist on the recovery ship.

Field Support

Field support consisted of two Y-12 engineers and a welding specialist to perform the final closure weld on the experiment package. These personnel coordinated all supporting services from the base and manned the support trailer during the flight. When the flight

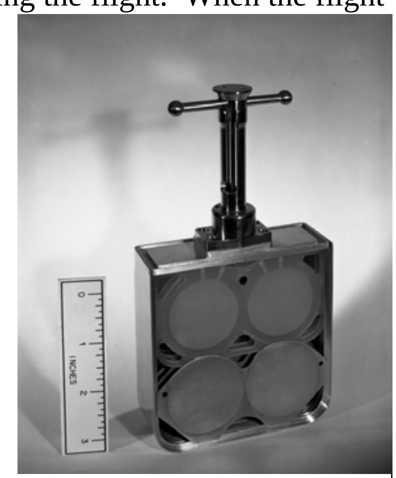


Figure 5

package was ready, the coordinator took the unit to the launch pad and handed it off to the NASA personnel at the capsule door.[1] This support crew monitored the NASA communication with the astronauts and activating the ground control unit at the same time the flight unit was activated. Subsequently, they maintained 2-way communication with the biologist on the recovery ship to insure simultaneous opening and processing of the ground control unit.

Experimental Results

Final testing indicated that, indeed, there seemed to be some difference in the damage sustained by the flight and ground control samples. While not as great as that suspected by the Soviets, it was

Figure 6

measurable. The conclusion caused the NASA to request a repeat test to be flown on Gemini XI. This was accomplished and the test failed to verify the differences found on the earlier flight.

Gemini XI Experiment

The same basic experimental equipment and method was repeated in the later flight but the procedure was complicated by the length of the space flight. Gemini III was a three orbit flight lasting only four and a half hours. Thus the blood was viable without any extraordinary treatment. No the other hand, Gemini XI lasted for three days. This required design and fabrication of a refrigerated housing for the experiment package. Since size, weight, and power consumption were important factors, a significant design and test effort was required. This was done and the resulting housing performed well, providing conditions which effectively protected the blood sample during the longer flight. The major problem encountered was finding a self-contained refrigerating element small enough and light enough to meet the strict requirements of NASA. General Electric had developed a thermoelectric unit for NASA to use on a previous Gemini flight which was state-of-the-art at the time. Y-12 Instrument Engineer R. C. Kinnamon adapted it for this use and designed a power source and control package to accommodate this unique refrigerator. See ***Figure 7*** for configuration of this unit. This required complete flight qualification testing for the entire package again. This was accomplished by Y-12 Standards and Test Lab.

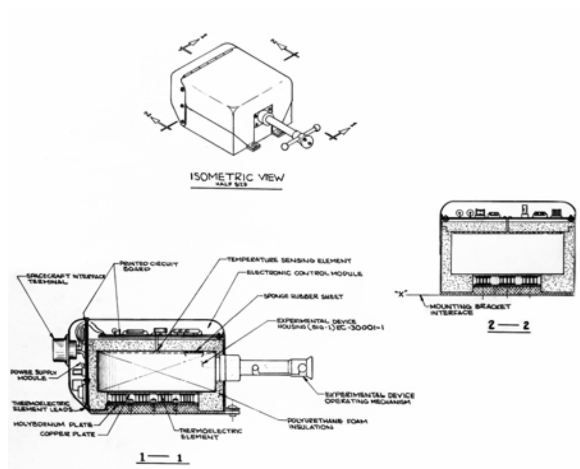


Figure 7

Similar field support was required for the launch of Gemini XI and the same equipment and personnel were utilized.

Additional Notes

This is a very brief summary of the project emphasizing Y-12 participation and concentrating primarily on those aspects which Walker Smith personally had a part in.

This project illustrated the capability and responsiveness of the Y-12 Plant to NASA. As a direct result of this work, NASA later approached Y-12 when they needed a container to bring rock fragments back from the moon without contaminating them either in the spacecraft or at the Space Center Laboratories. This led to our contract for the "Moon Rock Box."

Apollo Program

The Apollo Program began a whole new set of experiments and challenges. NASA hoped it would be the program which would fulfill Kennedy's promise and the American people's dreams of sending man to the Moon. Apollo begins with a series of unmanned missions called the Apollo-Saturn mission, or "AS," after the program Apollo, and shuttle name, Saturn.

An attempt at a manned AS mission was made on January 27, 1967 with a crew that included the Gemini Program's Virgil "Gus" Grissom and Edward White along with rookie Roger B. Chaffee. Tragedy struck the morning of the launch rehearsal test when the shuttle cabin, which was filled with supplies of pure oxygen, caught fire. All three crewmembers died on Launch Pad 34, and were given heroes' funerals. "Gus" Grissom is remembered for his selfless drive and desire to be a part of something bigger and greater than himself:

> *If we die, we want people to accept it. We are in a risky business and we hope that if anything happens to us it will not delay the program. The conquest of space is worth the risk of life.*[5]

Launch Pad 34 was dismantled and two memorial plaques were placed with it, bearing NASA's sentiments at the loss of three valiant astronauts:

> *In memory of those who made the ultimate sacrifice so others could reach for the stars. Ad astra per aspera, (a rough road leads to the stars). God speed to the crew of Apollo 1.*
>
> *They gave their lives in service to their country in the ongoing exploration of humankind's final frontier. Remember them not for how they died but for those ideals for which they lived.*

Apollo 4, 5 and 6 were unmanned so as to avoid another such catastrophe. Apollo 7 marked the first successful manned mission of the Apollo Program. This 11-day flight in Earth's orbit was crewed by Walter M. "Wally" Schirra, Donn Eisele and Walter Cunningham, and included the first live broadcast from a U.S. space flight. The Apollo 8 and 9 missions included the first manned lunar orbital flight; first successful rendezvous and docking of a spacecraft. The Apollo 8's Frank F. Borman, II, James A. Lovell and William A. Anders were the first humans to see the lunar far side and the Earthrise

(left to right) Virgil "Gus" Grissom, Edward White and Roger B. Chaffee

[5] "Early Apollo". Apollo to the Moon: To Reach the Moon - Building a Moon Rocket. Smithsonian Institution, National Air and Space Museum. July, 1999. Retrieved April 03, 2011.

with their own eyes in ten consecutive lunar orbits lasting 20 hours.

The "dress rehearsal" for the moon landing, Apollo 10, was crewed by Thomas P. Stafford, John W. Young and Eugene Cernan. Launching on May 18, 1969, Young piloted the command module, *Charlie Brown*, into lunar orbit allowing Cernan to bring the lunar module, *Snoopy*, within 8.4 nautical miles of the Moon's surface, then returned to the Earth.

Apollo 11, crewed by Neil Armstrong, Michael Collins and Edwin "Buzz" Aldrin, lifted off from the Kennedy Space Center at 9:32 a.m. local time on July 16, 1969. Thousands gathered on nearby highways and beaches to watch as mankind began its journey to the stars. The two space-crafts that would facilitate the flight were named the *Columbia*, for America's feminine personification, and the *Eagle*, for the national bird. Four days and 30 lunar orbits after launch, the *Eagle* lunar module separates from the *Columbia* command module, and on July 20th safely lands in the Sea of Tranquility or *Mare Tranquillitatis* in its Latin name. The "sea" was actually one of many dark, basaltic lunar plains visible from Earth, which early astronomers mistook for seas.

Images taken by *Ranger 8* and *Surveyor 5* showed the site to be relatively smooth and flat, which would make the EVA space-walks easier. *Ranger 8* was a spacecraft designed to transmit high-resolution photos of the Moon's surface. It managed to send 7,137 images back to Earth before it collided with the Moon on February 20, 1965. *Surveyor 5,* a lunar lander, was part of a series of *Surveyor*s whose job was to similar to *Ranger 8*. *Surveyor 5* landed on the Moon on September 11, 1967, and transmitted 19,049 images to NASA during its two week lunar stay.

On July 21, 1969 Neil Armstrong becomes the first man to set food on the Moon, thereby fulfilling President Kennedy's 1961 proposal of an American manned lunar descent. The *Eagle*'s ladder was left on the Moon after the astronauts' departure for Earth, and on it a stainless steel plaque was placed dedicating the accomplishment to all mankind:

Here men from the planet Earth first set foot on the Moon
July 1969, A.D.
We came in peace for all mankind

A memorial bag was also placed at the *Eagle*'s ladder. The bag contained a gold replica of an olive branch, the international symbol of peace and goodwill, and a silicon message disk. The disk was composed of "goodwill statements" from Presidents Eisenhower, Kennedy, Johnson and Nixon as well as from 73 foreign nations. Armstrong was able to summarize the experience perfectly when he said that his step onto the surface was "one small step for [a] man, one giant leap for mankind."

The United States continued to leap into lunar exploration with six more Apollo lunar missions. These subsequent missions continued the Apollo 11 tradition of collecting lunar rock samples which were transported back to Earth in sterilized, vacuum sealed containers.

These complicated devices were made at the Y-12 Plant. Apollo 17, the last Apollo mission, set course for the moon on December 7, 1972. It broke many Apollo Program records including the record for longest manned lunar landing flight; longest total lunar space walks; longest time in lunar orbit; and the largest lunar rock sample return. It was Apollo 17 that the famous "Goodwill Moon Rocks" were gathered. These rocks are named after a statement made by astronauts Eugene Cernan. Cernan told the American people during a call back to Earth that Harrison Schmitt, fellow Apollo 17 astronaut, had…

> *…picked up a very significant rock, typical of what we have here in the Taurus-Littrow valley…composed of many fragments, of many shapes, of many colors even…probably from all parts of the Moon, perhaps billions of years old.*

This "goodwill" rock of was transported back to Earth and distributed in fragments to 135 foreign heads of state, the 50 States and U.S. provinces. Most of these "moon rocks" are kept in the *Lunar Sample Building* at the Lyndon B. Johnson Space Center in Houston, Texas. The rest are stored the Brooks Air Force Base in San Antonio, Texas. All samples are stored in nitrogen for preservation, and are only ever handled indirectly using

Night Launch of Apollo 17.

special tools. The Apollo lunar samples are considered by most to be a priceless link to the Moon and, by association, the rest of the universe. As of 2011, Apollo 17 remains the most recent manned space flight beyond low Earth orbit.

A "GLOVEBOX WELL TRAVELED"

APOLLO LUNAR SAMPLE RETURN CONTAINER

Rodney B. Smith

ABSTRACT

Isolation of material from the environment is a challenge that glovebox designers, users, etc. must face in the field of isolation technology. An example of extreme isolation requirements was met by the Personnel at the Oak Ridge Y-12 Plant in the design, development, and fabrication of Apollo Lunar Sample Return Containers (ALSRC) for the National Aeronautics and Space Administration. This paper describes the work that was done in manufacturing the ALSRCs and some of their associated sample collection devices. The containers were successful in providing adequate storage and protection for lunar sampling equipment during the 240,000-mile trip to the moon and maintained the lunar samples in a near-lunar environment during their travel to the earth. In addition, the journey began with the equipment experiencing the loading from the combustion of six million pounds of high explosives and ended with the shocks and deceleration of earth re-entry.

SUMMARY

The Oak Ridge Y-12 Plant[a] was responsible for the design, development, and fabrication of a portion of the Lunar Geological Equipment which included the ALSRC for the storage and protection of the lunar samples and the special sampling hardware that was used on the mission, and a variety of sample containers including special experimental hardware and several types of sample containment bags. Overall performance of the hardware furnished by Y-12 for the Apollo program was considered excellent.

INTRODUCTION

In the late 1950's and early 1960's, plans were formulated to achieve the goal of a manned lunar exploration. The chosen program designation was Apollo, and it had as its prime objective the landing of American astronauts on the lunar surface and their safe return to earth with samples of lunar materials. President Kennedy accelerated the schedule when he announced his desire of accomplishing these goals before the end of the 60's. The unspoken goal was to beat the Soviet Union to the punch, since they had been first in practically every other space event up to that point.

Samples were to be carefully chosen from each landing site so that scientist would be able to characterize the moon and hopefully answer some questions regarding the genesis of the universe. Since only a small volume of samples could be returned to earth by each mission, the samples had to be carefully selected and carefully protected from anything that might affect their scientific content. Such detrimental agents as the earth's atmosphere, contamination from the collection hardware, and breakage due to vibration of the spacecraft were of prime concern. These reasons, along with the fear of the unknown (namely, biological contamination of the earth), led to the requirement for ALSRCs which would maintain structural and vacuum integrity throughout an Apollo mission.

Major design considerations were the work-capability restraints imposed on the astronauts by their spacesuits and lunar gravity. Human-factor testing and astronaut training caused many changes to be made and guided the designers in much of the development of the hand tools and the ALSRC. There was also a requirement that all of the hardware be cleaned to such a degree that residual organic contamination from earth could not interfere with the parts-per-billion analysis of the lunar samples.

Choice of the Oak Ridge Y-12 Plant to perform the design, development, testing, and manufacturing functions of the ALSRC and associated hardware programs resulted from the consideration of several factors. Complete capabilities were available including development in the requisite disciplines, available engineering, applicable testing facilities and experience, extensive manufacturing facilities, and extensive quality

[a] Operated by Lockheed Martin Energy Systems, Inc. for the United States Department of Energy.

control and quality assurance organizations. Extensive experience and expertise had been acquired in the design, development, testing, and manufacture of unusual components for other US Atomic Energy Commission (USAEC) (now Department of Energy (DOE)) facilities. Scientific support was readily available from the Oak Ridge National Laboratory (ORNL). Finally there was a ready integration of the ALSRC and associated hardware with the vacuum system in the Lunar Receiving Laboratory (LRL) since that system was also designed and built by the Oak Ridge Y-12 Plant.

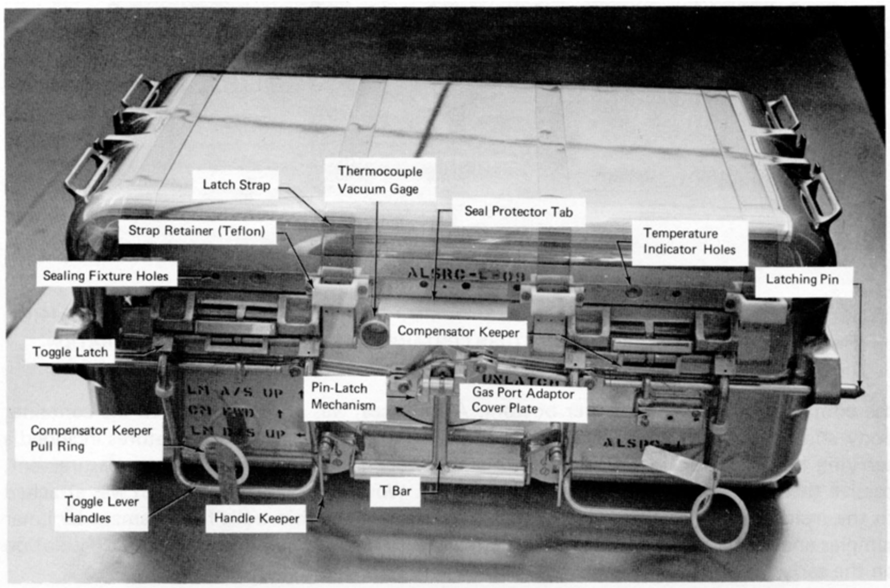


Figure 1

APOLLO LUNAR SAMPLE RETURN CONTAINER - OUTER

The ALSRC was designed to provide storage and protection for lunar geological samples and to maintain the samples in a near-lunar environment during the return mission to earth. Figure 1 provides a view of the ALSRC in the preflight conditioning configuration.

A major design consideration was the retention of vacuum prior to and during the translunar portion of the mission, and the retention of vacuum after the container was resealed on the lunar surface for the return to earth. The ALSRC was designed to have overall dimensions of 19 by 11 1/2 by 8 inches. The total empty weight of the ALSRC was to be less than 27.0 pounds with an internal volume of 1,400 cubic inches. The container lid and bottom were of unitary aluminum construction with thin walls (.045 inch) reinforced by integral ribs.

Pin-latching hardware was designed to secure the container in the Command Module (CM) and in the Lunar Module (LM). Lid-latching hardware was designed for sealing and securing the container lid to the container bottom. A triple seal was designed between the container body and lid to provide a reliable vacuum seal mechanism. Other design features included a carrying handle, temperature indicators, a thermocouple gauge for pressure measurement, passive thermal control, and a gas sampling port. Woven aluminum wire mesh was attached to the inside surface of the outer container to protect the thin walls from damage by lunar samples and other hardware. This wire mesh was also used for sample and hardware isolation on the early missions.

Stress Analysis

An analytical study was conducted concerning the dynamic stress response of the ALSRC. This analysis was based upon the specified load-time relationship of 78 g's acting for 10 milliseconds, and resulted in an equivalent gravity loading of 100 g's. Programs for the computer were written to calculate the load distribution produced in the indium-silver seal by selected latch forces. Bending and torsional stresses, deflections of the flanges, and corresponding deformation of the seal were also determined.

Thermal Considerations

In designing the ALSRC it was necessary to consider the lunar environmental conditions; namely, the extreme cold of the shaded surface and the heating ability of the unattenuated solar rays. The location of the ALSRC on the lunar surface during the mission became of utmost importance, since this determined the degree of its environmental exposure.

There were two major design areas of the ALSRC that were thus affected. It was necessary to be sure that the sun's rays would not melt the indium-silver alloy used in the metallic portion of the seal and that the extreme cold would not harden the elastomer O rings. It was also necessary to know that the difference in the coefficients of expansion of the steel straps and the aluminum ALSRC lid would not cause an unacceptable variation in the closing force if a large temperature shift occurred. These problems had to be resolved by using some method of passive thermal control. Initial information indicated that the ALSRC would be placed in the sun during the mission. Therefore, steps had to be taken to protect the ALSRC from overheating. The absorptivity and emissivity of the ALSRC surfaces had to be the controlling thermal factors. It was determined that if the mean ratio of absorptivity to emissivity was 0.9, the ALSRC temperature would not exceed 68°C for the projected time of exposure. This equilibrium temperature was acceptable, and the proper ratio could be achieved by coating the ALSRC external surfaces with aluminum oxide. The initial training hardware was plasma sprayed with aluminum oxide. However, before the first mission, NASA decided that the ALSRC would remain in the shade during its stay on the lunar surface since it would remain on the Modular Equipment Stowage Area (MESA) rather than be transported on the tool carrier. Therefore, it was necessary to take steps to prevent the ALSRC from getting too cold rather than too hot.

It was determined that highly polished external surfaces would afford the best protection from the cold. It was further determined that the strap latch system would work well with fluorosilicone O rings which would function satisfactorily at temperatures as low as -46°C. All flight hardware was produced with highly polished surfaces.

Lid-Latching Mechanism

The lid was held in place by four toggle latches, as can be seen in Figure 1. The two strap latches consisted of four high-strength straps connected to toggle lever handles. The four straps were anchored on the rear side of the container spanned across the lid, and toggled down on the front side of the container. There were two straps connected to each handle; thus, each of the two strap-latch assemblies applied a clamping force at four points on the seal. The toggle handles were designed for easy manipulation by an astronaut in a space unit.

The latch was designed to exert a clamping force of 1,000 pounds per strap; however, laboratory tests indicated that the most reliable seals were obtained with a 270-pound force per strap on the outbound seal and a 665-pound force per strap on the inbound seal. These loads required applying a force to the toggle handle of 4.5 pounds to unlatch on the lunar surface and 11.0 pounds to relatch. When fully engaged, the handles were locked against the ALSRC by a spring handle keeper, which had to be pushed aside to release the handle.

Pin-Latching Hardware

The pin-latching hardware was the system that was required to secure the ALSRC in the space capsule stowage compartments. The system had to be compatible with both the Lunar Module (LM) and the Command Module (CM). The pin-latch mechanism was designed as an integral part of the T-bar carrying handle. The handle was connected through a linkage system to the latch pins so that rotation of the handle extended or retracted the pins. Stops at the extremes of handle rotation, combined with a hard linkage system, provided positive indication of the latched or unlatched condition of the pins. The pin-latch mechanism and T-bar handle can also be seen in Figure 1.

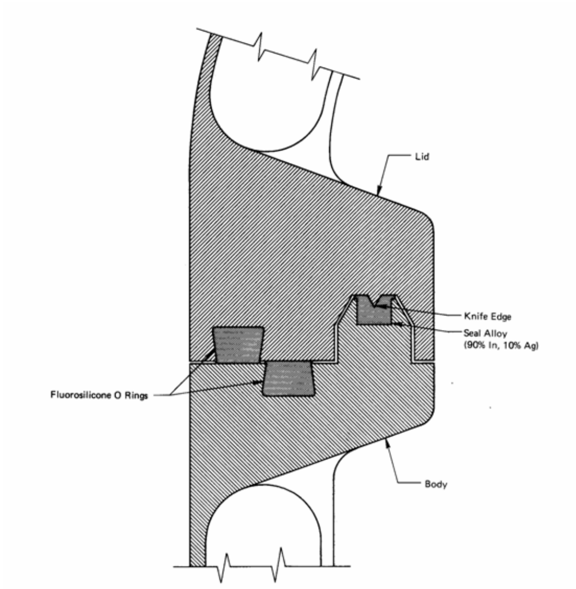


Figure 6. TRANSEARTH SEAL CONFIGURATION.

Figure 2

Locking the pins in position was accomplished by folding the handle downward against the box and forcing the handle into its latched position. The handle was retained in this position by two spring-loaded ball detents in the handle. A force of 1.5 pounds was required to unlatch the handle. This force, combined with the low mass of the handle, was sufficient to insure that the imposed shock and vibration conditions would not dislodge the handle.

Seal Mechanism

The ALSRC seal had one main function – to keep outside contamination from reaching the lunar samples, therefore it was necessary for the seal to be vacuum tight, as the atmosphere on the lunar surface is equivalent to a high vacuum on earth. Two important seal-design considerations were essential: (1) that the seal must not introduce any contaminants into the system, and (2) that a satisfactory seal must be made that utilized only a small force due to the fact that the astronaut's limited agility prevented him from exerting excessive force in closing the ALSRC.

ALSRC seal development work concentrated on designing an all-metal seal with a knife-edge that would cut into a soft metal to form a seal. The soft metal would be placed in a trough in the body of the ALSRC. Then, a mating knife-edge would be machined into the lid that would cut into the soft metal to make the seal. Since it was desirable to have a sealed ALSRC on the outbound journey as well as inbound, it would be necessary to effect two seals with the same surfaces. This double sealing would be possible with a proper design of the knife-edge and by applying additional sealing force for the inbound seal. However, alignment for the second seal proved to be extremely critical and beyond the capabilities of the ALSRC hinge system. Therefore, the all-metallic seal concept was considered to be unacceptable.

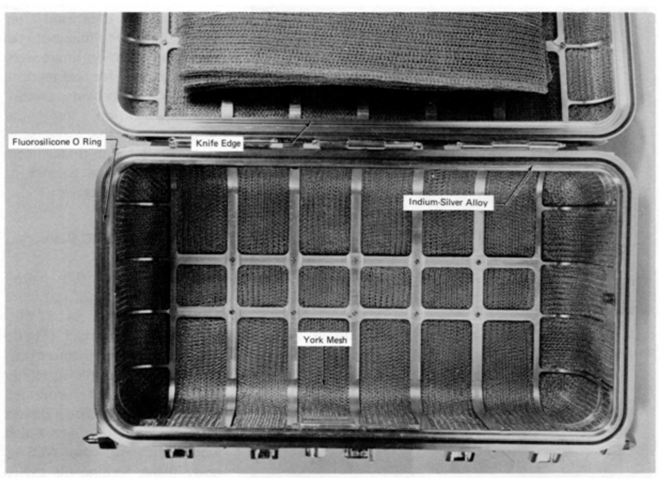


Figure 3

Composite Seal - NASA agreed to using a fluorosilicone 0 ring for the outbound seal, provided a metallic seal was used inbound and that the lunar samples could be isolated from the fluorosilicone O ring. Test results also indicated that it would be necessary to protect the sealing surface from being contaminated with lunar dust while the ALSRC was being packed.

The final composite seal design concept included a knife edge in the ALSRC lid, a trough of soft metal in the body, O rings in the lid and body, and a throwaway seal protector to cover the lid and body sealing surfaces during translunar flight and when the ALSRC was open on the lunar surface. An indium-silver alloy (90% In-10% Ag) was chosen as the material for the metallic seal. The final ALSRC vacuum seal system was capable of making a seal with an integrated leak rate of less than 1×10^{-7} std cc/sec.

Figure 4

Seal Cover and Spacer

For the outbound journey, the two fluorosilicone O rings were sealed against a Teflon seal protector. This Teflon seal protector is shown fitted on the ALSRC in Figure 15. The seal protector was removed just before closing the container on the lunar surface to permit the knife-edge on the lid to penetrate the indium-silver gasket in the trough of the container. This design provided the all-metal seal on the innermost edge of the flange, with the two fluorosilicone O rings providing secondary sealing.

Sealing Surface Protector

On their return to the LRL from the Apollo 11 flight, the ALSRCs showed evidence of leakage that was thought to be caused by lunar dust on the sealing surface. In an effort to correct this problem on future missions, a Sealing Surface Protector (SSP) was designed with flaps that would fold out over the entire lid as well as the seal protector.

Wall Protector

Selection of a material for a liner to protect the thin walls of the ALSRC during the mission was restricted since such factors as weight, resiliency, contamination, and outgassing had to be considered. Woven aluminum wire mesh was chosen and sewing layers of the mesh together with aluminum wire obtained the desired thickness.

Figure 5

For the Apollo 11 mission, 1/8-inch-thick pads were used as skin protectors. The pads were attached against the inside surfaces of the ALSRC between the ribs, as seen in Figure 3. The original designs of the ALSRC for the LM and CM were based on a loaded ALSRC having a maximum weight of 40 pounds. With experience gained from the Apollo 11 mission, a system study revealed that the ALSRC maximum weight could be raised to 80 pounds without making structural changes. However, to protect the LM from the additional impact loads it was necessary to isolate the ALSRC contents from the ALSRC proper. The desired isolation effect was obtained by lining the inside surface of the ALSRC with thirty precompressed layers of York Mesh.

Fifteen additional layers were used inside each end of the ALSRC.

ALSRC Fabrication

Ingots of Type 7075 aluminum were heated and forged to produce the ALSRC body blank (Figure 4). To allow stock for the handle attachments and other bosses to be machined from the blank, it was necessary to forge the front wall to a thickness of about 1 1/2 inches. In order to keep the die forces equalized, the rear wall was also forged to the same thickness. A similar forged blank was made for the ALSRC lid. The forged blanks were semimachined before heat treatment to remove the bulk of the excess stock and to leave, as nearly as possible, a uniform amount of stock for final removal. The heat treatment produced a yield strength of about 48,000 to 50,000 psi. Following the selection of a heat-treatment procedure, no difficulties were encountered in machining the blanks.

Few problems were encountered in the finish machining operation, even though the walls of the ALSRC between the reinforcing ribs (Figure 5) were to be only 45-mil thick.

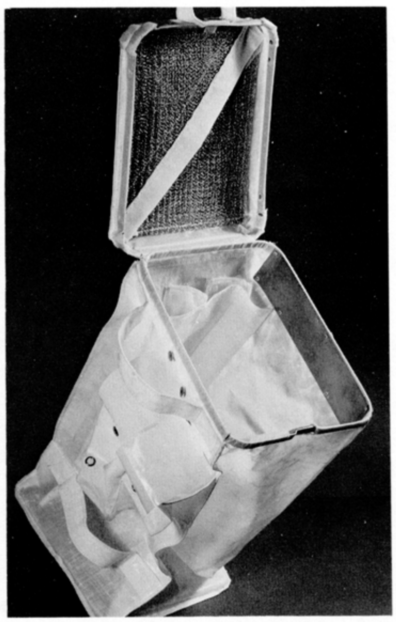


Figure 6

APOLLO LUNAR SAMPLE RETURN CONTAINER - INNER

Special Experimental Lunar Sample Return Containers

Several scientific requirements necessitated the inclusion of special sample containers within the ALSRC. There were four of these special sample containers, called inner containers, each of which was designed for a specific purpose. Included in this category of lunar sampling hardware were the Special Environmental Sample Container (SESC), the Gas Analysis Sample Container (GASC), the Core Sample Vacuum Container (CSVC), and the Magnetic Shield Sample Container (MSSC). These special containers provided additional protection and isolation for testing at the LRL.

Fluoroplastics in the Apollo Program

The Apollo program requirement that plastic materials used in the lunar sampling program be of the highest purity. TFE/FEP fluoropolymer was uniquely qualified for this service because of its good thermal and mechanical properties; and, more especially, because the polymer chains were composed of only carbon and fluorine atoms. Film and shapes molded of the polymer are extremely inert to both organic and inorganic chemicals; and, in addition, have low absorption coefficients for other elements and chemical compounds.

The following list presents the more important items which used TFE/FEP film and cloth:

1. Contingency Sample Bags
2. Contingency Sample Bag Pouches
3. Documented Sample Bags
4. Solar Wind Composition Experiment and Organic Sample Bags
5. Apollo Lunar Sample Return Container Seal Covers and Spacers
6. Apollo Lunar Sample Return Container Sealing Surface Protectors
7. Sample Containment Bags

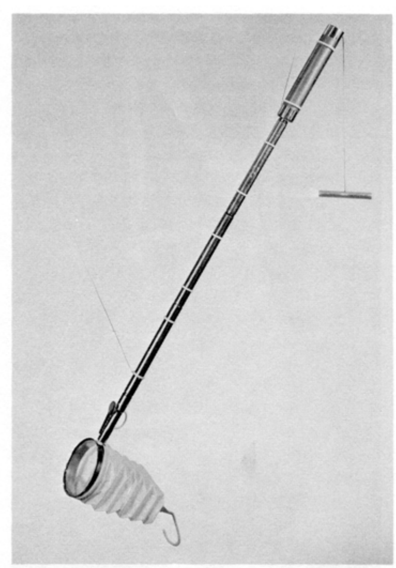


Figure 7

Bags for Containment of Lunar Samples

A variety of bags were required by Apollo astronauts in order to execute the sample collection activities efficiently and precisely. There were three generations of Sample Containment Bags (SCBs). The final type (Figure 6) was designed to segregate the hardware carried in the ALSRC by providing pockets for the SESC, MSSC, and three drive tubes. These SCBs were constructed of TFE Teflon cloth, sealed between two sheets of FEP Teflon film. Two straps were provided to permit easy handling of the SCB, and metallic hangers were included for mounting the SCB on the Lunar Roving Vehicle (LRV) and the Apollo Lunar Hand Tool Carrier (ALHTC). The inside surfaces of the Type-2 SCS lid and bottom were covered with a 125-mil pad of aluminum wire mesh to prevent puncturing of the SCB by sharp objects. The lid of the SCB was latched with a mechanism which would engage when the lid was pushed shut. In order to open the lid, the astronaut had to pull away from the SCB with the Teflon loop and lift up. This action released the latch and allowed the lid to be raised.

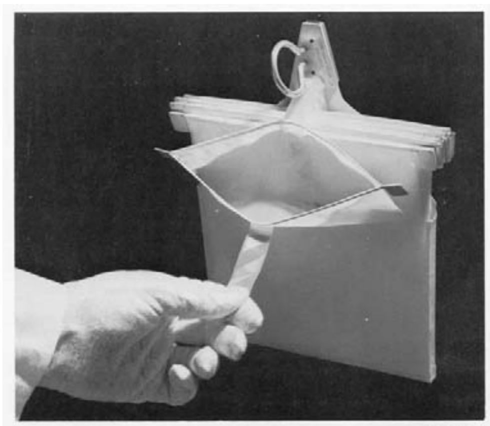


Figure 8

Contingency Lunar Sample Return Container - During the Apollo missions, sample collection activities did not start immediately after landing on the lunar surface. To ensure that a lunar sample was obtained from each landing site, the astronauts were provided with a sampler to obtain approximately one liter of lunar soil immediately upon reaching the lunar surface. During the translunar portion of the mission, the handle was folded up, and the CLSRC was stowed in the LM. Upon reaching the lunar surface, the astronaut grasped the end of the CLSRC handle, pulled the nylon cord through it until taut, and secured it in the notch that was provided. This action provided a stiff handle with which to scoop the soil.

Documented Sample Bag Dispensers (DSBD)- The documented sample bags and their respective dispensers all had a goal of providing the astronauts with a means of identifying and segregating individual samples. The types of DSBD assemblies reflect the evolution of documented sample bags for the Apollo program. Two distinct types of bags were used for these purposes – flat and cup shaped. The flat bag was included in the -DSBD and 20-DSBD, while the 35-DSBD had the cup-shaped bags.

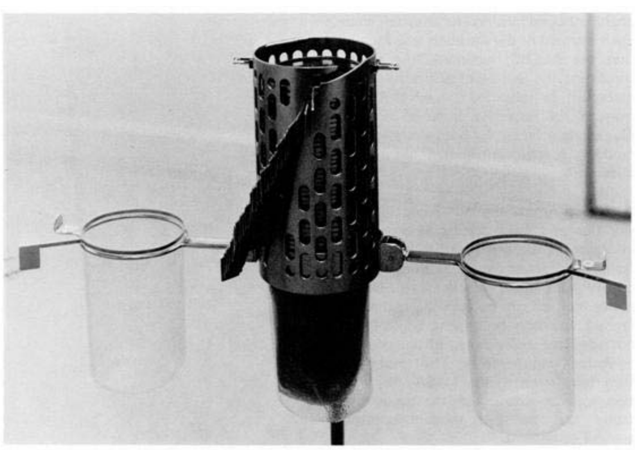


Figure 9

The bags in the 20-DSBD were fabricated from Teflon and in the same style as the bags in the 15-DSBD. The mounting bracket was designed to allow the 20-DSBD to be mounted on the astronaut's camera, his Portable Life Support System (PLSS), or the ALHTC, whichever was more convenient. The dispenser pocket, which contained the sample bags, was made from Teflon cloth/film laminate. The bags of the 20-DSBD were not preopened; but, rather, had tabs on each side. One tab was attached to the hanger ring and the other was free to be pulled by the astronaut. Upon pulling the tab, the astronaut would both open the bag and tear it free of the mounting ring.

The 35-DSBD provided a different type of bag for collecting and identifying individual lunar samples. The cup-shaped bags in these dispensers were held in a stack with the tabs offset to form

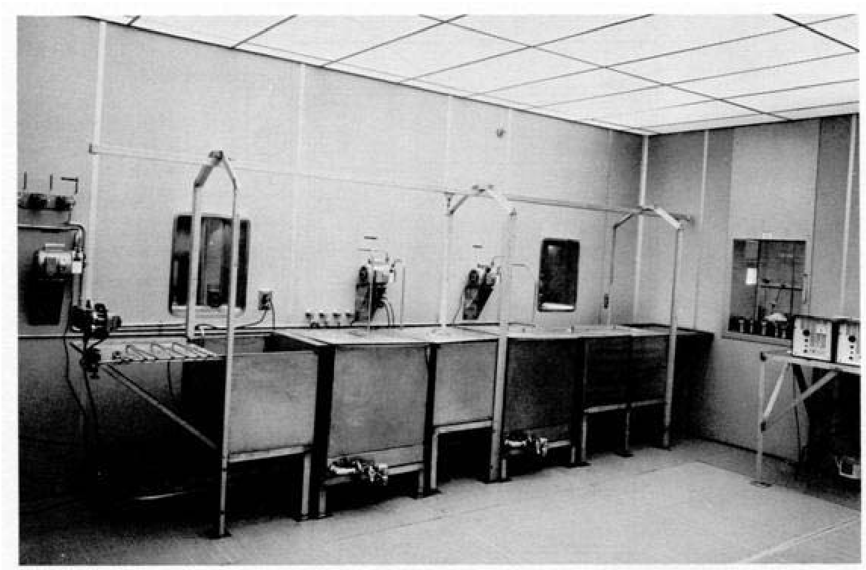


Figure 10

a helical shape. These tabs, which served as handles, were guided along a slot in the dispenser so that only one bag at a time could be removed. The dispenser was designed to mount on the ALHTC; and, when mounted, the two bag support rings were extended horizontally. During sample collection activities, the bags were removed one at a time and placed into the rings, as indicated in Figure 9. The samples were placed into the bags and the bags closed, sealed, and stowed similar to the other documented sample bags.

APOLLO LUNAR SAMPLE RETURN CONTAINER QUALIFICATION TESTING

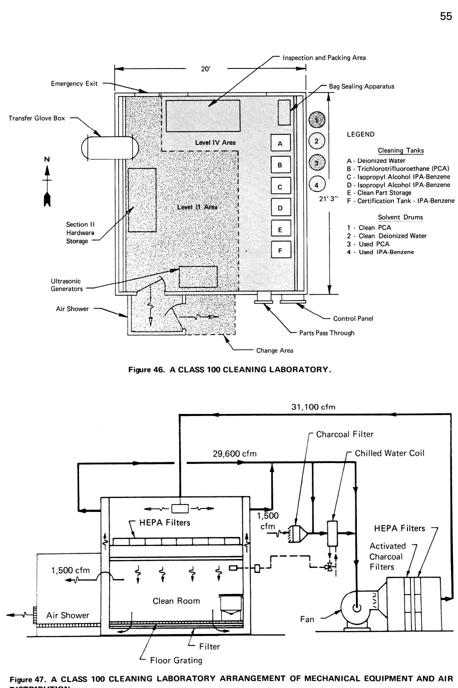


Figure 11

Qualification tests were performed on the ALSRC in order to demonstrate, by actual physical simulations of mission environments, the ability of the ALSRC and its contents to withstand these environments with no deleterious effects. Primary emphasis was given to vibration testing, since this activity subjected the ALSRC to the potentially most damaging mission conditions. The vibration qualification tests were conducted in stages paralleling the actual mission sequence: outbound mission - launch and boost phase and lunar decent phase; inbound mission - lunar ascent phase.

CLEANING AND CERTIFICATION

Clean Rooms, Cleaning Hardware, and Performance Tests

Two types of cleaning facilities were used: a Class 10,000[c] clean room for preliminary cleaning and a Class 100 clean room for final cleaning. The Class 10,000 clean room was used in precleaning the ALSRCs and hardware for Apollo Missions 11 through 14; the final cleaning was carried out in the Class 100 clean room. For Missions 15 through 17, both the precleaning and final cleaning were carried out in the Class 100 clean room.

The Class 10,000 horizontal-air-flow clean room was constructed from wood framing covered with sheet plastic. A high-efficiency particulate air (HEPA) filter system provided the air supply and recirculation.

A Class 100, vertical laminar flow (VLF) clean room, illustrated in Figure 10, was used for the final cleaning. Supply air, filtered through two prefilters and two banks of HEPA filters, was supplied through the room ceiling, discharged through a metal-grated floor (containing roughing filters), and returned through cavity walls on two sides of the room. As indicated in Figure 11, solvent vapor adsorption (benzene and isopropyl alcohol) was accomplished in the recirculated air by activated charcoal filters installed between the recirculating fan and the initial bank of HEPA filters. There were over 600 air changes in the room per hour. Both temperature and humidity control were maintained at 21 ± 0.6°C and 50 percent relative humidity.

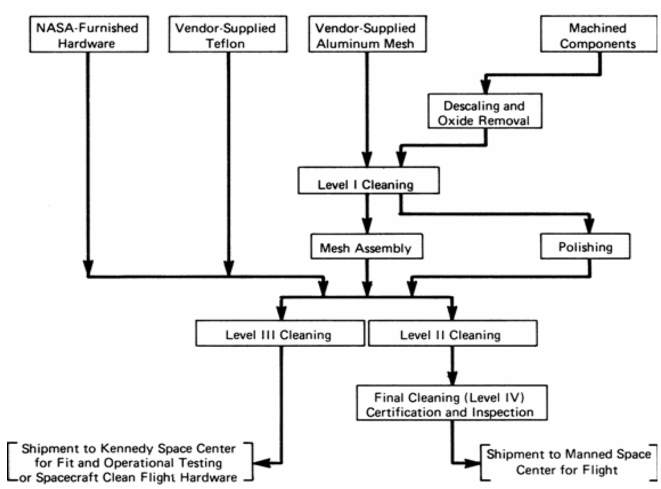


Figure 12

Certification of the Particulate Count in the Final Cleaning Area

Initial checkout of the Class 100 clean room indicated a cleanliness level of one particle (0.3 micrometer in size or larger) for each three cubic feet of air sampled in a test extending for over 400 hours[d]. Particulate counts were continuously monitored by the use of an automatic particle counter. These test results showed no degradation of the room's cleanliness from the initial startup of the facility through the ALSRC program, a period of over seven years.

Cleaning the ALSRC and Associated Hardware

In order to obtain maximum knowledge from lunar samples taken on the Apollo missions, it was necessary to develop special cleaning procedures for the ALSRC and associated hardware. It was mandatory that surface contamination be removed from all surfaces of the ALSRC and equipment, with specific emphasis placed on the removal of organic contaminants. Since the post-flight analysis could detect one part per billion of organic material in a lunar sample, it was necessary to clean the ALSRC and equipment to a cleanliness of 10 nanograms (10^{-8} gram) or less per square centimeter of surface area.

The precleaning procedure was divided into three basic operations, depending upon the desired cleanliness level required of the final product. These operations were identified as Level I, II, and III

[c] Clean room classes are defined in *Federal Standard 209.*

[d] Little, J. C. and Choat, E. E.; "Significant Parameters of Clean Room Design", *1965 Proceedings;* 45th Annual Technical Meeting of the AACC.

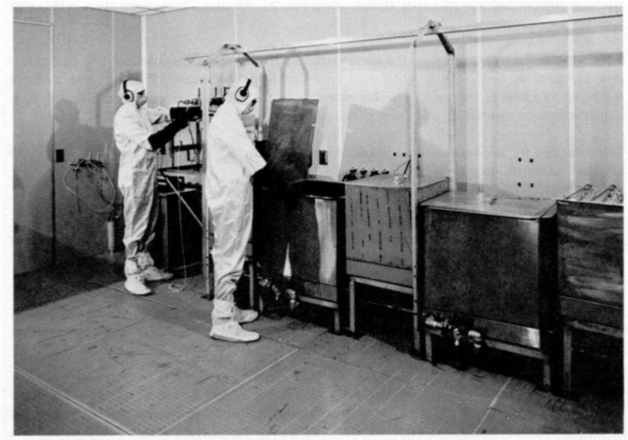


Figure 13

cleaning. Prior to these three levels of cleaning, all machined components were descaled and cleaned of their surface oxide coatings.

Final Cleaning - Level IV - Level IV cleaning was carried out in the Class 100 VLF clean room. Hardware cleaned to Level II was handled in the final cleaning area with Teflon gloves and stainless steel tools. Personnel in the final cleaning area wore surgical facemasks and monofilament nylon suits, as noted in Figure 13. Ear protection from ultrasonic noise and eye protection against ultraviolet light were provided for each employee. The operators wore surgical gloves underneath the Teflon gloves in order to retain body oils. Hardware that had been Level II cleaned and packaged was moved into the clean room area through a special pass-through window, unpacked, weighed, and given an additional ultraviolet inspection (Figure 14).

Figure 14

Chemical Certification

The method of cleanliness certification used for all of the Apollo sampling hardware involved a combination of nonvolatile residue measurements and gas chromatographic analyses. The methods of certification were used primarily because of their similarity to the methods used for the analyses of the lunar material for organics. Using this sampling procedure and analyses, all the Level IV-cleaned ALSRCs and hardware for Missions 12 through 17 were certified to contain less than ten nanograms of residue per square centimeter of surface area. The cleanliness specification of less than ten nanograms of residue per square centimeter of surface area was required only after the Apollo 11 mission.

Physical Certification

After final cleaning of the ALSRC and associated hardware, it was necessary to certify the operation of the many moving parts and perform certain physical tests to be assured of meeting the required specifications.

After the ALSRC was packed with all flight hardware and strap latches closed, the thermocouple wire was checked for continuity. The ALSRC was inspected under ultraviolet light for visible contamination, placed into two clean Teflon bags, and moved to the radiation monitor station.

DETECTION OF RADIOACTIVE NUCLIDES ON THE ALSRC AND ASSOCIATED HARDWARE

One of the major interests in the lunar material was to determine the levels of radium, thorium, and potassium, the most common naturally occurring radioactive nuclides in the earth's soil. To aid in this, it was required that all components of the hardware which could come in contact with the lunar material be fabricated from essentially radioactively free material. To assure that the ALSRC contained a minimum of the elements of interest, most stock materials and all finished components were measured for radioactivity, sometimes separately, and always as a complete package just prior to shipment.

USE OF THE ALSRC HARDWARE

Preparation Prior to a Mission

Following the fabrication, testing, cleaning, and certification of the ALSRC hardware, the appropriate items for each mission were prepared for flight. This preflight preparation entailed several activities both at the Y-12 Plant and at the LRL.

At Y-12, activities consisted primarily of packing the required hardware into the appropriate ALSRC. The packing sequence for Apollo 16 was as follows:

1. ALSRC with the OCS.
2. Add SCB with two drive tubes and the CSVC.
3. Add two 20-DSBD.
4. Add three drive tubes.
5. Add two drive tube cap dispensers.
6. Add one 20-DSBD.
7. Add two drive tubes.
8. Add one 20-DSBD.
9. Add SESC and drive tube cap dispenser.
10. Place filled SCB into the ALSRC
11. Fold sealing surface protector (Figure 15).
12. Close the ALSRC in the translunar configuration.

Figure 15

The packing was done in the clean room where the hardware was cleaned, and clean Teflon gloves were used to maintain the desired cleanliness level. Two considerations governed the packing of each ALSRC: (1) the order in which the astronauts needed to have access to the equipment, and (2) the capability of closing the ALSRC with all the desired equipment inside. Following the measurements of radioactivity of the ALSRC, it was shipped to the LRL for final preflight processing.

Prior to Apollo 16, activities at the LRL prior to the mission included unpacking the ALSRC, baking the hardware in an ultrahigh vacuum to drive off gases from the material, installing the vacuum seals, repacking the ALSRC, then sterilizing and sealing it in an ultrahigh vacuum. All handling of the flight hardware at the LRL was performed in a clean glovebox using only clean Teflon gloves. The outgassing bake was conducted in a vacuum conditioning chamber attached to the glove box via a sample transfer and sealing lock. Following this bake, the cool hardware was returned to the glovebox and the 0 ring and indium-silver seals were installed.

The ALSRC was then repacked for flight and placed into a special sealing fixture. This fixture supported the lid slightly above the body of the ALSRC to enable its interior to be evacuated. The ALSRC, in the sealing fixture, was then placed into the ALSRC sealing lock where it was heated to 121°C for 96 hours in a 10^{-8} torr vacuum for sterilization. After the hardware had cooled sufficiently (to ~ 50°C), the ALSRC was sealed remotely to maintain an evacuated interior. After sealing, the hardware was returned to the glovebox, the strap latches were fastened, the ALSRC was removed from its sealing fixture, and the miscellaneous external hardware was installed. The pressure rise in each ALSRC was monitored for three days after sealing in order to determine the integrity of the seal. While a slight pressure rise was noted due to residual outgassing, no abnormal rise in pressure was noted for any ALSRC, and the internal pressure at launch was estimated to be approximately 1 torr. Clean Teflon bags were sealed around the ALSRC and it was held in storage until time to stow it aboard the spacecraft at NASA-KSC.

For the Apollo 16 and 17 flights, only the sterilization and sealing activities were performed at the LRL. The outgassing bake was not performed due to the fact that each heating cycle softened the aluminum and, since the ALSRCs for these flights had been used before, they could not stand another bake without endangering their structural integrity. All such activities were completed between 45 and 90 days prior to lift off, and the ALSRCs were stowed aboard the spacecraft approximately 30 days prior to launch.

Use on the Apollo Missions

Two fully packed ALSRCs were taken to the moon on each Apollo mission and, with the exception of Apollo 13, were returned filled with lunar samples and surface experiments. No two ALSRCs were packed with identical configurations; in fact, there was a great diversity in the configurations. A summary of the hardware furnished by Oak Ridge for use on each mission is given in. The sealed ALSRCs were stowed on the MESA on the descent stage of the LM to allow easy access by the astronauts.

On the lunar surface, the astronauts removed one ALSRC at a time from its stowage compartment, set it on a special holding bracket, and opened it to use the hardware for the collection of samples. Upon completion of the sample collection activities, the filled ALSRC was closed and sealed. It was then stowed in the ascent stage of the LM for the return to the CM. Once the LM and CM had docked, the ALSRCs and other sample bags were transferred for the return to earth. Upon splashdown, all samples were rushed to the LRL for commencement of the scientific investigation. ALSRCs were opened within the LRL gloveboxes under vacuum or nitrogen atmosphere. The lids were removed to facilitate handling and some of the contents rushed to various time sensitive analysis.

Performance Analysis of the ALSRC Hardware

All items of hardware functioned reasonably well during their usage on the various missions. All ALSRCs were structurally sound when they returned to earth, and several were even used again on later flights after being refurbished. This reuse necessitated a slight modification of the gas analysis port, but it did not compromise the integrity of the vacuum container.

Several of the ALSRCs did not maintain a vacuum through the transearth portion of the mission, but these failures were not due to structural defects. Each time an ALSRC failed it was found that a foreign object (e.g., fabric from the SCB, dust, or even an aluminum bag tab) had managed to get into the seal area. The ALSRCs that did maintain a vacuum had a pressure between 50 and 100 millitorr when they were received at the LRL.

The only failure of an inner container was one GASC which was damaged when an attempt was made to place too large a sample into it. This action damaged the delicate knife-edge and prevented the container from sealing.

Several problems were encountered with the various sample collection bags. The originally designed SCBs, made of Teflon film, were found to lose their integrity after being packed in the ALSRC for several weeks and cooled during the flight to the moon. They tore and deformed as they were loaded with sharp lunar rock samples. This type of failure led to the bags being made of the Teflon fabric, which worked extremely well. A shortcoming of the documented sample bags in the 15 and 20-bag dispensers was the ease with which these bags tore away from their retainer rings. No attempt was made to modify the dispensers, but cautions were communicated to the astronauts on this subject.

Overall performance of the hardware furnished by Oak Ridge for the Apollo program was considered excellent. With only a few minor exceptions, there were no failures due to faulty design or fabrication of the hardware. The mission of the Apollo program, as stated in the Introduction, was successfully achieved, in part, by the performance and reliability of this hardware. And, since the design remained dynamic, this reliability improved with each mission. Cost of the ALSRCs were estimated to be $800,000 each, including development and testing.

ACKNOWLEDGEMENTS

We wish to acknowledge the valuable scientific and technical contributions made to this project by personnel from the Oak Ridge National Laboratory, the Oak Ridge Gaseous Diffusion Plant, and the Oak Ridge Y-12 Plant. Much of the information in this paper was obtained from “Apollo Lunar Sample Return Container - Summary Report”, Mundt, Schreyer, Wampler, February 16, 1973, and interviews with Dr. P. R. Bell, former director (and vacuum/ containment equipment designer) of NASA's Lunar Receiving Laboratory and nuclear physicist at the Oak Ridge National Laboratory.

Biography: Rodney B. Smith is a Mechanical Design Engineer specializing in glovebox/containment technology at the Y-12 Plant in Oak Ridge, TN, which is operated by Lockheed Martin Energy Systems for the Department of Energy. He has served on the Board of Directors of the American Glovebox Society in many positions including the office of President and served on the founding board.

Apollo "Moon Boxes" made at Y-12 by D. Ray Smith

Because of the 40th anniversary of the landing of a man on the moon, we will take a brief diversion in our Y-12 history series to jump forward in time to 1969.

Fig. 1. Apollo Lunar Sample Return Container (Moon Box) open showing plastic bags to segregate lunar material.

Here is the story of the Moon Box at Y-12.

Y-12 had a role in man's first landing on the moon. The historic record-setting landing was 40 years ago on July 20, 1969. Apollo 11 landed in the Sea of Tranquility and nearly 50 pounds of moon rocks and soil was returned to earth for study.

Y-12's role in support of the National Aeronautics and Space Administration (NASA) Apollo Program was to supply the "moon boxes" officially named the *Apollo Lunar Sample Return Container.*

The box was machined from a solid piece of aluminum. It was an exceptionally well made box that was seamless except for the lid opening which had a metalized gasket that firmly sealed when the lid was closed. Four metal straps secured the lid.

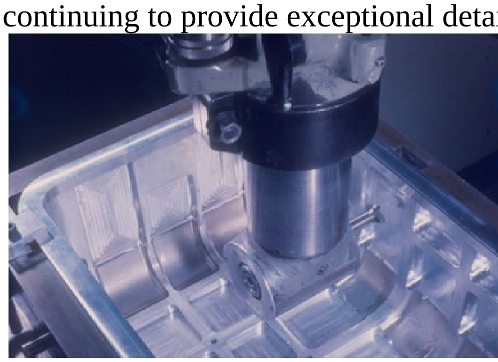
Six Apollo missions, flown between 1969 and1972, brought back a total of 842 pounds of lunar material including 2,200 separate samples of lunar rocks, core samples, pebbles, sand and dust. Most of the samples remain stored in the Apollo Lunar Sample Processing Lab and Storage Vaults at Johnson Space Flight Center in Huston, Texas.

Fig. 2. Machining the inside dimension and creating the rib construction for added strength on a milling machine at Y-12.

A small amount of the material is also located at the White Sands Space Harbor in New

Mexico. The samples have been studied by scientists in the United States and continue to be studied by various scientific groups around the world.

The result of this tremendous opportunity for studying the actual material from the moon has provided invaluable knowledge. Even now as NASA prepares to return to the moon, the materials are continuing to provide exceptional details



and much needed information.

In a report, compiled by F. D. Mundt, J. M. Schreyer and W. E. Wampler issued February 16, 1973, containing details of the design, development and fabrication of the moon box is found the following rational for its existence. While it was a wonderful conception in its heyday of actual use and proved to be a most practical tool, it is still a marvel of design and machining even today.

The report states, "In the late 1950's and early 1960's, plans were formulated to achieve the goal of a manned lunar exploration. The chosen program designation was Apollo, and it had as its prime objective the landing of American astronauts on the lunar surface and their safe return to earth with samples of lunar materials." "These samples were to be carefully chosen from each landing site so that earth-based scientists would be

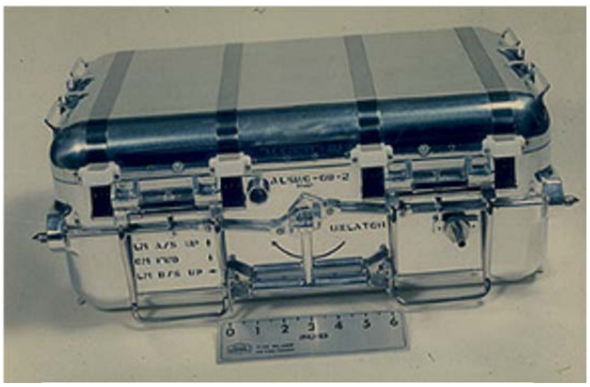


Fig. 3 Apollo Lunar Sample Return Container (Moon Box) packed up and straps

able to characterize the moon and hopefully answer some questions regarding the genesis of the universe."

"A Lunar Surface Experiments Program was established to fulfill these exploration experiments. This program consisted of two parts; (1) the Apollo Lunar Surface Experiments Package which was a self-contained group of experimental instruments and supporting subsystems that allowed lunar geophysical data to be returned to earth by radio frequency transmission, and (2) the Lunar Geological Equipment which included those tools used by the astronauts in gathering lunar surface materials for return to earth in the spacecraft." "Since only a small volume of samples could be returned to earth by each mission, the samples not only had to be carefully selected but also carefully protected from anything which might affect their scientific content. Such detrimental agents as the earth's atmosphere, contamination from the collection hardware, and breakage due to vibration of the spacecraft were of prime concern to the scientists awaiting the samples. " "These reasons, along with the fear of the unknown (namely biological contamination of the earth), led to the requirement for Apollo Lunar Sample Return Containers that would maintain structural and vacuum integrity throughout an Apollo mission." And that's where Y-12 came into the picture.

The moon box was not the first project Y-12 did for NASA. That was the "BIG" project or the "Blood in Gemini" sample container that was approximately two inches by four inches by one inch thick with a three inch handle on it. The container served to hold blood samples that were examined immediately upon the return of the Gemini spacecraft.

The project was used to determine if the flights beyond the earth's atmosphere would adversely affect human blood. Y-12 built the blood sample containers, took the units to the spacecraft, inserted the container of blood samples as the last item on the flight and then took the samples off as the first item to be retrieved from the spacecraft.

The experiment proved that blood was not altered when taken into space. But for Y-12 it proved to the lead in project that led first to the moon box project but has continued to provide a beneficial partnership between Y-12 and NASA over the years and even continues today.

Apollo "Moon Boxes" made at Y-12, part 2 — Y-12's moon mission, use of Teflon
By D. Ray Smith

Last week we noted that the 40th anniversary of landing astronauts on the moon was July 20. We also pointed out that Y-12 played a role in that tremendous achievement by supplying the moon boxes for the mission and for other Apollo missions as well. Y-12 also provided the Lunar Receiving Laboratory and managed its operation.

The report, compiled by F. D. Mundt, J. M. Schreyer and W. E. Wampler issued February 16, 1973, was quoted in last week's article. That report described the Apollo Lunar Sample Return Container (moon box) and the rationale behind its design, development and fabrication. Here are some additional details.

The report continues, "Major considerations in the design of the Lunar Geological Equipment program were: (1) the work-capability restraints imposed on the astronauts by their spacesuits, and (2) lunar gravity. Human-factor testing and astronaut training caused many changes to be made and guided the designers in much of the development of the hand tools and the Apollo Lunar Sample Return Container, especially the latching and sealing hardware design."

"In addition to the design requirements, there was also a requirement that all the hardware be cleaned to such a degree that residual organic contamination from earth could not interfere with the parts-per billion analysis of the lunar samples. "

"The contractual agreements implementing the development, design, test, and manufacture of the Apollo Lunar Sample Return Container were entirely based on interagency agreements between the National Aeronautics and Space Administration and the United States Atomic Energy Commission. Union Carbide Corporation's Nuclear Division as a prime contractor to the USAEC, accepted the work defined in the interagency agreement under the related-services clause of their prime contract with no change in the contractual fee (one dollar per year at the time … unlike Award Fee Contracts of today!). All work was performed in facilities owned by the USAEC."

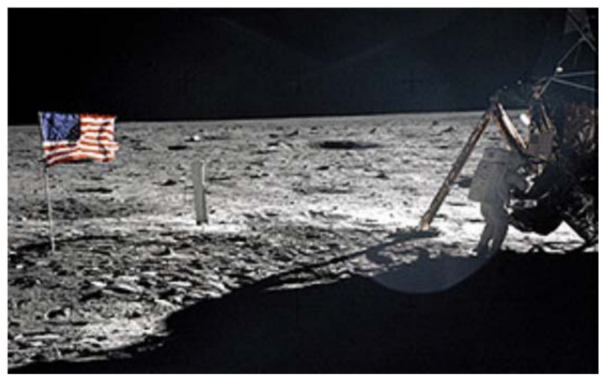


Fig. 1. Photo of Neil Armstrong, Apollo 11, Mission Commander at the Modular Equipment Storage Assembly's moon box (made at Y-12) of the Lunar Module "Eagle."

The choice of the Oak Ridge Y-12 Plant to perform the design, development, testing, and manufacturing functions of the ALSRC and associated hardware programs resulted from the consideration of several factors, including the following:

1. Complete capabilities were available at the Oak Ridge Y-12 Plant. These capabilities included development in the requisite disciplines, available engineering,

applicable testing facilities and experience, extensive manufacturing facilities, and extensive quality control and quality assurance organizations at both the contractor and government level.

2. Extensive experience and expertise had been acquired in the design, development, testing, and manufacture of unusual components for other USAEC facilities.
3. Scientific support in a large number of fields was readily available from the Oak Ridge National Laboratory.
4. There was a ready integration of the ALSRC and associated hardware with the vacuum system in the Lunar Receiving Laboratory (LRL) since that system was also designed and built by the Oak Ridge Y-12 Plant.

A Quality Assurance Program was implemented specifically for the project. The program was based on NASA's quality requirements but was also in accordance with UCC-ND Y-12 Plant quality doctrine which was understood to be among the very best in the world. The extensive quality program included all aspects of the project and related hardware to include both the moon box and the receiving laboratory, both of which had to be capable of maintain the lunar material in isolation from earth's environment.

Some 223 individual documents were written and issued that covered the requirements for the project and were provided to NASA for the project. The above quotes come from the completion report that covered all phases of Y-12's participation in the NASA Apollo program.

A major design consideration for the moon box was the retention of vacuum prior to and during the trans-lunar portion of the mission and the retention of vacuum after the container was resealed on the lunar surface. This was accomplished by a triple seal between the container body and lid. The body was fabricated from a single piece of aluminum, thus there were no welds or seams of any kind. The same seamless approach was taken with the lid, therefore, the only potential leak was the lid to body seal.

Y-12's metal working expertise was well known and obviously a primary reason for NASA's selection of the site for the work. There were many people who worked on the project and there were facilities created, such as dry rooms and other special purpose equipment items. The Lunar Receiving Laboratory was also an important part of the project. Y-12 personnel were engaged with most all aspects of the moon boxes and analytical laboratory.

There were two boxes on each flight. So there were many boxes fabricated, maybe as many as 16 or more. There is at least one in the Smithsonian Institute, maybe more. I am sure there are some still with

NASA in their Apollo displays around the country. There is a moon box at the American Museum of Science and Energy and, of course, there is a display at the Y-12 New Hope Center's Y-12 History Center that shows many of the specialty items. The display has a moon box that is open showing much of the contents. We also have a photo of the box on the moon.

The Y-12 History Center is open to the public from 8:00 AM – 5:00 PM Monday through Thursday and at other times by special request. There are several NASA sponsored events and online web pages that are commemorating the 40th anniversary of the moon landing.

The tremendous achievement of landing astronauts on the moon and returning them and their cargo of moon rocks and soil safely has resulted in a large number of technological advances. One such advance at Y-12 was the introduction of Teflon. The moon box was the first project at Y-12 where that product was used.

Conclusion:

The NASA program that would land man on the moon had been named Apollo after the Greek god of light and music during the Eisenhower administration. The name was given by then NASA director Ed Silverstein, who stated that he "was naming the spacecraft like I'd name my baby."[6] By 1969 when Apollo 11 landed on the Moon, President Kennedy's 1961 words rang true:

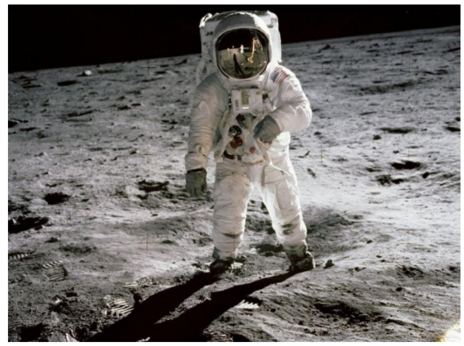
> *No single space project in this period will be more difficult or more important in the long-range exploration of space; and none will be so difficult or expensive to accomplish.*[7]

The Mercury, Gemini and Apollo Programs forever changed how man views the universe and even Earth. Suddenly, space was not so foreign.

Virgil I. Grissom with Gemini III spacecraft "Molly Brown"

However, in the same way space became more mysterious and confusing. With man's new knowledge gained from the lunar samples came new questions and more theories about the fabric of our universe.

Y-12 is grateful to the NASA website for many of the images used in this packet. For more information and images, visit NASA at http://www.nasa.gov/.



Apollo 11 astronaut Buzz Aldrin on lunar surface; Neil Armstrong is reflected in Aldrin's visor.

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[6] Murray and Cox, *Apollo*, p. 55.
[7] John F. Kennedy, *Special Message to the Congress on Urgent National Needs*.

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