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SURVIVAL AFTER DECOMPRESSION TO A VACUUM

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INTRODUCTION:

In the past, the use of pressure suits has been restricted in military and research aircraft to emergency conditions where cabin pressure is lost. The space suit used in Project Mercury had the same primary function, and the suits that will be used in the initial Project Gemini flights are also designed to operate only under conditions of emergency cabin decompression. In later Gemini flights, space suits will probably be used for the first time as the primary pressure shell for the maintenance of habitable atmosphere for the astronauts. In the Apollo lunar landing mission, the space suit will again be the primary means for protecting the astronauts against the virtual vacuum of the environment during exploration of the lunar surface. The development program for the suits that will be used in the space environment includes extensive testing schedules in space environment simulation laboratories.

While every precaution has been taken to incorporate into the extra-vehicular Gemini and Apollo space suits various devices that will prevent complete loss of pressure in the event of a failure of the primary suit pressurization system, or in the event of a small puncture of the suit fabric, the possibility of a fall of suit pressure to near vacuum conditions must be considered. The probability of such an emergency which would require a large tear in the suit fabric, loss or breakage of a visor, rupture of gas supply hoses or umbilicals, or a failure of both primary and secondary

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pressurization sources is extremely small. However, the consequences in terms of survival and mission success clearly require a maximum of advance knowledge of the effects of decompression to a vacuum and of the requirements for recompression in the critical few minutes following such an event.

The same questions regarding the consequences of decompression apply to the situation where the crew member is in the vehicle but is not wearing his helmet or gloves and where a vehicle decompression occurs.

In each of the preceding situations, that is, in simulators, during extra vehicular missions, or within the vehicle there exists the possibility of rescue action. In order to establish mission rules for such action it is important to examine each case in some detail.

1. Space Environment Simulation Laboratories: A brief description of the Manned Spacecraft Center Laboratory is given in the following paragraph (ref. 1).

The chamber building is a high-bay structure of approximately 26,000 square feet which houses two large man-rated space environment simulation chambers, related services, and work areas. The larger of the two chambers provides simulated space and lunar surface environments and is primarily intended for combined tests involving men and Apollo spacecraft. The smaller space chamber will be utilized for life sciences and astronaut training studies in addition to tests of single modules of the Apollo spacecraft.

The administration building (approximately 33,000 square feet) houses the facility offices, the biomedical services, and the control and data handling areas.

The refrigeration building contains the liquid nitrogen services with a 280-kw capacity for the chambers' heat sinks. A 100,000-gallon tank provides the storage facility for the liquid nitrogen. The building also houses two parallel helium units which have a total capacity of 3.5 kw for servicing the cryopump system in the larger chamber.

The pump building houses the roughing pump system repressurization system, service water pumps, and air compressors.

The larger chamber, designated as Chamber "A", consists of a 65-foot diameter vertical cylinder, measuring 80 feet in height with a spherical top head and a bottom heat of a semielliposoidal form. The vessel is constructed of stainless steel and has an overall height of 117 feet.

The chamber has the capability of handling a spacecraft of up to approximately 75 feet in height and 25 feet in diameter.

There are four individually operated 25-ton hoists located above the top head of the vessel. The lifting hooks may be lowered through the removable sections.

Chamber "A" has the capability of supporting a spacecraft weight of 150,000 pounds in a vertical position on a rotating platform (lunar plane) measuring 45 feet in diameter. The lunar plane rotation (±180°) can be controlled, manually or automatically, to a maximum rotational speed of 1-2/3 rpm. The lunar plane surface temperature can be controlled from 80° K to 400° K.

A side-hinged vertical door for vehicle loading is located in the cylindrical section of the vessel with the bottom of the opening approximately 4 feet below the lunar plane level. The door provides a 40-foot diameter clear opening. The door is hydraulically opened, closed, and clamped from a remote control panel.

The chamber interior will be equipped with guarded walkways around the perimeter at the mid-manlock level and the upper manlock level.

Chamber penetrations (12 inches in diameter) for utility servicing of the spacecraft are located at each manlock level. Instrumentation penetrations will be through the hollow shaft of the lunar plane assembly.

There will be two manlocks, one double lock at the lunar plane and one single lock at the mid-chamber level. Provisions are made for the future addition of a single lock at the upper level. All manlock doors are side-hinged and provided with quick action clamp devices on all doors for initial seal. The clamp devices on all doors, except to the chamber, can be operated from one side only and will fall away or disengage when the doors become pressure sealed.

The chamber vacuum system consists of a combination of mechanical and diffusion pumps and a 20° K cryopump using gaseous helium. The chamber can be pumped down to 1×10^{-5} torr in 19 hours with a gas leak load of 27.6 torr/lit/sec.

The interior of the chamber is lined with black, nitrogen-cooled heat-sink panels at approximately 80° K. To the maximum practical extent, all surfaces in the chamber viewed by the vehicle consist of heat sinks. Cryopump surfaces, cooled by gaseous helium, are shielded from the test vehicle by heat sinks.

Solar simulators of modular design are mounted external to the chamber walls on its side and top. The simulators irradiate the vehicle through penetrations in the wall at an intensity of 60 to 140 watts sq/ft. The solar simulators are of the carbon arc type with a spectral distribution of approximately 0.25 to 3.0 microns. The target area of the side sun is 13 feet wide by 33 feet high, expandable to 20 feet wide by 65 feet high. The target area of the top sun is 13 feet in diameter, expandable to 20 feet in diameter.

The smaller chamber, designated Chamber "B", consists of a 35-foot diameter vertical cylinder 20 feet high with a hemispherical, removable, flanged head 10 feet deep, and a bottom head of a semiellipsoidal form 12 feet deep. The vessel is constructed of stainless steel and has an overall height of 42 feet.

The chamber has the capability of handling a maximum sized vehicle measuring 13 feet in diameter by 27 feet in height.

Vehicle access is provided by the removable top head. A rolling bridge crane with a capacity of 50 tons will be utilized to remove the chamber head or insert the spacecraft into the test chamber.

Chamber "B" has the capability of supporting a spacecraft weight of 75,000 pounds on a fixed simulated lunar plane measuring 20 feet in diameter.

The lunar plane surface temperature can be controlled from 80° K to 400° K.

Chamber penetrations for utility servicing of the spacecraft are located at the ground level and consist of several 12-inch diameter nozzles. Instrumentation penetrations will be through the center of the lunar plant.

There will be one double manlock at the lunar plane level with the same provisions established for Chamber "A" manlocks.

The chamber vacuum system will consist of a combination of mechanical and diffusion pumps. The chamber can be pumped down to 1×10^{-14} torr in approximately 3 hours with a gas leak load of 25.7 torr/lit/sec.

The heat sink description for Chamber "A" is applicable to Chamber "B".

The Chamber "B" solar simulators are the same type as for Chamber "A" except that Chamber "B" has a top sun only. The target area for the top sun measures 5.6 feet in diameter and is expandable to 20 feet in diameter.

Both chambers will be used for experiments, development work and training, and subjects will frequently be present in pressurized suits in the chambers. It was decided at an early stage of planning that it would be unwise to rely on the subject's being removed by rescue workers in pressurized suits, since the time taken for them to enter the chamber, reach the unconscious subject, remove him to a lock, and initiate lock recompression was an unknown quantity and would result in the loss of valuable seconds. The main chamber will therefore be recompressed with oxygen or air according to whether or not the subjects are wearing masks supplied with oxygen from an emergency suit supply. The recompression schedule is shown in figure 1 for a chamber recompression with oxygen. Nitrogen is injected initially in order to minimize fire risk. It can be seen that oxygen partial pressure does not return to sea level conditions until 25 seconds after decompression has occurred. At 30 seconds, the lock doors are opened and the rescue workers are able to approach the subject. The temperature changes during recompression are shown in figure 2.

An emergency condition such as that described in the preceding paragraph will require rapid therapy by the medical staff. In order for this therapy to be effective, it is desirable to know in advance the pathological changes which are likely to have occurred and the chances of survival.

2. <u>Decompression to a Vacuum During Extravehicular Space Missions:</u>

Complete loss of suit pressure in situations where crew members are far removed from their vehicle, either during free space extravehicular activities or during exploration of the lunar surface, is likely to be fatal. However, situations will exist where rescue is possible. For example, initial extravehicular operations in the Gemini mission will probably be undertaken with the crew member attached to the vehicle by a tether or by an umbilical. If suit decompression occurs it may be possible for the remaining occupant or occupants of the vehicle to pull the unconscious crew member back into the vehicle and recompress to 5 psia. On the lunar surface, similar rescue procedures could possibly be instituted provided the distance from the lunar excursion module is not too great.

Where a crew member is inside a vehicle during emergency cabin decompression to a vacuum, and, as in Project Gemini, is wearing his suit but may not be wearing gloves or helmet, the chances of survival are probably considerably greater than in either of the extravehicular missions. In this case the remaining crew member must dress the affected man in helmet and gloves and repressurize his suit.

Several questions must be answered in order that appropriate rescue procedures may be established for each of the instances given in the preceding paragraphs.

a. What are the chances of survival for varying time exposures to a vacuum before recompression is instituted?

b. What emergency repressurization schedules should be planned for the vehicle cabin?

c. How soon will the crew member recover consciousness after varying periods of exposure?

d. How soon and how well will the crew member be able to carry out his duties after varying periods of exposure?

e. What first aid procedures and subsequent treatment should be attempted?

f. Will irrational behavior or sickness present any hazard to the completion of the mission?

g. Should the affected crew member's suit be removed?

h. What training procedures should be instituted to familiarize crew members with the emergency?

A survey of some of the existing literature was made to determine its relevance to these questions.

The majority of the extensive experimental studies on decompression carried out since 1939 is not relevant to the problems of decompression to a vacuum in situations simulating those of manned space flight for the following reasons:

a. Most of the studies have been concerned with decompression sickness. Before astronauts embark on space missions, a pre-oxygenation period adequate to deplete body nitrogen stores will have been carried out. Denitrogenation will continue throughout the mission, since the cabin and suit atmospheres will be 5.0 psia oxygen during normal operating conditions in the pressurized vehicle, or 3.7 psia oxygen during extravehicular operations in space suits. It is emphasized that it is not implied that no decompression sickness problems will occur, but that decompression to a vacuum and its effects are probably little related to decompression sickness in the normal sense of the word.

b. Many of the studies have investigated the effects of explosive decompression occurring over time periods of much less than 1 second (ref. 2) and have been concerned with the mechanical trauma induced during this period. It is not envisaged that decompression of space suits would usually occur with such rapidity, and the primary concern is with the effects of exposure to the vacuum after the suit pressure has fallen.

c. Only a few studies (refs. 3, 4, 5, 6, and 7) have been made on the effects on animals of decompression to altitudes where the ambient pressure is less than the vapor pressure of body fluids at body temperature, and the majority of these studies have investigated final ambient pressures in the 20 to 50, mm Hg range. Boiling of the body fluids is bound to occur more rapidly when the ambient pressure is 1 or 2 mm Hg. The effects of exposures of the human hand to altitudes in excess of 63,000 feet is well-known. Pockets of water vapor form in the loose subcutaneous tissues and the skin of the hand becomes distended and uncomfortable. However, it is not possible to extrapolate from these results to the picture which would be seen after decompression of the whole body to a vacuum.

In spite of these dissimilarities to the situation to be expected on decompression in the space environment, it is useful to examine a characteristic study (ref. 3) in which unanesthetized dogs were exposed for varying times between 15 seconds and 4 minutes to an ambient pressure of 30 mm Hg after explosive decompression from sea level atmospheric pressure in a period of 0.03 second.

Following the explosive decompression, the following observations were made. The respiration became deep and marked abdominal distension occurred. The animal collapsed with mild convulsions and then became quiescent except for respiratory gasps which ceased after 30 seconds. Lacrimation, profuse salivation, urination, projectile vomiting, and defecation were observed. All fluids were bubbling on emission. Between 30 and 40 seconds after the decompression, a secondary swelling was observed in the hind limbs and abdomen. This swelling progressed headward until all the skin area was affected. Occasionally a swelling of the tongue completely filled the oral cavity. Upon recompression to 55 mm Hg the swelling was suddenly reduced. On return to atmospheric pressure, respiration was evident only in those dogs kept at the low pressure for 30 seconds or less. The heart was beating in all but two dogs exposed for 2 minutes or less, but no heart beat could be detected in dogs exposed for 4 minutes. Within 30 seconds after recompression to atmospheric pressure, respiration reappeared in all living dogs and became normal in 9 to 10 minutes. Effects on the nervous system observed were the temporary absence of the corneal reflexes in all dogs and a transient condition of decerebrate rigidity in 60 percent of the animals kept at low pressure for 1 minute or more. The dogs regained consciousness about 10 minutes after return to atmospheric pressure and appeared normal after 20 to 30 minutes. All 10 dogs survived multiple explosive decompressions to 30 mm Hg and exposures of 15, 30, 45, and 60 seconds to this low pressure. Six of the ten survived exposures of 2 minutes while two dogs exposed for 4 minutes died.

It was believed that the abdominal distension observed was caused by the expansion of intestinal gases. The subcutaneous swelling was probably caused by the vaporization of tissue fluid which occurred as a result of the lowering of the ambient pressure below the vapor pressure of the body fluids. All other findings were probably the result of anoxia.

It was clear from this study that neither the decompression itself nor the exposure to the low pressure for up to 1 minute was lethal and that the crucial factor affecting the probability of survival and time of recovery in summary was the time period of the exposure between 1 and 4 minutes.

In a study of the effects of explosive decompression on Rhesus monkeys, Gelfan (ref. 4) maintained several of the animals for 5 to 10 seconds at pressures of 42 mm Hg or less and then recompressed them at free fall rate in oxygen. Only 1 out of 152 monkeys failed to resume respiration, probably as a result of an inadvertent overdose of atropine. A number of the animals died in the succeeding 186 days mostly from tuberculosis or severe infestation with intestinal parasites.

Corey and Lewis (ref. 5) showed that rats could be decompressed repeatedly to 80,000 feet (21 mm Hg) without fatalities provided recompression was immediate.

While the importance of the time spent at low pressure has been clearly demonstrated, previous work has not examined the situation now being faced by all those concerned in the planning of manned space flight missions but has been concerned more with decompressions in aircraft.

Human subjects cannot be exposed to a vacuum. It was felt, however, that some indication of the answers to the questions posed in preceding paragraphs would be provided by an intensive study of the effects on animals when they were decompressed to a vacuum. A research program was initiated by the Crew Systems Division at the Manned Spacecraft Center in March 1963. The program was designed to investigate the physiological, pathological, and behavorial sequelae of decompression of dogs and monkeys to a vacuum, and to investigate, in the case of the monkeys, the effects of the decompression on task performance.

The program is being carried out jointly by the USAF School of Aerospace Medicine, the Department of Psychology at San Diego State College, and the 6571st Aeromedical Laboratory at Holloman Air Force Base.

Succeeding papers in this Journal will describe the results of this research to date.

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ABSTRACT

Exposure of man to a vacuum is an emergency situation which could occur on space missions or during experiments in space environment simulators. The probability of survival and the degree of subsequent recovery in the survivors will depend on many factors, but principally on the duration of exposure to the vacuum before recompression is completed. Specifications for the design and operation of recompression facilities and the planning of rescue procedures will be dictated by physiological, engineering, and operational constraints. Examples are given for the Gemini mission and for the space environment simulators at the NASA Manned Spacecraft Center, Houston, Texas. A program to investigate the physiological, pathological, and subsequent behavioral changes in animals exposed for varying periods of time to a near vacuum and recompressed to a 35,000-foot altitude with oxygen was considered essential to provide some indication of the probability of survival, the immediate and residual tissue damage, and the subsequent ability to perform tasks. Such a program was initiated by the Manned Spacecraft Center, and is being carried out by the USAF Aerospace Medical Division and the San Diego State College. The succeeding papers present some of the results of this investigation.

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REPRESSURIZATION RATE AND OXYGEN PARTIAL PRESSURE FOR SPACE ENVIRONMENTAL FACILITY, CHAMBER A

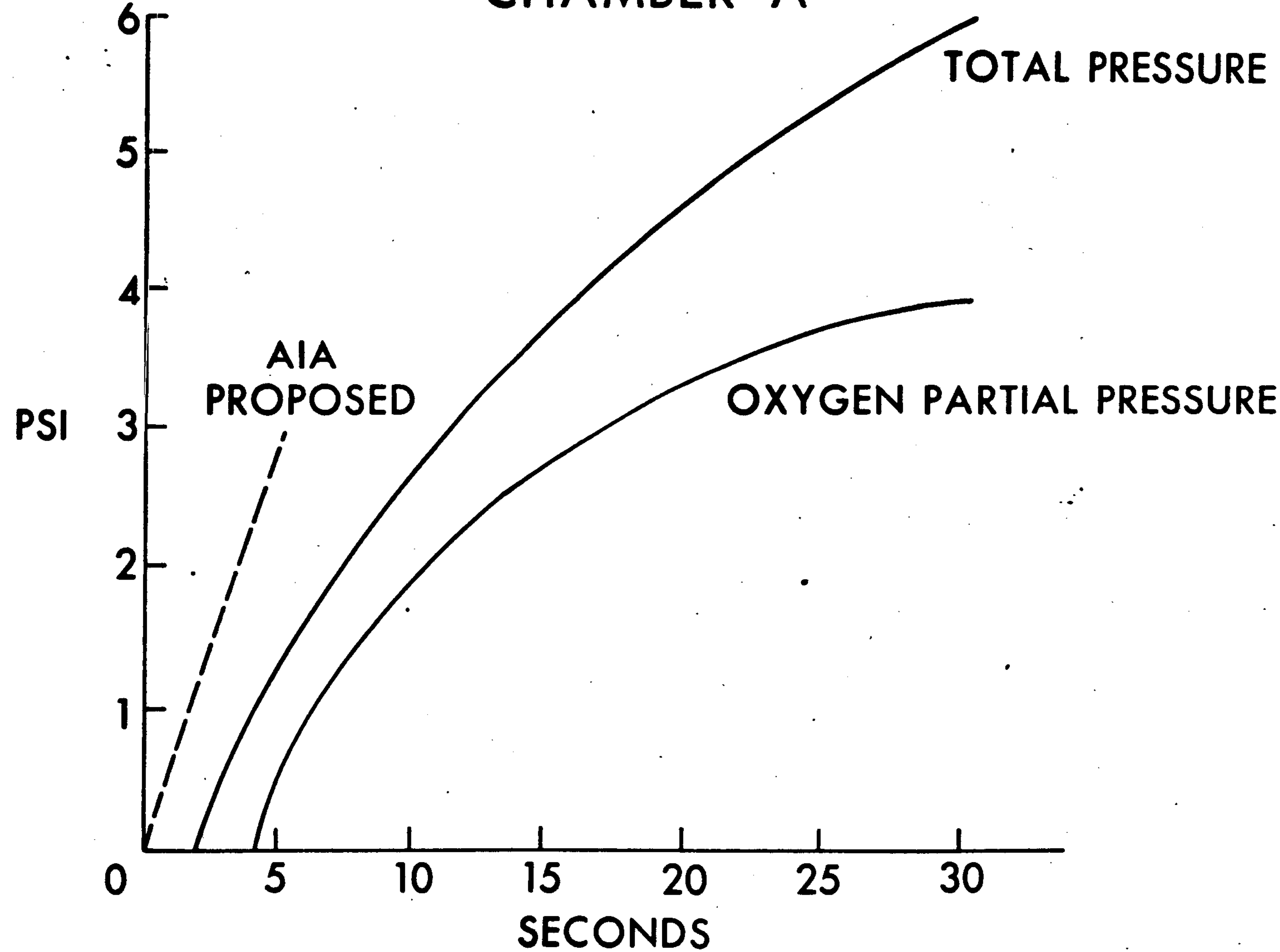

Figure 1

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ESTIMATED TEMPERATURE CURVES FOR CHAMBER 'A' DURING EMERGENCY REPRESSURIZATION

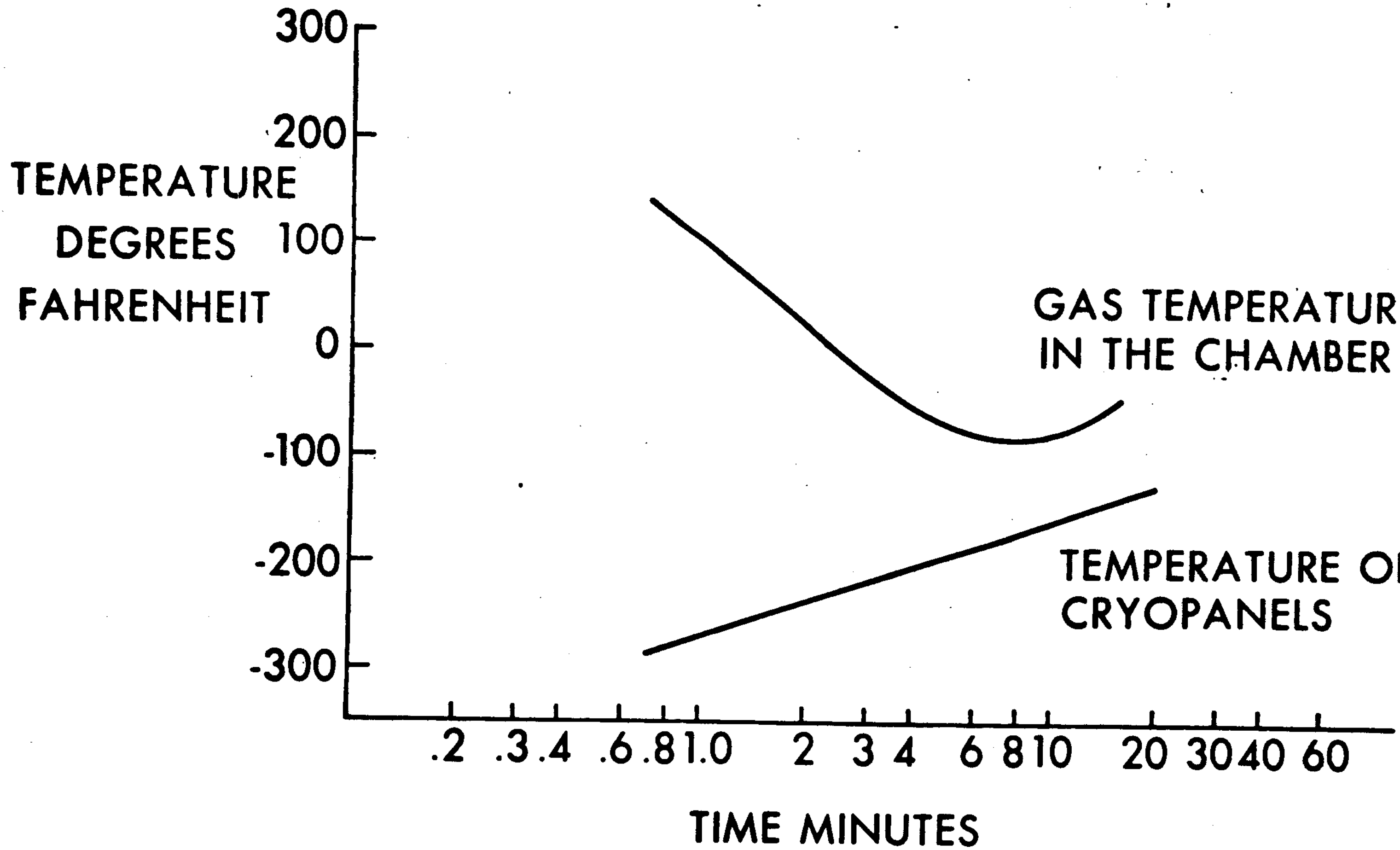

Figure 2

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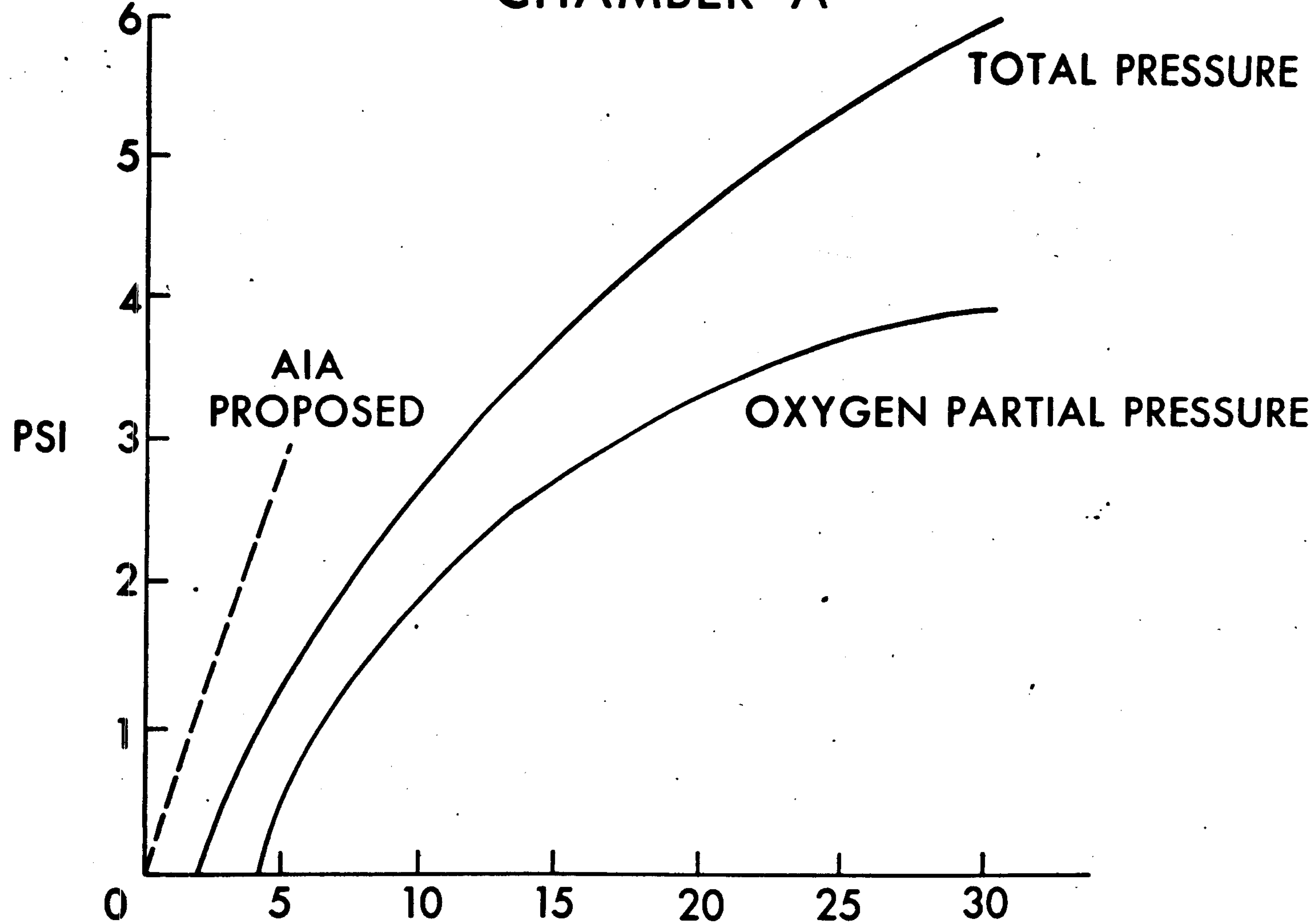
REPRESSURIZATION RATE AND OXYGEN PARTIAL PRESSURE FOR SPACE ENVIRONMENTAL FACILITY, CHAMBER A



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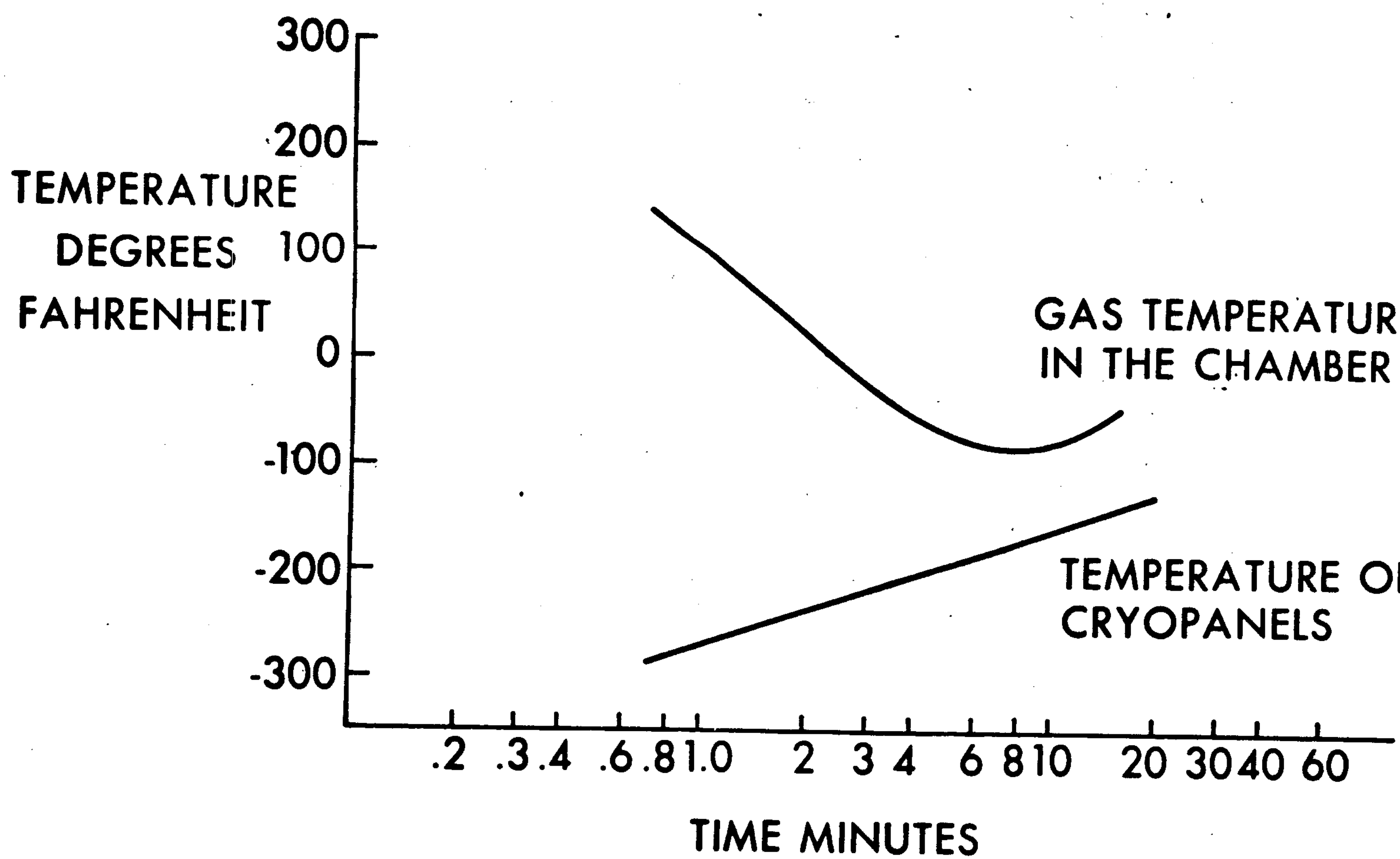

Figure 2