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21. A UNIQUE CHALLENGE: EMERGENCY EGRESS
AND LIFE SUPPORT EQUIPMENT AT KSC

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In early 1968, there were some unusual problems related to emergency egress and rescue of Apollo astronauts from atop the Saturn V rocket on the launch pad. The huge quantities of hazardous propellants in the launch vehicle and spacecraft required that all ground personnel be cleared from the launch danger area; yet the fastest possible action would be required should rescue become necessary. This had been dramatically demonstrated by the January 1967 fire, which took the lives of three astronauts. As a result of the investigation following the fire, new materials were developed, flight hardware was modified, and test procedures were rewritten--establishing the framework within which a more effective rescue concept was to be developed. The target date for implementing the new rescue operation, including equipment changes and the training of personnel, was October 1968, when Apollo 7 was scheduled to lift off.

FACTORS AFFECTING RESCUE

Distances, heights, and the limited space within which ground personnel have to work were critical factors to launch-pad rescue. Figure 1, which shows Saturn V on the launch pad with the White Room and Mobile Launcher swing arms in place, illustrates how high above the ground the command module sat at launch. This was the way things were when the six-man closeout crew placed the astronauts in their couches and closed out the command module for lift-off. The White Room, about 109.7 meters (360 feet) above the ground, required some 2.5 minutes to reach from the base of the launcher.

Figure 2 is a ground plan of the KSC launch pads. The closeout crew left this area, at Roadblock 5A, about the time the cryogenic oxygen and hydrogen propellant loading of the launch vehicle was completed. From here, the closeout crew went up to prepare the command module for the astronauts, who arrived approximately an hour later. During this time and throughout the launch, a special KSC Fire Department rescue team was stationed about 610 meters (2000 feet) from the launch pad. It normally took this crew about 2.5 minutes to go from its station to the base of the launcher. This time plus the time required for the crew to ascend the umbilical tower to the command module level totaled five minutes. Actually, this time had been bettered, but under ideal drill conditions and after much practice. This five-minute response was a crucial factor because the human brain has little chance of surviving without damage after four minutes with no oxygen.

So time and space became the principal factors in developing the new rescue operation. It would be necessary to reach an incapacitated astronaut quickly with equipment small enough to function in the limited space of the White Room

and command module, and the first thing that would have to be done would be to get oxygen into his lungs to replace the toxic fumes or smoke that he had inhaled.

Figure 3 shows the full-scale training mockup of the command module and White Room. The White Room, with launch support equipment installed, is about one half the size of a 2.7- by 3.6-meter (9- by 12-foot) room. The command module, with a 0.67- by 0.79-meter (26- by 31-inch) opening and suited crew in place is shown in Figure 4. From the beginning of launch operations, the size of this hatch had been the most severely limiting space factor in crew rescue. It created a problem because a rescuer had to be equipped with an independent air supply to prevent his being overcome by an atmosphere that would disable an astronaut. As can be seen in Figure 5, which illustrates a typical rescue exercise conducted by the Space Division contingency crew, it would have been very difficult for a man to enter the command module wearing an air pack. In fact, at the time the new rescue procedures were being developed, a self-contained air pack as described was not available at KSC for a rescue man to wear when entering the command module.

TESTING THE CONCEPT

The first test rescue was conducted in March 1968. There were two major test requirements: fast reaction time in getting an oxygen resuscitator on an incapacitated astronaut and ability of a rescuer to enter the command module without being overcome.

After two astronauts and a NASA life support engineer, all wearing bulky space suits, entered the command module mockup, the hatch was closed. Three standard 15.9-kilogram (35-pound) oxygen resuscitator units were hung on the mockup access arm, and the oral-nasal masks were connected to hoses long enough to reach into the command module. At the GO signal, six firemen entered the White Room. Each was outfitted in full rig with 0.44-kilogram (14-ounce) felt turnout coat and wore a low-profile rebreather chest pack. Each carried a 3-meter (10-foot) breathing air hose, which could be plugged into an air manifold on the White Room ceiling. Three carried the resuscitator oral-nasal masks, which were equipped with rubber straps that could be attached to the "incapacitated" astronauts.

The test rescue plan was as follows: Once the hatch was opened, a fireman was to enter the command module, remove the plastic helmet from each of the astronauts, and apply the resuscitator oral-nasal masks. The astronauts were not to be removed from the command module. As it turned out, the rescue left much to be desired. It took over four minutes to apply the first resuscitator and nearly eight minutes to put on the last one.

THE SEARCH FOR BETTER EQUIPMENT

Clearly, better life support equipment was necessary. Over the next several days, every life support-related trade magazine was searched and many telephone calls were made to life support equipment companies and military installations. A miniature resuscitator, made for military field use, was finally located. Because it was small, it mixed a quantity of ambient air with the oxygen in the supply bottle to extend its period of operation to 30 minutes. Its size was attractive, but the mixing would not do; during a fire, the ambient air in the command module may be toxic. However, the unit did use some oxygen, the necessary ingredient and the miniature size was required.

The resuscitator company was asked if it could eliminate the air mixing and use pure oxygen without shortening the operating time by more than half. It was felt that if oxygen could be given quickly to the astronauts to stabilize their breathing, the chance of rescuing them would be greatly increased. A 15-minute resuscitator operation was sufficient for either removing the astronauts to safety or for obtaining another oxygen supply. The resuscitator company was very cooperative; it modified the unit and sent one to KSC.

Meanwhile, a way was developed by which the time required to get help to a disabled astronaut could be shortened. Since the closeout crew was with the astronauts until about 55 minutes before launch, time would be saved if they were trained to handle most incapacitating contingencies that occurred during closeout. The Fire Rescue Team would stand by at its usual place to respond if the situation got out of hand and could be responsible for its normal role after the closeout crew departed.

While this procedure was excellent for saving time, it had its drawbacks. Rather strict cleanliness standards were required for the command module interior and White Room. While these requirements would not apply in an emergency, the dirty residue from standard flame-retardant-treated coveralls could not be tolerated for normal closeout operations. On the other hand, the use of highly flammable Dacron clean room clothing used by past closeout crews had to be discontinued. The TV coverage of White Room activities also presented a problem. Emergency rescue or fire-fighting equipment had never been shown during astronaut insertion operations. Whatever was found to protect the closeout crew from fire or other hazards had to be clean and look normal or be stowed out of sight.

THE SEARCH FOR BETTER MATERIALS

Thus began another search, a tough one that continued into the early summer. No progress was made except to consider ordering the same cotton poplin coveralls fire jumpers wear. In an issue of Safety News magazine was an article on the results that Longhorn Arsenal, in Texas, had obtained in testing Nomex, a new, clean, fire-retardant material made by Du Pont. Coincidentally, the KSC Fire and Rescue Service was testing a new aluminized Nomex proximity fire suit.

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The individual in charge of developing Nomex for industrial use had achieved some success in outfitting race car drivers with flame-retardant coveralls, so he did not require much explanation to understand the rescue problem at KSC. His advice and help were sought, and the next day at 10 a.m. investigators at KSC concerned with astronaut rescue were looking at his samples and reviewing material test data. By 3 p.m., a garment had been designed and a supplier contacted.

The resultant closeout-crew coveralls are shown in Figure 6. Actually, the suit was a protective clothing system. The elements were a miner's bump cap, race driver's gloves, heavy shoes, and inherently flame-retardant coveralls with Velcro closure and a protective hood that folds into a quick-opening pouch on the back of the coveralls.

The suit looked good, and the fabric tested better than was anticipated. However, one problem had to be corrected before the suit could be used. Like all nylon garments, the coveralls could build up sufficient static electricity to discharge a spark. In the oxygen-rich atmosphere surrounding closeout operations, a spark could have a catastrophic effect. The Nomex developer was aware of this problem and provided a wetting agent. By allowing the coveralls to soak in a washing machine filled with water and the agent, the fibers were coated with a thin film of hygroscopic material that ensured a conductive surface to dissipate static electricity before it built up.

MORE PROBLEMS

Two problems had been resolved, but two others remained. No one had found a low-profile breathing unit small enough to be worn by a rescuer through the command module hatch opening nor had they found an efficient way to apply the rubber straps of the resuscitator mask while the astronauts were in their couches.

Only the resuscitators used on incapacitated personnel supplied pure breathing oxygen. In the interest of safety, rescuers breathe air. Thus the literature and telephone search was continued for a small, reliable self-contained air pack. In late summer, a small unit that appeared promising was located. Three were ordered for test and support of the Apollo 7 launch, and they arrived in time to be submitted to Bendix, the life support equipment contractor, for servicing and cleaning. Unfortunately, the unit not only was too dirty to service but did not meet the flow rates and time specifications claimed by the manufacturer. It was made to work, however, in time to support the launch.

The inadequacy of this unit focused attention on a problem that had been overlooked, one with possible serious consequences. The desire to obtain miniature, long-duration breathing equipment had caused the investigators to proceed in many directions attempting to combine the best features of several manufacturers' equipment. The Fire and Rescue Service was virtually building its

own equipment. At KSC, fortunately, a single function was responsible for servicing, testing, and certifying all life support equipment. As the different combinations of masks, regulators, tanks, hoses, and valves began to arrive for servicing, the life support technicians became increasingly concerned that the combinations might not be interchangeable. Enough workable equipment was put together to support the Apollo launch but it still needed improvement. As it turned out, the search for good rescue breathing equipment that satisfied the varied requirements of the several astronaut rescue configurations was to last a number of years.

Meanwhile, the miniresuscitator was being tested by the astronaut flight surgeon at KSC and by the life support contractor. The unit worked fairly well except for two difficulties: (1) the standard rubber-strap arrangement was still time consuming and (2) the seal around the oral-nasal mask was inflatable.

The latter became evident when the unit's compatibility with the altitude chamber was tested. One of the requirements in checking out an Apollo spacecraft was to run it through manned simulated missions in the steel vacuum chamber. Here the systems that had to operate in the vacuum of space were tested by the astronauts who would man them. The chamber simulates an environment of about 60.8 kilometers (20×10^5 feet) and, since this was a hazardous test, emergency egress requirements had to be met. Significant to the mask seal design was that rescue was programmed to occur at a simulated altitude of 7.57 kilometers (2.5×10^4 feet). Ingress and egress were made through an airlock. The problem with the inflatable rubber seal was that it changed size and shape when subjected to outside pressure changes. A seal inflated to fit an astronaut at 7.57 kilometers (2.5×10^4 feet), which is 37.9 newtons/meter² (5.5 pounds/inch²), would have been a poor seal at sea level.

This problem was solved when, on a trip to the home plant in Downey, California, one of the investigators was shown some of the life support equipment trailers that the Space Division physiologist had set up to support altitude chamber operations. The system included a large trailer with five or six seats at which breathing oxygen was available through a sweep-on head harness. (This arrangement is used by commercial airline pilots in the event of inadvertent cabin depressurization. In the airline operation, oxygen under light pressure is supplied through the mask.) The harness was of sturdy, nonflammable plastic that held the breathing mask tight against a person's face. The question was, would it also hold a resuscitator unit against a person's face while the mechanism force-breathed him? It was obvious that the sweep-on feature could be applied much faster than could the rubber-strap configuration.

The harness was quickly modified so that the miniresuscitator head could be securely attached (Figure 7). In forced breathing or resuscitation, there is a significant difference between the inflation resistance of the lungs of a conscious person and that of an unconscious one. Since it was impossible to get a volunteer to be an unconscious test subject, the investigators called on the expertise of the KSC physiologist, who simulated an unconscious victim as closely as possible. The astronaut flight surgeon and the physiologist tested the rig and it worked.

So a miniature, quick-don resuscitator was available for the Apollo 7 launch. This little unit supplied oxygen for 15 minutes at both sea level and 7.57 kilometers (2.5×10^4 feet); weighed 3.63 kilograms (8 pounds) (compared with 15.9 kilograms (35 pounds) for the usual unit); could be securely installed on an incapacitated person in less than 15 seconds (compared with several minutes for the standard oral-nasal mask); and its face seal was self-venting at any altitude. These attributes met the needs of the new rescue procedure, but another problem was to arise (described later) that set off a new cycle of investigation.

DEVELOPING THE BREATHING UNIT

Developing a lightweight, low-profile rescue breathing unit was a concerted effort by a team of NASA and Space Division personnel. Each team member was responsible for peculiar requirements in his own phase of the rescue operations, and all had made several false starts on inadequate or incompatible units. The missing link was a set of requirements and specifications that encompassed all needs and used available hardware of proven compatibility. A task team was set up to develop these requirements and specifications. Users, designers, testers, procurement specialists, and medical personnel combined their ideas in an effort to produce the best unit. The Surviv-Air Company, a division of U.S. Divers, presented the best combination of hardware that met the requirements.

There were two designs of a lightweight, low-profile mobile rescue apparatus that provided a 15-minute air supply and a self-contained, two-way communications assembly. One, called Astronaut Rescue Air Pack (ARAP), was worn by the Fire and Rescue Team that stood by from the time the astronauts were placed in their couches through launch. If rescue should be necessary before launch, the team would rush up the umbilical tower to the command module and pull the astronauts to safety. Figure 8 shows a fire rescue man in ARAP, which he put on before entering the hazardous area.

The second unit, called Emergency Egress Air Pack (EEAP), was placed on the command module level, and could be quickly donned by the closeout crew in the event that a fire or a toxic propellant leak suddenly made the atmosphere in the White Room unbreathable. The astronauts could also use the EEAP as a breathing unit if they had to leave the command module in an emergency without assistance from the Fire and Rescue Team or the closeout crew. They would remove their protective plastic helmets before putting on the unit. Figure 9 shows a closeout crewman in protective coveralls wearing the EEAP.

Both the ARAP and the EEAP units used had a quick-don Wilson Tite-Seal mask to which 7.9 cubic centimeters (2.8 cubic feet) per minute of air was supplied at null pressure of 0 millimeter of water. To exclude toxic vapors, the face mask incorporated an exhalation valve with a cracking pressure of 58.42 ± 7.62 millimeters (2.3 ± 0.3 inches) of water, thus maintaining a positive gage pressure at all times. A low-profile alarm whistle warned the operator when the pressure in the cylinders indicated the breathing air remaining was

down to about two minutes. This allowed time to reach a place with better air or to get another set of air cylinders. (More complete descriptions of these units, as well as recommended areas of use, are included in NASA Tech Brief 70-10680, which is available from the KSC Technology Utilization Officer.)

DEBUGGING THE RESUSCITATOR

The miniresuscitator, as previously stated, uses pure breathing oxygen. In terms of benefitting a person who is overcome from inhaling smoke or toxic fumes, pure oxygen is quite a different gas than air, which contains 20 percent oxygen. But oxygen presents a handling problem because of the ease with which certain materials ignite in its presence and because it greatly increases their burning rates. Indeed, these properties of oxygen caused an incident that complicated the investigation.

One night a life support technician was preparing a miniresuscitator for use. He stripped it, cleaned and checked the inner workings of the main regulator, reassembled it, and turned on the oxygen valve to test the unit. As he turned on the valve, a blue flame jetted from the regulator. Fortunately, no one was injured, but the investigation that followed revealed that the soft goods, the valve seats, and the regulator body were not compatible with oxygen.

In searching for a replacement regulator, it was found that no resuscitator on the market used materials compatible with oxygen. Moreover, there had been regulator fires, but injury or damage had not been of an extent that resulted in a demand for replacement of the incompatible materials with safer but more expensive materials. In addition, it was discovered that, while the U.S. Bureau of Mines closely checked portable breathing equipment, no federal agency regulated the safety of high-pressure oxygen resuscitators. The construction, flow rates, and cycling times were left to the manufacturer. This situation put KSC into the business of manufacturing oxygen equipment long enough to make the needed number of safe units. The Bureau of Mines and the National Institute of Occupational Safety and Health are trying to solve the problem, but it is a slow process.

The compact miniresuscitator now being used at KSC is shown in Figure 10. It is operated by turning one valve, which starts the process of automatically inflating and deflating a victim's lungs if he cannot breathe, thus supplying life-giving oxygen. A clear plastic window in the top of the oral-nasal mask permits the operator to observe whether the patient has spit up anything that might block his breathing. (A more complete description of the miniresuscitator is included in NASA Tech Brief 69-10319, which may be obtained from the KSC Technology Utilization Officer.)

Fortunately, there has been no reason to use the resuscitator, the rescue equipment, the procedures, or the training developed since the Apollo fire. This has not diminished their value, however. The concerted NASA-Space Division efforts have not only greatly improved the probability of a successful rescue on the launch pad, but may have benefited other rescues having no connection with the space program.

SPACE SHUTTLE: A NEW CHALLENGE

Today at KSC, plans are being made for launching and landing the Space Shuttle. This vehicle, which is launched like a rocket, will ferry payloads and passengers to and from earth orbit on missions lasting from 7 to 30 days. The Shuttle Orbiter makes a controlled landing like an airplane on a runway. There the similarity to an airplane ends, however, because when it is approached for safing and servicing, it will be like no airplane ever flown. Having just entered the earth's atmosphere at orbital speed and, through a series of glide maneuvers, it will have slowed to about 346 km/hr (215 mph) and made a controlled dead-stick touchdown. It will be spewing ammonia fumes from several outlets, as well as gaseous hydrogen, nitrogen, and possibly highly toxic hydrazine and nitrogen tetroxide vapors. Parts of the Orbiter will have been heated by the friction of entry to temperatures in excess of 2632°C (2000°F). This much frictional heat may be accompanied by a large static charge on the nonconductive ceramic tile surface.

The first tasks of the ground crew, after verifying that the Orbiter is not leaking propellants, will be to attach cold Freon lines and large air ducts to commence cooling the internal voids and compartments and the underside of the Orbiter's thermal-protective skin. Many ground-servicing tasks will follow, and they raise some important questions. What protective equipment will be required? What equipment is now in inventory to satisfy these requirements? What new equipment will have to be developed? One of the most important lessons learned from Apollo was to start answering such questions early, to keep pace with the program to ensure that its requirements were understood, and to work long lead-time items as soon as they become apparent. One Shuttle need already known, for example, is a new type of glove that will protect the landing-area technician's hands from heat and burns from propellant spills, yet not impair the dexterity required to perform the demanding task of connecting the cooling lines and ducts.

There will be other special requirements for protecting personnel during various hazardous tasks throughout Shuttle launch and landing operations. A team is already at work on these requirements. When the time comes, both personnel and procedures will be ready.

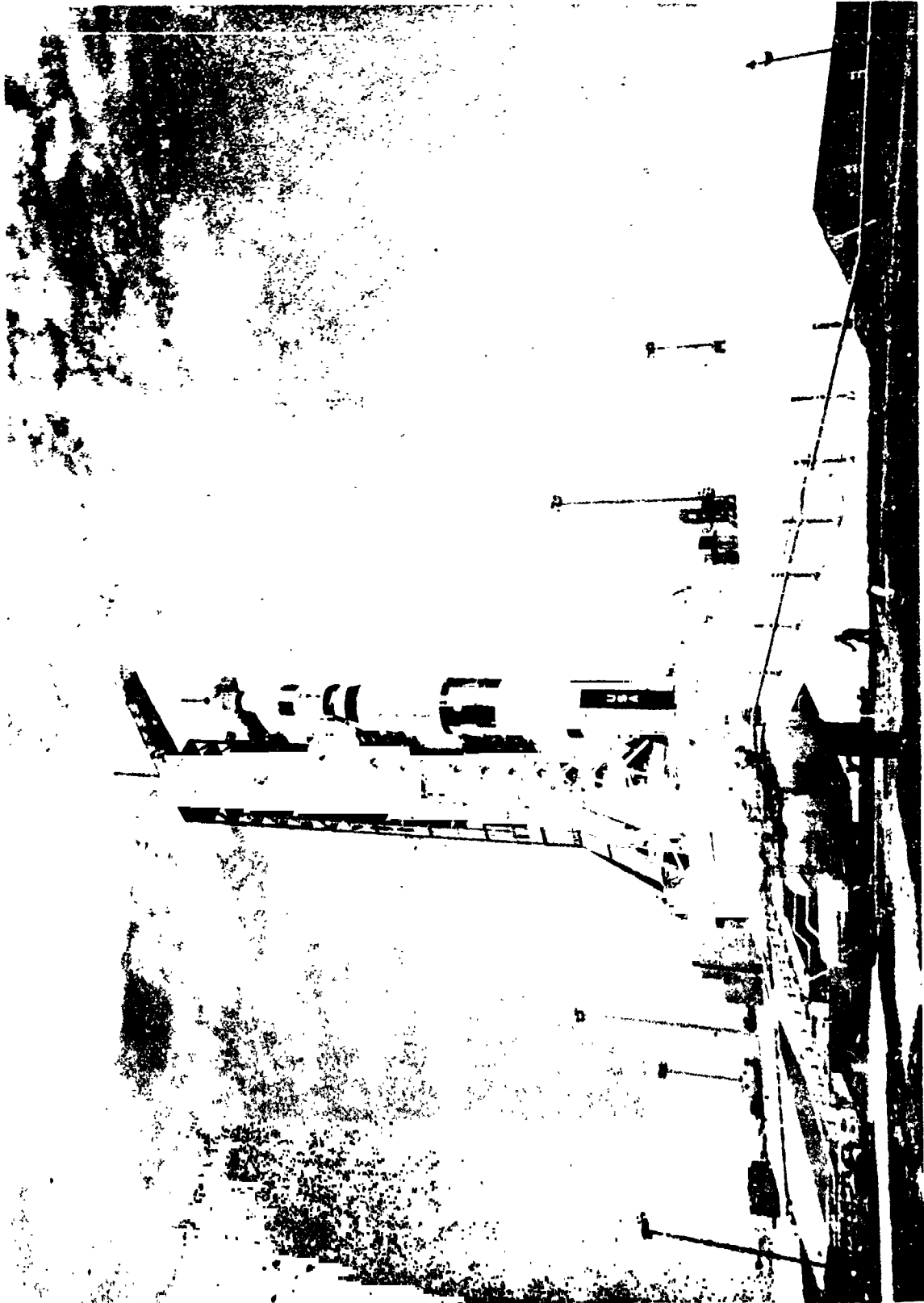


Figure 1. Apollo and Saturn V on Launch Pad

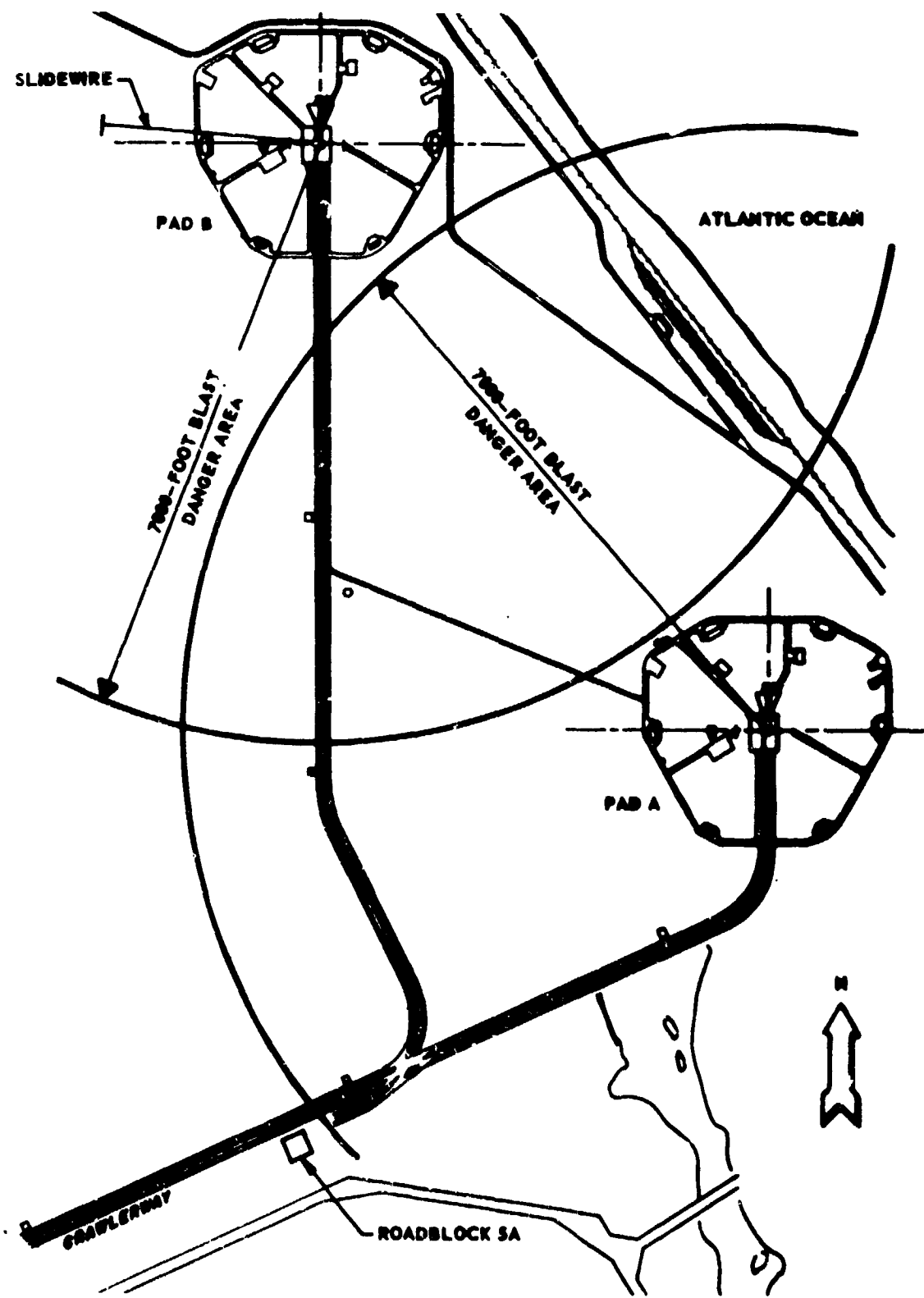


Figure 2. Launch Pad Ground Plan

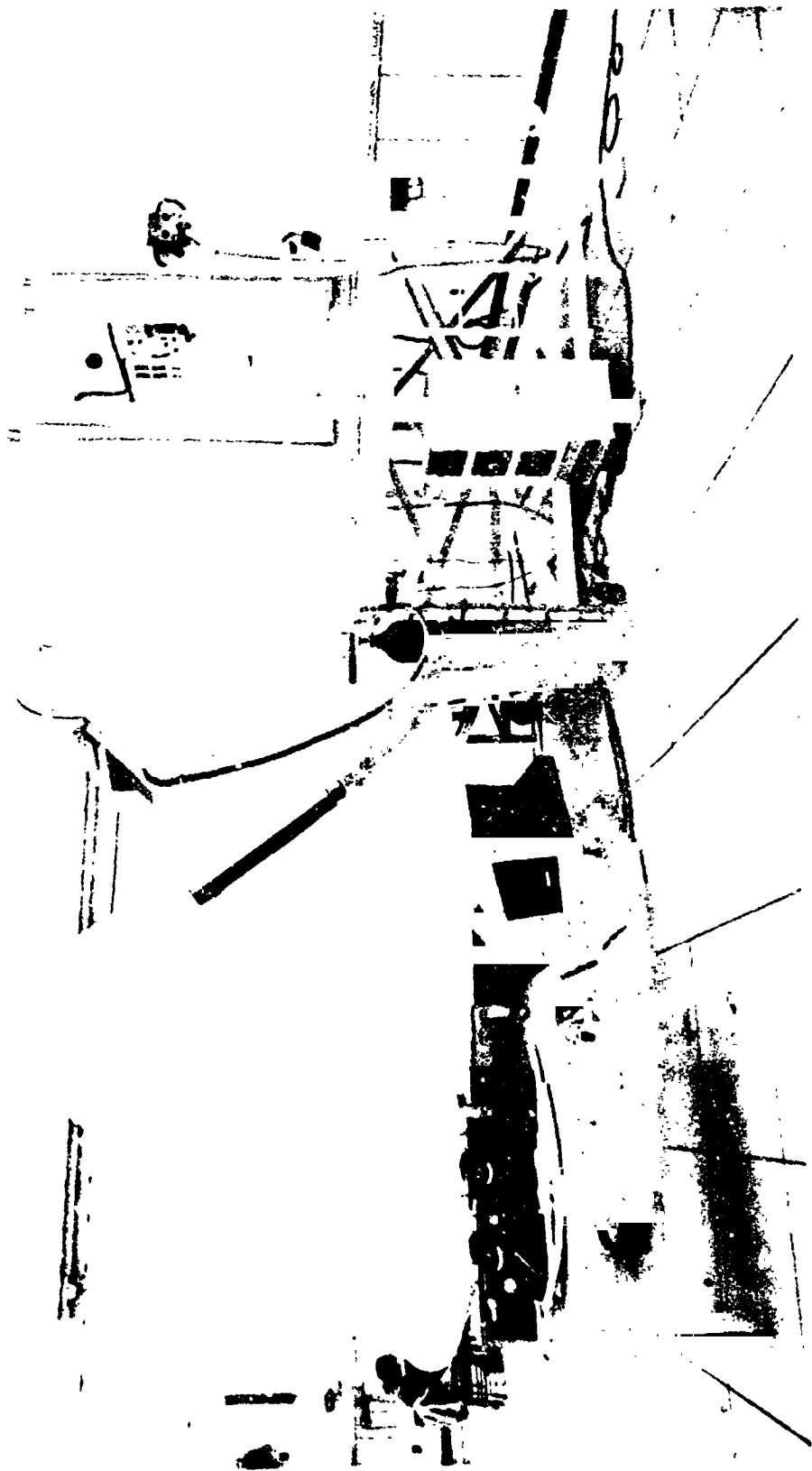


Figure 3. Mockup of Command Module and White Room

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Figure 4. Command Module Entrance Hatch



Figure 5. Test Rescuers, Wearing Scott Air Packs, Pulling "Victim" From Command Module Mockup



Figure 6. Closeout Crewman Dressed in Closeout Protective Clothing System

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Figure 7. Puritan Sweep-On Head Harness With Resuscitator Head Attached



Figure 8. KSC Fire Rescue Technician Dressed in Aluminized Nomex Proximity Protective Clothing and Wearing ARAP

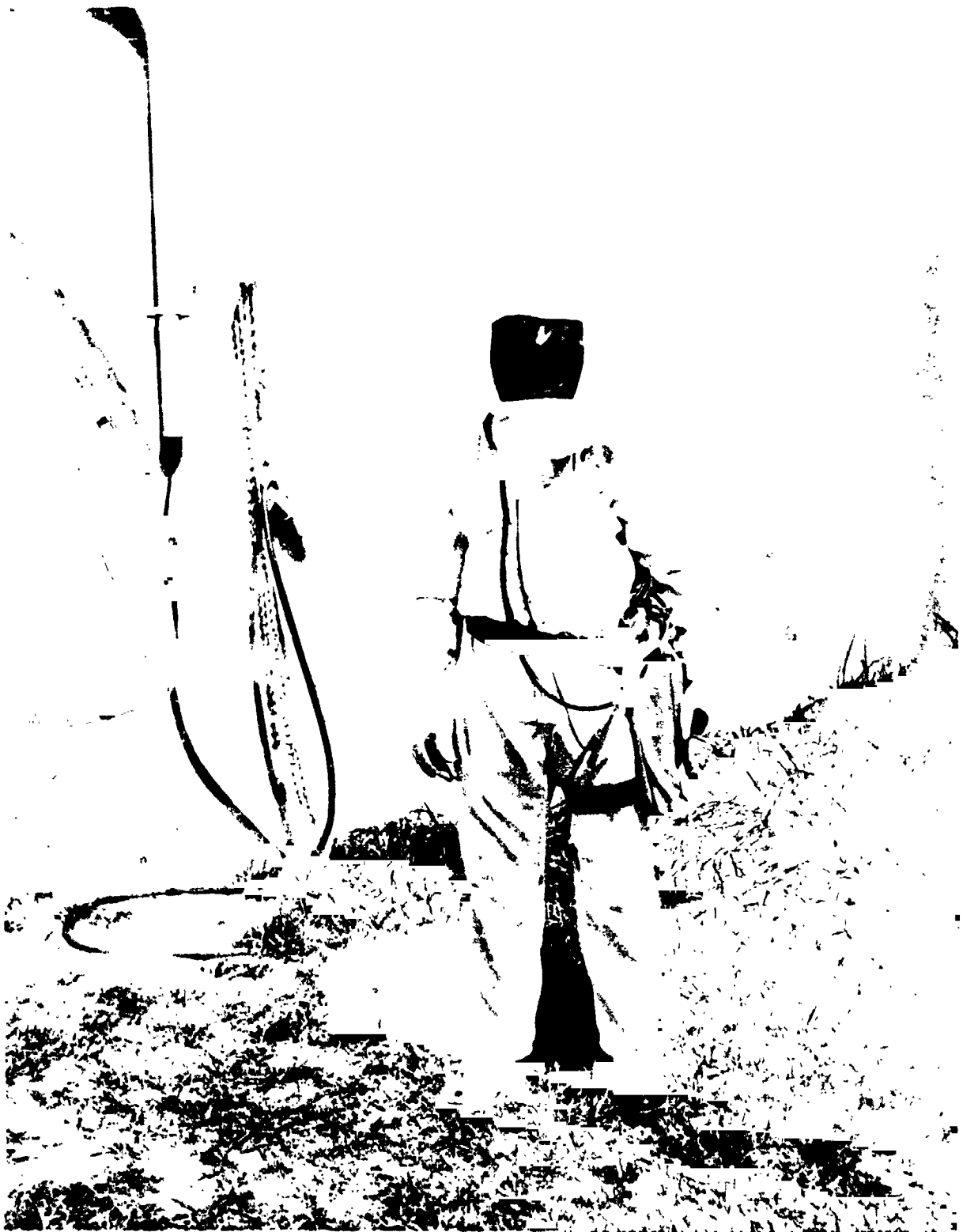


Figure 9. KSC Closeout Technician Dressed in Nomax Protective Coveralls and Wearing EEAP

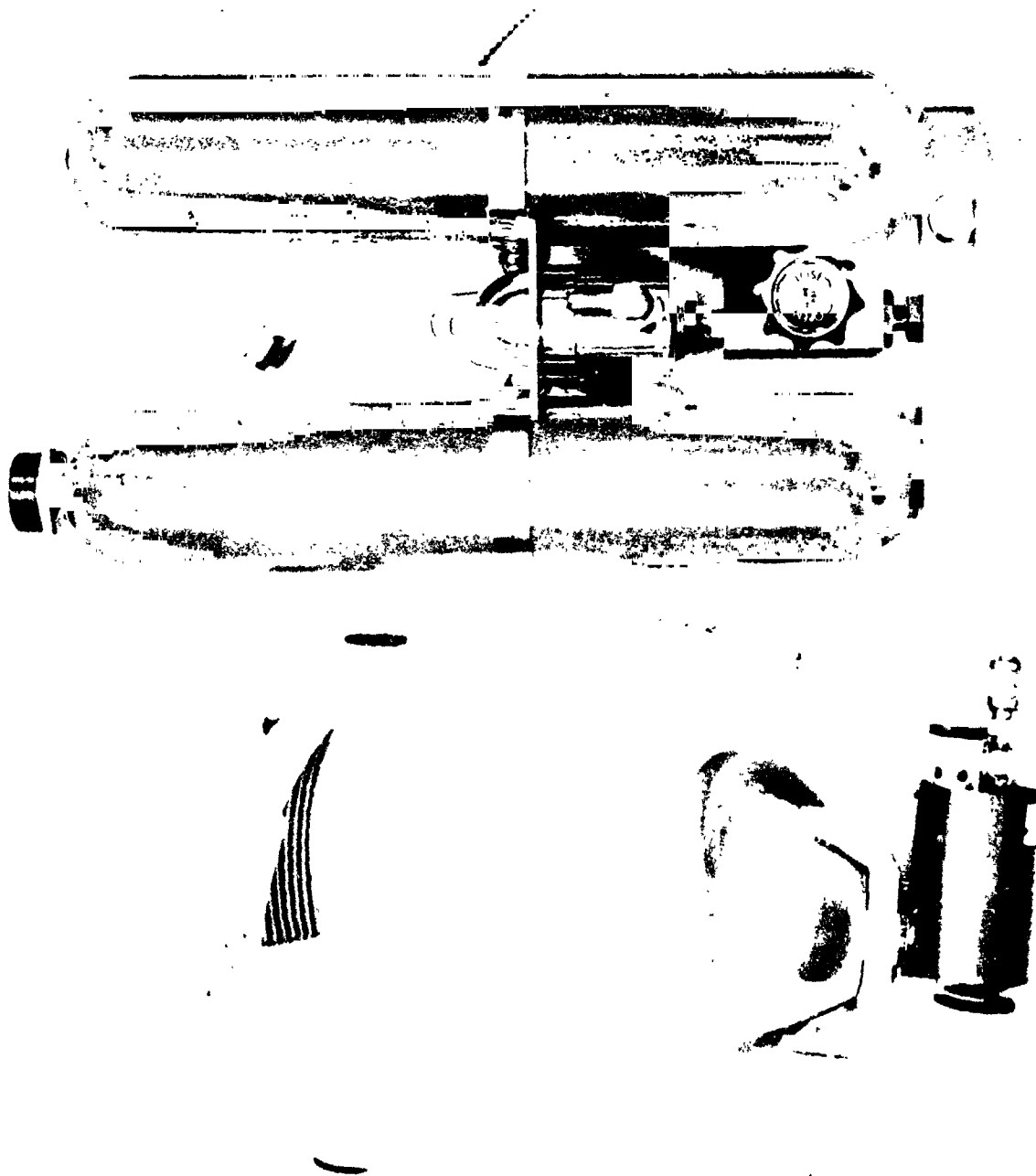


Figure 10. KSC Miniresuscitator