NASA Conference Publication 10140

Space Station Hyperbaric Medicine Ad Hoc Committee Meeting

Proceedings of a workshop sponsored by the National Aeronautics and Space Administration and held in Houston, Texas September 26-27, 1991

January 1996

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Michael R. Barratt, Editor,
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Acronyms

A&T	assembly and test
ACLS	automated control and landing system
ACRV	assured crew return vehicle
ADF	Avionics Development Facility
ALS	advanced life support (pack)
ARCHRS	advanced regenerable carbon dioxide and humidity removal system
ATA	atmosphere absolute
ATD	astronaut translation device
ATU	audio thermal unit
BIB	built-in breathing
BIBS	built-in breathing system
BTU	bus terminal unit
CHeCS	Crew Health Care System
CL	crew lock
CLDF	Clear Lake Development Facility
CMO	chief medical officer
CMRS	crew medical restraint system
CPA	combustion products analyzer
CPR	cardiopulmonary resuscitation
DCS	decompression sickness
DDS	data display system
DMS	data management system
DRIS	diagnostic radiologic imaging system
ECLSS	environmental control and life support system
EDU	engineering development unit
EL	equipment lock
EMCC	extended manned capability
EMT	emergency medical technician
EMU	extravehicular mobility unit
EVA	extravehicular activity
FEAT	final engineering and assembly test
GI	gastrointestinal
HAB	habitation
HAL	hyperbaric airlock
HBO	hyperbaric operations
HECA	hyperbaric environmental control assembly
HGPCA	hyperbaric gas and pressurization control assembly
HMF	Health Maintenance Facility
HSF	hyperbaric support rack
ICU	intensive care unit
IMS	ion mobility spectrometer

IV	intravehicular (e.g., IV hatch) intravenous
JSC	Lyndon B. Johnson Space Center
LESC	Lockheed Engineering and Sciences Corporation
MB	mission build (e.g., MB7)
MDSSC	McDonnell Douglas Space Station Corporation
MIA	missing in action
MMH	monomethylhydrazine
MPAC	multipurpose applications console
MRS	medical restraint system
MTC	man-tended capability
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
OPS	operations oxygen purge system
ORU	orbital replaceable unit
PIT	preintegrated truss
PMC	permanent manned configuration
POST	power-on-shelf test
ppb	parts per billion
ppm	parts per million
psi	pounds per square inch
PVC	photovoltaic controller
R&D	research and development
RCS	reaction control system
RTOP	Research and Technology Objectives and Plans
SCLS	space cardiac life support
SEI	systems engineering and integration
SLS	Space Life Sciences mission (e.g., SLS-1)
SMAC	spacecraft maximum acceptable concentration
SOMS	Shuttle Orbiter medical system
SPCU	service and performance checkout unit
SPDS	stabilized payload deployment system
SS	Space Station
SSATA	Space Station airlock test article
SSD	Space Station Division
STS	Space Transportation System
TCS	temperature control system
USC	University of Southern California
WETF	Weightless Environment Training Facility
WP	Work Package (e.g., WP-1)

Introduction

In September 1991, a previously established working group convened to discuss aspects of hyperbaric medical care for the Space Station (SS). A vigorous extravehicular activity schedule planned for SS construction and maintenance led to the inclusion of an on-orbit hyperbaric treatment facility known as the Hyperbaric Airlock (HAL). This presented several technical and procedural challenges requiring expert consultation. The Ad Hoc Committee for Space Hyperbaric Medicine, which had been involved since the early planning stages of the Space Station, had been formed to address these issues. Seven highly experienced and world-renowned specialists in hyperbaric medicine and decompression related disorders, representing a wide experience base in the aviation and undersea environments, have participated. This latest meeting at the Johnson Space Center, which involved five of these specialists, was the third convening of this group. The meeting enjoyed heavy support and participation from local hyperbaric and space medicine specialists from the NASA community. Specific topics addressed included the risk of on-orbit decompression sickness (DCS), treatment options for DCS on orbit, overviews of the HAL layout and operation, crew duty constraints following DCS, and specific hazards of hyperbaric treatment on orbit. Over the course of several formal presentations and panel discussion, decompression disorders and the role of hyperbaric medicine in manned space flight were covered thoroughly. These proceedings reflect this enormously productive meeting, and will serve as a benchmark for further work in this highly specialized and critical aspect of manned space flight.

Space Station Hyperbaric Medicine Ad Hoc Committee Meeting

September 26-27, 1991

DR. MICHAEL BARRATT: I'd like to introduce our committee members quickly. It seemed appropriate at this time to combine the two committees that have been involved with the hyperbaric aspect of the Space Station, and those that have been the Safety Committee and the Ad Hoc Medicine Committee per se. Now that we've somewhat solidified the major design aspects of the hyperbaric airlock (HAL), we're going to define the operation – the best use. This is, in effect, a conference of users who will be defining how we're going to optimally use the product. We had seven members we tried to get together; we had two who couldn't be with us: Dr. Hallenbeck and Dr. Flynn. They've been apprised of our proceedings and will be getting input by the mail.

First, I'd like to introduce Col. Thomas Workman. Col. Workman is an aerospace physiologist. He's been a full-time hyperbaric aerospace physiologist for the last 11 years or so. He is currently Chief of Hyperbaric Medicine at the Air Force Hyperbaric Center at Brooks Air Force Base. And, he's been involved in this committee since 1987.

Dr. Alfred Bove has extensive practical and research experience in hyperbaric undersea medicine spanning military service with Navy diving operations to bench-level research in diving physiology. He's on the editorial board for several prominent medical journals and has participated in several national and

BARRATT: (Cont'd) international committees on physiology, medicine, and safety in the hyperbaric and marine environments. He's currently Chief of the Cardiology Section at Temple University.

Mr. Steve Reimers: Mr. Reimers has a background in mechanical engineering. He has concerned himself with safety and engineering evaluation of countless hyperbaric facilities and hardware components. He was the past project officer for the Navy experimental diving unit and provided all construction and engineering services related to the design and layout of the man-rated chambers at the Naval Medical Research Institute. He's published extensively on chamber design, environmental control systems, and component evaluation, and he is currently the owner and chief engineer of Reimers Engineering in Arlington.

Dr. Hamilton: Dr. Hamilton has used his background in physiology and biophysics in extensive application to diving and aerospace environmental physiology, and has a particular interest in decompression, breathing gases, and effects of pressure. He served as a fighter pilot in the Air Force and Air National Guard, and earned the Distinguished Flying Cross in Korea while also solving ejection system equipment problems. He has developed numerous and creative decompression tables for specialized applications, including working on our own hyperbaric airlock. He is currently the principle of the consulting firm Hamilton Research, Ltd., in Tarrytown, New York.

Dr. Pilmanis: Dr. Pilmanis is a Ph.D. in physiology. He specialized in aerospace physiology and is currently chief of the high-altitude protection function for the U.S. Air Force Crew Systems Division at Brooks Air Force Base. He has done

BARRATT: (Cont'd) extensive research in altitude decompression sickness – in particular ebullism and, most recently, denitrogenation at altitude. He is a former Director of the USC-Catalina Hyperbaric Treatment Facility and has extensive practical experience in the treatment of air embolism and decompression sickness.

With that, I'd like to go ahead and get started a little bit early. Dr. Charles Lloyd, who is the NASA project director for the Health Maintenance Facility, will give us an overview of the current Space Station configuration as a result of recent restructuring.

Overview of the Current Health Maintenance Facility

DR. CHARLES LLOYD: Good morning. It's welcoming to see some old faces and many new faces representing NASA. I appreciate that you folks took the time to come in and talk about a very important aspect of medical care for Space Station Freedom that, so far, has survived and stayed with the Station. I'm going to talk about some of the restructuring aspects of it. There has been a fair amount of time and effort directed at making sure that we keep the medical aspects in place. We have good medical care for Space Station Freedom as well as for projection to the advanced programs for lunar and Mars and so forth. There have been many changes, not only in the Station but in personnel. Mike Barratt is now representing KRUG Life Sciences for hyperbarics, and there are several old faces in here: Before him, it was Bill Norfleet; over on the other side, Barb Stegmann by him; and you didn't see me at the last conference because we had Joe Boyce at the helm. So, we've

LLOYD: (Cont'd)

lost a fair number of folks, and we all define the hyperbarics area. We have a changeover in many other positions – such as Jeff Davis as branch chief. We now have Roger Billica as our branch chief. There's been a restructure of SD2, the Medical Operations Branch, and of Space Station folks in this particular area. The restructure of Station is even more fascinating. We have had a restructure of turbo, scrub; I think they're running out of words, so that means they have to lock down now. And, I'm really happy to see that; but there is one on the forefront out there.

I like to watch The Weather Channel. You know, the weather changes every day; and Space Station is sort of like that. The latest is a 90-day Orbiter we're going to reconsider – it was considered in the past, and it's being brought up again. So, in light of everything you're going to hear, there's something I'm not going to talk about. That is this 90-day Orbiter Program, which I'll highlight in part where it would stop us in the development of Station for a while. But with that aside, let's take a look at the handouts (FIGS. 1, 2, and 3). Before we went through scrub, turbo, and so forth, we had the following layout: There was a first element launch in March of 1995. Now, I'm too old for this program because I remember when first element launch was in 1993. And, I had slides that said the whole Station was going to be up in the early 1990s. It is refreshing to see that first element launch in the program says, "We've got to get it off the ground; we've got to go forward, so let's not move that date"; and that has remained the same. One of the subtleties, however, is that the complexity of what first element launch will be has been downsized. Back in the old program, we went to what was known as man tended and, in this particular phase, there was going to be a short period of time in which you see us going to permanent manned – it really

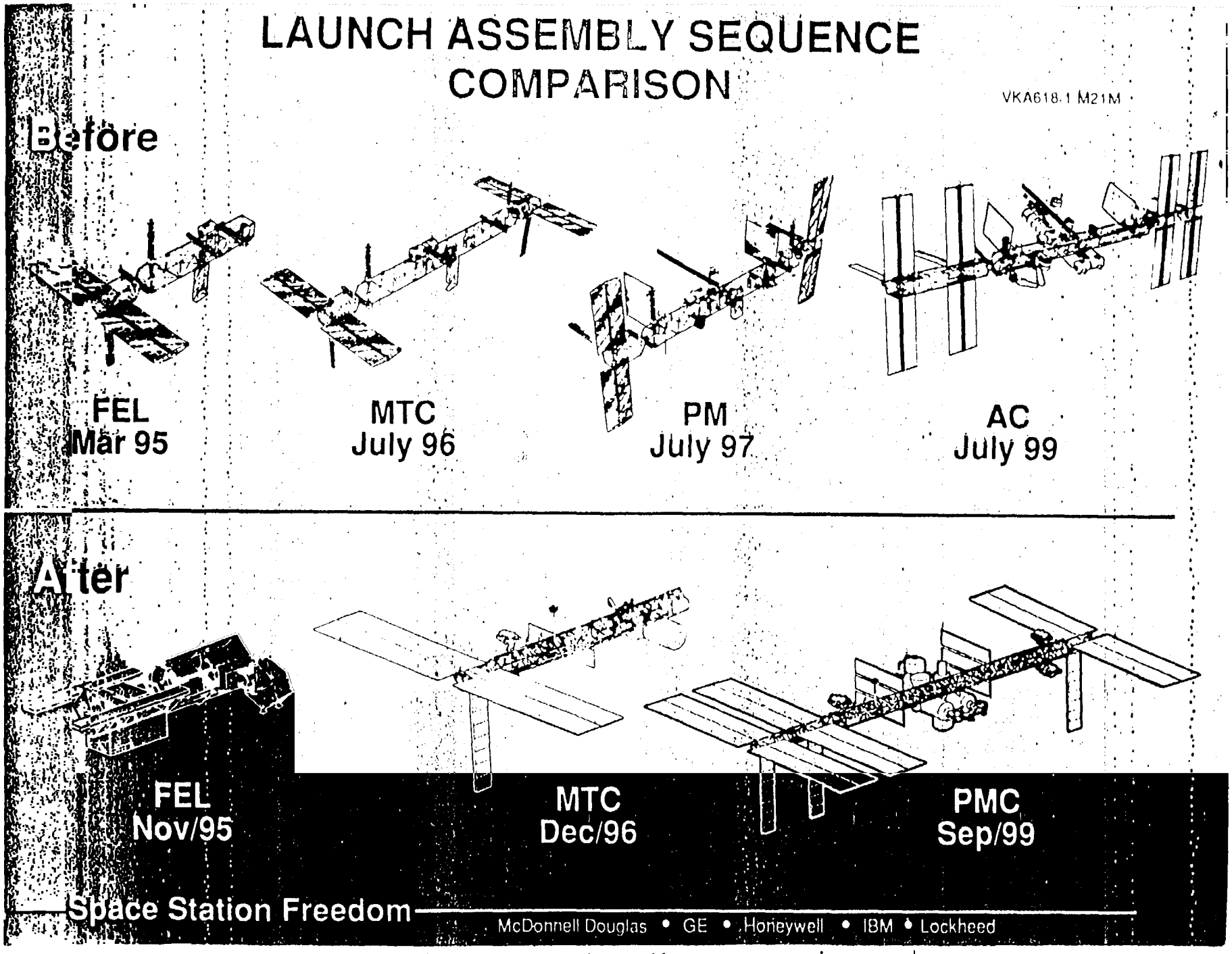


FIG. 1 Launch assembly sequence comparison

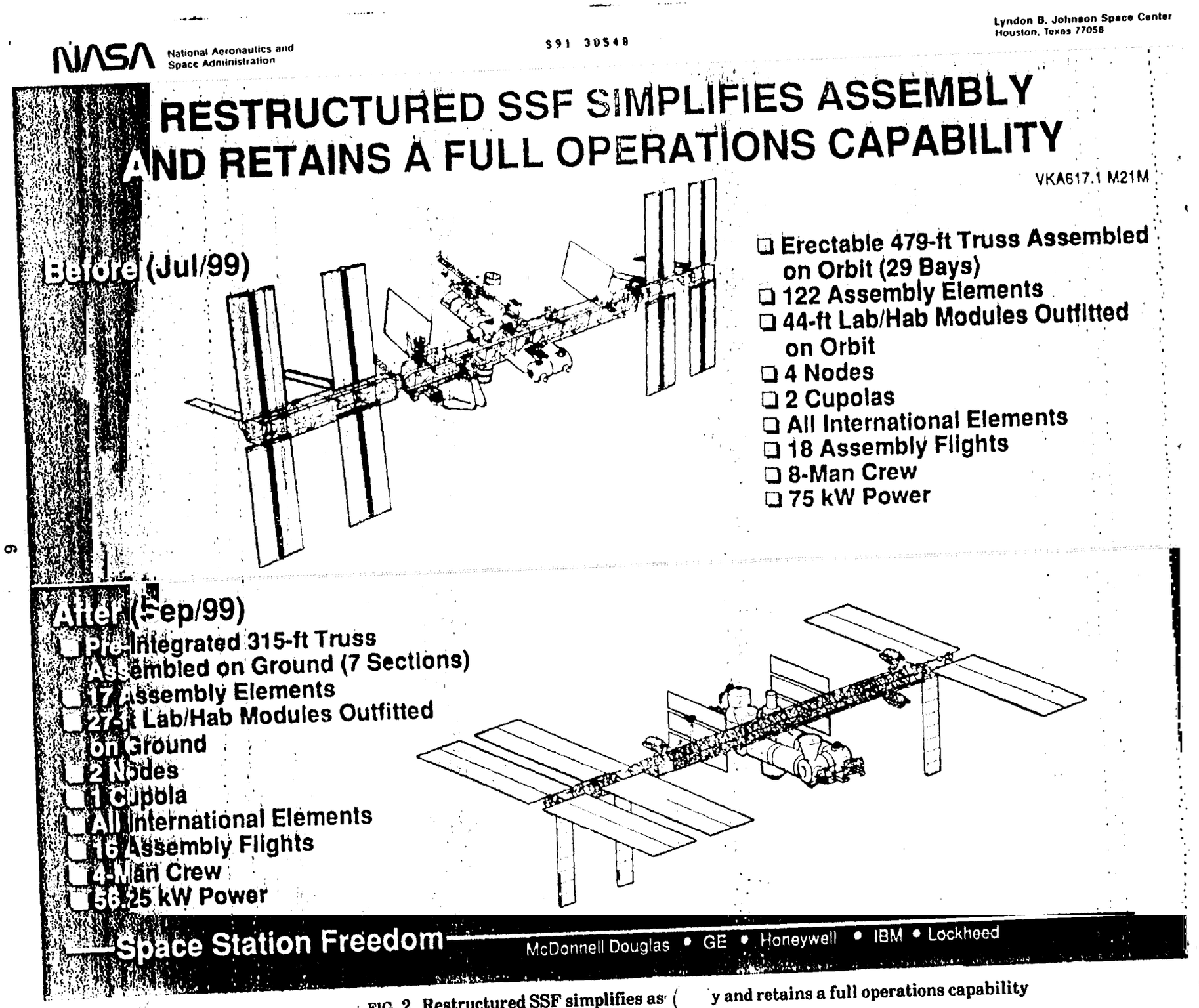


FIG. 2 Restructured SSF simplifies as y and retains a full operations capability

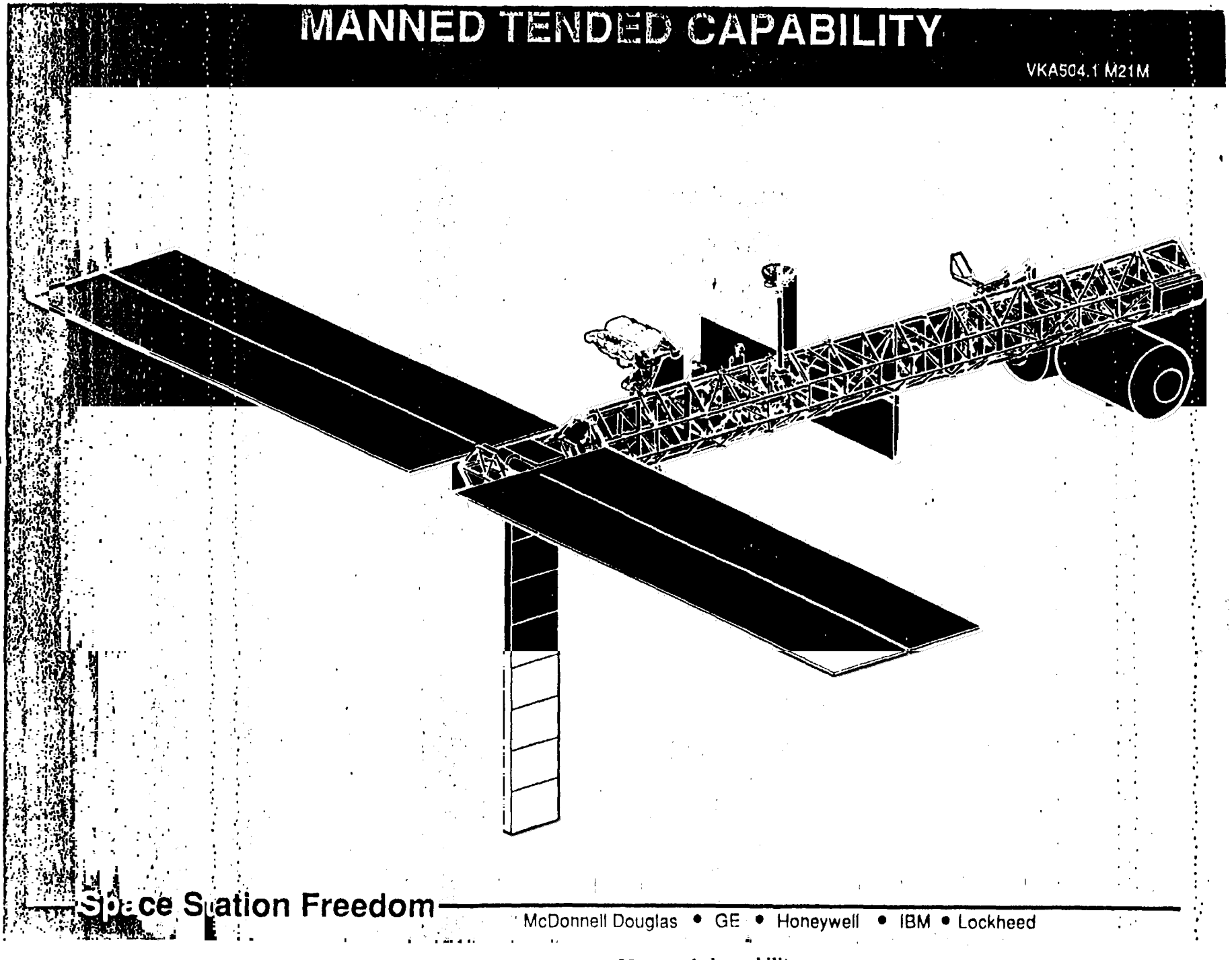


FIG. 3 Man-tended capability

LLOYD: (Cont'd) was about a year in length – and there was no major human activity on board. Therefore, in the old program we considered the Health Maintenance Facility, crew health care systems, would come on board at PMC, and that's fine. There was no particular problem with that. It finally would end in about mid-1999 with the assembly complete. This is where we would have a full crew compliment of up to eight personnel. What has in fact happened is they've scrubbed down the man-tended phase. They've kept it about the same – maybe a 6-month slip here – and, in this configuration, they were going to stay like this for about 3 years now (not 1 year). To get better detail in terms of how they're building it up, going from first element launch up to man-tended launches are called mission builds. There are six of them to get you into this configuration.

As we discuss hyperbarics over today and tomorrow, we are more interested in mission build 7. MB7 brings up the airlock, and I've added a couple of extra photos at the back end of the handout that show you the layout of what it will look like at MB7 without the truss network (FIGS. 12 and 13). In this configuration in man tended, there will be one lab – it will be called a "lablet." I had to change the name because it's not the same size anymore, so they're not "HABs" and "labs." They're "lablets" and "HABlets," and you take two to make one and so forth. You have one lablet and you have a node, and you will have the airlock at MB7. Because you're staying in this phase for 3 years, we made a push to bring on aspects of crew health systems, environmental health, and the Health Maintenance Facility, and to bring them up from man tended. I'll highlight some of that equipment. So, that's a big change for us. We're going to phase in medical care, something that was not really believed in back in 1987 and earlier programs. We felt then that it was a house of cards: "Put it all up, or nothing" and

LLOYD: (Cont'd) make sure of what we're doing there. Regarding the permanent manned capability: Here again, it looks like the old PMC. It's not as big, and I'm going to show you the differences between the two PMCs. You'll notice one other thing: there's no "assembly complete" anymore. It's now called "post-PMC," and that means, when it goes off the vugraph, there's no funding for it. I'm going to show you what we lost in that.

[Break in tape.]

LLOYD: A comparison at PMC is very helpful because it tends to tell us what we're up against medically. To go from MB1 through MB6, I should make a note that you're doing up to two to three 2-person EVAs per mission build. And, those are planned. So, you've got a fair amount of EVAs, you've got a fair amount of construction, and you will be doing your laboratory activities at MTC. So, that's the workload and the characteristic of what happens in that earlier phase. When you look back to the PMC aspect, what in fact has happened is that we've shortened the truss network, although I'm not sure what that means to us. The number of assemblies is reduced slightly. As I mentioned, they went from naming of "HABs" and "labs" to "HABlets" and "lablets" because they've been reduced from 13.41 m (44 ft) down to about 8.23 m (27 ft). And, the reason they did that was so they could integrate them on the ground and bring them up loaded. That *is* a good thing. There is a major concern about what we were going to do with a lot of onloaded construction in assembly on the internal aspects. We reduced the number of nodes by two. We reduced the cupolas, which were the large observation viewing ports, from two to one; maybe you'll have access to go into one

LLOYD: (Cont'd) of those when you go over and tour the site. You can see about 50 to 60 m away from the Station for docking purposes.

The international partners are still with us. That is a strained relationship by far because we're changing our program: not to their liking in many cases. We reduced our assembly flights; we've reduced our crew size, from a possibility of eight down to four crew members. That's probably going to hurt our internationals more than it will hurt us, because there's always a percentage of activity involved with the production on the Station. And, the power's down. That is also a disadvantage to us because, for the investigators and users inside that Station, power is critical, and we're not the first ones as investigators to get power. We're actually, in fact, the *last* ones to get it. And, if you watched any portion of the Space Life Sciences (SLS-1) mission last June, when it was in flight they had to be very concerned about the amount of power used or they were going to do absolutely nothing on their last day. So, there's always a concern over conserving that power to continue activities.

Here, you have the lablet, or Lab A, and the node (FIG. 3). You probably do not get a good appreciation from that view that you have there of where the airlock would connect. This is MB6. MB7 is when the airlock comes up. I told you that medical hardware was going to be phased in, and I think Mike and other personnel may come back and talk a little bit more about the actual hardware itself. This aspect I'm excited about because this brings us help in the program. It doesn't push us out. And, I think that I have a large crew of people that are getting tired of writing requirements and not seeing something come for it. In the phase program – if you may, bear with me – it will be more of a get-and-go. It's an expanded

LLOYD: (Cont'd) Shuttle Orbiter Medical System (SOMS) kit. But it's much finer than a SOMS kit ever thought of being. I don't say that with malice to the Shuttle Orbiter Medical System; it was designed to do a job and it has done it. But, it was designed to support ambulatory care, limited duration stay, and first start (meaning "injection of medications and bring them home").

In this particular program, one of the components is the advanced life support pack that can be redesigned for PMC (FIG. 4). It will be reconfigured on the internal aspects so that it's user friendly and so that we, as medical personnel, can change it as much as we do the SOMS kit. In the Edge are your physician's instruments, some startup fluids such as you might have on an emergency medical truck for first response. We're going to bring up a defibrillator – the Lifepack-10 is the design unit – and a ventilator. We have switched from the Siemens, along with other very advanced ventilators, back to the minitransport ventilators (possibly a Bird or one of the other little ones that are again fairly simplistic to use; they're pneumatic in nature). You notice that we reduce our power, reduce our weight and volume, and so forth, which are all critical.

I've had a heck of an education. I worked ICUs for 3 or 4 years, but then I had a fair number of intensivists and other people come to me and I would say, "Well, if I had some extra space, what do you want up there?" "How about if I have a little enlarged space? Fluids!" It became very clear what was needed if we were going to do a first response, because we'd like to have as much fluids as we could feasibly get. We brought up 1 ft^3 – that's about 12 L; the ALS pack has 2 L more.

NASA Lyndon B. Johnson Space Center

MTC Phase Hardware	Health Maintenance Facility	
	C. Lloyd, Pharm.D.	September 26, 1991

- Advance Life Support Pack
- Defibrillator
- Ventilator
- Prepackaged IV Fluids
- Crew Medical Restraint System for MTC
- Portable Oxygen Supply
- Hyperbaric Airlock Rack (MB7)
- BIB's Mask System - 3 units (MB7)

FIG. 4 MTC phase hardware

LLOYD: (Cont'd) The crew medical restraint is a system for MTC. It's folded very nicely. It probably could go across the front end of the windshield of your car. He'll show that to you. It is an incredibly different design from what we flew on SLS-1. There may be some stories that can be told; it's not preplanned to talk about medical restraint. I know for sure that Mike Barratt's got a heck of a lot of stories about what happened with the other restraint system.

Portable oxygen supply: This is *not* to support the patient for the entire duration of medical care at MTC. It is simply to move the individual from point A to point B; that's it. So, we're going to look for other sources of oxygen in the event that we need to ventilate our patients. Other aspects are what you folks are going to talk about: it's the hyperbaric airlock rack and the built-in breathing (BIB) mask system (I think there's a new name; Mike Stolle tells me all these new names and I keep forgetting them). But, that has not changed; it just appears in MB7. As you tour through the mockup here, it will be important for everyone to get a feel for the change of where HMF will be during our medical activities. We're not in the HAB module anymore, and I can't remember if that had happened the last time you were here. Once we had moved to the node (FIG. 5), a couple of things happened. Number one, we did that because our prime contractor owns the nodes and we have better control of it over here at JSC. And that's, quite frankly, an important step for us. The other aspect is: There is enough pressure to move us out of the HAB module from the astronaut corps, who didn't feel they wanted us between the living quarters and the galley. It *would* make a fairly cluttered area, and I think, if you folks get an opportunity to ever see one of the simulations happen – Smith Johnston is in charge of our simulations – you will see that it gets to be fairly busy and we really tie up that area.

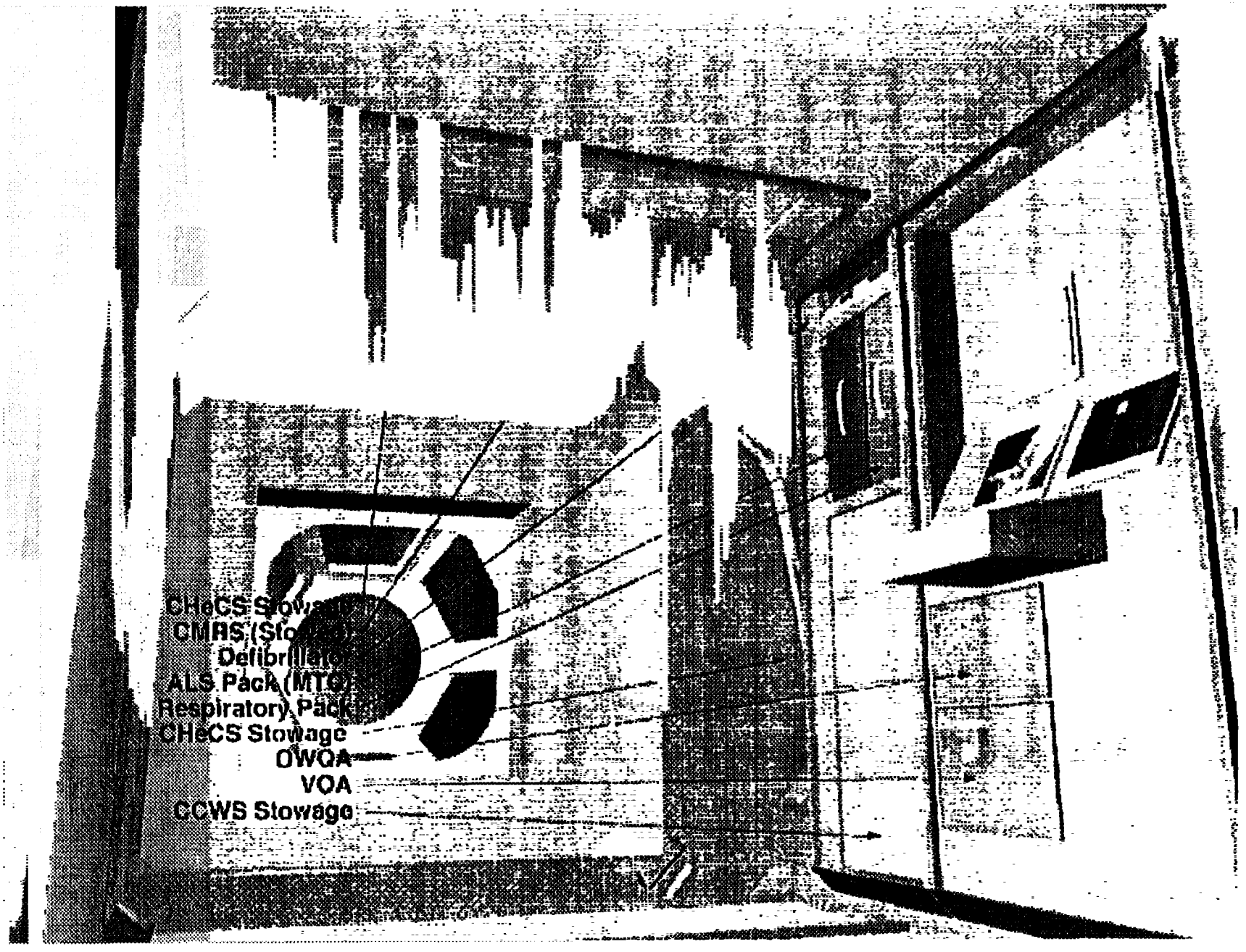


FIG. 5 MB7 node

LLOYD: (Cont'd) It's a fairly interesting environment to perform simulations in. The MRS that they will show you – the medical restraint system – is laid out here, showing how you'd have restraint over the body itself. It's a pliable type of material, but I'm not going to get into that to any great extent. It has restraint systems that Mike is very proficient at talking about to restrain the medical officer, your patient, and your equipment. It lays out on any one of the surfaces; all that is in a stowed configuration right here, right along the upper portion along the side wall. And predominantly at man tended, it's environmental health monitoring equipment; it's not medical equipment.

The essence of what is going to happen at MTC, as I said then: if you have a major medical event, you activate the HMF. All other medical activities for 13-day missions with crew sizes up to eight – if you come up in the Orbiter, and the same going home – would be your headaches, coughs, other aches and pains, with treatment out of the SOMS kit. You do not activate HMF at man tended unless a major medical situation has occurred; you stabilize the patient, wherever they are. You can bring them back to the node if you feel that is the appropriate thing to do, or you can move them straight on out to the Orbiter. You can stabilize them there, get them ready for the trip home, and they come home. The contingency scenario is 24 hours from start to finish. That's all we have for that phase.

Now back to what we're used to, and that is a permanent manned configuration (FIG. 6). Crew size is now at four; and, as you can see, the Orbiters are parking over here where there used to be nodes set up. Now there are just docking ports, and you would move right into the module itself, either into the HAB or the lab –

FIG. 6 Permanent (ıed configuration

LLOYD: (Cont'd) or HABlet, because it's half size, so the crew size is four, and that's what that really means. So again, you can start to see how your scenarios would work.

When we get to permanent manned, what would appear here is that you would have added on assured crew return vehicle (ACRV). It would be one of these, and I'm going to show you that last in this presentation. But also, we wanted to expand our care and we have now determined that we'd like to maintain our patient there for up to 3 days and then, if need be, transport. It gives us a little bit of an added window; if there's a potential chance to pick up a Shuttle and bring them home, we would. We would only use the ACRVs as a last resort, and that we were in fact running out of time for convalescence on the Station. This tends to show you what comes up, and if there's anyone who's very proficient in the room on all the components of HMF, we miss a few here (FIG. 7). I'm really trying to focus on the hardware aspects because the last vugraph I have here will demonstrate what we do *not* have anymore.

During PMC, we now begin to do IV therapy. This is where we bring up our pumps and formulation devices, and we make our own sterile water and solutions; we're not depending upon packaged fluids anymore. We expand out the physician instrument care, dental care, surgical instrumentation, all independent of Shuttle now. So, we're beginning to separate those programs simply because there is going to be a period of time that the Orbiter would not be attached. We'll begin to introduce our medical analytical laboratory capability – for doing standard chemistries, blood gases, and so forth. Other monitoring equipment will come up, such as pulse oximetry for some of your advanced care of the patient here. One thing that is missing is the patient monitor. We're going to have to

NASA Lyndon B. Johnson Space Center

PMC Phase Hardware Additions	Health Maintenance Facility	
	C. Lloyd, Pharm.D.	September 26, 1991

- IV Formulation Device
- SWIS
- Powered IV Pump #1
- Pharmacy & Central Supplies
- Phy. Exam. Equipment
- Powered Phy. Instrs.
- Dental Instruments
- Dental Hand Tool
- Surgical Instruments
- Clin. Chem Analyzer
- Centrifuge
- Hematology Analyzer
- Pulse Oximeter
- Blood Gas Analyzer
- General Task Lighting
- Ventilator #2
- Cautery Device
- Macroscopic Imaging System
- Cardiac Compression Device
- Transport Monitor
- Transport Aspirator
- CMRS Expanded Functions

FIG. 7 PMC phase hardware additions

LLOYD: (Cont'd) do that through the transport monitor or the defibrillator in the monitoring mode at this phase.

We expand out our lighting capability and imaging capability, and we bring out the second ventilator. It'll be the same type of ventilator that we had at man tended – it'll be the the little Omnivent or Bird transport ventilator, or whatever. So you'll now have two; they will be identical, so it improves our situation in terms of criticality and redundancy. We simplify the aspects in regards to the crew member who doesn't have to train on two different types of ventilators. Another aspect that is an advantage in this configuration: You're there for 3 days. You're not up there for the old philosophy of 45 days for weaning and other more complex respiratory support needs that might be necessary to consider.

Other surgical equipment becomes more prominent at this stage. Devices such as the cardiac compression assist device appear. Our transport capabilities improve. But, interestingly enough, at man tended, we were doing it without these items. We were transporting without that aspirator and without that monitor. So, we're not quite sure what's going to happen to a couple of these components. They may or may not be necessary. You're left in the program to allow us some freedom as we begin to activate the hardware built. If we feel there are some changes that are necessary, it would be this type of equipment that might be attacked. And, the crew medical restraint system will be expanded or improved. It may not be flat anymore; it may be up in the air. So, you have more of a one-g access. Yes?

DR. R. W. HAMILTON: Excuse me. Is this imaging system an X ray?

LLOYD: No.

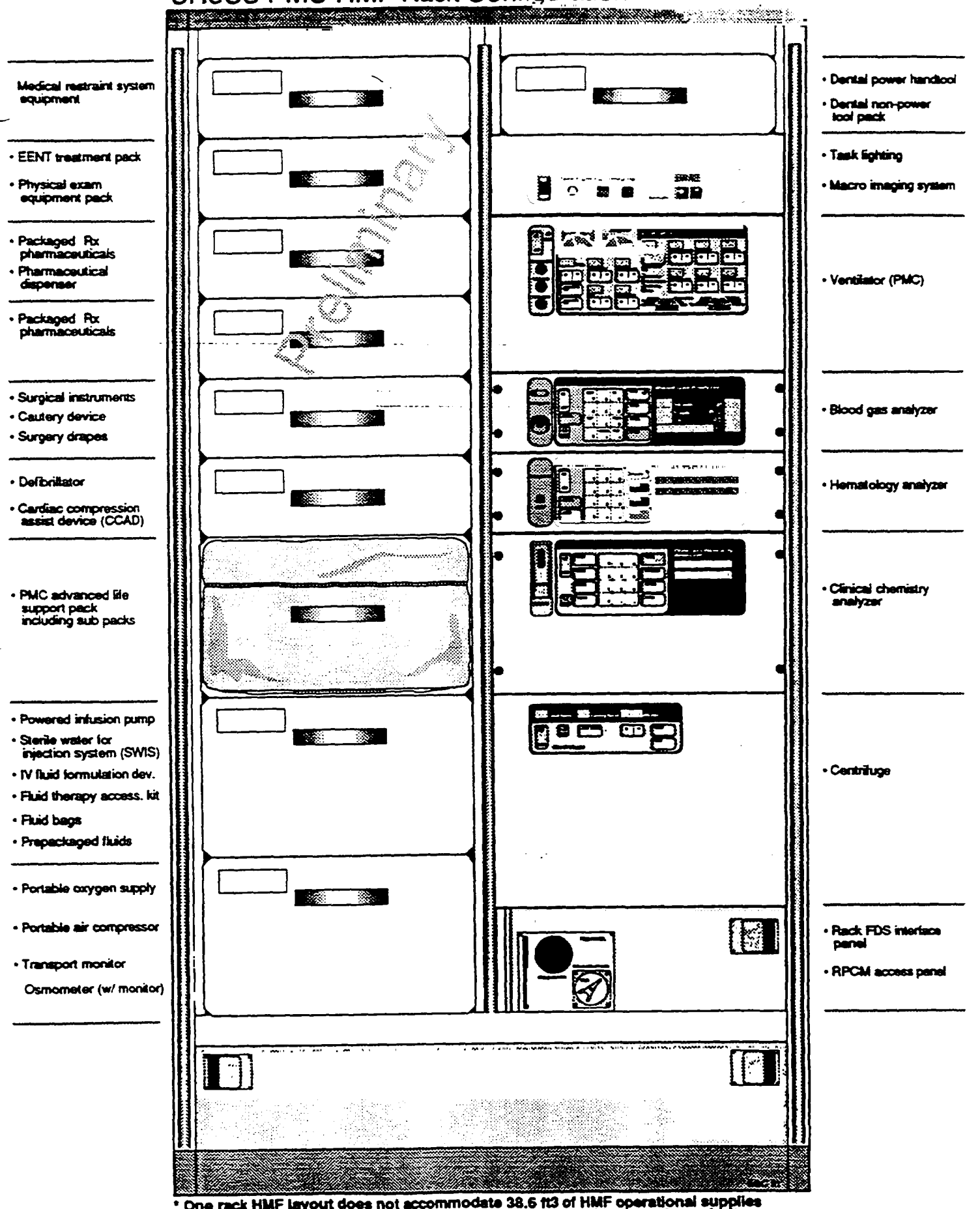
HAMILTON: Or, is it guided?

LLOYD: That's a good point. No, Bill, that's the macroscopic imaging system; it's video. It is simply to hook up and give you a visual link of what you would be doing as the crew medical officer in support of the Space Station Control Center where flight surgeons are on console.

At this phase of the program, HMF looks something like this (FIG. 8): It's one single, double rack that's 13.41 m^3 (44 ft^3) of space. Predominantly, it would carry stowage on one side and more of your instrumentation may be on the other side. Your interfaces for power and so forth will be up either at the bottom of a rack or below the rack or however the engineering aspects have been offered to us. In these configurations – and that simulation scene has come back – you take a look at, if you had to do a particular scenario, what are the issues that we need to worry about? Are we getting tubes and wiring all mixed up around our patient? Do we have good access? And so forth. And, all that has been going on as they continue to develop these layouts.

I should say, through any and all of the development of hardware over the next 5 or 6 years, we'll mount a certification team working in harmony with the medical simulations team and the operation personnel – which is really beginning now to

CHeCS PMC HMF Rack Configuration



* One rack HMF layout does not accommodate 38.6 ft3 of HMF operational supplies and resupply consumables. Layout also assumes deployed location for majority of CMRS components.

FIG. 8 CHeCS PMC HMF rack configuration (preliminary)

LLOYD: (Cont'd) expand under Kyle Brantley's group. Those three groups are going to work in harmony in terms of saying, the hardware is very similar to what we use in the terrestrial setting, and that we have a good medical confidence that's going to operate in the same fashion, the same level of reliability; that it is laid out human factors wise, the medical human factors aspects, and that it is appropriate the way it's been set up. The operations team will begin to really pull and consider what is needed and what steps are required to perform any one step.

Figure 9 shows the hardware and system losses to the PMC program, which will hopefully re-emerge as post-PMC phase additions. Regarding the X-ray machine: Diagnostic radiologic imaging system, the infamous DRIS, that has lived with us since the mid-1980s has been put on the shelf for the post-PMC era. That doesn't make me happy. I do not like losing hardware, but no one asked me if I had a real opinion on that. Everyone was scrubbed. I'm not the only one that was reduced; environmental health, exercise, your data management systems, your power, everybody got hit. So, that tends to make me feel a little bit better, in that misery loves company. Losing my X-ray system was one of those items. We gave up one of the IV pump systems since the pump systems we're using have two heads, two pairs of supplemental heads on them already. We gave this up just because of some redundancy problem without having the two units. We've given up some of our air-fluid separating capability. With the invasiveness and types of things we might be doing with our patient, we fill the use with mechanical and transport aspirators. But, the actual complexity of being able to take fluid, separate it out from the air, and recycle or something is being shelved.

NASA Lyndon B. Johnson Space Center

POST-PMC Phase Additions	Health Maintenance Facility	
	C. Lloyd, Pharm.D.	September 26, 1991

- DRIS
- Powered IV Pump #2
- Air-Fluid Separator
- Patient Monitor
- Coagulation Analyzer
- Surgery Overhead Canopy
- Laminar Flow Device
- Prep Tent
- Electronic Stethoscope
- Parenteral Nutrition Kit
- Pneumatic Anti-Shock Garment
- Doppler Flow Probe
- Perip. Nerve Stimulator
- Warm Blood Collection System

FIG. 9 Post-PMC phase additions

LLOYD: (Cont'd)

The patient monitor was *another major loss* to us: a very *large* box, but it tends to have a fair amount of software and capabilities to configure your transport monitor into the proper setting. *That* was the problem. As it is now, we have to somehow get our transport monitor configured by another computer system to do what we wanted to do.

Another desired item that was lost is a computer system for medical care. It has not been baselined. We're fighting very hard to bring that component back. We do not feel that we can take a crew medical officer up there without optimal resources. Even if he was a physician, surgeon, or so forth, I think they would want some medical support in terms of computers. At least in terms of data files, library, and so forth. Our chances of having MDs flying on that are probably minimal until we get further along in the program, so we're going to have EMT-level personnel. I think we need to provide them with the best support that we can. The computer system hopefully will come back and reappear on that other list. Other types of equipment that we've lost: a coagulation analyzer, and more advanced surgery capabilities for the overhead canopies and abilities to contain the environment itself. We've lost advanced nutritional care, and we dropped the electronic stethoscope. We assume that the crew medical officers are on their own. A whole series of equipment was deleted right on down to very small things that are critical, such as peripheral nerve stimulators. Some of these things may come back. They tend to be like the tide; they sort of shift back and forth.

Actually, one of the most exciting things – I think the last time you folks were here, at least for the hyperbaric conference, is the ACRVs (FIGS. 10 and 11). They didn't exist or it was a dream. I have almost lost my thunder, because I really

ACRV Typical Mission Sequence

- Space Station Freedom emergency is declared
- Crew transfers from Space Station Freedom to ACRV
- ACRV isolates crew from emergency and activates lifeboat systems
- ACRV separates from Space Station Freedom and initiates deorbit
- Retrosystem is staged and entry is initiated
- Chutes are deployed and ACRV lands on Earth
- SAR forces transfer crew to safety

FIG. 10 ACRV typical mission sequence

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NASA National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston, Texas 77058

FIG. 11 ACRV

LLOYD: (Cont'd) want to say, "Here it is; it's going to be with us," and we do have that capability to come home for either crews of four or eight. We may *not*, if the 90-day Orbiter system goes up. It may freeze this earlier than PMC in the development. That won't hurt us, maybe, in some aspects of the medical care that might be there. We do *not* know; it's been undefined. And for sure, they would not bring up the ACRV because they would have the Orbiter attached. The ACRV looks very much like an Apollo capsule – only a little newer in its design – and would be attached to the Station. There would be one at PMC, and there would be two at the post-PMC configuration. With the crew of eight, we'd need two of them; they are designed to carry four people. In the event that they needed to utilize that vehicle to bring home an injured or ill crew member, they may all come home. It may be a policy that, once the ACRV is gone, you have to evacuate the Station. There is no other way off, so we may bring the whole crew back.

Because CHeCS and HMF were fairly well developed by the time the era of the ACRV began, they are coming to us and looking at what our needs are for bringing ill or injured crew members home. So, one of the couches will be properly designed to take a crew member that is ill; also as a consideration, they may have C-spine or other injuries that would require them to stay very flat in the configuration. We'd load them in; we've gone through the scenarios – egress and ingress, and this thing would be released from the Station, would reenter the atmosphere like the old Apollo capsules, and would land with chutes. And, I always keep asking, "People, will it be a water landing, or will it be a dry landing?" They say, "Well, Chuck, just go get that photo and it tells you." I went and looked at this photo. You can probably see it better on yours. It's a swamp! So I guess it's either a water or a dry landing. You know, it's a little bit of both.

LLOYD: (Cont'd) They'll land somewhere, and we would pick them up and bring them home. There are of course the added concerns we have there of the g-loads that might be inflicted upon your ill or injured crew member.

So with that, I think in very short order I'm telling you that we have a major change in our programs, that we have survived a big, big restructuring program. We *have* taken our losses of 14 to 19 components of hardware that have now gone by the wayside, and I declare that, simply because post-PMC, when I see money, maybe I'll see them come back. Our duration of care is very far from what Dr. John Schulz – who was one of the early folks on the HMF group – is used to; this was a 45-day care scenario; that is not in the wings. Maybe it'll come up in later programs. I do not think that we have attempted to change some of the important aspects, though. I think we will continue to bring up hardware that's never been there before and determine that we can do medical care – advanced medical care – in a microgravity environment and in very close quarters. Hopefully, we will not have any major events in the duration of our care for the safety of our crews. But if we do, I think that we can still successfully do an excellent job in providing what is necessary. I once again am glad to see each and every one of you here, and I hope that we come away with some important comments in regards to the hyperbaric capability. Thank you.

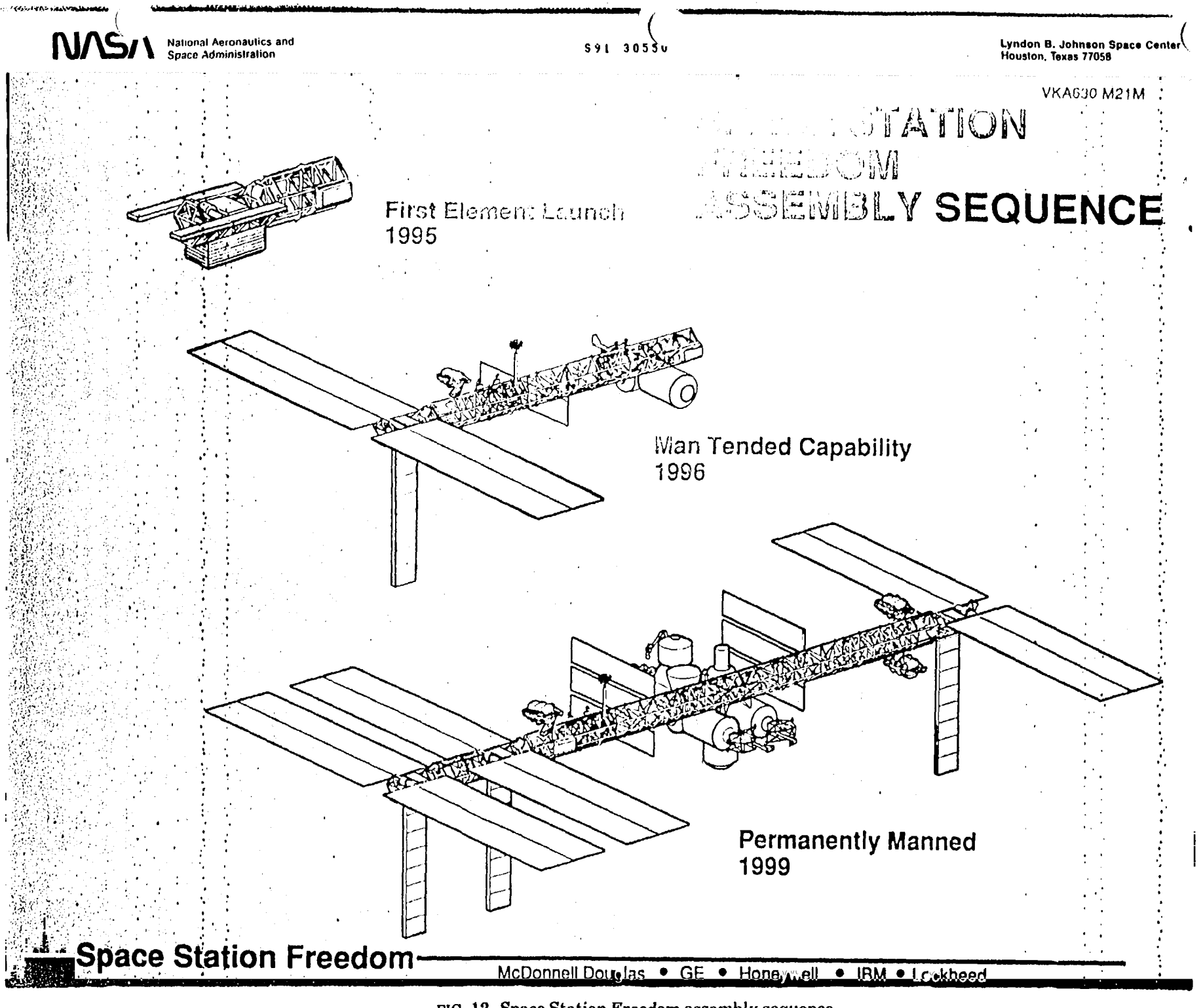
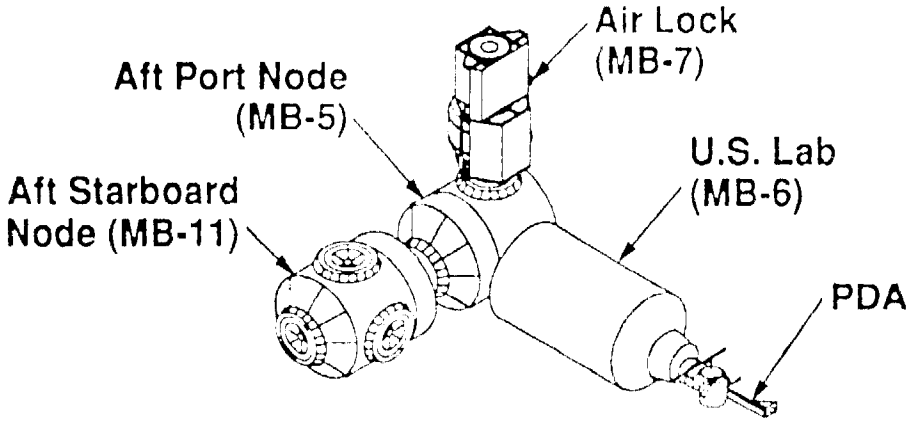
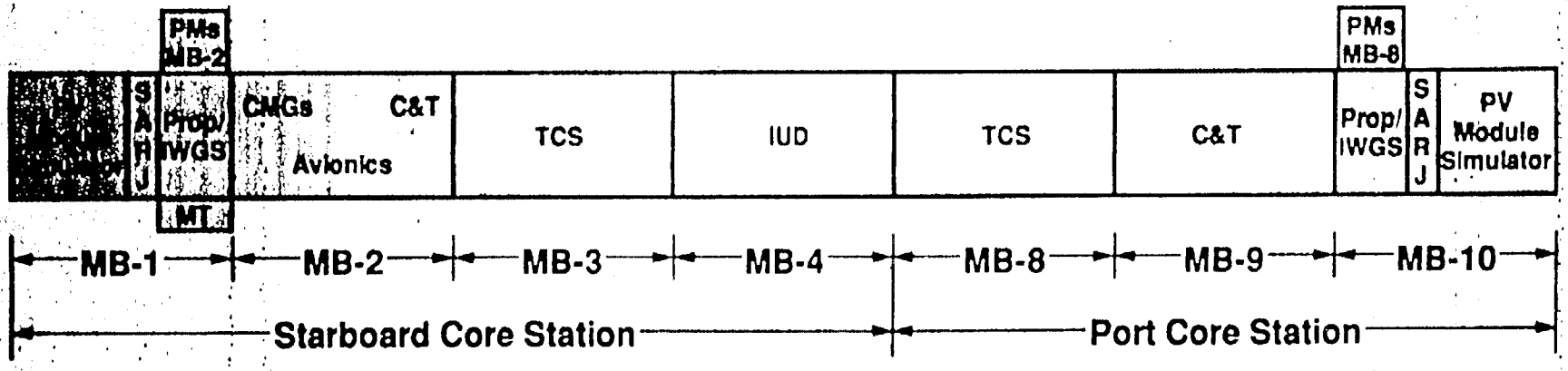


FIG. 12 Space Station Freedom assembly sequence

ASSEMBLY SEQUENCE
PRE-INTEGRATED STRUCTURE

VKA628 M10DB





Space Station Freedom

McDonnell Douglas • GE • Honeywell • IBM • Lockheed

FIG. 13 Assembly sequence integrated structure

Space Station Freedom Man-Tended Capability (MTC) Phase

Medical Hardware Review

BARRATT: This will be a bit of a show-and-tell session about the man-tended capability hardware. I think it's pretty clear that the Station is planned to be an evolving facility, and the medical care facility is to evolve along with it – our capabilities are to advance as we get more crew members, more power, and more sophistication. I won't talk about the 90-day Orbiter plan with the exception that, it may very strongly drive our medical hardware. We may be stuck or suspended in an MTC capability for an extended period of time – that being the philosophy of load and go. We would not be maintaining patients who are critically ill, for instance, on station for the 3 days of PMC or the 10 days of EMCC that was previously planned. So with that in mind, we would maintain the ability to deliver acute care, ACLS, etc., and maintain that for an extended number of crew members but also for an extended amount of time.

Now, the hardware. For the committee members, I think you've got some descriptions of that in the JSC-31013 requirements document. The medical restraint system, which you've seen some pictures of that Dr. Lloyd mentioned, is something that is very much in the development stage right now. Everybody recognizes the need for the restraint system to put the patient, the CMO (the chief medical officer), and the equipment in the same inertial reference frame. We can do no useful CPR, for instance, unless the patient is tacked down – quite securely, quite quickly. And also, this would be a transport vehicle. We need to transport the patient and equipment, again together; and, as such, we'll have to interface with whatever vehicle brings the person home – the Orbiter or the

BARRATT: (Cont'd)

ACRV. This is the current generation MRS. The next one is on the drawing board. This is to be a rapidly deployable system that can be rapidly destowed and attached to seat tracks on the floor of the node at predetermined positions.

Now again, we're totally driven in our medical requirements by the ability to restrain quickly and thoroughly. We've done several simulations – I mentioned Dr. Johnston is our local simulations king – both in the one-g and zero-g environment in parabolic flight, again trying to nail down how fast we can get this thing deployed and how fast we can get a patient or an ACLS mannequin onto it. For the purposes of Station, we have to bear in mind that we cannot do CPR, we cannot defibrillate until a person is actually restrained on this device. We'll have a bi-layer restraint eventually, something that will insulate the restraint against the Orbiter or the node floor. (We don't want to deliver too much electricity through the Station.) And, it will also be necessary to have the crew people actually restrained clear of the patient during defibrillation. We will assume that the fabric top would be saturated with body fluids and be a conductive surface, and that will drive the requirements. There's a preliminary suggestion that, because of electromagnetic interference, there will be time periods where we'll have to waive the requirement to defibrillate on station because of the sensitivity of the avionics. So, there are a lot of considerations for us in trying to design our system and baseline our outlook.

We've recently done some modifications to ACLS protocols that adapt them to the microgravity environment. We did some tests on the KC-135. One of the things we found out is that we need to get this deployed much more rapidly. We were not able to actually get a person down on this thing and administer the first

BARRATT: (Cont'd)

shock before 4 minutes or so, and that was as a result of a well-choreographed exercise. Again, the training of the chief medical officer is yet to be determined but will probably be no greater than a paramedic level, and that may be somebody who is an astrophysicist who we actually take and train rather than somebody who's had extensive experience. So, we want a very user-friendly system, something that's rapidly deployed and actually may even be stored in the partially deployed position so we can whip it out and get somebody on it.

We have the standard Lifepack-10 defibrillator, which I did not bring up here. Again, everything we pull out has to attach to the CMRS so it doesn't float away. We are coming up with various systems for attachment. And, of course, paddles are not useful. We don't have the ability to apply the 25 lbs of pressure like we do down here, so we use adhesive pads and the paddles will be removed from the Lifepack-10. There will be a data management system interface, so whatever rhythm is monitored on the Lifepack-10 will be downlinked. However, I must emphasize that we *do* want an absolutely autonomous capability. During loss of signal or other breakdowns in communication, in the heat of battle, we want to make sure that the capability for delivering acute care that we have required is totally within the confines of the Station, both personnel- and equipment-wise.

Portable oxygen supply: Again, a very transient supply, as Dr. Lloyd was mentioning. The idea is to deliver oxygen to the airway, to the endotracheal tube via the Ambu Bag, and power the ventilator, and no longer than an hour. This will get us into the Orbiter, into the ACRV, or whatever we have to get us down, and this is baselined for the man-tended capability. This, of course, also has to be restrained.

BARRATT: (Cont'd)

Now the ventilators – I'll show you two (you may or may not be familiar with these) – the two that we've been testing most recently as candidate ventilators. I think it's safe to say that our selection process is absolutely driven by the hyperbaric performance of these ventilators. And, this is an issue that we'll be soliciting feedback from the committee members on extensively over the next couple of days. The Stein Gates Omnivent (both of these are time-cycled pressure ventilators) is a relative newcomer with very little actual published hyperbaric data and experience. We've had some problems in keeping this thing stable as we descend to pressure. The control inputs are extremely fine and close together; it's very difficult to adjust on the way down. It's very light; it's very transportable; it's capable of delivering the ranges that we require at pressure, and we've tested it down to 102 fsw. But again, a lot of problems with adjustments and, again, we're considering a CMO and maybe an astrophysicist on the way down trying to adjust this ventilator and tend the patient at the same time.

The Bird TXP: Also somewhat of a newer ventilator. It has a proximal source pressure regulator; this little magic device is the Phasetron, which is the actual breathing circuit. And it's very light, supposedly very crash resistant, and is very user friendly. I would say that, as far as adjustability and availability of controls, this one is much more amenable to the common user. We expect, obviously, a low occurrence of use, and we don't expect a high proficiency on the part of the person who may be running this – and that's a very strong driver in selecting this one. However, at this time, it is *not* capable of delivering the range that we require. When we start this thing out with a tidal volume of 1.5 L at sea level and dive to 80 ft as we did yesterday (Mike Stolle and myself), the delivered tidal volume decreased to the mid-200 cc's. So we have some problems here.

BARRATT: (Cont'd) We're in contact with manufacturers of both of these, and modifications are being looked at. Again, Bird TXP is much more user friendly but needs to expand to cover the range; Omnivent is much less user friendly, or what I would consider user hostile, but is capable of delivering the range.

The last bit of hardware at this point is the Ohmeda Respiratory flowmeter, which is a modified version of what's often seen in the anesthesia machines, in the anesthesia circuits. It's a very nice little flowmeter, and we've had very good success with this one. There are minor exceptions. It's very amenable to data management system interface; it's got a port in the back, and we just have to modify the signal input. It's capable of quickly giving us tidal volume and minute volume, and also has the added capability of pulmonary function tests. The pulmonary function test equipment for spirometry for investigation purposes has been removed and this may give us some capability to do some investigations as well. So, this is our hardware. I'll take some questions, and then I'd like people to come up and take a look at it. John?

DR. JOHN SCHULZ: How about pulse oximetry?

BARRATT: Pulse oximetry was not actually baselined for MTC. That would go on the transport monitor with us into the chamber eventually, during PMC.

SCHULZ: Aren't they adding, at the most, rescue squad oximetry?

BARRATT: Apparently, pulse oximetry and end tidal CO_2 are showing up more and more commonly in rescue squads and transport scenarios. So, the answer is, *Yes*. "Do we have it?" *No*. There'll be a lot of presumptive treatment decisions up there. The skill of the CMO is going to be paramount. We've taken upon ourselves to define the capability first: The capability is to deliver advanced cardiac life support. Of course, from that we have to match the hardware and the capability of the CMO. So, our hardware selection is going on parallel with our plans, our formulations for training the CMO to deliver the required capability. This entails lots of simulations, lots of hardware evaluations.

DR. ALFRED BOVE: If we have to measure blood pressure?

BARRATT: I'm sorry. The blood pressure cuff is in the ALS pack.

This is the ALS pack or advanced life support pack. This contains almost everything you would need to run your standard code. This is similar to what the paramedic might have in the field. Everything is subpackaged, such as the emergency drug kit. Everything can be destowed and restowed quickly. And, in our simulations, we found out that it's really in the CMO's best interest when he pulls something out to actually take the time and put it back, for two reasons: there's a lot of trash floating around, as you all know, from a cardiac arrest. There's just a lot of trash generated on the floor, on the bed, needles stuck everywhere. In our case, they'd float away, they'd float around. So, it's worth the time to restow it. Second, you may need it later.

BARRATT: (Cont'd)

The airway kit contains all airways, nasal and endotracheal intubation sets. Everything is here that you would need to establish an airway. The one thing that I would mention that the simulations have shown us: It's much easier to establish an airway than to start an IV. IVs involve a lot of subpackage components, lots of trash, a lot of hand motions. We're trying to design a new system that will give us more rapid IV access. But, the endotracheal tube and airway management is really emphasized. It gives us a route of drug delivery and our protocols have changed somewhat accordingly. So, the airway kit will come out very quickly and, hopefully, will be restowed very quickly.

There are also tracheostomy kits in here. IV fluids: Again, lots of small components to have to put together. We're working on a system that would come out as a unit that would include a non-patent system incorporating the fluid bag, the angiocath, some kind of pressure delivery system that would double as a tourniquet, and attachment systems. Essentially a quick, anicubital access that we could leave in there and establish a firmer IV at a later time period. Other equipment is here: blood pressure cuff, stethoscope, scissors.

One of the other things that we have determined after running our code is that very small things in the pack that smooth out our process – such as placement of the stethoscope – matter a great deal. Since we're emphasizing the airway kit, we'll probably be moving the stethoscope to the airway kit so we can check placement quickly. All these little things influence our design and construction of these packs. The current generation, I think, is very effective. We were able to demonstrate that ACLS could be delivered with this kit. However, some of the little changes – like moving the stethoscope, like the new IV-access kit – I think

BARRATT: (Cont'd) will smooth out our process a great deal. We have a collar. Part of the ACLS protocols that we developed (by the way, we call them SCLS protocols for "space cardiac life support") suggested – and also as a result of working group meetings – that spinal stabilization may not be necessary. We've determined that, unless there's known or suspected cervical spinal trauma, we wouldn't go out of our way to put a collar on. It's a little bit more difficult, it's overhead to your timeline, and there are other ways that we can stabilize the spine; for instance, getting down on the medical restraint and using the head restraint. The main thrust would be for airway management and for keeping the endotracheal tube from slipping along. But for actual spinal stabilization, generally the cervical spinal injuries result from gravitational forces, which we won't have up there. That's one little change.

Manual pulmonary resuscitator: This probably looks familiar. A pressure delivery IV device that will, of course, make up for the fact that we won't have gravitational flow on our IV sets. At this point for MTC, we won't have metered flow. It will just be fluid bolusing and maintaining a line for drug delivery. We have assorted bandages, rolls, fixative devices, and gloves. There is a small hypobaric treatment kit, primary assessment kit with Afrin, etc., that the CMO would have at ready in the chamber. I should mention that the capability for advanced life support is baselined for the chamber as well. So, everything here should also work and go into the chamber. The very idea of a single CMO doing all of this in a chamber during a treatment dive boggles the mind, but we've made that requirement. And certainly, the scenario might be more likely that the patient would be stabilized first at the HMF if that patient were critical. Although you want to start treatment as soon as possible, they would hopefully

BARRATT: (Cont'd) have the appropriate orifices tubed and catheterized before ingress into the air-lock for treatment. That would become a complex management situation, a complex assembly situation, for the CMO.

SCHULZ: What else is in the kit?

BARRATT: An otoscope, what we call the drit wheels for neurologic assessment, and a pin.

HAMILTON: Is the pack going to be opened on a day-to-day basis, between Band-Aids on minor cuts and bruises and listening to a chest for something, or is there another set of equipment?

BARRATT: Well, at MTC, the SOMS kit will be there also. And, for a lot of the day-to-day things – correct me if I'm wrong, John – the SOMS kit would probably be utilized. We would try not to crack the pack for the very routine things. But, many of these things we wouldn't necessarily use during an ACLS scenario. There are lots of pads, four-by-fours, and bandages in here. And, since there are not a lot of alternatives up there, I can imagine that this would be available.

HAMILTON: Are there fluids in the kit?

BARRATT: We will have 2 L of fluids. There's 1 L here; there is another one that should be going in here.

BOVE: Is that a pneumatically powered device?

BARRATT: Yes, it is. Again, we don't have metered flow delivery at this point.

BOVE: Isn't that available now?

BARRATT: There are metered devices that, if you keep the pressure up, that's true. We won't have the pump delivery.

HAMILTON: Right. But, you'll have a way of controlling the drip.

BARRATT: Right. We don't have a drip, of course, as long as we keep the head of pressure there. It won't be an unattended delivery. The pressure goes down, you need to pump it up so that it maintains positive pressure on the orifice.

HAMILTON: Well isn't this done also with clips that put pressure on the bag?

BARRATT: Not to my knowledge. As far as I know, the pressure on the bag is pneumatically supplied.

HAMILTON: I know that. Another approach to the clip is spring tension on the bag.

BARRATT: Maybe.

HAMILTON: The HBO people know about them for the monoplace in small chambers because they can't hang anything up. They have gravity, but they don't have the space. So, they just throw it on the patient's chest.

BARRATT: I don't know if that had been considered for a recent pack.

MIKE STOLLE: We have considered this system because any metered flow device is bulky and heavy and cannot be contained in a small area.

BARRATT: The drug kit is the final subcomponent. Essentially everything that you would have during a normal ACLS protocol down here: atropine, epinephrine, etc. And again, we've emphasized in our recent drills endotracheal delivery of whatever drugs are amenable to that, but rapid IV access is one of the main things we're looking at right now. There is a suction device – a manually powered suction device – that we normally place here that is MIA right now; nobody knows where it is. That's another thing actually that we need to work on a little bit there. There is a suction device being developed for PMC by the Umqua Corporation that maintains its suction continuously. With this device, the Vevac, you pull, you get suction during the pull; at the maximum pull, the suction stops. And, we've had some problems with that. So, that may be another area that we want to improve for the ALS pack.

LLOYD: And, there will be a Lifepack-10 that goes with this thing.

BARRATT: Yes. I'm sorry; I didn't bring the Lifepack-10 up, but the Lifepack-10 is our baseline system right now. I'm certainly welcoming any feedback or suggestions that may go with the ALS pack.

Airlock Orientation and Restructuring Changes

BARRATT: I would like to introduce Miss Courtney Buck. Courtney is one of the lead engineers in the airlock outfitting world from McDonnell Douglas in Huntington Beach, California. She will elaborate on the specific aspects of airlock design after restructuring.

COURTNEY BUCK: Good morning. I'd like to give you a general overview of the airlock on Space Station. There are some of you in here that know quite a bit about the airlock and others that may not be as familiar. So, what you've gotten already this morning is a good background as to where the airlock fits into the Station and some of the medical equipment that will be used in conjunction with our hyperbaric treatments. I'd like to give you a general overview of the airlock. We'll talk a little bit about the requirements that we work to in designing the chamber: our equipment lock, our crew lock, the CHeCS medical equipment that we'd expect to use in the event of a hyperbaric treatment, a little bit about the hatches in our airlock, and a few details on construction and schedule.

As Dr. Lloyd mentioned, the airlock is an element that will be launched on MB7 and located on the zenith port of node 2 on orbit. I have a vugraph here of that location; but I noticed that, in Dr. Lloyd's package, he had a pretty good picture of MB7 and exactly where the airlock is located, and you may want to refer to that. Our airlock has two chambers: there's an equipment lock, which is the larger of the two chambers, and a crew lock. The crew lock acts as the hyperbaric chamber.

BUCK: (Cont'd)

We provide capability for transfer of crew and equipment between the Station and space; that is really our primary objective as an airlock. We also provide additional stowage for EMUs, which are the extravehicular mobility units or the space suits, and we have the means to stow those spares and also to provide servicing and performance capabilities on the EMUs. We provide atmosphere control and volume to support campout pre-breathe period, which is something I think we'll be talking a little bit more about tomorrow.

As I mentioned, the crew lock serves as the hyperbaric chamber. In the hyperbarics world, the requirements that we work to are out of a document that we refer to as JSC-31013, Rev. C. Right out of the requirements, we need to be capable of "treating the whole range of decompression sickness problems in one patient attended by a second crew member." As you can see, when we are at man-tended capability we have four crew members on board. We don't have a whole lot of hands. When we're down one crew member, who's the patient, we put an attendant in the chamber with the patient, we have another attendant outside, and that takes up three of your crew members right there. So in terms of operational procedures, there are some interesting issues there.

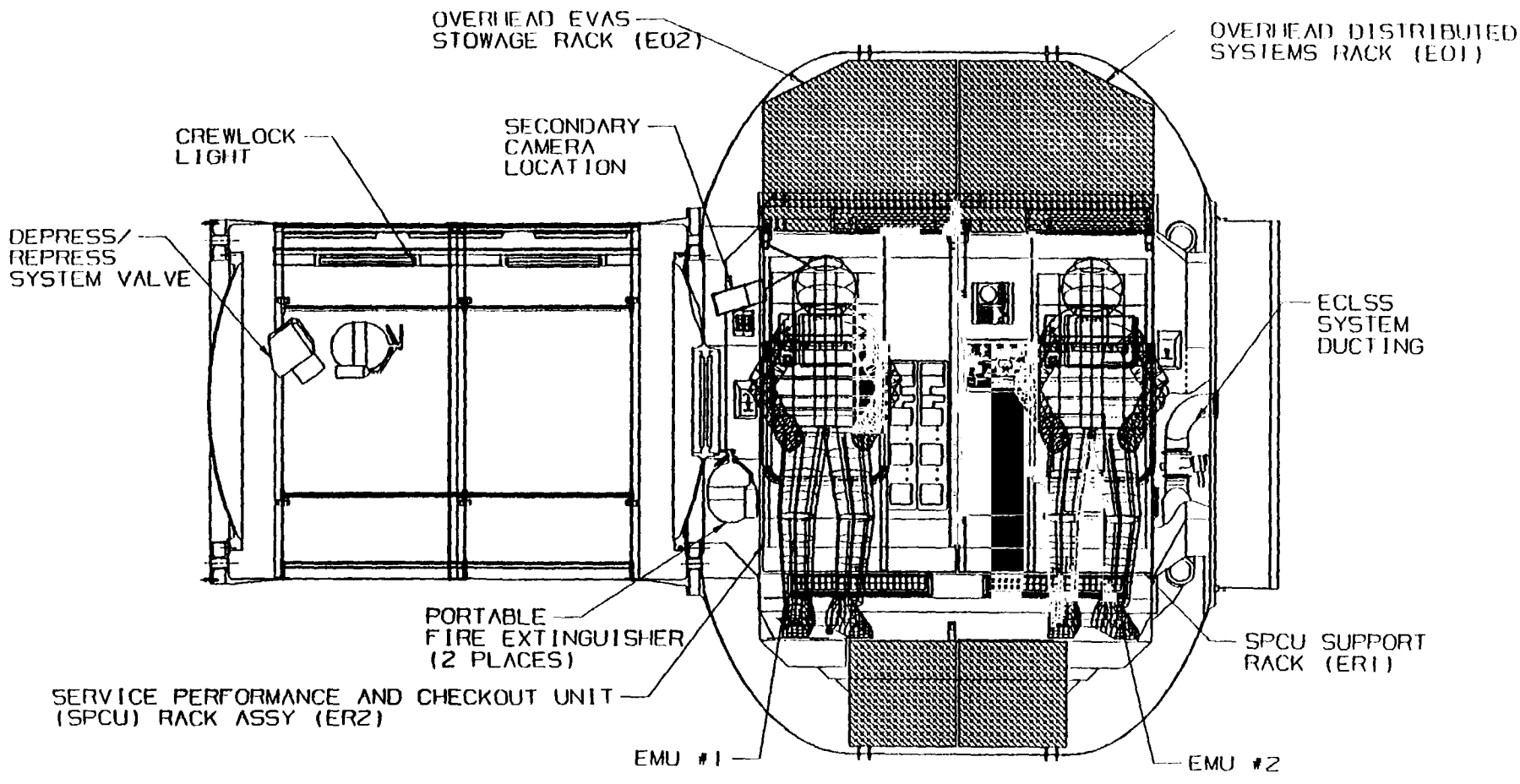
Our chamber currently goes up to 2.8 ATA. For those of you who were at the last ad hoc committee meeting, at that time we were designing a chamber that actually went up to 6 ATA. That requirement has changed; now we provide pressure up to 2.8 ATA. Full medical treatment capabilities are provided by the CHeCS medical transport equipment, which was described a little earlier. The hatch between the equipment lock and the crew lock has windows whereby we can have some indirect viewing by the macroscopic imaging camera or another portable

BUCK: (Cont'd) camera and direct viewing, as well, by the crew members. We also have the means for communication between the attendants, the patient, and the ground.

Our equipment lock, as I mentioned, is the larger of the two chambers. It's approximately 289.56 m^3 (950 ft^3). There are eight articulating racks in there, two on each surface. Just to give you an idea of some of the things that are in the equipment lock: For hyperbarics, one of the important ones is the hyperbaric gas and pressurization control assembly. This is our atmosphere control for the chamber. Other equipment that is stowed in the equipment lock includes a medical pass-through lock and the hyperbaric treatment mask assemblies, which, during treatment, will be taken out of their stowage and thrown into the chamber. The EMUs and spares are stowed in the equipment lock, as are the service and performance checkout unit and some of our distributed systems – the data management system, an electrical power system, communications and tracking, etc. On the right side, as you'd be looking from the node, will be the location of the EMUs on the SPCU, which is the service and performance checkout unit (FIG. 14). Again, the crew lock will act as the chamber. On the left side (FIG. 15), viewed from the node, you will get a better view of the rack and the crew lock; there's only one rack.

The secondary camera location on the IV hatch in the equipment lock (EL) is important for hyperbarics; that will give us our indirect viewing through the hatch. On the left side is more of what is important in terms of hyperbarics. The EL 2 rack, also known as our hyperbaric support rack (FIG. 16), contains – as I mentioned before – the HGPCA, which is our atmospheric control. Near the HGPCA, we have located an ATU, and that's an audio terminal unit for

Internal Airlock Layout
Right Side



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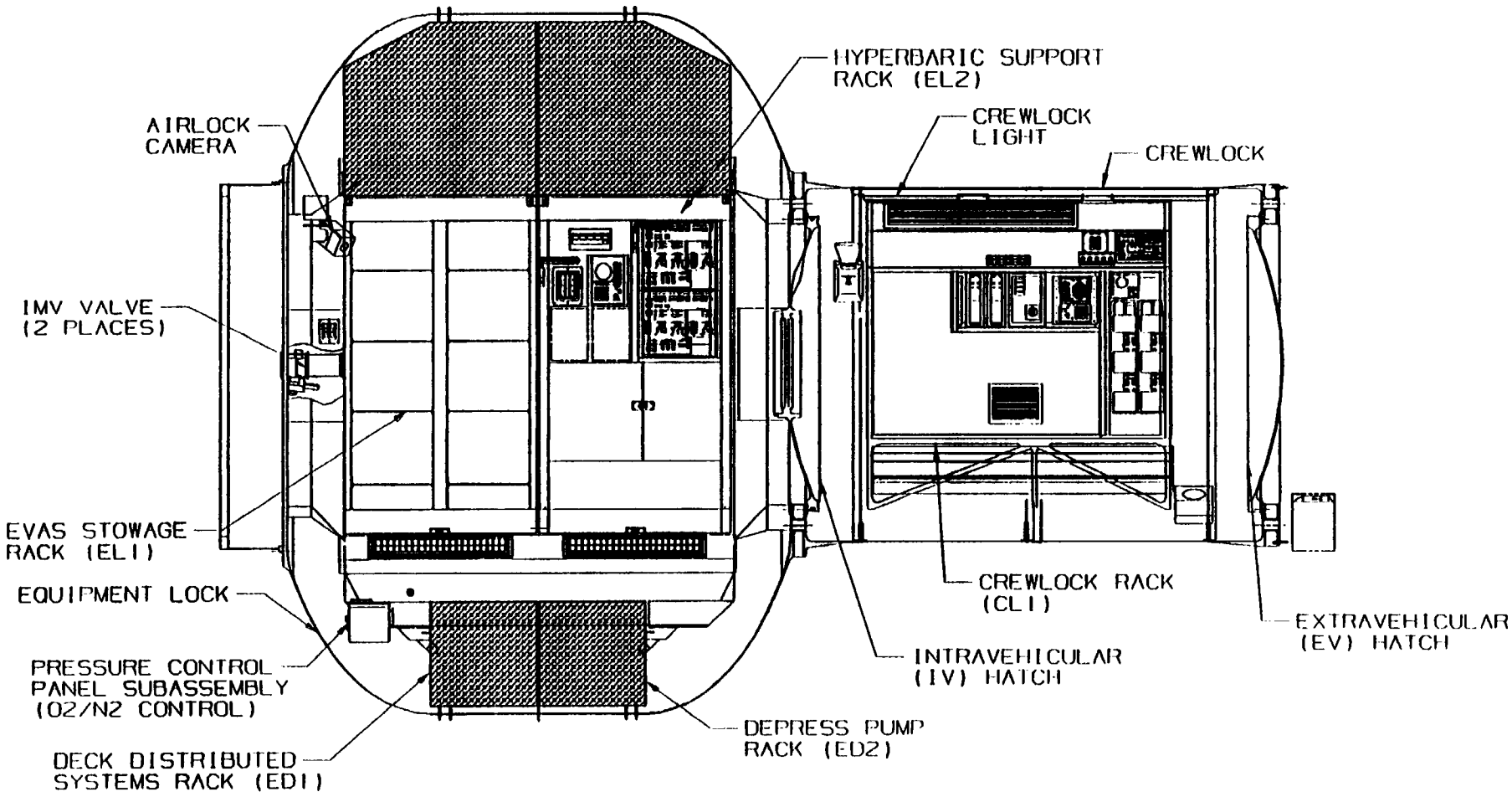
Airlock Overview

FIG. 14 Internal airlock layout (right side)

Internal Airlock Layout
Left Side



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Buck 7 Airlock Overview

FIG. 15 Internal airlock layout (left side)

Hyperbaric Support Rack (HSR)

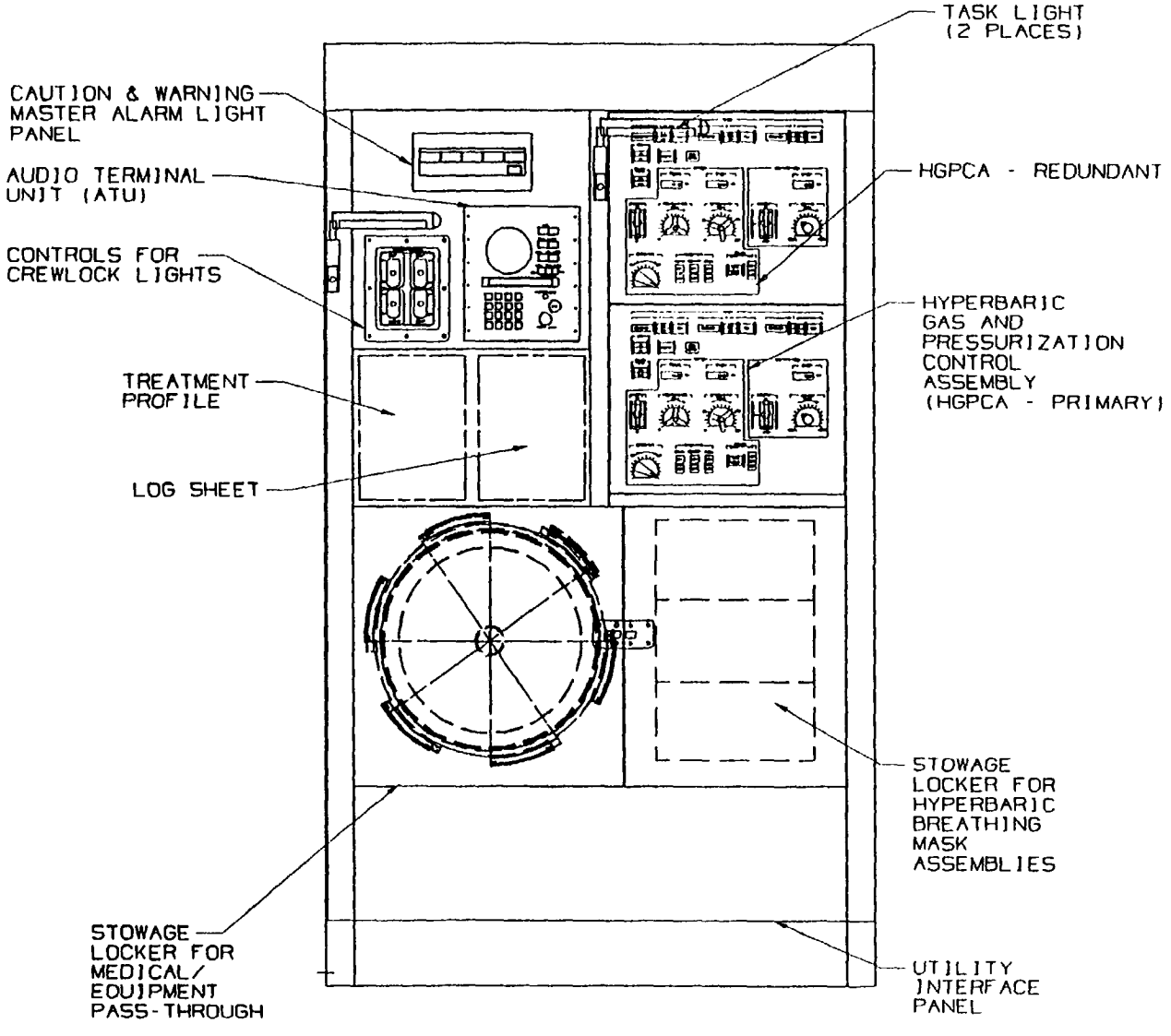


FIG. 16 Hyperbaric support rack (HSR)

BUCK: (Cont'd)

communications. There is a caution and warning panel up there and a place for logs and treatment tables. There is stowage beneath – stowage for the masks and for the medical pass-through.

In the crew lock, there is one rack; the space in this rack is taken up by what we refer to as HECA, or the hyperbaric environmental control assembly. And, this controls the CO_2 and temperature and humidity in the chamber. Dan Schimenti from Lockheed is here this morning to give us a little bit better detail on the HECA. A section to the right of the HECA rack is for umbilical interfaces with the space suits. There's another ATU located in the chamber here, and this may be moved in the near future.

The diagram (FIG. 15) shows where one of the attendants will be stationed during the entire length of the treatment, at this rack in the EL. It's located just adjacent to the chamber so that it would provide this attendant with the capability to view into the chamber while also having control here of the chamber. Again, this is the HGPCA. We've got a primary and redundant unit. Treatment profiles and log sheets are in close proximity. I should note also that we're now using treatment profile log sheets and we have some dedicated displays on the HGPCA. We used to have a workstation here that had a computer and access to all the DMS information. We no longer have that. So, now we've gone to some dedicated displays on the HGPCA for pertinent information, and the log sheets and treatment profiles just on paper right here. We will have access to all the information through an MPAC somewhere else in the Station, at one of the workstations.

BUCK: (Cont'd) Getting down into a little bit more detail, this diagram (FIG. 17) shows a concept of the HGPCA display and control. We have three timers located across the top. Located within these boundaries are your chamber controls: you've got your pressurization control, an oxygen concentration control, and then your readouts close by. The gas supply ON/OFF is your overall ON/OFF for the chamber. These are depress valves and indicators showing whether it's opened or closed. We also have a crew lock equalization valve to be used in a situation where, for some reason, the guy can't get out of the chamber. Something's happened to the other two crew members that are in the Station, and the crew members need to get out of the chamber. They have a slow-bleed valve that's available to them, and that's the only control they have available to them in the crew lock. Yes?

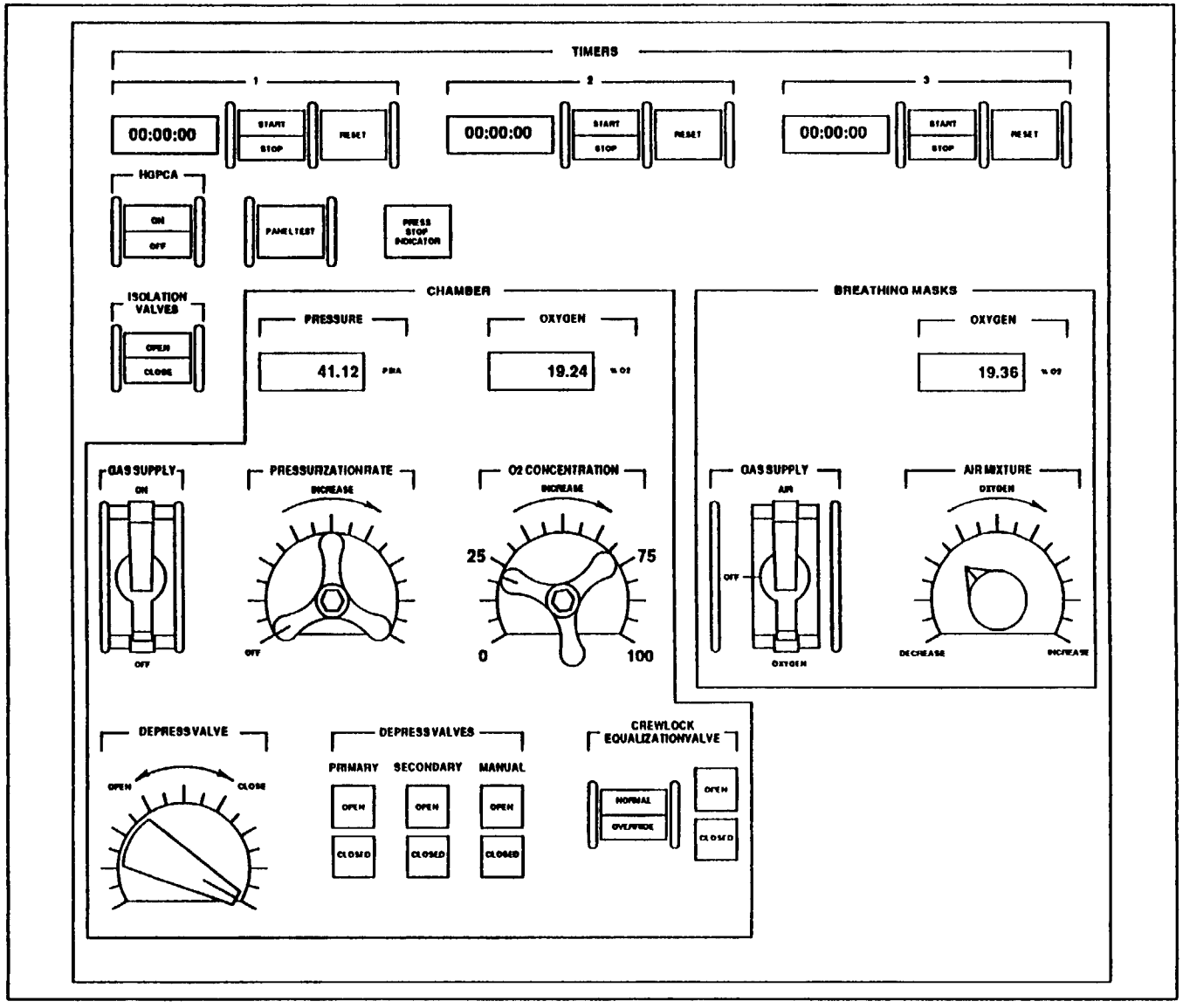
COL. THOMAS WORKMAN: You show an oxygen concentration control there (FIG. 17).

BUCK: Right here.

WORKMAN: Right there. That suggests that you can make oxygen at any concentration on there. Why bother to put that on there when we really only need two concentrations? Why not just a switch?

BUCK: That *is* a good question; there are a couple of parts to that answer. First of all, let me ask, when you said two concentrations, what did you mean?

HGPCA Display and Control



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Airlock Overview

FIG. 17 HGPCA display and control

WORKMAN: Air and oxygen.

BUCK: Okay. The HGPCA is suppled by an oxygen and a nitrogen line. Those are diverted within the HGPCA. We'll get oxygen and nitrogen that will get mixed for chamber pressurization and then we'll have oxygen and nitrogen that will get mixed for the delivery of breathing air to the masks.

WORKMAN: Will you start with pure nitrogen?

BUCK: Yes, from the source tanks.

WORKMAN: Not air?

BUCK: I have a schematic I can show you, but let me go ahead and address this question a little further. We have a requirement to provide chamber oxygen in the concentration of 18 to 21% for the chamber at all times.

WORKMAN: Why is it variable to 100% then on the chamber control side?

BUCK: Right. That's the question. We need to have some kind of detent here. The reason it's variable all the way to 100% is because HGPCA will also provide oxygen for our campout procedure. Our campout procedure is performed down at 70 kPa (10.2 psi), and we need a 30% oxygen (or 28 to 30% oxygen) environment. And, in order to establish that environment, we need to pressurize partially with 100% oxygen. So, the HGPCA itself has the capability to pressurize with 100% oxygen but, for hyperbarics, that is not used. For hyperbarics, we stay at 18 to 21%. So,

BUCK: (Cont'd) this control right here will have some kind of detent on it. You'll actually have to make a push, pull, turn, some type of detent so you are not allowed to go out of the 18 to 21% range.

DR. WILLIAM NORFLEET: Point of information before you go on. That was pointed out to the program, the potential problems with plumbing pure nitrogen, a non-respirable gas, to this assembly. And, the program managers reviewed that and decided that this was the way to go.

HAMILTON: There have been hyperbaric chambers – medical ones – built that ran on reconstituted air that came from liquid oxygen, liquid nitrogen sources and they blended it as they went. Not a new idea. But, it does have a whole gamut of misfortune that can await you.

BUCK: Col. Workman, does that answer your question?

WORKMAN: Partially. I'm still concerned about it.

SPEAKER: Let me, if I may, mention one thing. There's another end where you need to add pure nitrogen to the chamber, and that is: if you get a leak of the mask, you can drive the oxygen concentration in the chamber high. And, you'd have to go through something to adjust it. If you have only air to adjust it, you'd have to use an awful lot to get it back.

WORKMAN: Where's your ventilation control? Or is there a ventilation control?

BUCK: The ventilation control is associated with HECA.

HAMILTON: He's talking about ventilation in terms of net airflow through the hyperbaric chamber. I don't believe, from what I'm seeing here, that you're doing that.

BUCK: No. We're not.

WORKMAN: That's all in review.

BUCK: We have air that's circulated through the chamber, but not a chamber ventilation system comparable to terrestrial chambers.

SPEAKER: We can make a point about that, in that there aren't enough expendables on the Station to go to that type system.

HAMILTON: Does this chamber exchange gas with the main cabin itself?

BUCK: No, it does not.

HAMILTON: Does it throw away gas when it's finished with it?

BUCK: Yes. It's vented overboard.

HAMILTON: That seems a little bit, well, profligate to me. But, maybe people have made decisions that I am not aware of.

SPEAKER: Well, when you do a weight trade-off, the weight required to save that gas versus the probability of using it becomes a bad trade-off.

LOU PANZARELLA: A year or two ago, we tried to force it to reuse the air, but our suppliers of the air – Work Package-1 of the Marshall Space Flight Center – did not want any air from the hyperbaric chamber going back into the Station. They did not want Station pressure affected by hyperbarics. They thought it probably would be easier just to dump it overboard than to have to worry about air going back to the Station.

BUCK: Right. As a contingency operation, they don't like that to affect nominal Station pressure and the balance in the Station.

HAMILTON: Hospitals have the same problem with hyperbaric chambers. They don't understand them and, therefore, they're afraid of them. But, if it's a weight trade-off that's been thought about, then that makes sense.

BUCK: Yes, it has been thought about. It has been addressed.

HAMILTON: That's why you're so concerned in all the procedures with the amount of gas that's available.

BUCK: That's *used*; correct. We have to be as specific as we possibly can when requesting these consumables from Work Package-1. We have to ask for a certain amount of gas to be used in these situations.

HAMILTON: Are there gas stores for the chamber, for the Space Station itself, that are separate from these? Is this a separate gas storage bank for the HAL?

BUCK: No. It's the same as used for the Station. There are cryogenic tanks located outside the Station.

EDITORIAL COMMENT: EVA prebreathe oxygen is vented directly back to the cabin.

STEVE REIMERS: You mentioned before, there are some situations where they may need to add pure oxygen. Now, they've got to have some sort of very reliable diffusion mechanism in the chamber when they're doing that. You don't wind up with little pockets of oxygen?

BUCK: Yes, we do have a circulation system.

SPEAKER: Are there manual controls?

BUCK: Yes. When you say manual controls, these are the valves to pressurize, so these are manual.

SPEAKER: The system is basically all manual.

SPEAKER: On the depressurization side, the valves are located in the crew OPS, so they are electrically linked to the panel on depressurization so that all pressurization valves on both the breathing gas and the chamber are manual in the panel.

BUCK: Just to finish up the explanation, too, for the breathing gas: There's a 3-way toggle switch here, and you're either OFF, you're supplying 100% oxygen, or you're supplying air. This mixture control comes out of a requirement that has us providing (I believe it's) 21 ± 2% oxygen as the air mixture.

HAMILTON: Well, to go back a little bit to the timers. I see colons (i.e., HH:MM:SS) in there, whereas in fact it has been found with experience with diving that running minutes, not broken down into hours, is a far better way of doing it.

BUCK: Okay.

HAMILTON: Actually, we should be doing this in fortnights so that the time units are from the same era as the pressure units that you're using.

BUCK: Okay. But again, this is just a concept right now.

HAMILTON: This is a suggestion that at least one of the timers and perhaps a couple of them should be running minutes.

BUCK: Okay. A little bit of information about the crew lock or the chamber: It's 1.9 m (75 in.) in diameter and approximately 7 m^3 (250 ft^3). It will withstand pressures from zero to 345 kPa (50 psi), and so will the important hyperbaric equipment that's located in the chamber: the HECA, as I mentioned, that controls CO_2, temperature, and humidity; and the breathing masks that will be thrown in there along with the ventilator and the other medical equipment. We also have some dedicated pressure and time displays in the chamber for the attendant. The

BUCK: (Cont'd) EMU umbilicals, which I pointed out before in the picture, and the depress/repress control console. The depress/repress control console is part of the EVA operations, so I won't be too concerned with that in this discussion.

The diagram shows more detail on the crew lock rack layout (FIG. 18). Note the location of the HECA. There are two interfaces right here for the breathing masks. There is a total of four ports to supply breathing gases. Two ports go back to the primary HGPCA, and the secondary ports go back to the redundant HGPCA for gas supply. You've got a hookup for each of your masks; you're going to have a hookup for gas supply, gas exhaust, and the communications link. The HGPCA display panel right here, as I mentioned, will have a timer readout, and this timer readout will be the same; that is, it will be reading the same thing that the attendant on the outside is reading. There's also a pressure display here; and there will be, as I mentioned before, a valve control for them to depress the chamber in some kind of an emergency. Normally, all the chamber functions – depress and repress – are controlled from outside the chamber. This control would be a last resort. The vent line coming from the bottom of the rack is where gases are vented into space, and this is both for chamber depressurization and for the mask exhaust. Our ATU console is part of our communications link. We've got a grill above the rack; this duct is tied to HECA, and this is where our circulation comes. The DMS power outlets are for the other CHeCS medical equipment in the chamber to provide the appropriate interfaces.

WORKMAN: What type of check valves do you have in the vent line?

BUCK: We don't.

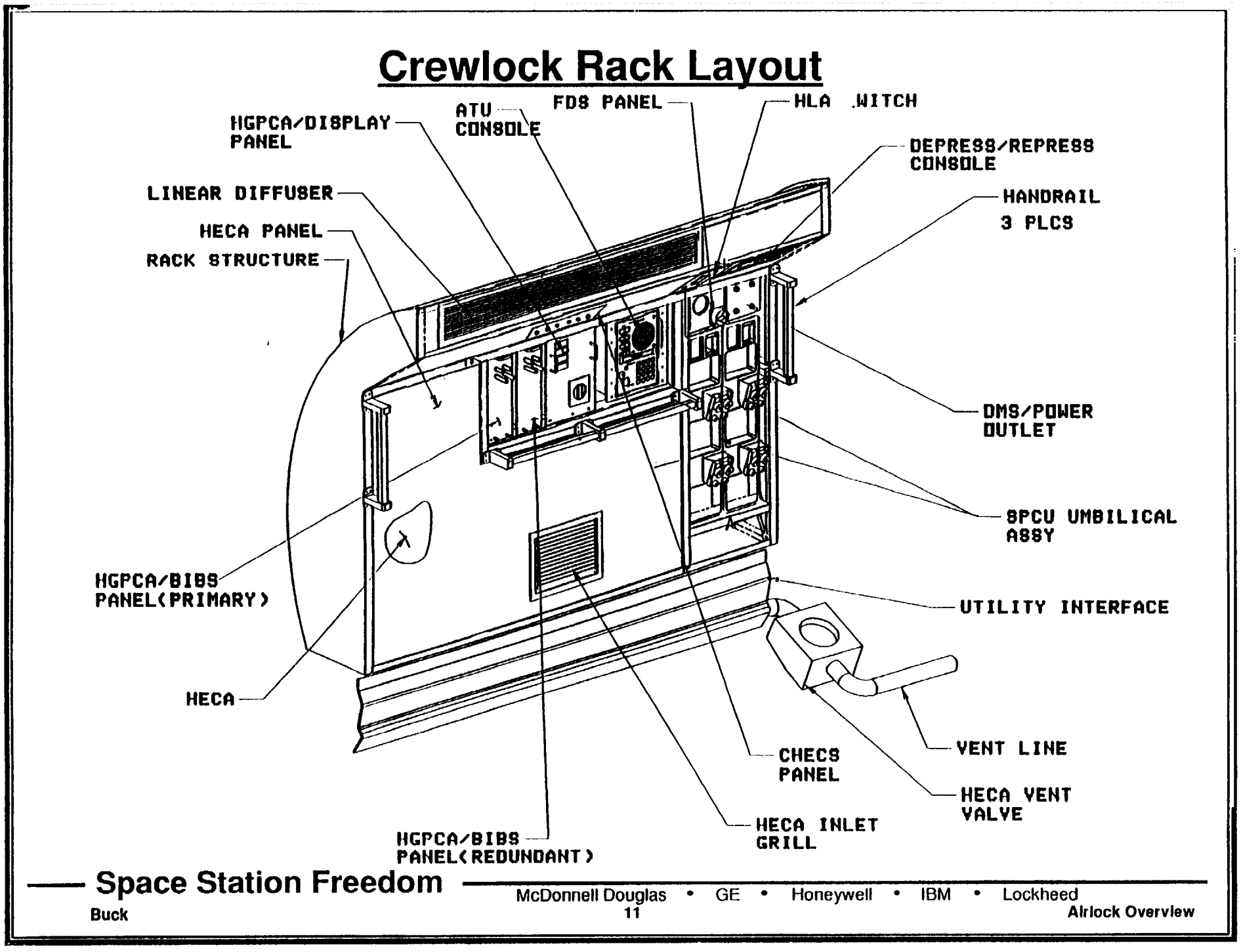


FIG. 18 Crew' ' rack layout

STEVE FROST: We don't. We have shutoff valves.

BUCK: Yes, they're isolation valves. Actually, too, I believe I misspoke. This vent line is for HECA, and this is for use during CO_2 removal and water and humidity removal. We have two other lines that are similar to this one for our depress and our BIB exhaust that aren't shown here. And, those are the lines you'd be asking about, and they have isolation valves as does this one right here. Now, when the chamber is in use as a hyperbaric facility, we've got the medical restraint in there. The medical restraint is attached to the front of the rack, with the patient's head being down toward the hatch. The rest of the equipment will be configured around the chamber. We're planning right now to do a one-g evaluation in the next month or so out in California in a mockup to find out where to best locate all of this equipment in the chamber. We get pressed for room in there, and, right now, we're not sure what the best way is to locate all that equipment in the chamber for the most efficient operations.

BOVE: What do you do about CO_2? I notice there's no meter for CO_2. Is that automatically scrubbed out?

BUCK: Yes.

BOVE: Under feedback controls?

BUCK: Yes.

DR. BARBARA STEGMANN: Do you have anyone breathing on the chamber, or are both your tender and your patient on a mask?

BUCK: For oxygen, they are. Nominally, they'll be breathing chamber air.

STEGMANN: Okay.

BUCK: But they will breathe off a mask when they go to oxygen or in the event that, for some reason, the chamber atmosphere isn't breathable. This you've seen this morning already (FIG. 19), but I just wanted to give a breakdown of what is located in the crew lock and what will stay in the equipment lock. We bring, as I mentioned, the medical restraint in for the patient. The respiratory support pack, which is the ventilator and flowmeter, ALS pack, IV pumps, transport monitor, part of the transport aspirator, the separation containment unit, and pressure regulation unit are in the chamber. The vacuum pump and power control stay in the equipment lock. And, there's a link across the bulkhead. There are the hyperbaric treatment mask assemblies – which include the mask, a microphone, and a headset. The defibrillator stays in the equipment lock due to its electronics, and the electrodes are passed through a bulkhead feed through to the patient.

A little bit about our hatches (FIG. 20e). There are three hatches total in the airlock: one between the node and the equipment lock, one between the equipment lock and the crew lock, and a third between the crew lock and space. The one we're concerned about here mostly is the IV hatch. The hatches use a pressure-

CHeCS MEDICAL EQUIPMENT

- Crewlock
  - CHeCS Medical Restraint System (CMRS)
  - Respiratory Support Pack (includes ventilator)
  - ALS Pack (includes hyperbaric sub-pack)
  - IV Pumps and Accessories
  - Transport Monitor (includes pulse oximeter)
  - Transport Aspirator *
    - separation/containment unit
    - pressure regulation unit
  - Hyperbaric Treatment Mask Assemblies (HTMA)
    - breathing mask
    - microphone
    - headset

- Equipment Lock
  - Defibrillator (includes pacer) *
  - Transport Aspirator *
    - vacuum pump/power control

* Indicates operation from the EL with leads passing through the IV bulkhead into the CL

FIG. 19 CHeCS medical equipment

BUCK: (Cont'd) assisted sealing technique, and our IV hatch can seal on either side of the bulkhead because, for EVA, you want it on one side; for hyperbarics, you want it on the other side. And, the IV hatch also has an accommodation for a medical pass-through lock, in case you forgot something, or to pass through food or pass out trash, etc. And, this hatch also, as I mentioned before, has two windows: one for direct viewing by the crew members and the second for indirect viewing by a camera. Just a few minor details on construction. The airlock will be manufactured in Huntington Beach. It's all aluminum, and these are the primary structure components. Isogrid patterns are used for weight savings and strength (FIG. 20f). And, these are three of our major milestones as they currently stand, launched on MB7 in March of 1997.

HAMILTON: Excuse me. Would this be designed so that the thickness and the configuration and everything are precisely adjusted for the pressure that it's going to contain? You have a 345 kPa (50 psi) design pressure rather than 283 kPa (41 psi).

BUCK: Correct.

HAMILTON: But, where will be the limiting factors in pressure capability? Has that been determined?

BUCK: Three hundred forty-five kPa (50 psi) is the maximum operating pressure, and it will be optimized to the extent possible, remembering that the airlock has several other jobs it needs to accomplish as well. There's external structure, there's micrometeoroid and debris shields that are placed on the outside, and trusses that are placed on the outside to hold additional structures outside for

BUCK: (Cont'd) EVA purposes. That bulks it up a little bit. So like I said, it's optimized to the extent that it can be, but hyperbarics is not the primary use.

HAMILTON: Today, when someone builds a chamber, they pick a thickness of plate that is available, and then they form it to the chamber. And, that really dictates what the pressure capacity of that vessel is.

BUCK: Okay, I see what you're saying.

HAMILTON: The dimensions of it plus the fixed thickness. If you can make the thickness exactly what you want it to be, it can be optimized.

BUCK: Right. In that sense, it will be optimized.

HAMILTON: What I'm getting at is whether we will have a known pressure limit that might, in fact, be higher than the 345 kPa (50 psi) design limit.

BUCK: I wouldn't think so. Primarily because they're using the 345 kPa (50 psi) as a design limit.

HAMILTON: So the thickness will be adjusted to where that's optimized?

BUCK: Correct.

NORFLEET: That's especially true of the IV hatch. That's been whittled on to the point where 345 kPa (50 psi) is indeed its optimal pressure limit.

BUCK: Right. In fact, it helped when we went from 6 ATA down to 2.8 ATA. We did incur a weight savings there because of the reduced pressure.

HAMILTON: The hatches were the big problem.

BUCK: Hatches are a big thing, yes.

FROST: Hatches are big and the wall size factors in also. We went through quite a bit of an exercise to see if we couldn't design a relief valve or see what it costs to design a relief valve to lower the 345 kPa (50 psi) a little bit so they could save the weight accordingly in the air line.

SPEAKER: Do you remember what kind of weight savings that was? Was it between 6 and 2.8 ATA?

FROST: I never heard.

NORFLEET: I can get you that information.

BUCK: We have it; I don't remember off the top of my head.

HAMILTON: Was it a lot or a little bit?

NORFLEET: It involved somewhere around 68 kg (150 lbs) and an increase in cost due to 1000 manhours of redesign. So, it saved about 68 kg (150 lbs) and cost about 1000 manhours to redesign.

SPEAKER: Don't you like the factor of safety above that 345 kPa (50 psi)?

BUCK: The structures and strength people, I'm sure, used some factor and I don't know what it is. Any other questions?

SPEAKER: Have you considered using thermoplastic?

BUCK: For the pressure shells?

SPEAKER: Yes.

BUCK: I couldn't answer that with a *Yes* or *No*. But, I've never heard of it.

BARRATT: Okay, thank you very much. We're going to go right into the next presentation. Dan Schimenti from Lockheed will talk about the hyperbaric environmental control assembly and elaborate on aspects of temperature and humidity control.

Airlock Temperature and Humidity Control: Hyperbaric Environmental Control Assembly (HECA)

DAN SCHIMENTI: I'm going to give a brief overview today on the hyperbaric environmental control assembly that, as Courtney says, is located in the crew lock and deals with maintaining the temperature, relative humidity, and CO_2 level within the stated

SPACE STATION FREEDOM AIRLOCK

- Launched on MB-7, and located on the zenith port of Node 2 on orbit
- Two chamber airlock (Equipment Lock and Crewlock)
- Provides capability for transfer of crew and equipment from within the pressurized volume to space for EVA maintenance and servicing
- Provides volume for the stowage, preparation, and maintenance and servicing of EVAS equipment
- Provides atmosphere control and volume to support a campout prebreathe period in the PMC Space Station
- Crewlock serves as the hyperbaric chamber

FIG. 20a Space Station Freedom airlock

HYPERBARIC CHAMBER REQUIREMENTS

- Major design and performance requirements found in JSC 31013, Rev. C
- Capable of treating the whole range of decompression sickness problems in one patient attended by a second crew member
- Chamber treatment pressure range is from nominal station pressure up to and including 2.8 ATA
- Full medical treatment capabilities are provided by Crew Health Care System (CHeCS) medical transport equipment
- Hatch windows allow for both direct and indirect viewing of chamber activities
- Accommodates communications between the attendants, the patient and ground

FIG. 20b Hyperbaric chamber requirements

EQUIPMENT LOCK (EL)

- 148 inch inner diameter pressure shell (volume = 950 cu. ft.)
- Eight articulating racks provide stowage for:
  - Hyperbaric Gas and Pressurization Control Assembly (HGPCA)
  - Other hyperbaric support equipment (medical equipment pass-through lock, Hyperbaric Treatment Mask Assemblies)
  - EMUs and spares
  - EMU Service and Performance Check-out Unit (SPCU)
  - Distributed systems hardware (power, data, communications, and ECLSS)

FIG. 20c Equipment lock (EL)

CREWLOCK (CL)

- 75 inch inner diameter pressure shell (volume = 250 cu. ft.)
- Capable of withstanding pressures from 0 - 50 psia
- Crewlock equipment rack accommodates the following:
  - Hyperbaric Environmental Control Assembly (HECA)
  - Hyperbaric Treatment Breathing Mask Assemblies (HTMA)/ventilator interfaces
  - Medical equipment interfaces
  - Hyperbaric pressure and time displays
  - EMU umbilicals
  - Depress/repress control console

FIG. 20d Crew lock (CL)

HATCHES

- Hatch locations:
  - Node Hatch - Node/Airlock bulkhead
  - IV Hatch - EL/CL bulkhead
  - EV Hatch - EL/Space bulkhead
- Hatches use a pressure-assissted sealing technique. The IV hatch seals on either side of the bulkhead to accommodate both EVA and hyperbarics
- IV hatch accommodates a medical/EVA equipment pass-through lock

FIG. 20e Hatches

CONSTRUCTION AND SCHEDULE

- The Airlock will be manufactured in Huntington Beach
- It is an aluminum, all-welded construction. The primary structure components are:
  - Equipment Lock
    - Ellipsoids (2)
    - EL cylinder
  - Crewlock
    - Outboard CL cylinder
    - Inboard CL cylinder
  - Bulkheads
- Isogrid patterns are integrally machined into the cylinder external surfaces for launch stability and weight savings
- Schedule:
  - Critical Design Review - 11/30/93
  - Flight Readiness Review - 11/30/96
  - Launch - 03/31/97

FIG. 20f Construction and schedule

SCHIMENTI: (Cont'd) requirements (fig. 21). Those requirements primarily are: thermal control, between 18.3 and 26.7°C (65 and 80°F) and not to exceed 45°C (113°F) during the pressurization intervals; a CO_2 partial pressure less than 1 kPa (7.6 mmHg), and not to exceed 2 kPa (15 mmHg) for anything but an exceptional case; relative humidity between 50 and 95%; and maintaining an airflow for the crew of between 4.6 and 12.2 m/min (15 and 40 fpm). This environmental control also will be used during campout, and the specific requirements for that are still being worked out at McDonnell Douglas. Basically though, the thermal and CO_2 levels will be the same; and we believe the relative humidity will be at Station nominal of about 25 to 70%.

WORKMAN: When did the specifications for maximum CO_2 concentration change? In some of the earlier documents, didn't it show about 1 kPa (7.6 mmHg) or something like that? In earlier documents, there was a lower value.

SCHIMENTI: It's been zero to 1 kPa (7.6 mmHg) nominally, and then a 2 kPa (15 mmHg) maximum.

WORKMAN: And, that's a surface equivalent of what? About 2%?

HAMILTON: Well, 1 kPa (7.6 mmHg) is 1%.

WORKMAN: No, the 2 kPa max. That's a surface equivalent of about 2%.

SPEAKER: What is the unit of airflow control? Is it cubic feet per minute or is it velocity?

HECA FUNCTIONS

CREW LOCK: HYPERBARICS

THERMAL CONTROL 65-80 F 113 F maximum

CARBON DIOXIDE CONTROL 7.6 mmHg 15 mmHg maximum

RELATIVE HUMIDITY CONTROL 50-95 %

AIRFLOW CONTROL 15-40 ft/min

AIRLOCK: CAMPOUT

FIG. 21 HECA functions

SCHIMENTI: That's a requirement right out of JSC-31013, and it's a velocity measurement. We are translating that into cubic feet of volumetric flow for circulation within the crew lock.

SPEAKER: Where is that in the JSC document?

SCHIMENTI: That is in JSC-31013, Para. 2512, Part 3, Rev. C.

SPEAKER: Well, that's a number that was generated back during Skylab. It's for comfort. It's ventilation; it's velocity over the volume.

HAMILTON: That's been determined to be effective?

SPEAKER: Yes. If it's less than 4.6 m/min (15 fpm), you think you're in a closed-up closet.

SPEAKER: Is this the time to ask about camping out? Are we going to talk about that here?

SCHIMENTI: I'm perfectly willing to address it here. I don't really have a presentation.

SPEAKER: I'm wondering what you mean by campout at this point.

SCHIMENTI: We are currently baselining a campout scenario for a minimum of 8 hours in the airlock at 70.1 kPa (10.2 psi).

SPEAKER: By airlock, you mean the crew lock.

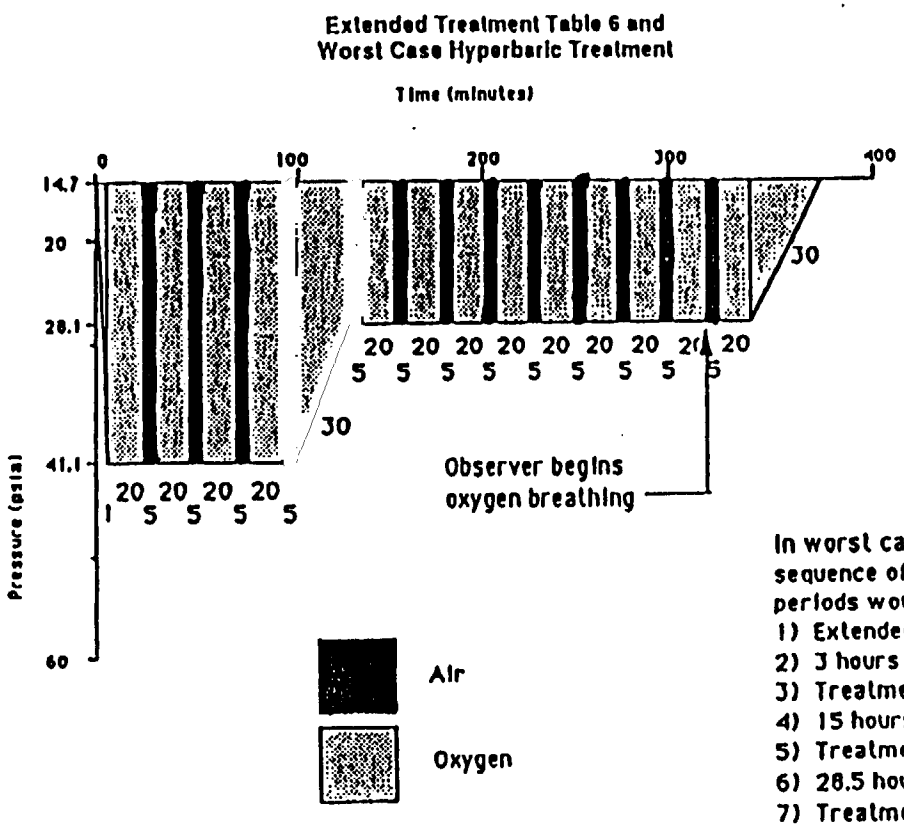
SCHIMENTI: I mean the entire equipment lock and the crew lock together will be completely open. The IV hatch will be open, and the airlock will be at 70.1 kPa (10.2 psi). The Station will be at sea level pressure.

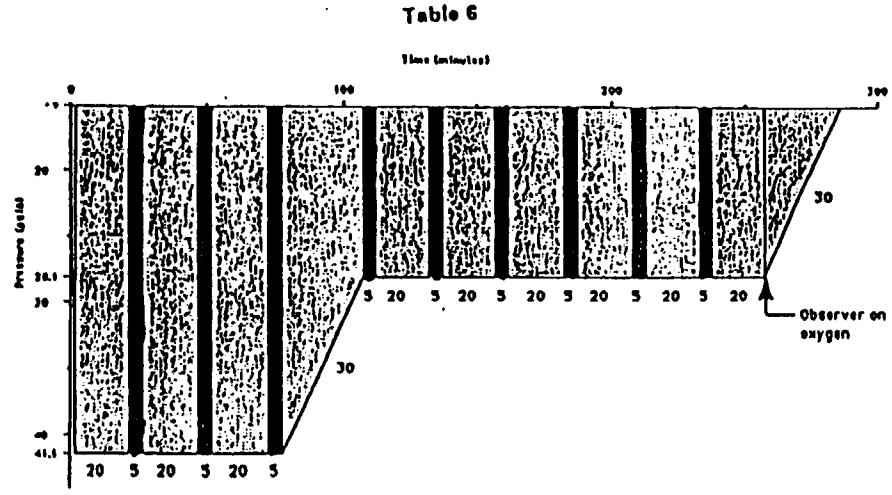
HAMILTON: Isn't the Station going to be at 70 kPa (10.2 psi) also?

SCHIMENTI: That's not my requirement at the moment.

The tables you are familiar with out of JSC-31013 are the extended Table 6 and followed by nominal Table 6's (FIG. 22). The patient will be breathing masked at these 20-minute intervals and will be on chamber air in these 5-minute intervals. And, the attendant will only be using masks at the final depressurization intervals. We used these profiles and tried to generate a metabolic profile to get a handle on what kind of loads we would be dealing with for environmental control, both metabolic, CO_2, and total water produced by the crew individuals. We baselined this as our expected metabolic profile for a worst-case use of the chamber (FIG. 23). We started out at a high BTU level for each individual, and tapered that off and baselined for the majority of the treatment what amounts to a resting state. The only requirements we had previous to this were the ECLSS station 24-hour averages. So, we used a profile based on similar kinds of work done on the EMU or Shuttle to come up with expected load scenarios so we would not over-design the equipment in our system. We used this profile to come up with an expected CO_2 production per individual, in which we used the LESC 41 node model, oxygen, and CO_2 production (FIG. 24). And, this model was used for the Shuttle environments and the EMU configurations, which is the suit life support systems.

TREATMENT PROFILE



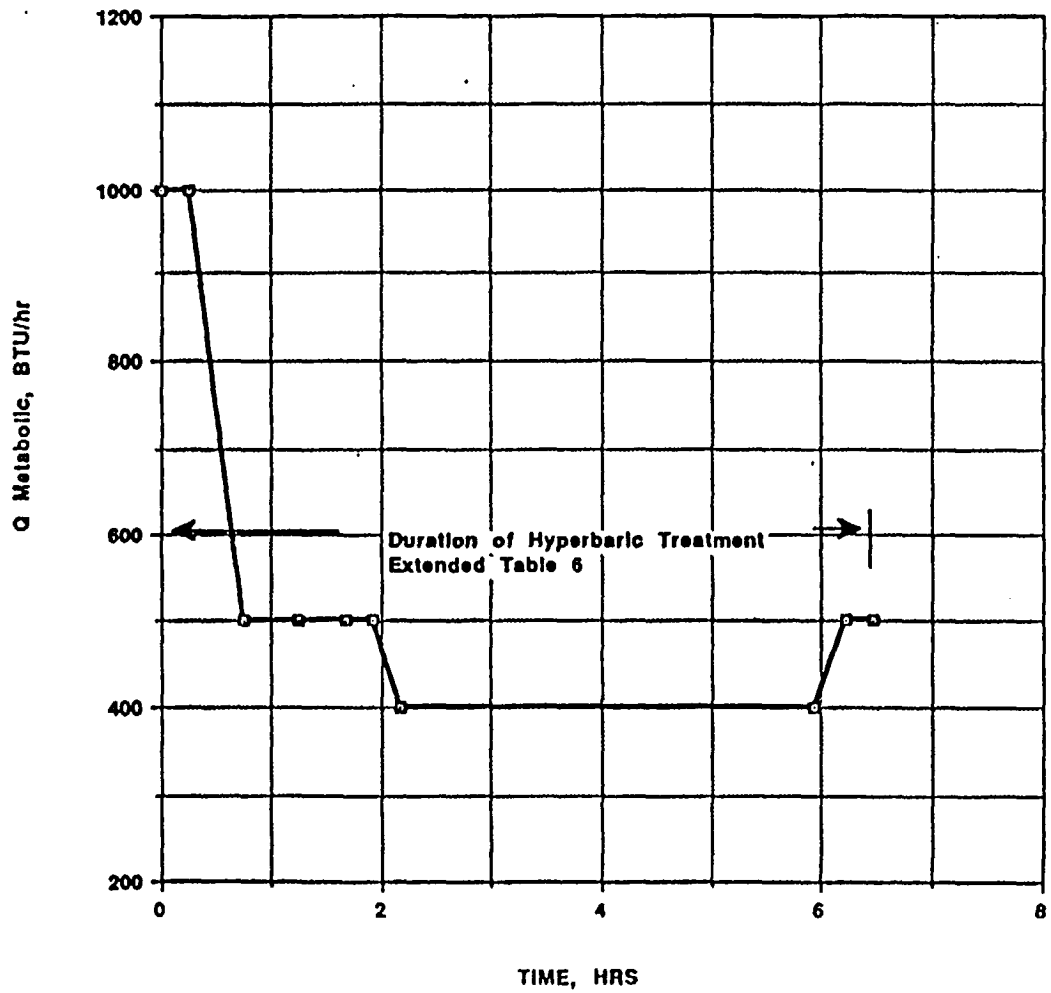


In worst case treatment, the following sequence of treatment tables and rest periods would take place:

1) Extended Treatment Table 6
2) 3 hours rest
3) Treatment Table 6
4) 15 hours rest
5) Treatment Table 6
6) 28.5 hours rest
7) Treatment Table 6

FIG. 22 Treatment profile

METABOLIC PROFILE PER INDIVIDUAL



SPACE STATION FREEDOM

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FIG. 23 Metabolic profile per individual

CARBON DIOXIDE PRODUCTION PROFILE PER INDIVIDUAL

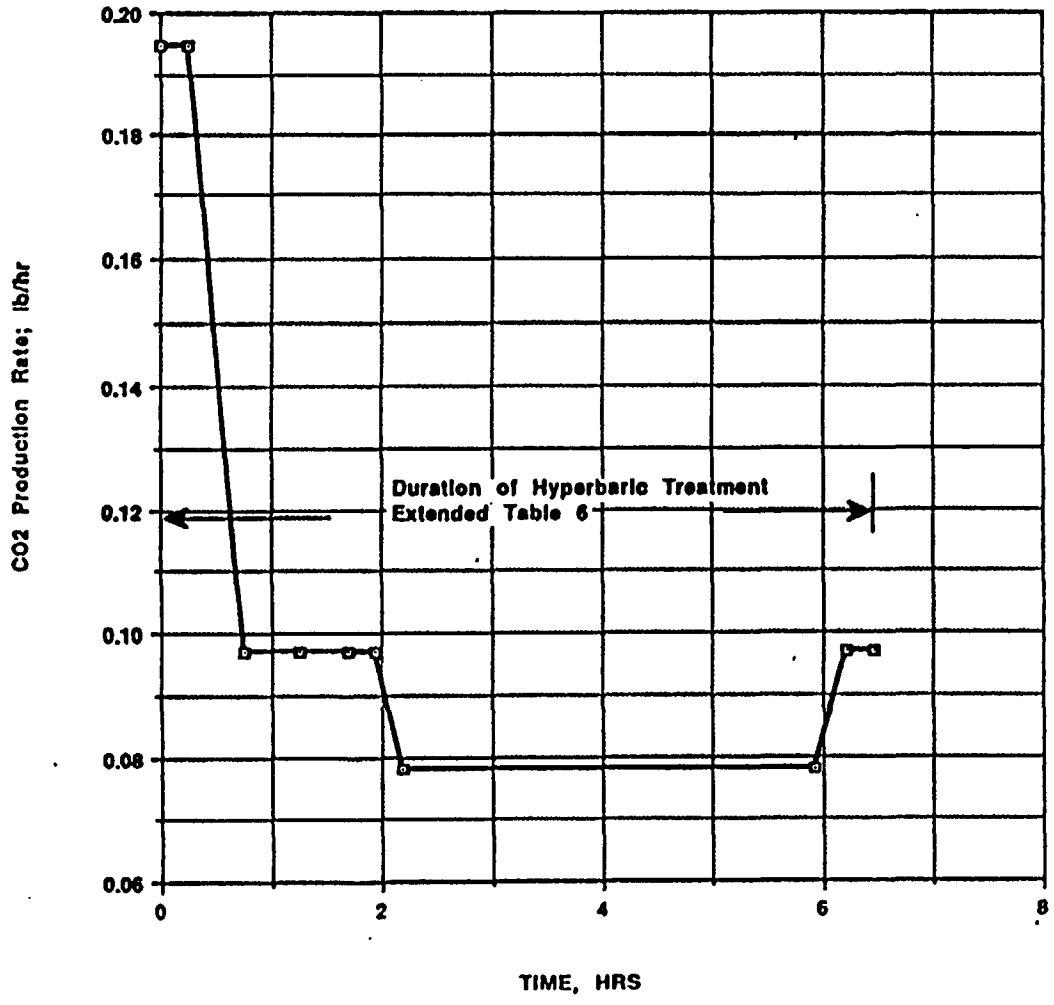

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FIG. 24 CO_2 production profile per individual

SCHIMENTI: (Cont'd)

We are currently baselining this type of expected CO_2 levels over the treatment profile. This is for an extended Table 6, roughly 6½ hours long. We did a similar profile, again using the LESC 41 node model, to come up with an expected total water production per individual (FIG. 25). This takes into account the pressure effects of the various treatment levels; the steady-state intervals of 283 and 193 kPa (41 and 28 psi). Total water production here is made up of the respiratory losses, sweat, and diffusion. The sensible convection varies with pressure, so you get a kind of a flattened-out curve due to the pressure effects. The largest integrals for both water and CO_2 are naturally a result of the initial high metabolic level we started out with. We felt it would not be unreasonable to assume a 15-minute interval at a high metabolic level of 250 kCal (1000 BTU) – which is equivalent to a rapid walking or a very light exercise state.

Basically, what is inside the HECA environmental control unit is a temperature control loop that consists of a heat exchanger and some fans utilizing the Station Temperature Control system water loop (FIG. 26). It deals with the delta-temp from pressurization, the initial spike to get from sea level up to 283 kPa (41 psi), and the metabolic loads of the individuals and the equipment that are in the crew lock. It also is responsible for regulating the airflow over the crew people. The ARCHRS loop – and that's an acronym that I inherited that is "Advanced Regenerable Carbon dioxide and Humidity Regeneration System" – takes care of CO_2 and relative humidity. They are linked together; they utilize two molecular sieve beds that operate in half-cycle tandem to adsorb and desorb to vacuum CO_2 and water. Zeolite is a silicon or aluminum oxide that's doped to create the desired molecular grid that acts as a trap, if you will, for specific sized molecules. Two different types of zeolite are used: one is a desiccant to remove water and one

TOTAL H2O PRODUCTION PROFILE PER INDIVIDUAL

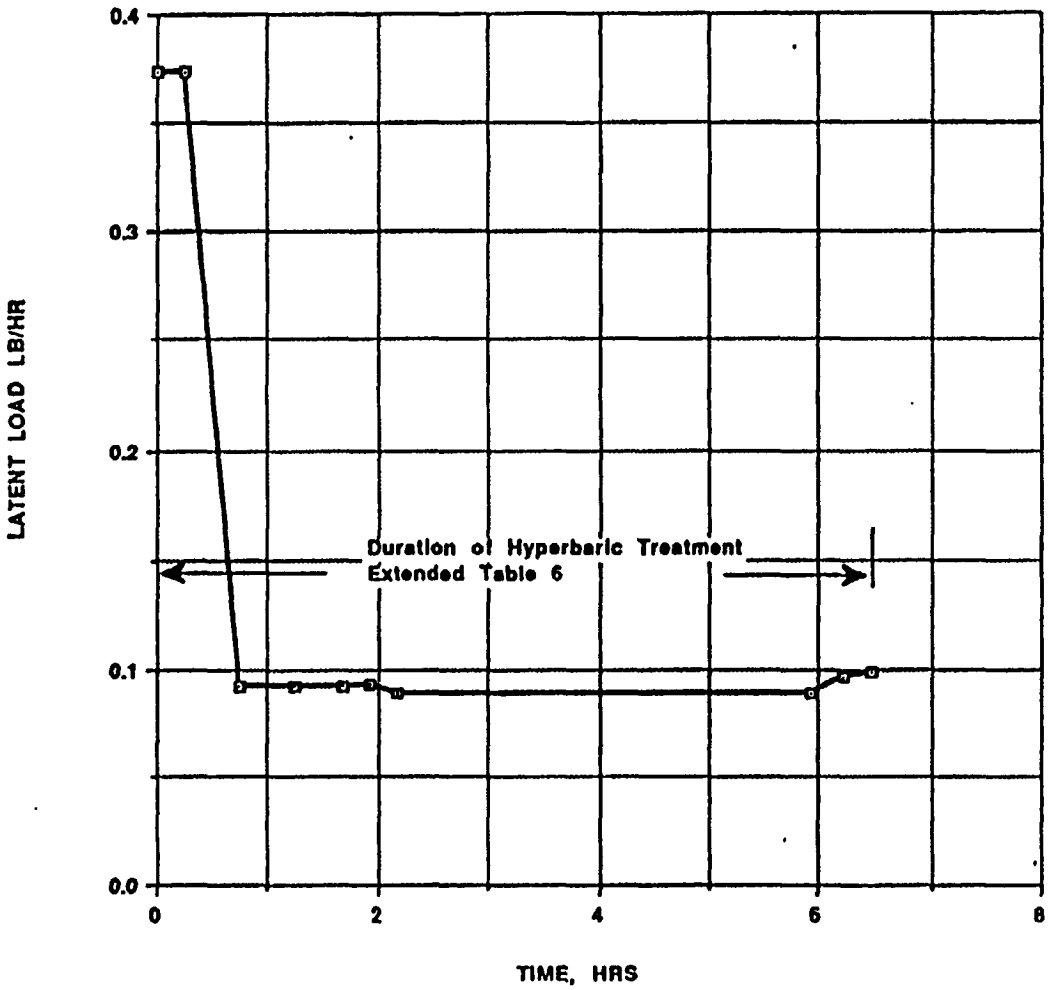

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FIG. 25 Total water production profile per individual

HECA OPERATIONS

TEMPERATURE CONTROL LOOP
- DELTA T OF PRESS, EQUIP, METABOLICS & AIRFLOW
  - STATION TCS WATER LOOP
  - HEAT EXCHANGER
  - FANS

ARCHRS LOOP
- CO2 & H2O
  - MOLE SIEVE - ZEOLITE VACUUM DESORPTION
  - FANS
  - CHARCOAL FILTER

DATA MANAGMENT SYSTEM
- SENSOR MONITORING
- SYSTEM CONTROL
- CREW INPUTS

HECA

SPACE STATION HYPERBARIC MEDICINE AD HOC COMMITTEE 9/26/91

FIG. 26 HECA operations

SCHIMENTI: (Cont'd) to trap CO_2, which are then flushed by the delta-pressure to vacuum to empty them for the next half cycle or absorption phase.

There's a charcoal filter that controls human odors in the chamber. This system is basically transparent to the crew. It is run by the Data Management System, which looks at the sensors for the CO_2 level, temperature, relative humidity, delta-pressure, of the fans, and determines fan speeds and, in the extreme, the cycle times of the valves of the molecular sieve beds to control the environment.

There is also provision for crew inputs for airflow and temperature. The crew *can* request that it be warmer or colder and that the airflow be brought up or down within certain limits. They will have to be input. Control of the system is totally through the MPAC or the workstation, which currently is located in the node. And, any changes to the system have to be input to the computer, which will be monitoring and running the equipment. This is a brief sketch of how these loops would look should one option we're currently considering be taken: This would be a temperature control loop through the heat exchanger, which will either be controlling temperature by regulating the amount of air through it or regulating the amount of water through the heat exchanger. And, then there's an ARCHRS loop that takes air that's already been cooled, processes it through the beds, and routes it back out into the chamber removing CO_2 and water.

NORFLEET: Dan, in the latest analysis with two people in the crew lock, in the task internal characteristics, is it going to be running hot or cold now?

SCHIMENTI: You mean, the crew lock temperature thermal profile?

NORFLEET: Yes. I understand there's been some new work done.

SCHIMENTI: The final analysis of the crew lock temperature profile is being worked by McDonnell Douglas and we have not as yet received it. And, that will include the entire heat load for pressurization, the cold soak on orbit, the steady-state intervals that one would expect. I don't have the data yet.

SCHULZ: Have you done a scenario with someone at 2.8 ATA doing CPR as far as metabolics are concerned?

SCHIMENTI: No. We have not really come up with any hard evidence for metabolic rates previously done, and we have ballparked that profile based on anecdotal discussions with various people at NASA, etc. I do not have data for an actual metabolic run of people during a Table 6 event.

BUCK: That's one thing I'm interested in, though, to get a feel, and this goes back to our operations, for what kind of metabolic loads we'll be looking at. When you say CPR, you are assuming a pretty high metabolic load from whoever is performing the CPR. Normally, the general feeling is, "Well, during hyperbaric treatment, you've just got people sitting in the chamber." Just to give you an idea, that's the general feeling.

SCHIMENTI: Any comments to this would be appreciated.

BUCK: We're trying to get a better feel for, and come up with a better idea of, what metabolic loads we should be using. We're kind of at a loss for requirements

BUCK: (Cont'd) because they haven't been done. There are requirements for EVA metabolic loads, but I'm not sure how those translate to hyperbaric metabolic loads.

DR. ANDREW PILMANIS: At 6 ATA, we used to use four people inside because, doing CPR for a half hour, at least two of them had to stop from exhaustion.

SCHIMENTI: Part of the problem in generating a higher than 250 kCal (1000 BTU) level on orbit is the weightless environment. The length of this 250 kCal (1000 BTU) period we've baselined is 15 minutes, with approximately an hour before you get down to a 125 kCal (500 BTU) level. However, the system design will be able to handle a higher level for CO_2 and relative humidity, and certainly will be able to handle a higher metabolic heat load. In the EMU suit, they baseline intervals where the crew member might be at 400 kCal (1600 BTUs) for short intervals due to the work that he's doing out in space, exertion, etc. And, there is a profile that they've put together. It's similar to this; there are just peaks in different places. However, if anybody had some additions to what they think we should be looking at, we would appreciate that.

WORKMAN: You design for this metabolic profile. Does that give you the 1 kPa (7.6 mmHg) of CO_2 or what?

SCHIMENTI: The system is currently designed to stay *well* below 1 kPa (7.6 mmHg). As a matter of fact, we are currently a little over designed.

WORKMAN: What's designed up to this metabolic profile, if anything?

SCHIMENTI: The CO_2 and water production. In other words, the total amount of CO_2 and water that we have to remove and the time intervals that they may impact the 1 kPa level or, in the extreme, the 95% relative humidity level (which we're not going to reach, however), that is what the impact will be. This would entail a greater CO_2 rate that we might have to deal with. But, there is a lag time for the removal of CO_2.

SPEAKER: There would also be the cooling capacity, I would think.

SCHIMENTI: Yes, but, since the system is designed to deal with a *large* heat spike during pressurization, another 250 kCal (1000 BTUs) for another hour is not going to affect this significantly.

JAMES WALIGORA: Here's the question. If you had a case where, during one treatment or something, you were at 380 kPa (1500 mmHg) or the observer was at 380 kPa (1500 mmHg) for the whole time, what would it impact? It seems that CO_2 would go up to 2% in that one case, I would think.

SCHIMENTI: The problem would be at CO_2 level, not heat load and not necessarily relative humidity either.

WALIGORA: Do you think we ought to see what a really worst case would be and how it would impact them?

BOVE: I don't think you'd do CPR for 6 or 7 hours, though, to tell you the truth.

WALIGORA: No.

BOVE: And, you know, thinking on CPR; I don't think CPR is much more than two-and-a-half to three times resting. You've got two-and-a-half times resting built in as your workload. Also remember, the victim isn't producing any CO_2 or heat at all.

SCHIMENTI: He's comatose.

BOVE: The provider is probably running at about two-and-a-half to three times, which is pretty close to where you have it now.

SCHIMENTI: We've currently designed the system to handle this profile times two, each person undergoing this. Now, it doesn't really make any difference for the system design whether this peak occurred in the middle or at the beginning or at the end. However, this is the kind of max interval that we're thinking of, and comments to that would be appreciated.

HAMILTON: What do you have to do here? Don't change your design; change the accepted limits, because there's absolutely no problem, as you'll get in the handout from me later, with letting the CO_2 go up considerably above 2 kPa (15 mmHg), which is what you have as your upper limit now. And, you can go to 3 or 4 kPa (22 or 30 mmHg) without any real problem for a short period of time, because it's going to catch up after the guy or the people stop working there.

SCHIMENTI: That's correct.

HAMILTON: So, you don't need to worry about it. It's a problem that you should accept, a possibility that should be accepted by the system, and not be worried about.

SCHIMENTI: My problem is, I don't have the luxury of being able to design to that. They stick me with a requirement and the interpretation of that.

HAMILTON: You have designed it adequately, it looks like, from what you've shown us here.

SCHIMENTI: Now, in a practical application scenario or in an operations use, we may be able to state that certain levels will be exceeded given a change in the treatment or unexpected events so that the levels will get pushed higher. And, this would not be detrimental to or violate system performance. That is something that may be written into the document later on.

REIMERS: Those kinds of considerations of what happens, you know, how bad is a thing that happened to you if you trespass on the limit. Those are the kinds of things that weigh heavily on your decisions with respect to redundancy.

SCHIMENTI: That's correct.

REIMERS: If nothing much bad happens, you really don't need much in the way of redundancy.

SCHIMENTI: We are currently forced into a two-failure level of redundancy; in other words, the system has to continue operations after one failure. For instance, if something should happen in the molecular sieve operation where one bed – due to

SCHIMENTI: (Cont'd) valve or plumbing or etc. – was no longer in operation, the treatment could continue but it would continue at closer to the 2 kPa (15 mmHg) level. And, that's the way we're interpreting that requirement to continue operation. Now, to be able to exceed the 2 kPa (15 mmHg) level is *not* allowable the current way that the document is written.

PANZARELLA: As far as redundancy is concerned, the program has set our redundancy levels for us. We're not looking at each possible case; they're just given to us.

HAMILTON: How much effort, or how much cost, in your design is because of the temperature spike on pressurization? Is that the limiting factor on the size of the heat exchange?

SCHIMENTI: Yes, the initial heat load is our limiting factor.

HAMILTON: Is it very big compared to what it would be if you didn't have that?

SCHIMENTI: Well, yes.

HAMILTON: Because that, to me, is relatively unnecessary.

SCHIMENTI: Well, the heat of pressurization, depending on what the final configuration analysis of the actual crew lock heat coefficients, etc., and its orbital positions (which will ultimately determine its wall temperature) are, we did some initial studies about a year ago that indicate that that heat spike could be as high as 5800 kCal (23,000 BTUs) in that initial 2-minute interval. There's some more

SCHIMENTI: (Cont'd) recent information and analysis of the crew lock, giving different materials and orbital conditions, that have halved that level. But that is still in work. That *is* the driver for the size of the heat exchanger, is the initial 2-minute level, keeping it below 45°C (113°F).

REIMERS: On that, you can reduce your thermal loads a lot by making the system design such that you don't lose the refrigeration that occurs in the pressurization control valve. And, people have done this in hyperbarics. If you reconfigure your design a little bit so that the expansion valve and your pressurization control valve are physically inside the vessel, you get *much* less heat. What happens in those situations is the gas expands across the valve; of course, it gets cold. Well, now you have cold gas going down a warm pipe going into the chamber, picking up heat all along the way. Now, when it gets in the big chamber, it pressurizes, it gets hot. If you can stop the heat pickup along the way and make use of the cooling that occurs in the primary expansion valve, you get a much lower heat spike on pressurization. In fact, if you look at the thermodynamics books and you equalize two vessels, you're at a different pressure to equalize, you come to the very shocking conclusion that temperatures aren't supposed to change.

BUCK: I don't know what temperature area you're considering as supply. Right now, we're looking at −18 to 0°C (0 to 35°F) air for supply.

REIMERS: Coming into the chamber?

BUCK: Coming into the HGPCA where it's mixed and then, subsequently, into the chamber.

REIMERS: Okay. But it's being mixed there. What pressure is it coming into the HGPCA?

BUCK: It comes in at 2340 kPa (340 psi) and then it's regulated.

REIMERS: So, it's a fairly substantial expansion there. The point is, if you can capture the cooling in terms of the result of that expansion, you'll cut down on that temperature spike in the chamber by a significant amount. Now, the practical facts of doing that and the hardware requirement may not be worth it, but that's a possibility that's there.

FROST: Here, we have a cost trade-off. What you have to do is move the valve into the crew lock and make it a remote operated valve, and there's a trade-off with "How much more does that cost for saving of the size of the heat exchanger and fans?"

REIMERS: There's a middle ground in that, if you could just somehow insulate that line so that gas isn't picking up heat as it goes into the chamber, you don't lose. The main thing is you don't want to lose the cooling that's created at the expansion.

FROST: Yes, I understand. Well, all of that's weight, and there's a big delta-V implication. It's a complex trade-off to optimize the system.

SCHIMENTI: We are also faced with significant limits as to how much we can fit in this crew lock. The crew lock is extremely crowded at the moment, even without people in it. We are currently trying to make our system smaller. The rack envelope that Courtney had shown – which is that L-shape on the previous presentation in the

SCHIMENTI: (Cont'd) crew lock rack – is approximately 2.13 m^3 (7 ft^3), and we are trying to get that down to a smaller level. Is there anything else?

SPEAKER: Do you all have a requirement for ORU transfer through the crew lock?

SCHIMENTI: Yes, that determines placement of components and the rack size. That's one of the limits.

SPEAKER: That rack that you're talking about having in there, is that going to have to be taken out during ORU transfer?

SCHIMENTI: No, all of the crew lock equipment is meant to be untouched during any EVA or ORU transfer.

BUCK: That's one reason that there's a premium on lowering volume in the airlock – so that we can accomplish the ORU pass-through.

BARRATT: Thank you, Mr. Schimenti.

Airlock Contamination:
Detection and Thermodegradation Products

BARRATT: The next presentation is by Dr. Tom Limero, who's going to give us a rundown on contamination issues for the airlock.

DR. TOM LIMERO: What I was asked to present were some of the contamination and detection issues dealing with hyperbaric airlock operations. The breakdown of what I'll present is: the contamination sources during hyperbaric operations; what the most likely potentially toxic compounds are, what selected monitoring levels we have developed for those; the detection strategies; what types of technologies are available, what instrument, and what some of those characteristics of those instruments are; some results off of Shuttle dealing with these instruments we have targeted; and some concerns overall about the entire issue.

It appears that, in the hyperbaric situation, the two most likely sources of contamination are a contaminated EVA crew member or a contaminated ORU coming in, and the other one is a thermodegradation event (FIG. 27). When we talk about thermodegradation, we're talking about the whole range of anything from just kind of overheated wiring to a full-blown fire. The materials that we consider most likely to be brought in through contamination of a crew member or an ORU are (FIG. 28): hydrazine, which is found both on the Station and on the Orbiter when it's up there; monomethylhydrazine (MMH), which is a Shuttle propellant; nitrogen tetroxide (N_2O_4), which is a fuel oxidant (but inside we expect it to be mostly in the form of nitrogen dioxide); and finally, perhaps, ammonia, if one of the external cooling loops began to leak.

The maximum levels that would be acceptable – and, of course, in actuality you would not want to come near the actual highest levels that would be acceptable – but the numbers that have been set forth by the toxicologist and have been concurred upon by the NRC committee on toxicology, are as follows (with the exception

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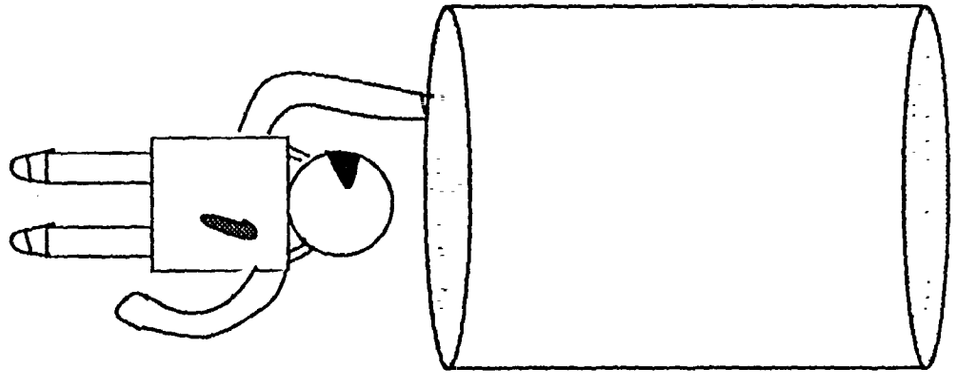
HYPERBARIC AIRLOCK

BIOMEDICAL OPERATIONS AND RESEARCH BRANCH

CONTAMINATION SOURCES

- EXTRAVEHICULAR ACTIVITIES (EVA)



- THERMODEGRADATION EVENT

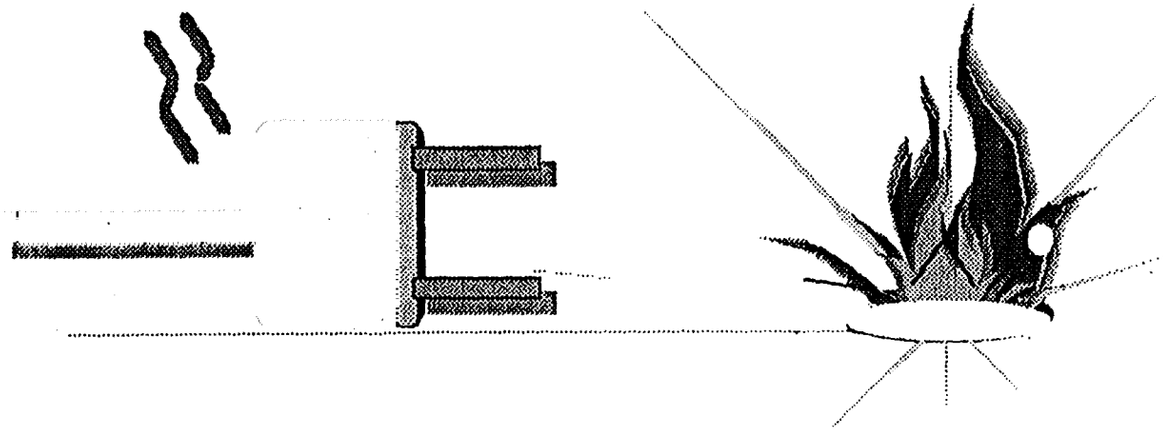


FIG. 27 Hyperbaric airlock contamination sources

EXTERNAL CONTAMINANTS THAT COULD ENTER THE AIRLOCK DURING AN EVA

- Hydrazine
  - -SSF and Orbiter propellants
- Monomethyl hydrazine (MMH)
  - - Shuttle propellant
- Nitrogen tetroxide
  - - Shuttle fuel oxidant
  - - Probably present as nitrogen dioxide
- Ammonia
  - - external coolant loops

FIG. 28 External contaminants that could enter the airlock during an EVA

LIMERO: (Cont'd)

of hydrazine, which is still under review): monomethylhydrazine has been accepted at a very low level; nitrogen tetroxide and ammonia at a couple of orders of magnitude difference (FIG. 29). So, what we look at is the risk of one or all of these being brought into the airlock, and the availability of such compounds in the areas of likely EVA activity. Questions include how much of it is actually around, what might be the opportunity to contaminate the crew members, and what is the stickiness on the suit – how likely is this stuff to get on to the suit and to stay on the suit long enough for the crew members to bring it into the airlock – and finally the compound toxicity. When you put all of those together, you come out with a risk of contamination (FIG. 30) being, in descending order, hydrazine followed by MMH, ammonia, and, finally, nitrogen tetroxide at the bottom.

For combustion products, we have some experience with this on Shuttle. It's important to recognize that, up to this point, we have no evidence that there's been contamination brought into the airlock during Shuttle operations. However, we *do* have experience of Shuttle thermodegradation events (FIG. 31). We had one in 1983, where some Kapton wiring fused; on STS-28, a teleprinter cable paralyzed; and, most recently, in December 1990, we had two DDSs that overheated, leading to a degrading of the electronic components. These events, especially the STS-28 event, got us thinking about what we want to monitor. The problem with thermodegradation products is trying to figure out what you want to monitor, because there are so many variables that determine what's going to be generated. The obvious question is, "What materials are burned?" But then, you get into things like the temperature of the fire, the oxygen content around the fire, the surrounding materials, and so on (FIG. 32). It comes down to the fact that you have to target what you're going to measure.

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HYPERBARIC AIRLOCK

BIOMEDICAL OPERATIONS AND RESEARCH BRANCH

HIGHEST ACCEPTABLE CONTAMINANT LEVELS IN THE AIRLOCK

COMPOUND	SMAC* LEVEL IN PPM				
	1 Hr.	24 hr.	7 day	30 day	180 day
HYDRAZINE**	5	0.4	0.08	0.02	0.003
MMH	0.002	0.002	0.002	0.002	0.002
NITROGEN TETROXIDE	1	0.1	0.05	0.05	0.05
AMMONIA	20	20	10	10	10

* SMAC: Spacecraft Maximum Allowable Concentration

** Under review by JSC Toxicology Group

FIG. 29 Highest acceptable contaminant levels in the airlock

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HYPERBARIC AIRLOCK

BIOMEDICAL OPERATIONS AND RESEARCH BRANCH

RISK OF CONTAMINATION ENTERING AIRLOCK FOLLOWING AN EVA

- FACTORS CONTRIBUTING TO RISK
  - Availability of compound in the areas of likely EVA activity
  - Opportunity to contaminate the EVA crewman
  - "Stickiness" on the suit
  - Compound toxicity

INCREASING RISK OF CONTAMINATION →

NITROGEN TETROXIDE | AMMONIA | MMH | HYDRAZINE

FIG. 30 Risk of contamination entering airlock following an EVA

SHUTTLE THERMODEGRADATION EVENTS

- STS-6, May 1983
  - Kapton wiring fused
- STS 28, August 1989
  - Teleprinter cable pyrolyzed
- STS 35, December 1990
  - Two Digital Display Systems(DDS) overheat thermally degrading electronic components

FIG. 31 Shuttle thermodegradation events

VARIABLES AFFECTING GENERATED THERMODEGRADATION PRODUCTS

- Materials burned
- Temperature of the fire
- Oxygen content around the fire
- Surrounding materials
- Ignition source
- Extinguishant used

FIG. 32 Variables affecting generated thermodegradation products

LIMERO: (Cont'd)

To be selective, we had to narrow down what we wanted to monitor. We can't monitor everything. So, we came up with a criterion; the toxicologist set the task on this (FIG. 33). Basically, we looked at the quantity that might be generated; in other words, "Do we have a lot of a particular toxic compound generated off a particular material?" And, "What materials on spacecraft are most likely to be the ones that are degraded?" So, we're looking for what is of real toxic concern that could be generated in significant quantities on materials that are in a position to be thermally degraded on spacecraft. From that, we came up with a list of five compounds: hydrogen cyanide, hydrogen chloride, carbon monoxide, hydrogen fluoride, and carbonyl fluoride (FIG. 34). These come from such materials as Kapton, Teflon, and PVC (FIG. 35). Of course, all three of them are going to give off carbon monoxide; Kapton gives off hydrogen cyanide; and Teflon gives off hydrogen fluoride. Carbonyl fluoride is the fluorine analog to phosgene, and that also comes off; the carbonyl fluoride comes off Teflon; and then HCl comes from the PVC.

Probably the two materials of most interest for airlock considerations are Kapton and Teflon. Generally, the ranges that we are considering monitoring are for the acid gases going from about 2 ppm to 100 ppm, and for carbon monoxide measuring somewhat below 10 ppm to 1000 ppm; a bigger range for carbon monoxide (CO) (FIG. 36). We expect perhaps more of it to be generated. An additional 100 ppm of hydrogen cyanide (HCN) is a lot more of a problem than 200 or 300 ppm of CO. So, we've defined what we need to measure, and what we think are the most likely problems to occur in a hyperbaric situation.

SELECTION CRITERIA FOR TARGETED COMBUSTION PRODUCTS

- Compound Toxicity
- Quantity of the compound likely to be generated
- Materials likely to thermally degrade

FIG. 33 Selection criteria for targeting combustion products

COMBUSTION PRODUCTS TO BE MONITORED

- Hydrogen cyanide (HCN)
- Hydrogen chloride (HCl)
- Carbon monoxide (CO)
- Hydrogen fluoride (HF)
- Carbonyl fluoride (COF_2)

FIG. 34 Combustion products to be monitored

SOURCES OF SELECTED COMBUSTION PRODUCTS

KAPTON	TEFLON	PVC
CO HCN	CO HF COF_2	CO HCl

FIG. 35 Sources of selected combustion products

SELECTED MONITORING LEVELS

HCN	2 ppm - 100 ppm
HCl	2 ppm - 100 ppm
CO	<10 ppm - 1000 ppm
HF/COF_2	2 ppm - 100 ppm

FIG. 36 Selected monitoring levels

LIMERO: (Cont'd)

We now have to ask, "What can be used to monitor the situation in there if one of these events should occur?" and be able to detect that event. Basically, for the desired instrument characteristics, we wanted to be able to monitor as many compounds simultaneously in real time as possible. Obviously, it will be compact, light, rugged, compatible with microgravity, without external resources, and highly reliable; and one of the Station requirements is that this be able to survive a depress cycle (FIG. 37). This is what we were working before we learned about hyperbarics, so there were no high-pressure constraints. I'll deal with that in a few minutes. In addition, it should be a portable instrument, and the instruments we're going to talk about *are* portable.

For the contaminants that we expect from the EVA – the hydrazines, ammonia, and nitrogen tetroxide or nitrogen dioxide – there are really about five available technologies on the market. These are the major ones (FIG. 38). Indicator tubes: A lot of people know them better as Draeger tubes. Their sensitivity is just not going to meet our requirements and their reliability is very much in question, especially since, for orbit, we would have to repackage them because you can't break glass in orbit. Electrochemical: Again, MMH and hydrazine usually can't be distinguished. There's some interference with ammonia, not a major problem, but again it doesn't get down to the required levels. Mass spectrometer: It is a much more complicated, power-hungry instrument that probably cannot get down to the levels required. Colorimetric paper cassette: This is a bulky system and the paper tends to degrade over time, and some moisture/humidity effects also are a problem. Dosimeter badges: They don't give you the kind of real-time updates of what's going on. So, we are left with an ion mobility spectrometer. This is the unit we've chosen.

DESIRED INSTRUMENT CHARACTERISTICS

- Monitor all targeted compounds simultaneously in real time
- Compact
- Lightweight
- Rugged (withstand vibration and shock of liftoff)
- Compatible with microgravity
- Low maintenance
- No external resources required (e.g. coolant, carrier gases)
- High reliability
- Survive depress cycle

FIG. 37 Desired instrument characteristics

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HYPERBARIC AIRLOCK

BIOMEDICAL OPERATIONS AND RESEARCH BRANCH

DETECTION TECHNOLOGIES FOR EVA CONTAMINANTS

- Indicator tubes (length of stain)
- Electrochemical
- Mass spectrometer
- Ion mobility spectrometer
- Colorimetric (paper cassette or dosimeter badges)

FIG. 38 Detection technologies for EVA contaminants

LIMERO: (Cont'd)

This is a prototype unit that was developed out of a military program for measuring chemical warfare agents; in fact, it actually saw duty in the Gulf, and it was hard to get work done for our own people during that time. But anyway, this is very simple. There's a button here; it's a one-button operation. You push the button; there's an 8-bar display. The more bars you get, the worse off you are. Note the very simple display. They turn it on, let it warm up for about 2 or 3 minutes, and take off the black cap, and they're ready to go and get the readings. The advantages to the ion mobility spectrometer (FIG. 39): It's got low detection limits. We're looking at less than 9 ppb for hydrazines; we think we can go down to 1 or 2 ppb with some materials engineering. It's rugged. It was developed by the military to be used in the field, and it's gone through tests like dropping off the back of a Jeep going 40 mph and that type of thing. It's waterproof; you can put it in water and it'll come out and be fine. It's reliable. It's easy to operate (as I said, one button), minimal interferences, and it can simultaneously detect hydrazine, MMH, ammonia, and nitrogen dioxide, although we really haven't taken a look at this just yet.

The ranges of performance on the instrument (FIG. 40): The IMS goes from about zero to 600 ppb for MMH and hydrazine; ammonia is in the low ppm range; lower detection limit is somewhere below 9 ppb; we haven't really checked ammonia; and the resolution is somewhere below 2 ppb. The reason this chart is incomplete is that it's very difficult to generate hydrazines down at these low levels. We tried generating up to about 600 ppb with a new Kentech generation unit, and it took us 24 hours before we even saw any hydrazine coming through the system. It just sticks to everything, and it's very difficult to work down, so that's why these numbers are somewhat nebulous and not really pinned down.

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ION MOBILITY SPECTROMETER (IMS)

- Low detection limits (<9 ppb for hydrazines)
- Rugged
- Reliable
- Easy to operate
- Minimal interferences
- Simultaneously detects:
  - Hydrazine
  - MMH
  - Ammonia
  - Nitrogen dioxide (not confirmed)

FIG. 39 Ion mobility spectrometer (IMS)

IMS SENSOR PERFORMANCE*

	MMH	HYDRAZINE	AMMONIA
Range	0-600 ppb	0 - 600 ppb	low ppm
Lower detection limit	< 9 ppb	< 9 ppb	??
Resolution	< 2 ppb	< 2 ppb	??

* Preliminary testing

FIG. 40 IMS sensor performance

SPEAKER: What happens if the unit suddenly sees a lot of hydrazine? Do you find that out, or does it just go blind?

LIMERO: No. It does respond to it. Like any monitor or sensor, you're going to swamp it for a while. It depends on how much it sees. If you go above the 600 ppb range, if you're up around 1 ppm, it may take it some minutes to recover. Now, if you go up to the 50 or 100 ppm range, it may really do a job on the sensor and it may take you 20 or 30 minutes for it to recover.

BOVE: I don't understand what you mean by sticking. Is hydrazine a gas or a liquid when it's contaminating things?

LIMERO: Actually, they're doing some testing at White Sands right now on that. But what happens is that, from the testing they've done at White Sands, it's a solid form and it kind of sticks on to the EVA suit. When they come in, I've heard differing opinions of what happens. That, when you repressurize, it just vaporizes off the suit. Talking to the people at White Sands, it sounds more like water. If you have ice and you come inside, you've got snow on your suit from being outside or whatever; you come in, and it just gradually melts. Some of it turns to a liquid. And, that's a real concern because, if it does, it may saturate into the suit and then you have a real problem. But, as I say I've heard evidence from basically the same group of people on both sides: one, that it vaporizes as soon as it comes in; and one, that it is slowly given off.

BOVE: Your detector is detecting molecules of gas suspended in the air, and so you would have to assume that the hydrazine would volatilize and it would be drawn into the sensor.

LIMERO: Right. We assume that; at least, when they come back in and they repressurize, a portion of it *will* volatilize.

BOVE: Then you wouldn't use your sensor to go over the suits themselves, would you?

LIMERO: Around the suit; but, if they're very close to the suit, the operational system scenario might be: If they came in and they detected hydrazine, they would then move that hydrazine sensor around and use it as a kind of a detector to pinpoint where the problem is.

SPEAKER: This thing only works at cabin pressure?

LIMERO: No. In fact, it *will* work at reduced pressures, but we have not done the testing on the reduced pressures. We know it works at 70 kPa (10.2 psi) because it's been on board Shuttle and it did just fine. So, we know it will go down to at least 70 kPa. The manufacturer feels, without any problem right now, it'll go down to 34.5 kPa (5 psi) and *operate* at 34.5 kPa (5 psi). Beyond that, we don't have a feel for it. We can make it so it'll survive space vacuum because it has an outlet to the outside and it's always equalizing inside the instrument itself. So, you don't have a pressure differential where you're going to blow out gaskets or membranes or anything like that.

JAMES KAUFMAN: Are you concerned about a contaminated crew member coming in and, by the time you've detected it with this device, he's already dirtied the airlock itself? If he goes back out, he leaves a dirty airlock.

LIMERO: Yes, I don't think there's any doubt about that. The problem is that I don't know how you're going to detect it on the outside. And, the problem is that when you go outside, you have a good opportunity to miss the hydrazine. So, you said it's safe and the guy's coming in anyway; and I have not seen any good way, as yet anyway, to detect on the outside. And, the other problem that you have is that it's going to have to be a *Yes* or a *No*, because you have no way to quantitate. You don't know how much is actually there.

SPEAKER: I thought White Sands was also testing a unit to work in vacuum.

LIMERO: They *are* working on a quadripole unit, but I don't think that's the unit that they will go with. They're thinking about actually an ion mobility time of flight; and it's essentially the same as this, only you evacuate it. This one works at atmospheric pressure. The time-of-flight unit works at vacuum. The difficulty is the same thing. Somehow, you have to get the molecules off the suit and somehow you have to be able to quantitate them. And, in space it's going to be very difficult to do that.

SPEAKER: This has not been tested under hyperbaric conditions either, I assume.

LIMERO: No, it has not. And, I don't know how it would react under hyperbaric conditions.

HAMILTON: You wouldn't really need it under hyperbaric conditions. Bleed the sample out of it.

LIMERO: Right. That's a possible option.

HAMILTON: Would you take a second and tell us how this thing works? Is it like a mass spectrometer?

LIMERO: It's similar. As in a mass spectrometer, the sample is pulled in and you ionize it. You now have an ion, and you have an electronic gate. That electronic gate lets a pulse of those ions come through into a drip region. What you're doing is measuring the time that it takes the molecule to traverse that drip region. That drip time is key to a particular drip, a particular molecule; each molecule will have a particular drip time to get through that region. And so, it's similar to a mass spectrometer. That drip region has an electric field applied to it, so you're helping move the molecules along. The difference is, in a mass spectrometer you're separating according to molecular weight, and here it's molecular weight and also the size and shape of the molecule being measured. As I said, this unit works at atmospheric pressure, so these molecules are going in the opposite direction of the drip gas. As you go down in pressure, of course, the pressure within the unit gets lower and lower, and that drip gas gets lower and lower in pressure. If you get down to vacuum, then you probably need a time-of-flight mass spectrometer. And there, you're measuring the time of flight it takes the ion to traverse a vacuum.

HAMILTON: Is there a little pump in there that sucks the gas into it? Then it wouldn't work in a vacuum.

LIMERO: No, it will not work in a vacuum. That's the difficulty, even with the other units. The problem you have is how to get it into the unit. The only available technology I know that *might* work on the outside is like near infrared, where you can actually scan a surface. The problem is, it just doesn't have the sensitivity that's required; this doesn't even come close right now.

HAMILTON: Are the molecules drifting through air?

LIMERO: Yes.

HAMILTON: Then would it be effective if you put it in an environment that has a different composition than air?

LIMERO: In terms of different composition, do you mean totally different? Are we talking, 70, 80, 80:20 versus 70:30, because that will not make any difference.

SPEAKER: That won't make any difference?

LIMERO: No. What's going to make a bigger difference is the increased pressure, because the increased pressure is going to cause them to drift slower through that region. What that's going to do is broaden your peaks a little bit, so you're going to lose some sensitivity unless you go to a peak width. At 70 kPa (10.2 psi), we saw just the opposite; we got more sensitivity on peak height and nice sharp peaks, but

LIMERO: (Cont'd)

they came quicker through the drip region. That is going to be your limiting factor as to how low this can actually detect because, eventually, the peaks are going to come faster than your electronics can keep up with them.

For combustion products, what we have developed is a combustion products analyzer. This has been flying on board Shuttle for about a year. It is a very simply operated instrument. All the crew has to do is turn this button. They can scan and they'll look at HF, HCl, HCN, and CO; it'll just go from one to the other automatically or, if they want to, they can sit on a particular compound. It'll also indicate low flow, low battery. The alarm is disabled right now. The inlet is a particulate filter. Inside, essentially what you have is a small diaphragm pump that pulls air over the sensors – HCN, HCl, HFCl (FIG. 41). We're in the process of testing HF, but we believe HF will pick up the COF_2 as well. If there's any moisture at all in the air, it's going to go to HF, so we feel this sensor will serve that purpose as well. These normally work in a passive mode, but we use a pump to improve our response and recovery times. And so, the pump only has to maintain a very minimal phase velocity over the pump. We go about 800 m/min. This is a little bit better characterized at this point.

As you can see, the ranges are within the monitoring levels that we need (FIG. 42). The ranges go from zero to 100 on the acid gases and from zero to 1000 on CO. Resolution is around 0.1 and 1 ppm on CO. The accuracy says ±5%, but that is limited by the method that we use to calibrate them, and that accuracy is certified at ±5%. The exception is CO. For CO, we use bottle standards that are certified to a much more stringent accuracy, and you'll see we get ±2%. So, that's more appropriately where the sensors fall. And, as you can see, the

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CPA SENSOR BLOCK

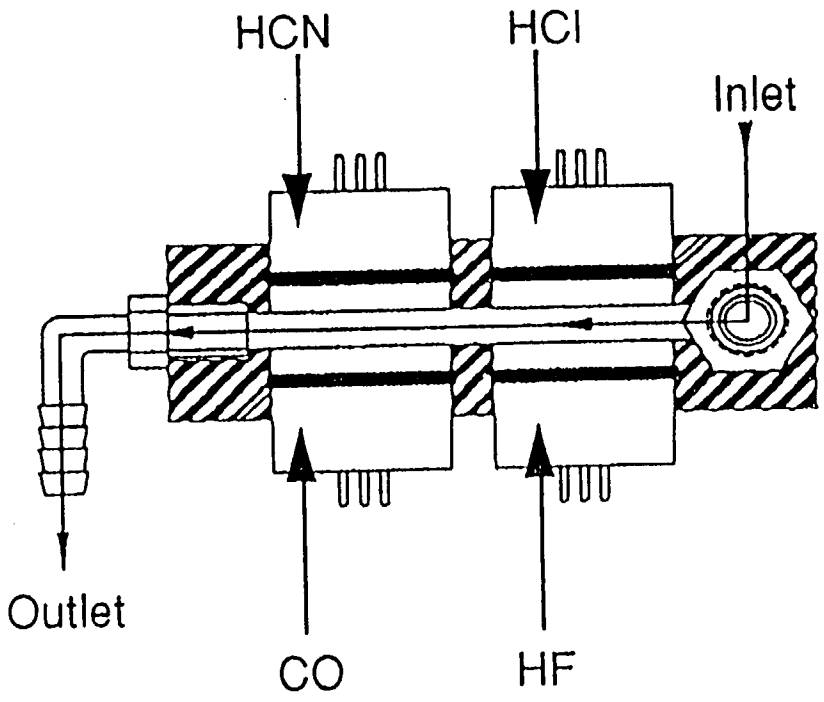

FIG. 41 Combustion products analyzer (CPA) sensor block

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RESULTS OF CPA SENSOR PERFORMANCE TESTING

	HCl	HF	HCN	CO
RANGE	0-99.9 PPM	0-99.9 PPM	0-99.9 PPM	0-999 PPM
RESOLUTION	0.1 PPM	0.1 PPM	0.1 PPM	1 PPM
ACCURACY*	± 5%	± 5%	± 5%	± 2%
REPEATABILITY	± 2%	± 2%	± 2%	± 1%
RESPONSE TIME RISE TO 80% DECAY TO 95%	 60 seconds < 5 minutes	 120 seconds < 5 minutes	 24 seconds < 5 minutes	 15 seconds <5 minutes

*. Accuracy is limited by the accuracy of calibration standards used. Permeation tubes for HCl, HF, and HCN are certified as ± 5% devices.

FIG. 42 Results of CPA sensor performance testing

LIMERO: (Cont'd)

repeatability, which is not affected by the certification of the standards that we're using, does come in about ±2%. Response time is good. HF is a little bit long; that's because that's an indirect reaction. These are all electrochemical sensors, and they are all oxidation reactions except for the HF, which is an indirect acid reaction, I think, with iodide and is then reduced. We're working to try and get that reaction time down.

We have flown the hydrazine monitor on one Shuttle mission, the purpose of the mission being to look at pre- and post-flight calibration and see how well it stayed in calibration (FIG. 43). That also gives an indication of the precision and accuracy you can expect out of this instrument when we fully characterize that. You can see that this did very well. We're looking from zero to 600 ppb, and that's a pretty good pre- and post-flight. You're looking at about 2 months in between those two calibration lines, and a lot of "shake, rattle, and roll" in the meantime. In addition, we did get back a data logger on this instrument, and we did look at the spectra that came back. We've not seen any hydrazine during this mission; it was not expected. It was a low-risk type of mission. We did see what we think is a little bit of ammonia present, which would've probably been 1 or 2 ppm, but that was it. From the spectral analysis, we could tell that this instrument was functioning fine, both at sea level and at 70 kPa (10.2 psi).

The CPA just pulled one mission. This was an extremely nice crew. We asked them to take one measurement and they took three measurements all the time. They took measurements on the middeck, the flight deck, and this was the SLS-1, and they took measurements in the laboratory as well. What you can see is that, basically the CO level or the sensor reading remained fairly constant (FIG. 44).

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PRE AND POST FLIGHT CALIBRATION

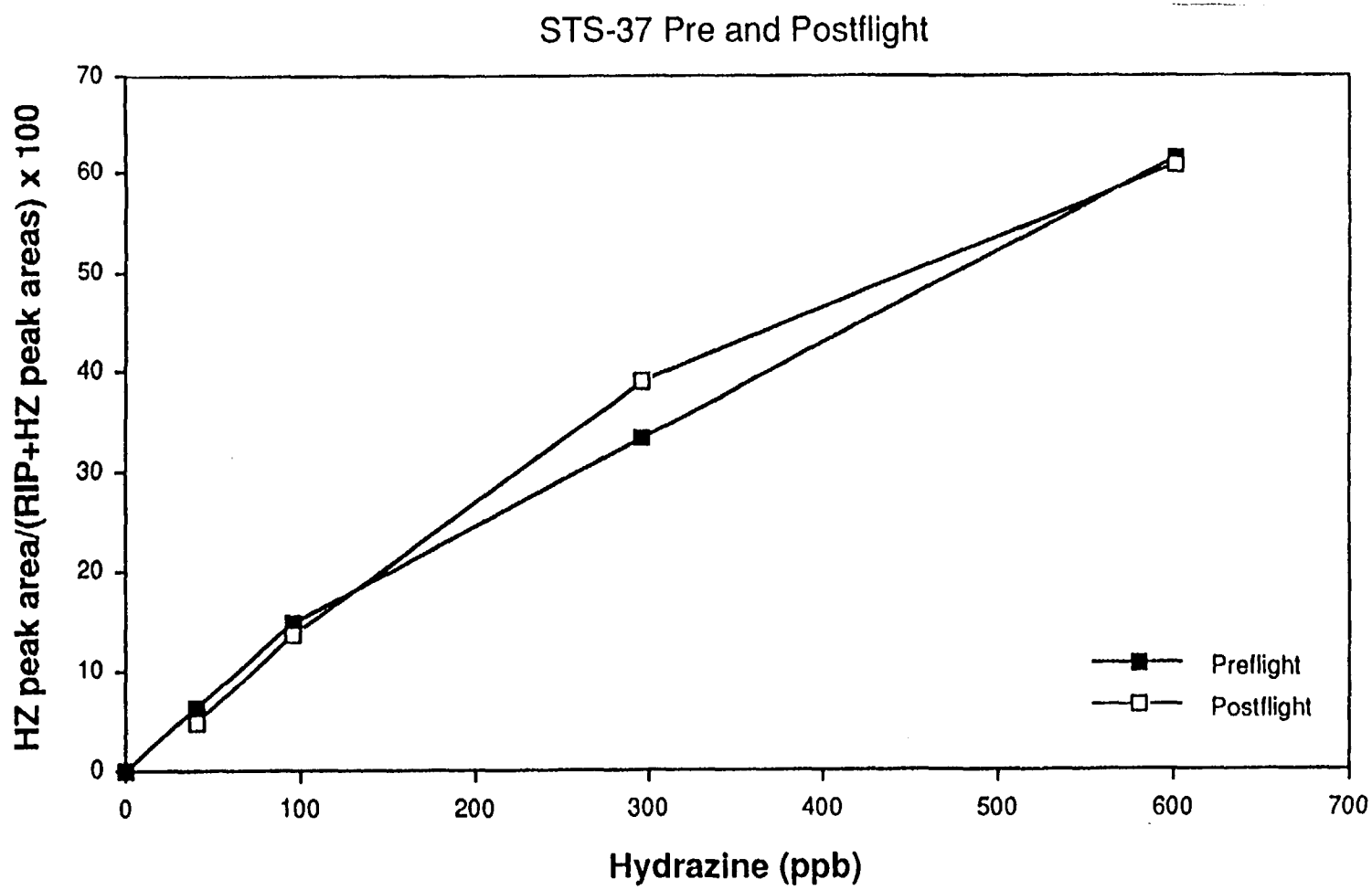

FIG. 43 Pre- and post-flight calibration

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STS40 CARBON MONOXIDE SENSOR RESPONSE

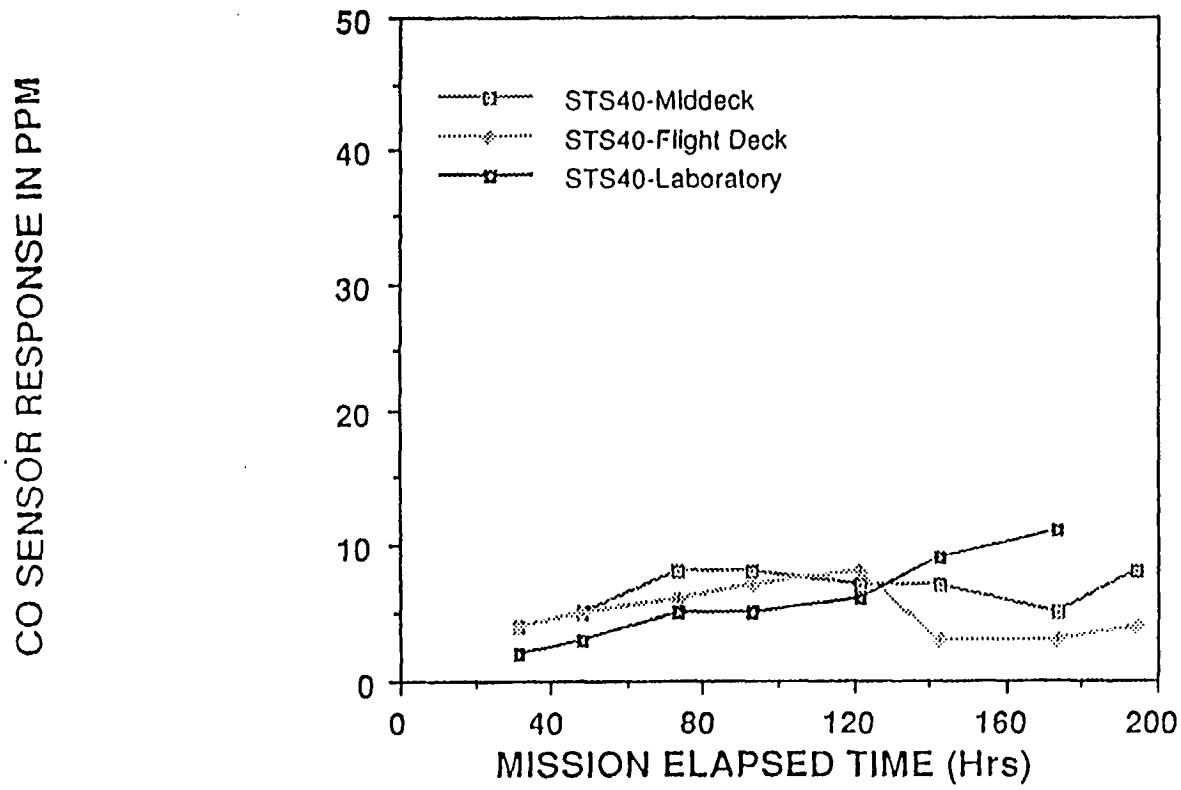

FIG. 44 STS-40 CO_2 sensor response

LIMERO: (Cont'd)

We do know on the CO from previous flights that we have a hydrogen interference, and that's why you're seeing the CO levels being elevated a little bit. But, we have worked on that, and we're down now to where we're getting a hydrogen cross sensitivity of at least 10:1. So, it's taken about 10 ppm of hydrogen to give us one reading – 1 ppm on our sensor. We're working to overcome that to get it down to zero. On this mission, you're looking at about 100 or so ppm of hydrogen, which is about right for a 10-day mission because the lab was doubled. We'd normally look for 200 to 300 ppm of hydrogen on a mission of this length and with this many people. And, that's all metabolic as far as we can determine.

The other sensors, again – HCl, HF, HCN – showed that readings from the middeck, the lab, and the flight deck were basically similar (FIG. 45). Again, this is all below 1 ppm, which is probably the lower range that this instrument will really look at. This may be real, this little elevation on the HCl, but we don't know for sure.

The last thing that I want to mention is some concerns I have, some questions from our perspective (FIG. 46). One is that, as I mentioned in the beginning, I put up a list of instrument characteristics and, when we were developing these instruments, we weren't thinking about hyperbarics. And so, none of these instruments has been thought about or considered for certifying for hyperbaric conditions. Probably more important is that the calibration at hyperbaric conditions is going to be a problem. I think there are ways around it. Regarding the CPA, for instance, one of the ways we get around calibration of an electrochemical sensor is to actually have pre-calibrated sensor blocks, so they just pull out one sensor block and put in another one and it's ready to go. You might have

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SENSOR RESPONSE OF HCL, HCN, AND HF DURING STS-40

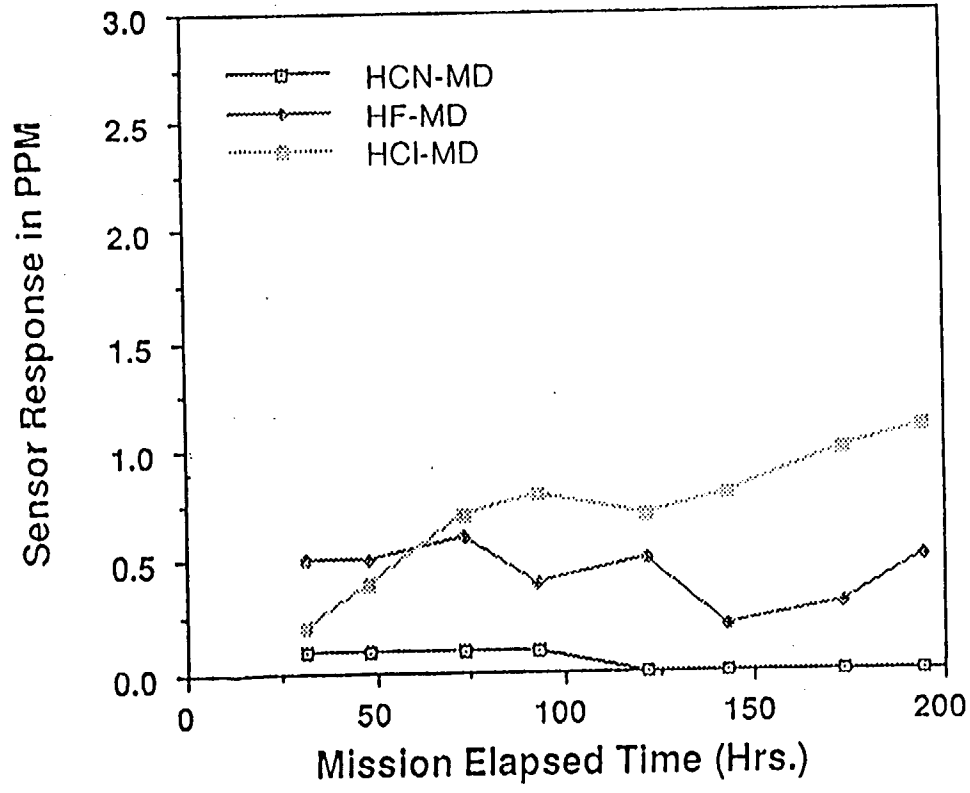


FIG. 45 Sensor response of HCL, HCN, and HF during STS-40

CONCERNS

- Certification of instrumentation to operate at hyperbaric conditions
- Calibration of instrumentation at hyperbaric conditions
- Instrument cost impact
- Decontamination strategies

FIG. 46 Hyperbaric airlock concerns

LIMERO: (Cont'd) one of those sensor blocks that has specifically been calibrated for the hyperbaric condition; that is, if you're going to be at one pressure. Now, if your pressure is going to wander all over the place, that's going to create some other problems. These two lead to a cost impact.

The third thing that I'll leave you with is that I think you have the potential to contaminate the airlock one way or the other, whether it be thermodegradation or through an EVA crew member coming in. I think you've got to be thinking about how would you clean up in there. How would it be done? What provisions would be made for decontaminating the airlock? Because our experience from Shuttle over the last 2 or 3 years has been that you can plan and you can do the best you can, but it just seems that Murphy kind of flies on along. Any questions?

BOVE: I guess one of the concerns we have, as you're talking about detecting background contamination, is the scenario where an instrument fails, some wires burn, and HCN or HF is released into the air in fairly large amounts. There ought to be some process that allows people to quickly protect themselves from breathing the gases while they go around getting their detector ready. I just wonder whether that's been considered.

LIMERO: Right. On Space Station, the CPA will be a first-alert instrument to do just that, to serve as a first alert to catch something before it does become a major incident. But, sometimes if you have a short and this stuff pyrolyzes in a hurry, you're still going to be well above levels that you consider safe. I presume – and I don't know, Mike may be able to answer that better than I, but I know for Shuttle – they are

LIMERO: (Cont'd) working on a quick-don mask and that that work will flow over into the Space Station Program.

SCHIMENTI: The SMAC value for hydrazine on the 1-hour level is 5 and your detector range is zero to 600 ppb. Can you relate that to a patch of hydrazine on a suit outside? Or, what are we looking at? What is the detector capable of measuring?

LIMERO: You didn't ask me the question I thought you were going to ask, but I think I can answer by telling you the question I thought you might ask. If you'll notice, there's a big discrepancy between the MMH and the hydrazine, between the detection levels. And, part of that is that there was a study done at White Sands with MMH where they had one breath of MMH, one sniff of it, that caused nasal lesions. The toxicologists poured over that study and they could not find anything fundamentally wrong with it. You tend to think, "That just seems unusual," but the study was very well done. For hydrazine, there was no such study done. After MMH, they stopped that. So, they set the limits higher, but that is under review and that limit is going to come *down*; I don't think there's any doubt about that. How much it'll come down remains to be seen, but I think you'll see a much, much lower hydrazine limit when they finally get set in. I think I did the calculation, and it was around 0.1 ppm; it was in the milligram range for the Shuttle airlock. Now I may be wrong; it's been a while, and I don't remember exactly. But, I think it was in that range. Five ppm in the airlock isn't going to translate into grams of material. You're going to be looking at a very small quality. And for MMH, when you look at 0.002 and, unfortunately (if you notice that's 0.002 all the way across, which includes the 1-hour SMAC), that's a small amount. And, that's the other thing. That amount probably is

LIMERO: (Cont'd) going to be very difficult; visually, you're not going to see it. Dr. Johnson at White Sands is pretty adamant about the fact that it's going to be very difficult to visually see white hydrazine on a white suit, and I would probably agree with him.

HAMILTON: What is the requirement to use this instrument in hyperbaric pressure, under hyperbaric conditions?

LIMERO: Do you mean, either one?

HAMILTON: Either one, yes.

LIMERO: Right now, I think the changes are in the works. There is no requirement now for us to have that instrument working in those conditions, and that's why the original instrument constraints that I put up did not include hyperbaric.

HAMILTON: But, if there were a fire and you wanted to look and see what's in the chamber, you would have to put this instrument through the lock into the chamber. You couldn't bleed the gas into some space. Otherwise, it would go into the cabin.

LIMERO: Yes, right. And not only that, we had talked a little bit about sample lines, but sample lines become a real problem when you get down to the low levels. In fact, I imagine the scenario would run that you would actually have this in during your hyperbaric processes so that you would not have to open up at any time to pass this through. So that as a standard procedure, when you started doing hyperbaric operations, you'd have the CPA in there.

PANZARELLA: You're coming back in from EVA and, should you detect something with the sensor, how would you take care of the contamination on the suit? Would you take care of it inside the airlock, or would you have to go back outside?

LIMERO: Right now, the way in which it's done is that: If they detect it, they go back out, and, if they *visually* see it, they have a brush that looks kind of like a paint brush with which they can brush the hydrazine off. But, as we said, I think you probably have to have a lot on you to be able to see it. If they came in and there was hydrazine detected on the suit, the way in which the protocols are written right now is that they go back out again and they bake for an hour or two. They turn to the Sun and bake it off, then they come back in.

PANZARELLA: Well, I'm more concerned about a patient with decompression sickness. I know, it's like a double failure.

LIMERO: Yes, it is. But, I think if he comes in with hydrazine on him – I'm not a medical doctor, but you'd probably have to make a decision of which was more dangerous. And, probably the bends would be the thing you would take care of, would be my guess. Try to clean it up inside, because the real problem with hydrazine is the cancer causing potential of it, so that may be years down the road where, if he has the bends, that's probably pretty immediate.

KAUFMAN: This potential liquid form of hydrazine, do you know much about it? If it became a liquid form – say the suit somehow contaminated the crew lock, then he decided he could go through his hyperbaric treatment – is there a possibility for that to vaporize because of the increased pressures there?

LIMERO: I don't think it would vaporize. The hyperbaric conditions, I would think, would lessen the chance that it would vaporize off the suit. On Shuttle they have some cleanup towels, and I'm not sure exactly what those are made of, but they're used to sop up any hydrazine. But, that's kind of a primitive method of doing it.

SPEAKER: Is carbonyl fluoride detected in the HF channel?

LIMERO: Yes. We're in the process of testing that but, with all indications, there's no reason to believe that that shouldn't be because, again, COF_2 goes immediately to HF in the presence of any kind of moisture. So, if you're in any kind of humidified air it's going to go to HF.

REIMERS: I'm under the impression here that, if an astronaut is out with the bends and you get him into the equipment lock, you get him out of his suit and then back into the hyperbaric chamber first without doing anything hyperbaric, so all this stuff that's coming in on his suit is going to be more an equipment lock problem than a hyperbaric problem. It may contaminate the hyperbaric chamber on the way through, though.

WORKMAN: If it's under the physiological response to surface equivalent, it's going to be enhanced under hyperbaric conditions. And so, a given amount of contaminant, perhaps, will be more physiologically reactive and I don't know how that needs to be factored in with your alarm limits.

LIMERO: Yes. I'm glad you brought that up, because I meant to mention that. That's true; for none of the limits that I have mentioned, either for the combustion products or

LIMERO: (Cont'd) the hydrazine, have hyperbaric conditions been looked at. They put a lot of correction factors for space flight in there already. But, whether more would need to be added for the hyperbaric condition or not would remain to be seen. My guess is, on some of them, there probably would be.

WORKMAN: I think you'd need to take a look at that, because I think you're going to find your limits are going to be much lower.

LIMERO: Yes.

HAMILTON: Much lower is a matter of relative values. Typically, what you're dealing with in any kind of toxicology situation, in my experience, is partial pressure sensitivity. And, you're only looking at the difference between 1 ATA and 2.8 ATA, so it's not that big a deal. Those of us coming from the diving world are looking at multiplying by 30, where life gets a little bizarre; not so much here.

LIMERO: I would think that eventually, as this gets farther along in the program, we'll at least be asked to look at it. I'm sure.

BARRATT: I'm going to move us along a little bit. I'll mention quickly that the requirements being examined for Station now call for a quick-don mask within 4.6 m (15 ft) of each crew member at any given time. We are currently looking at the MAGIC mask made by Intertechnique in France.

The next speaker is Jim Waligora, who is very well known in the EVA and decompression sickness world.

Overview of EVA for Space Station

WALIGORA: Hello. I'm Jim Waligora. I've been involved in the tests we've done at the Center on decompression sickness, in atmosphere selection and limits on CO_2, etc. What I'd like to talk to you about this morning is our anticipation of the number of EVAs during Station operations, construction, and maintenance; the particulars about the suit, suit pressure, the options for denitrogenation; and a little bit about our assessment of the risk of decompression sickness.

The next planned EVA is on STS-49 early next spring. It will have three EVAs; and, after that in early 1994, we'll have the mission to revisit the Hubble telescope, which also will be a 3-EVA mission (FIG. 47). Those are the only missions that we have firmly scheduled before the first assembly mission in 1995, although I think it's quite possible that there might be one or two additional missions that are not identified right now. During the same period of time, there are 10 unscheduled or contingency payload EVAs – that's an EVA that you practice and plan for but does not occur unless it's required to support a payload deployment of some kind, to support a failure in some system in the payload. We had one like that on our last mission; the first EVA on that mission was of that type where we went EVA to back up a deployment system. Also, on each STS mission there are contingency EVAs to support the vehicle such as closing the payload doors; we always train for that.

During Station construction, there will be from two to four scheduled EVAs per construction mission. Once we are into STS, there will be up to 52 EVAs per year. The range is probably between 12 and 52; every effort is being made to minimize

EVA ACTIVITY IN MANNED SPACE FLIGHT

STS: There are currently 3 planned EVAs from now until 11/93 and we can expect at least one EVA mission per year until the 1st assembly mission 4/95. There are 10 unscheduled or contingency payload EVAs in the same time period and there are STS contingency EVAs for each mission. There will be from 2-4 scheduled EVAs for construction or repair during each construction mission in addition to the potential for contingency EVA during each mission.

SS: There will be up to 52 EVAs per year. Every effort is being made to minimize EVA activity. Current projections indicate that much if not all of the maximum will be utilized.

SEI: Mission senarios are not well defined, but it is anticipated that at least 5% of crew activities will be devotes to EVA.

FIG. 47 EVA in manned space flight

WALIGORA: (Cont'd) the EVA activity, especially for maintenance, but we can expect that it might approach 52. And SEI, we really don't know. You can read that as you will.

During the Station construction period from the Shuttle that involves 17 construction flights beginning in 1995, we have the airlock available here after the seventh flight (FIG. 48). And as I said, each one of those will have from two to four EVAs; most will probably be planned for two, some of them for three. Each one will have the capability of being backed up with an extra EVA so that the range will be 2 to 4 hours for each. So you're talking about 17 × 2 to 4.

We'll be using the Shuttle suit configuration with an operating pressure of 29.6 kPa (4.3 psi). This suit has a hard torso and the rest of it is soft suit construction. It has a liquid-cooled garment, and you can see some indication of the level of flexibility of the arms and legs. The protocol for denitrogenation has a number of options (FIG. 49). In STS, we're talking about a 4-hour pre-breathe from sea level pressure or options involving staged decompression. The basic option for staged decompression in STS is a 1-hour pre-breathe prior to a 24-hour stay at 70 kPa (10.2 psi) and then a 40-minute pre-breathe. The initial 1-hour pre-breathe is to prevent the formation of any bubbles going to 70 kPa (10.2 psi). Then there's a 24-hour stay at 70 kPa with increased oxygen pressure at 28%, so you're equilibrating with a nitrogen pressure of 52 kPa (7.5 psi) in this atmosphere (FIG. 50). Forty minutes pre-breathe occurs here at 70 kPa (10.2 psi); most of that is operational time in the suit, but we count it in as part of the denitrogenation procedure. And finally, the exposure to 29.6 kPa (4.3 psi).

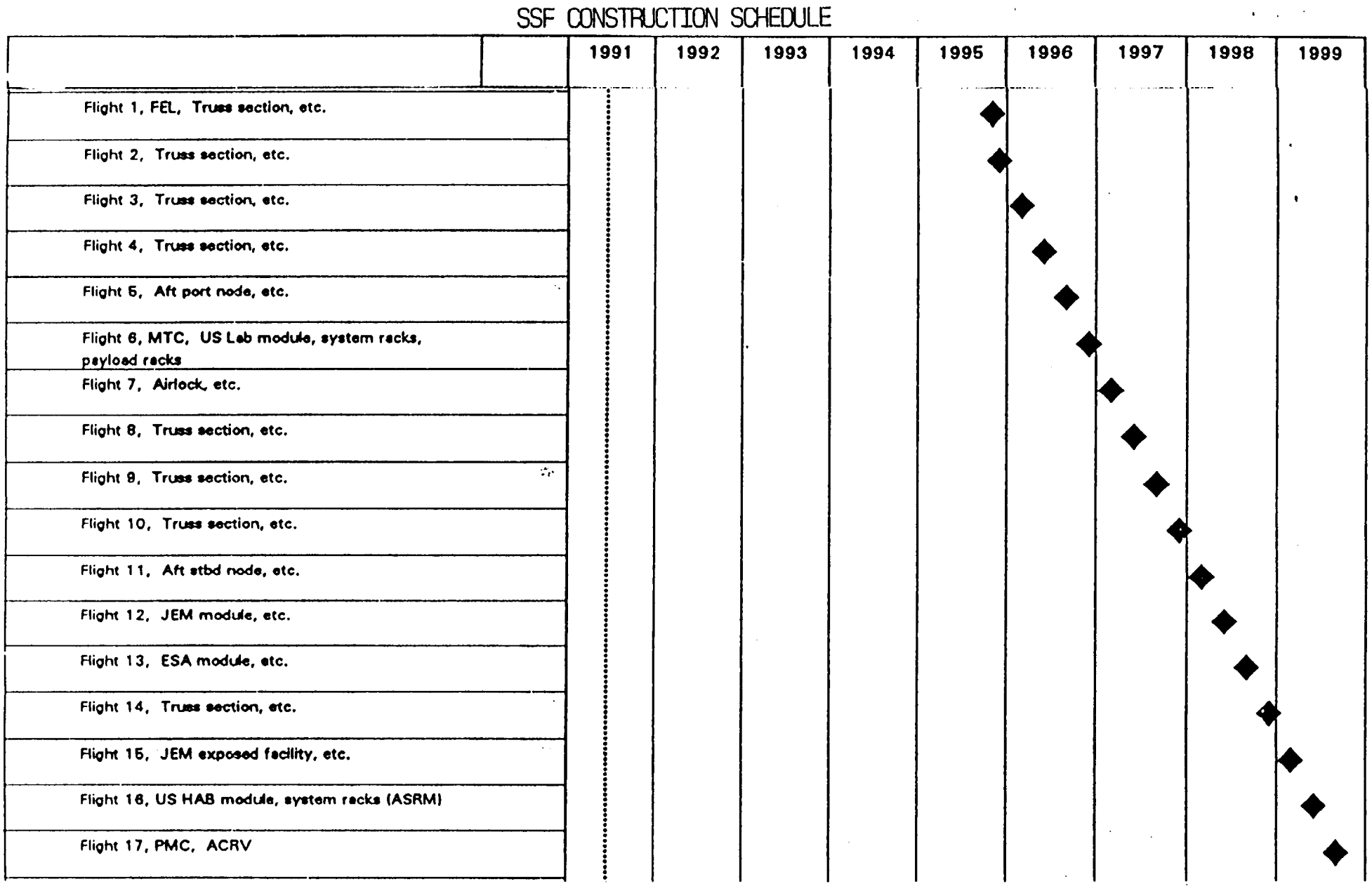


FIG. 48 SSF construction schedule

EVA SUIT AND PROTOCOLS

- Suit - Shuttle Configuration
- Pressure - 4.3 PSI
- Protocol - 4 Hour Prebreathe from 14.7
- Alternate Protocols -

1 Hr Prebreathe	24 Hr 10.2 PSI	40 Min Prebreathe
1 Hr Prebreathe	12 Hr 10.2 PSI	75 Min Prebreathe
1 Hr Prebreathe	8 Hr 10.2 PSI	100 Min Prebreathe

- Campout Procedures

  Sleep in Airlock

  Mask Prebreathe

FIG. 49 EVA suit and protocols

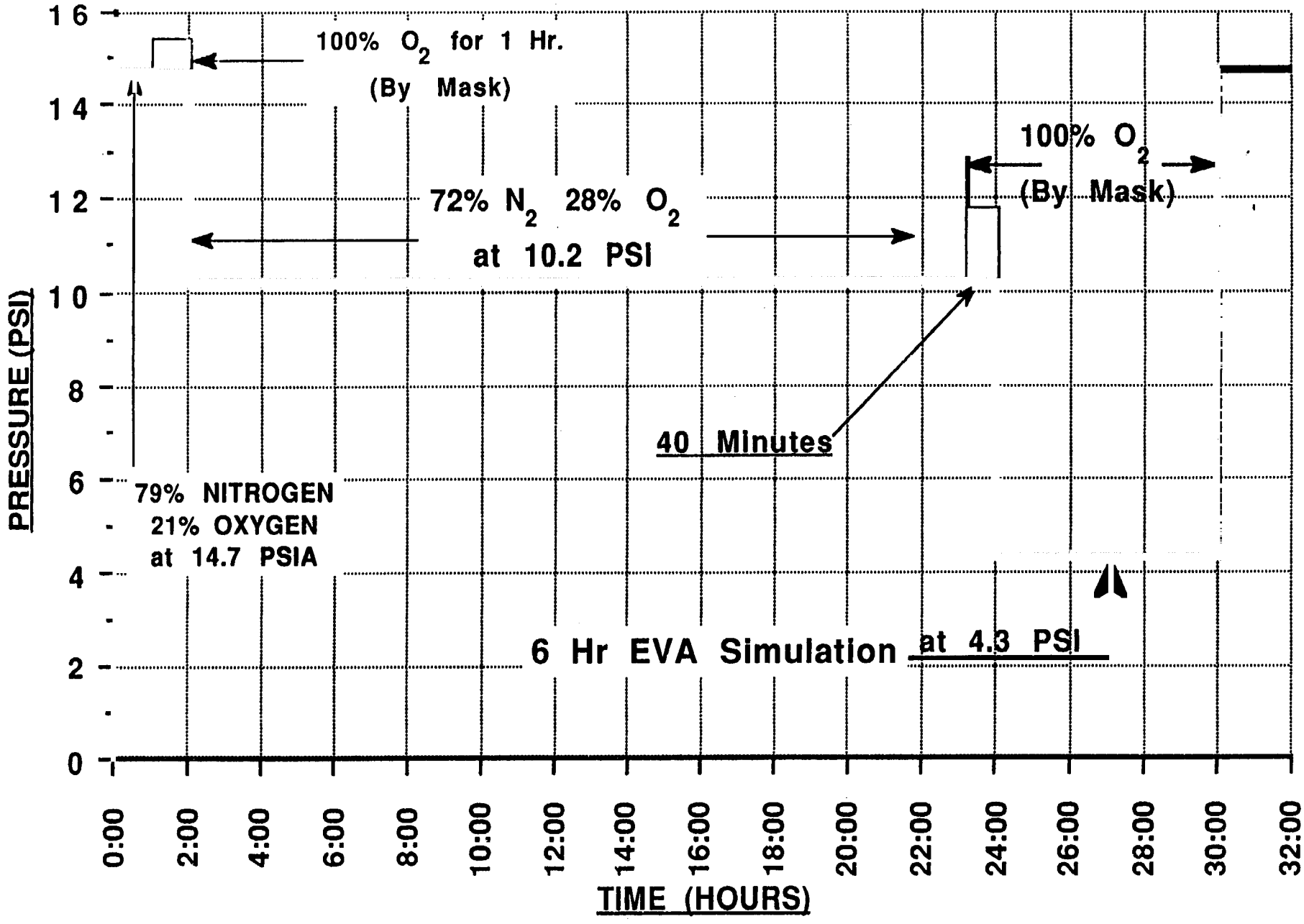


FIG. 50 Six-hour EVA simulation at 29.6 kPa (4.3 psi)

WALIGORA: (Cont'd)

For Station, we are looking at some modifications of that staged decompression protocol with shorter stays at 70 kPa (10.2 psi). The reason being that, at permanent manned configuration, the Station will be operating at sea level pressure. At the man-tended operation phase, the Station will be operating at 70 kPa (10.2 psi) and it will be at the same basic pressure as the Shuttle during the staged decompression. But, a permanent manned configuration is at sea level pressure; it's a big volume. We're not going to lower the cabin pressure for the Station to 70 kPa (10.2 psi) prior to EVAs. The concept is the campout procedure that you've heard about, and that's to go to 70 kPa (10.2 psi) in the airlock. It's called campout because there are no food facilities/waste management facilities in the airlock, and basically you're taking some of your meals with you. It means that you're going to have a reduced time at the stage – 8 or 12 hours. There's some potential for bubbling when going to a lower pressure, and we want to be very conservative in our first pre-breathe to eliminate any possibility of bubble formation at the beginning of this stage. So, if we go to some pressure lower than 70 kPa (10.2 psi), we've increased this initial pre-breathe. The initial pre-breathe doesn't do you much good out at the end; that's not very effective or efficient.

We believe right now that the baseline will be the 1-hour pre-breathe up front, with a stay of 8 hours at this stage and a pre-breathe of 100 minutes before we depress in the suit. The campout procedure also involves some other things. Basically, you'll be sleeping in the airlock, so much of this stage time is with sleep that may have some impact on the effectiveness. We're also going to do this with shirt sleeves. There's no waste management system in the airlock. The crew members will have to put a mask on, breathe oxygen, come back up to sea level, use the waste management system in the vehicle, go back into the airlock, and

WALIGORA: (Cont'd)

close it. You're at sea level now, and it costs gas to go to 70 kPa (10.2 psi) as a stage. So, what we would do then would be to break pre-breathe and don the suit at sea level and make up the break in pre-breathe by a 2:1 factor. That break in pre-breathe would be added to the 100-minute pre-breathe, and you then depress.

Breaks we're talking about right now are estimated to be as long as 19 minutes, so you'd make that up with a 38-minute additional pre-breathe, and this goes to 138 minutes. Total time on some kinds of pre-breathe gets fairly long.

We can talk now about our estimates of risk. They're based primarily on our decompression sickness database that represents over 1000 chamber exposures at laboratories at JSC, the School of Aerospace Medicine, and Duke University (FIG. 51). They were all done with masks, breathing oxygen in a chamber with the chamber pressure equivalent to suit pressure. All tests were done with the same average EVA work rate and duration. The work rates were selected to be representative of EVA activity. They're upper body work rates, upper body activities, but we do some activities standing, and we walk from station to station to do these activities. The actual activities themselves are at the same metabolic rate as EVA, but again we do have some lower body involvement in the course of this exercise. The subjects were selected to be representative of the crew in physical factors including age, physical fitness, and percent body fat.

There are a number of different types of exposures in the database and we've used a nitrogen ratio to try to bring them all together. Basically, the database includes our values of nitrogen tissue ratios over final ambient pressure values from 1.1 to 1.8. These tests involve straight pre-breathe, no pre-breathe with

DECOMPRESSION SICKNESS DATA BASE

- N = 925 at three laboratories JSC, SAM (Air Force), Duke University
- All tests with representative average EVA work type and rate and duration
- Subjects selected so that the range of certain physical factors that may influence DCS was within the range of the crew population. Physical fitness, percent body fat, age
- The magnitude of the decompression, the extent of denitrogenation and the effect of staged denitrogenation were combined in an R value a measure of risk of DCS. R values ranged from 1.1 to 1.8. The higher the R value the greater the risk of DCS.
- R value = $\dfrac{\text{tissue } N_2}{\text{final ambient pressure}}$

FIG. 51 Decompression sickness database

WALIGORA: (Cont'd)

different pressure differences, and staged decompression. And, again we've used the R or tissue ratio value to bring these together. This is the level of protection that's provided by the 4-hour pre-breathe and the staged decompression we've been talking about.

You can see that we've got three curves here; one for detectable bubbles using a Doppler bubble detector, the other for any level of decompression sickness including very mild forms of decompression sickness or awareness in the knee, to levels of decompression sickness that interfere with performance (FIG. 52). We *have* continued our test exposures and kept people at chamber altitude through detection of pain (constant pain) to the point where that pain began to interfere with performance, so that it caused limping or favoring of a limb. We did this because we were concerned that, in fact, the mild levels of decompression sickness would not be detectable in a pressure suit where a lot of things hurt. So we wanted to come up with a meaningful grade of decompression sickness that would be clearly detectable in a suit. At that point, with the protection that we have, that's about 4.7%. Using all of the available data points – and that's about 600 that we carried out to that point; some tests we had to stop early at different investigation sites so that we couldn't include those in the Grade 3 plot – but those 600 or so tests that continued up to a Grade 3 endpoint are shown in figure 53. Again, about 4.7% here plus or minus about 3% (FIG. 53).

This diagram (FIG. 54) simply shows the different types of tests that we had; the staged decompression profiles, the zero pre-breathe profiles, and the oxygen denitrogenation profiles. This is the bubble curve. But, what I think it shows is that it seems to fit the three types of data and allows a parallel look at the different

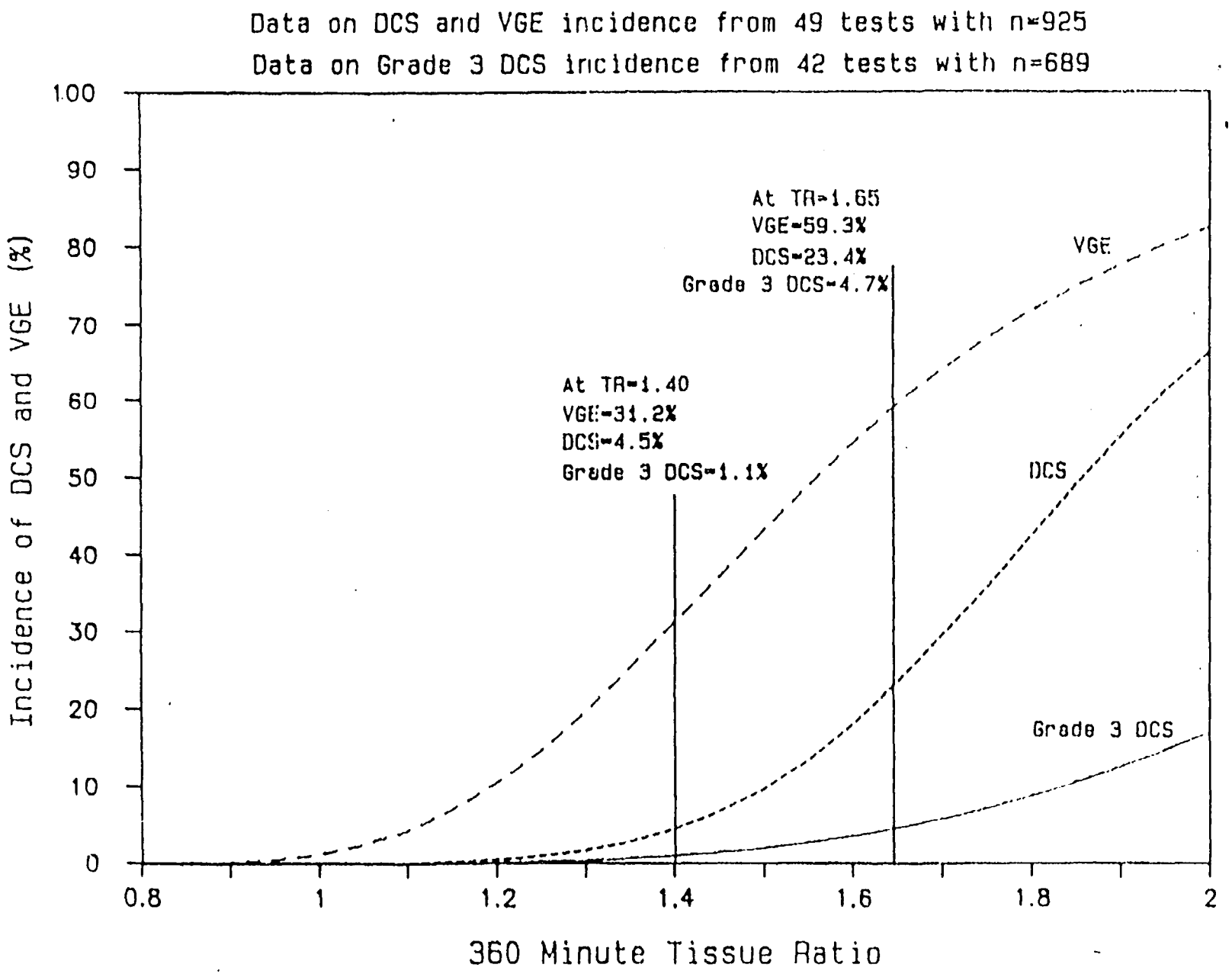


FIG. 52 Data on DCS and VGE incidence from 49 tests with $n = 925$; and on Grade 3 DCS incidence from 42 tests with $n = 689$

Backup 6

DCS3 CONFIDENCE PLOTS

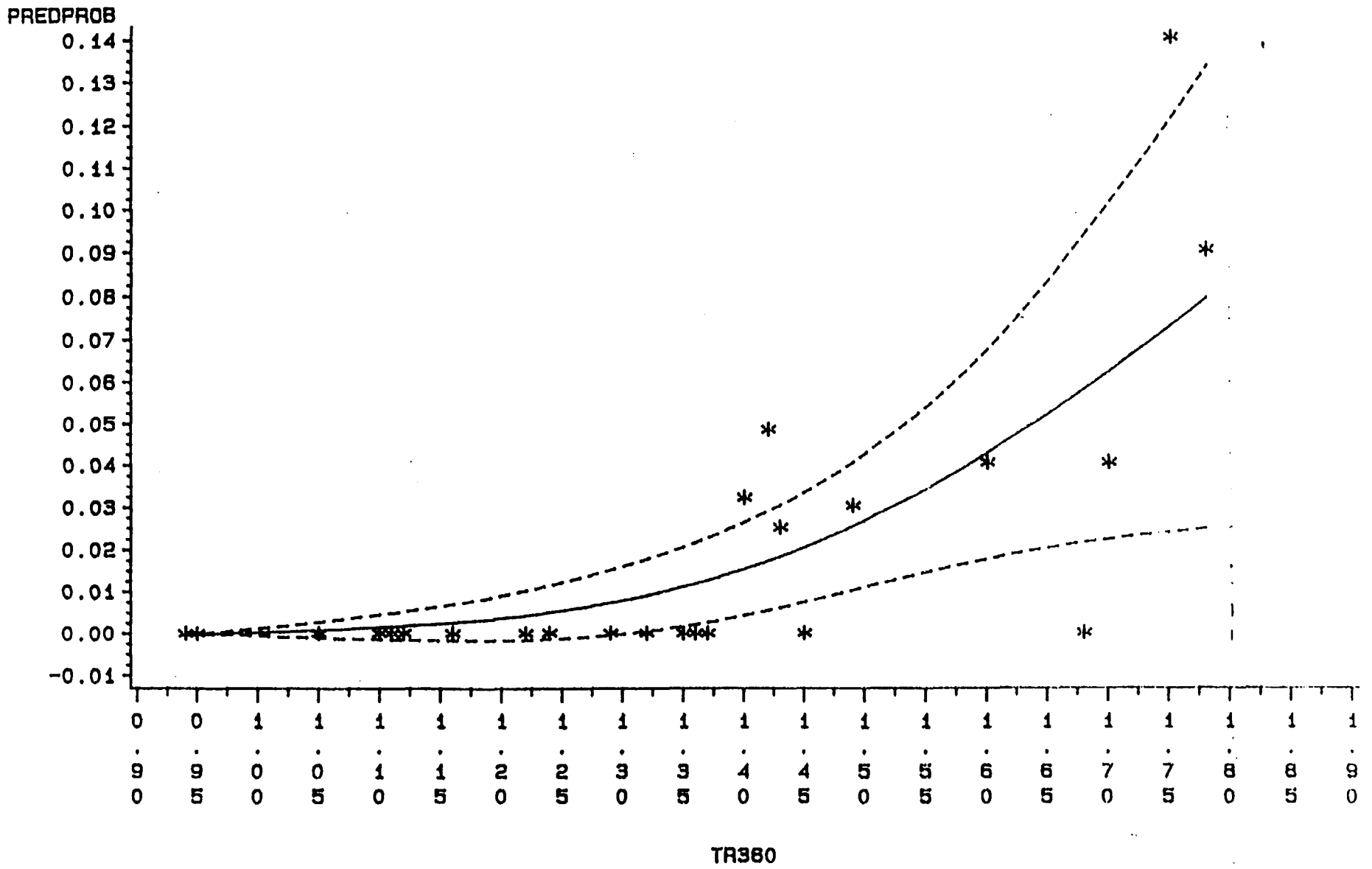


FIG. 53 DCS3 confidence plots

Backup 9

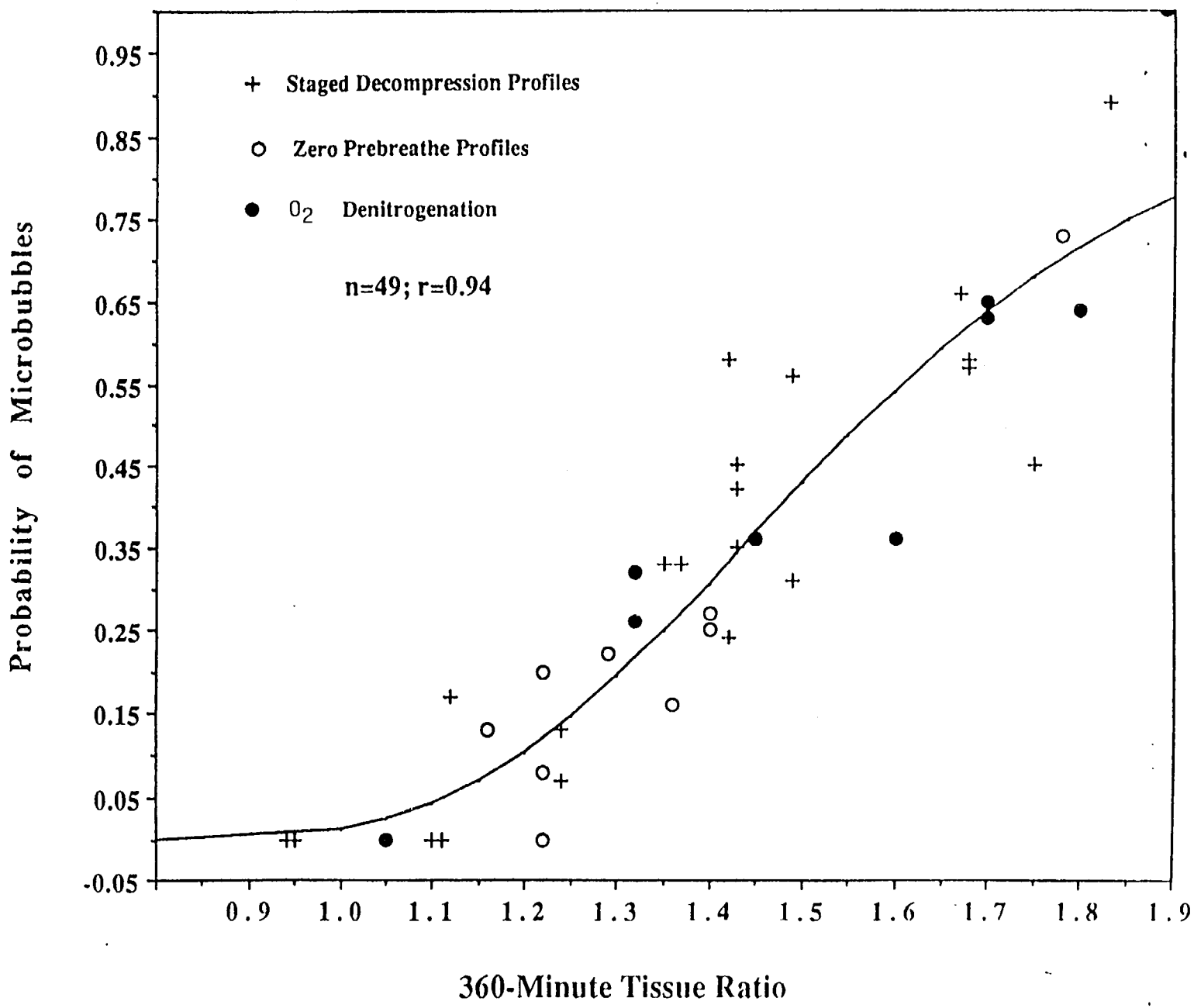


FIG. 54 Three hundred sixty-minute tissue ratio

Backup 12

WALIGORA: (Cont'd)

grades of the symptoms. The scatter on this is scatter when you use a 360-minute half-time tissue ratio to calculate your R values. We obtained the 360-minute tissue by creating this same type of plot for an infinite number of tissue half times; and we found that 360 just happens to bring the data together as well as anything else (FIG. 55).

That's our chamber database. Now I'm going to talk about our operational experience. We've done 15 EVAs and had no decompression sickness (FIG. 56). The R values we've had have averaged 1.59 at a little bit less than our minimum. The first one was done on a different protocol (1.8). Metabolic rates during these EVAs average about 200 kCal/hr (800 BTU/hr). There was no reported decompression sickness. The Russians have done 37 EVAs and their metabolic rates are very similar to ours. You can see they're in watts, so you can take them home and do the conversions (FIG. 57).

I can tell you that the metabolic rates are essentially the same as ours. They have a higher pressure suit; it's a 38.6 kPa (5.6 psi) suit, and they've used the same R value calculation that we do. They pre-breathe for only about 40 minutes at the end. If you use R value as a measure of risk, their risk would be possibly a little higher than ours (R values are around 1.8, average). You'll see that, in same cases, there are two R values given. That's because the Russian suit has the capability of going to a lower pressure. They've used that operationally once, during a first EVA for a few minutes, and they've used it by accident a couple of times and bounced back out of it. They're very much aware that, when they go to this lower pressure, they're at risk of decompression sickness. They use it for a very limited time period. Based on our chamber data, we're saying that we've

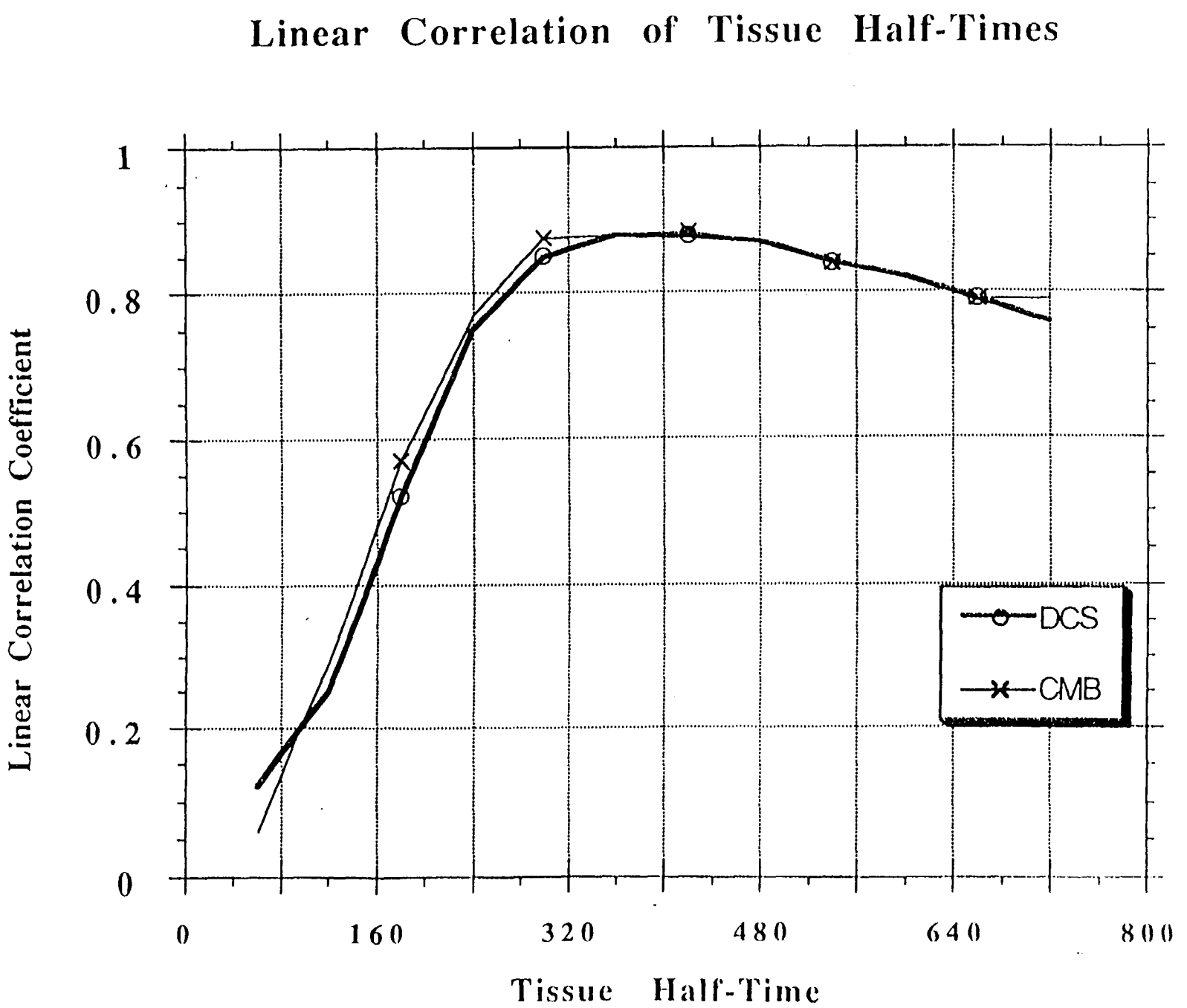


FIG. 55 Linear correlation of tissue half times

Backup 15

Shuttle EVA Metabolic Rates.

EVA #	Mission Date	STS Mission	Duration (Hrs:Min)	METABOLIC RATE (BTU/h) EV1	EV2	Tissue PN2 Ratio*
1	4/7/83	6	3:54	584	824	1.8
2	2/7/84	41B	5:35	764	956	1.54
3	2/9/84	41B	6:02	664	744	1.58
4	4/8/84	41C	2:59	934	1092	1.67
5	4/11/84	41C	7:07	938	1062	1.63
6	10/11/84	41G	3:29	962	650	1.65
7	11/12/84	51A	6:13	610	908	1.55
8	11/14/84	51A	6:01	698	842	1.59
9	4/16/85	51D	3:10	888	724	1.64
10	8/31/85	51I	7:20	814	784	1.65
11	9/1/85	51I	4:31	1086	794	1.43
12	11/29/85	61B	5:34	1068	784	1.67
13	12/1/85	61B	6:46	920	686	1.6
14	4/7/91	37	4:00	918	960	1.3
15	4/8/91	37	5:30	735	972	1.55
Mean			5:13	838.87	852.13	1.59

*Ratios based on 360 minute tissue half-time

FIG. 56 Shuttle E[illegible] metabolic rates

EVA	EVA Date	Elapsed time, days	EVA Duration min	Metabolic cost, W Average	Metabolic cost, W Range	O_2 Consumption, nl/min	Breathing rate, min	Heart rate, min^{-1}	Body temperature °C	$R = -P_{N_2}/P_{sat}$ ($t_{1/2}$ = 360 min)	Age, Years
I.	I8.03.65	I	I2		> 290	0,8	26–36	87–I32	< 37,6	2,0–2,8	30
2.	I6.0I.69	2	37	280	I00–490	0,8	27–49	95–I54	< 38,3	2,0	35
				230	I00–470	0,7	32–36	85–I44	≤ 38,3	2,0	36
3.	20.I2.77	I0	88	300	I50–420	I,0	I2–30	74–II4	36,7	2,0	33
				2I0	I00–4I0	0,7	I2–30	72–94	36,7	I,9	46
4.	29.07.78	45	I25	270	I70–4I0	0,8	I4–34	63–I53	36,I	I,9	36
				350	250–490	I,I	I6–25	60–I40	35,6	I,9	38
5.	I5.08.79	I72	83	300	230–520	0,9	I4–23	70–II0	36,I – 37,2	I,9	38
				350	250–590	I,2	I0–36	66–I50	36,4 – 37,7	I,9	39
6.	30.07.82	78	I53	240	I40–430	0,7	I2–32	68–I42	36,6 – 38,0	I,9	40
				300	2I0–520	0,8	6–25	30–I39	34,0 – 35,5	I,9	40
7.	0I.II.83	I28	I70	270	I40–350	0,7	I0–48	8I–I32	34,3 – 36,8	I,9	42
				340	240–540	I,0	I6–36	75–II7	34,0 – 36,4	I,9	40
8.	03.II.83	I30	I75	230	I50–350	0,7	I0–40	74–I32	35,3 – 36,7	I,8	42
				300	2I0–420	0,9	I6–36	66–II4	34,I – 35,7	I,8	40
9.	23.04.84	75	260	370	220–9I0	I,2	I6–28	68–92	34,3 – 35,9	I,8	43
				340	220–770	I,0	I2–32	80–I52	34,7 – 37,0	I,9	38
I0.	26.04.84	78	300	270	I50–640	0,8	I6–36	72–II6	35,2 – 36,4	I,6	43
				3I0	I50–840	0,9	I6–28	84–I28	34,2 – 35,6	I,7	38
II.	29.04.84	8I	I65	240	260–540	0,7	20–32	68–I20	35,4 – 36,5	I,5	43
				270	250–720	0,8	I2–28	80–I28	34,7 – 36,4	I,5	38
I2.	04.05.84	87	I65	220	200–550	0,6	20–36	68–II2	35,I – 36,6	I,5	43
				240	220–500	0,7	I6–32	80–I28	34,I – 36,3	I,5	38
I3.	I3.05.84	I0I	I85	240	I40–660	0,7	I6–26	60–I34	35,6 – 37,8	I,7	43
				270	250–550	0,8	I2–28	75–I40	34,2 – 35,7	I,7	38
I4.	25.07.84	7	2I5	380	220–700	I,I	I6–40	70–I44	35,5 – 36,8	I,8	42
				280	2I0–420	0,8	II–42	85–I52	35,8 – 37,0	I,8	36
I5.	03.08.84	I63	300	320	2I0–690	0,9	I2–40	68–I48	34,3 – 37,5	I,8	43
				250	2I0–530	0,7	I6–32	80–I50	34,I – 37,5	I,8	38
I6.	02.08.85	57	300	200	I40–350	0,6	I2–36	72–I20	35,5 – 37,I	I,8	43
				240	I40–420	0,7	I0–32	75–I30	34,6 – 35,7	I,8	45
I7.	28.05.86	77	230	240	I40–570	0,7	I5–32	63–I00	36,4 – 37,3	I,8–2,7	45
				220	2I0–360	0,7	I2–32	76–I24	35,4 – 36,I	2,0	40
I8.	3I.05.85	79	300	2I0	I40–420	0,6	I2–28	65–I04	36,6 – 37,2	I,7	45
				200	I40–200	0,6	I2–28	72–I28	35,4 – 36,8	I,7	40
I9.	II.04.87	65	2I5	230	90–490	0,7	I2–28	76–I20	35,4 – 35,8	2,I	42
				2I0	I00–400	0,6	I6–32	60–I20	35,4 – 35,4	2,I–2,6	36
20.	I2.05.87	I27	II3	340	I70–460	I,0	I2–36	80–I28	35,9–37,4	2,I	43
				280	80–350	0,7	I2–32	52–II6	35,4 – 37,2	2,0	36
2I.	I6.06.87	I3I	I95	240	I40–490	0,7	I2–28	72–I20	35,7 – 36,6	I,9	43
				200	70–220	0,6	I2–32	60–II4	35,3 – 36,5	I,9	36
22.	25.02.88	67	265	300	I70–550	0,8	I2–24	72–I04	35,7 – 37,0	I,9	4I
				320	I70–490	0,9	I2–28	72–I04	34,7 – 37,4	I,9	37
23.	30.06.88	I93	3I0	270	I50–4I0	0,7	I2–30	80–II6	35,I – 35,4	2,05	4I
				290	I40–460	0,8	I0–32	80–I24	36,I – 36,6	2,0	37
24.	20.I0.88	304	252	240	I70–3[illegible]0	0,7	I2–28	72–II6	35,9 – 36,4	I,8	4I
				320	2[illegible]0–4I0	0,9	I6–32	76–I20	35,7 – 36,6	I,8	37
25.	09.I2.88	I2	330	200	80–5I0	0,6	I2–20	75–I20	35,2 – 36,2	I,8	40
				3I0	I[illegible]	0,9	I2–28	72–I[illegible]	35,0 – 36,9	I,8	50
26.	08.0I.90	I25	I76	255	I30–4I0	0,8	I5–24	78–I24	35,2 – 36,4	I,95	42
				3I0	I75–520	0,9	I4–24	80–I26	36,5 – 37,4	I,95	45
27.	II.0I.90	I28	I74	290	I40–465	0,8	I2–23	70–I24	35,6 – 36,3	I,9	42
				360	230–535	I,I		90–I34	34,I – 37,0	I,9	45
28.	26.0I.90	I43	I82	270	99–430	0,8	I4–28	78–I32	35,8–36,9	I,9	42
				275	I70–430	0,6		62–I06	36,8 – 37,7	I,9	45
29.	0I.02.90	I49	299	2I5	80–390	0,6	I2–26	66–II8	35,7 – 36,I	I,8	42
				I70	76–290	0,5		54–96	36,0 – 36,9	I,8	45
30.	05.02.90	I53	225	I75	99–477	0,5	II–I9	72–I02	35,6 – 36,0	I,8	42
				250	I00–535	0,7		58–II8	36,6 – 37,0	I,8	45
3I.	I7.07.90	I57	420	240	99–454	0,7	II–20	56–I32	34,3 – 36,3	I,8	42
				320	I50–580	0,9	I5–25	80–I40	36,0 – 37,I	I,85	37
32.	26.07.90	I66	2II	250	I50–384	0,7	I2–22	58–96	34,6 – 35,5	I,8	42
				300	I80–628	0,9	I3–24	90–I36	35,4 – 37,I	I,9	37
33.	30.I0.90	89	I65	4I0	270–686	I,2	I2–24	82–I56	36,4 – 37,6	I,8	40
				2I5	II5–465	0,6	I2–28	74–I62	35,7 – 37,4	I,8	50
34.	07.0I.9I	37	3I8	240	I28–378	0,7	I2–34	72–I52	35,5 – 36,7	I,9	43
				290	I30–605	0,9	I6–36	78–I50	35,3 – 37,I	I,9	40
35.	23.0I.9I	53	333	3I0	I40–5I0	0,9	I3–32	90–I60	35,6 – 37,2	I,8	43
				290	I70–500	0,9	I2–36	94–I46	35,8 – 37,I	I,8	40
36.	26.0I.9I	56	380	320	I45–480	0,9	I2–32	88–I66	36,2 – 37,2	I,7	43
				3I0	I70–465	0,9	I6–32	94–I40	34,8 – 36,4	I,7	40
37.	25.04.9I	I45	2I4	290	220–370	0,9	I6–36	80–I46	36,I – 37,4	I,9	43
				360	I30–590	I,0	I6–34	94–I44	34,7 – 36,2	I,9	40

FIG. 57 Soviet EVA biomedical data metabolic rates in watts

WALIGORA: (Cont'd)

got a 5% risk of decompression sickness with this protocol that's going to impact performance and should be fairly apparent to somebody in a pressure suit. We've had 30 of our own manned EVAs plus another 74 that the Russians have done, and there have been no reported incidents of decompression sickness at comparable, provocative decompressions.

We're in the process of doing a number of things to look at possible reasons for that. One possible reason is that incidents of decompression sickness are not being reported. Some of the other possible reasons: The Russians believe that, in fact, it may be due to the pressure suit restricting the level of motion and reducing the incidence of decompression sickness. They have recently, in the past few months, done some work with an in-suit bubble detector. It's a simple detector, by the way, and they stopped the test to make the measurements; and, if they weren't hearing anything, they'd move the body around until they could hear something. If they still didn't hear anything, they'd go on and get another subject. But, they have done 12 experimental runs and seen a 50% bubble incidence in the suit. Their control is at the same metabolic rate without the suit, which means the control is going through more motions to achieve the same oxygen consumption. Really what they're saying the suit does is lower the number of motions and flexions to achieve a certain metabolic rate. So, there is some effect here; but the suit certainly doesn't eliminate all bubbles and, presumably, it wouldn't eliminate all decompression sickness (FIG. 58).

What we're looking at is the possibility that microgravity may interfere with the production of micronuclei prior to the exposure. So, we have put people in bed rest for a 3-day period prior to chamber test, and then also during the chamber test.

RESEARCH EFFORTS ADDRESSING APPARENT DIFFERENCE BETWEEN CHAMBER AND OPERATIONAL EXPERIENCE

- Soviet in-suit bubble detection
  - Cont N = 10 90%
  - EX N = 12 50%
- JSC 3-day bed rest
  - Both groups bubble
- In-suit doppler
  - Required to resolve questions

FIG. 58 Research efforts addressing apparent difference between chamber and operational experience

WALIGORA: (Cont'd) We'd have them go through all the same activities on their back. We've just gotten into that. We're doing a 20-subject crossover study with about 5 of the 20 done. Both groups bubble, but it seems that the ambulatory people bubble considerably more if you want to look at two people versus three people or that kind of thing. We certainly will pursue this; and, as I said, some of the initial data (and we've tried to convert the bubble rate to bubble volume) would indicate that, based on the number of people we have done, there may be a difference in bubbling and bubble volume at grades of bubbles for the people who are bubbling (FIG. 59).

SPEAKER: Do you know what the units are like on the Y axis? cc's?

WALIGORA: Dr. Powell, the units?

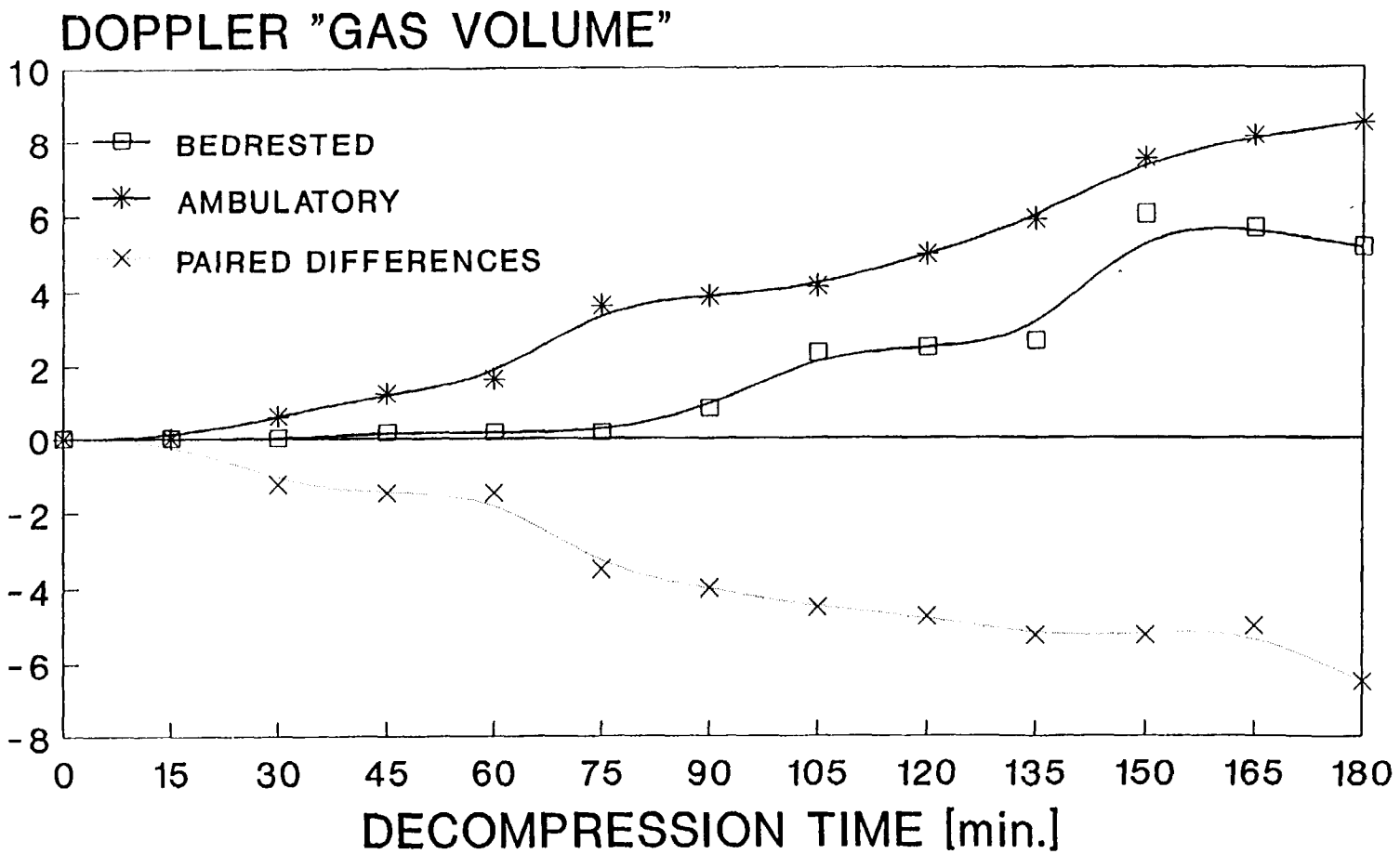
DR. MICHAEL POWELL: On the Y axis, it would be cc's per minute.

WALIGORA: But, that's using some approximation. That's using some conversion of bubble grade to volume that Dr. Powell is working with.

HAMILTON: Excuse me. Jim, you've got the paired differences on the bottom curve in Doppler score. How do they get down to 6 where the maximum score is 4?

WALIGORA: This isn't a direct Doppler score. It's a Doppler score that's converted into an estimate of volume. And so, this is the difference between this and that. What we're talking about now is having six people ambulatory, five people bed rest. Two of the five people bubbled; three of the six people bubbled. So, we're not

DECOMPRESSION STRESS IN AMBULATORY AND HYPOKINETIC INDIVIDUALS



"Paired Differences" = Spencer Doppler

Grade *[bed-rested]* - Grade *[ambulatory]*

FIG. 59 Decompression stress in ambulatory and hypokinetic individuals

WALIGORA: talking about much. So far, it looks as if the people who are bed rested may bubble at a lower grade. And the other thing is that, they *do* bubble. What we have said is that, "Our best estimate of risk is our clean database of 1000 people in the chamber." We have said that, "This is what we should use." And, we have also said that, "That's too high, that we ought to go to something lower." We have gone to program offices, and we are not going to go to anything lower. So, this is the risk that has been accepted: 5% impairment per EVA per person (FIG. 60). From that, what may be more important is that from our data it works out to be about a 2% risk of symptoms that were not resolved and returned to ambient pressure, and 1% that resulted in systemic symptoms. So, that's what we should be planning on when we consider these numbers of EVAs. Admittedly, we may find there are some other factors in EVA that are giving us lower values, but I think that this is what we should be doing. Yes, sir?

SPEAKER: A couple of pages back, you were talking about the Russian EVA experience versus the United States, and you were saying something to the effect that the mobility of the suit during EVA ought to be decreasing the chance of bubbling. During our pre-breathe in the chamber, I don't know if you still do it or not, when an astronaut opts to sit in the suit for 4 hours, every 15 or 20 minutes we ask him to get up and move around. Is that kind of going against their theory, or do they do the same thing on a pre-breathe type basis?

WALIGORA: Their pre-breathe is so short – 20 to 40 minutes – that I don't think that's critical on their data. Another piece of data I didn't mention is that we do all kinds of operational chamber runs. Out of about 120 operational chamber runs with significant exercise that would be comparable to this, we've had two decompression

ACCEPTED RISK BASED ON CHAMBER TESTS

- 5 percent impairment / EVA / MAN
- 2 percent risk of a symptom that is not resolved on return to cabin pressure
- 1 percent risk of a systemic symptom

FIG. 60 Accepted risk based on chamber tests

WALIGORA: sickness hits. We happened to have them one after the other. It seems to fit some kind of pattern. But, because of that we investigated and did a lot of things. One thing was, we *did* implement the advisory that we have that people move around once every 10 or 15 minutes.

SPEAKER: But, that's to cut down on the rate of bubbling.

WALIGORA: That's actually to do two things: to make sure we don't get stagnation of anything in the suit during the purge; and the other more important thing is that we have them moving their joints and so forth so that they're getting, perhaps, better perfusion in different areas.

SPEAKER: Can you put your last slide on, please? That seems high, the 1 and 2%.

WALIGORA: Yes, it does. And, it kind of surprised me when we worked it all out; but that's what we got. I think that's because most of the people we've treated, most of these people have not necessarily been Grade 3 people. Because we've had 5% of the people that had Grade 3 symptoms, but in fact the Grade 3 symptoms are not the people that we've had to treat. Because once they go to Grade 3, we take them out. The people we've had to treat are the people at Grade 2, and either the symptoms didn't go away when they returned to ambient pressure or they suddenly went from some level of limb bends to systemic symptoms.

SPEAKER: When they recurred?

WALIGORA: Yes. And that's based on our own JSC database. It's modified a little bit. Most of our tests are at a lower R value than the operational one, because we were looking for ways to lower risk, and so we were looking at, "How effective is lowering the pressure delta, and how effective is increasing pre-breathe, etcetera?" So, a lot of our data are at lower R values so that this is corrected with the R values.

PILMANIS: It's hard to compare because at Brooks we've come down on Grade 2, not Grade 3. But in the last year, out of 77 bends cases, only 6 required hyperbaric treatment. The others resolved by returning to ambient pressure. So that's 10%.

WALIGORA: Yes. But, we didn't have 5% bends; we had about 25%.

BOVE: Jim, what's the scenario in terms of time of exposure to 29.6 kPa (4.3 psi)? These are long exposures, aren't they?

WALIGORA: Yes, they're 6 hours.

BOVE: So, you're assuming that the exposures will stay the same as you work these things out? Because one way to reduce this obviously would be to shorten the exposures.

WALIGORA: Yes. That might be useful for emergency contingency EVA: you had to go out to save the vehicle and suddenly you only had 2 hours to pre-breathe. You'd want to shorten that EVA as much as possible. But, I don't think it makes much difference between 4 and 6 hours.

BOVE: The plan is to have 6-hour work shifts going out, though, and I guess that's what you're basing your trials on.

WALIGORA: Well, the backpack basically has a 6-hour capability, and we'll probably leave it at that.

SPEAKER: The last time we had this meeting, which was in the summer, there was a lot of talk about a new 56 kPa (8 psi) suit. Has that disappeared?

WALIGORA: Yes. It's still out there, possibly for a permanent manned configuration. It's in the RTOP activity.

STEPHANIE TRAUSCH: I worked on that program, and they *were* developed and evaluated, but they are not funded for Space Station. But, we've got them up and functioning.

WALIGORA: You see, when we had that suit – this is a sad story – we didn't write the specs saying we had to have a 56 kPa (8.3 psi) suit. We wrote the specs saying we had to have a certain level of protection, and that you could meet that protection by a 56 kPa suit. It was a greater level of protection than this. And, when we threw away the 56 kPa suit, they said, "Obviously, we don't need that level of protection either." So, it's hard to protect yourself from derision like that.

HAMILTON: In these data, how do you account for the reporting or non-reporting? These are all chamber tests and people presumably reported all the decompression

HAMILTON: (Cont'd) symptoms; whereas, in actual EVA, you may still end up with the same 1% risk of the systemic system, because those are going to be hard to conceal.

WALIGORA: Yes, and that's what we don't know.

HAMILTON: They probably will be lower in actual practice.

WALIGORA: That's what we don't know. I think that at least some of it is a reluctance to report, and we don't know how much. Not only a reluctance, because that implies you have people lying, and I've gotten into a lot of hassle about that. But in reality, the limb bend symptoms that we have are symptoms that people have felt before. And, if you feel them in a suit and you don't know if it's because of decompression sickness or something else – and you know if you report it, it's going to be assumed that it's decompression sickness – you have a certain reluctance to do that.

SPEAKER: I've worked on an experimental dive myself, on one of the 4 hours for 400 ft tables the Navy used that turned out to have disastrous results, but fortunately not in my case. As part of that, I wound up with some joint pains that were kind of unclear. It's hard to *tell* what it is. Thinking about it later, it probably *was* DCS.

WALIGORA: Even with myself as a subject, I've felt this inclination not to report. So, I don't have myself as a subject anymore. But, I can fully believe that many people don't report everything, even in our tests.

SPEAKER: I had other pains on that same dive, the compression arthralgias that hurt a whole lot worse.

WALIGORA: Yes. And, there are a lot of other sources of discomfort in a pressure suit.

WORKMAN: You'll never overcome the reluctance to report.

WALIGORA: Certainly.

WORKMAN: I mean, it's a given fact. It's there.

SPEAKER: It only gets reported when you can't ignore it anymore.

WORKMAN: Well, that's true. But those borderline cases, human nature says, "Well, I'll ignore it."

WALIGORA: Any other questions?

BARRATT: Thanks very much. We're obviously somewhat behind schedule, so we'll try to bump things up a bit to ensure adequate time for Dr. Norfleet's presentation.

NORFLEET: It's going to be audience participation.

DCS Treatment Scenario for Space Station Freedom

BARRATT: Now I want to introduce Dr. William Norfleet, who most of you actually know. He was my immediate predecessor as hyperbaric subsystem manager with KRUG Life Sciences. I've asked him to talk a little bit about the treatment scenario, what would actually be involved in chamber use over a spectrum of conditions.

NORFLEET: As Mike says, I've been on the research side of things for about 7 months. Prior to that I was working with Joe Boyce, mostly dealing with program managers and restructuring efforts and, as you can see, I've nearly completely recovered from my injuries. Joe Boyce is convalescing in Albuquerque, and he says, "Hello." What I'd like to do here is just go through a little bit of discussion about possible (in fact, highly likely) scenarios. There is nothing here that is off-the-wall. This is simply an effort to try with this group to spend a few minutes and go through in a step-by-step fashion a little bit of discussion about: how we would use this facility, some of the decisions that might need to be made, just to see if there are any really gross things that have been missed to this point. To start off with, we can talk about a crew member who's out doing an EVA. He develops some pain. We'll start out saying that, at 3 hours into an EVA, a crew member reports moderate pain in his left shoulder. At that point, is there anything else that want to know? Is there anything you would like the crew members to do? And, do you consider aborting at that time? Pain in the left shoulder. Any problems with that? Any comments on that at this point?

BOVE: I think somebody ought to point out, though, the fact that, as in diving, you want to really know if the guy did anything. Did a truck just run over his left shoulder, or did a meteorite hit his shoulder? There are a lot of questions you want to ask him. Did he do something strange to his left shoulder? Because if it's just a mechanical injury, then it's a totally different scenario. He may still be disabled from a mechanical injury, but he should come back; it changes your way of doing things. So, the key is to find out if this just sort of evolved spontaneously or whether he did something to his shoulder that may have induced an injury. You want to know if he has an arrow or a knife sticking out of the back of his pressure suit.

NORFLEET: Do you think that it would be important to be able to talk directly to the crew member without having to go through some intermediary like capsule communication?

SPEAKER: Immediate communication with a flight surgeon would be mandatory, I would say.

NORFLEET: So, you'd want to definitely be talking directly to the crew member.

HAMILTON: You're talking about the person on the ground who's making these decisions?

NORFLEET: Yes.

SPEAKER: I agree.

BOVE: I feel like you definitely have to ask if there's a knife sticking out of his pressure suit.

NORFLEET: Yes. Go back a little bit and say, "Pain interferes with the work. The crew member returns 10 minutes after recompression to the 70 kPa (10.2 psi) pressure of the Station, with the crew member in the suit, so that's an additional 29.6 kPa (4.3 psi). The pain is entirely gone." So, back on the Station, recompressed, 10 minutes, pain is gone.

HAMILTON: He intentionally stays in the suit after returning to pressure?

NORFLEET: Yes.

HAMILTON: How long would that normally carry on? How long would he stay in the suit, where he'd have the extra 29.6 kPa (4.3 psi)?

NORFLEET: Well, that is a possible option.

HAMILTON: Would he normally wait 10 minutes?

NORFLEET: I don't think he'd wait that long. It's too bad Richard Fullerton's gone, because he might have a lot of additional insight into this. But generally, you'd be going ahead and getting out of the suit. But, that is an option. Some of the possible courses of action that you could take would be: you'd have no change in the routine; or you could hang on the wall, that is, stay in suit and just hang out in that situation for a period of several minutes. There is an option of over pressurizing

NORFLEET: (Cont'd) the suit to an additional pressure that disables the suit for further EVA work, but that *is* an option.

BOVE: I don't think there's any advantage at all to gaining another 29 kPa for treatment. I think the key here is, in this scenario, you go back to a surface pressure, just about 101 kPa (14.7 psi); it's a pain level. It's like an altitude decompression sickness where you bring him back to surface and the pain goes away. The question is, "What do you do then?" I think most people would say, "Okay, you ought not to go back to altitude in the next 12 to 15 hours anyway. You wait a day and go back then." So I think, after the second point here, 101 kPa (14.5 psi), the pain goes away, it's essentially a factor of surface pressure; if the pain is going, you probably ought to get out of the suit and not do anymore EVA that day.

NORFLEET: Now he's breathing 100% oxygen at that point; and some hypobaric chamber facilities, when somebody has developed symptoms, have a period of an hour or 2 of oxygen breathing after the event.

BOVE: Do you put them right back to work?

NORFLEET: No.

SPEAKER: No. At this point, you say, "Okay, come in and take a break for half a day or something like that."

PILMANIS: The standard is 2 hours of post-breathing on this, if everything clears at ground level.

BOVE: Yes. The point is that, if he clears, even if you did the post-breathing, you wouldn't just send him right back out on the EVA. I think you'd want to wait until the next day.

NORFLEET: If I could put that issue aside for just a few minutes, we'll get to that in a little bit more detail. But at this point, would you keep him in the suit at that pressure for an hour or 2?

PANZARELLA: I just want to bring up a point here. If you keep him in a suit, you *do* have a limiting consumable. Your CCC cartridge is only good for 7 hours. So, you've got to be careful about your oxygen.

BOVE: There's no logic to keeping him in the suit. If he had real decompression sickness that interfered with his work and he was asymptomatic on return to 1 ATA of pressure, basically his work is done for that day.

PILMANIS: There is. Because, if you take him out of the suit, you're going up to 3050 m (10,000 ft), that's relative to ground level.

BOVE: That's really for how long? A couple of minutes? You can get him right back inside the main cabin.

HAMILTON: That's the pressure of the main chamber and of the entire Station. We have different phases in different years; we start out with a Station pressure of 70 kPa (10.2 psi). So, you've got him going down to pressure and then coming back up again. You're re-exposing to altitude.

NORFLEET: During the initial phases of the Station, until about 2000, it's 70 kPa (10.2 psi) all the time. After that, it may be 70 kPa (10.2 psi); it may be sea level pressure. I think the smart money at this time is guessing that the Station will remain at 70 kPa (10.2 psi). But, that's a guess.

HAMILTON: One other factor that enters here in terms of leaving him in a suit: If he stays in a suit and he's on oxygen at closed circuit, you're consuming very little consumable. You take him out, you've got to put him on oxygen; now you're burning oxygen up at a huge rate.

NORFLEET: That's true. And, there is a potential advantage to leaving him in the suit – perhaps preventing a recurrence that would then perhaps need to be treated with hyperbaric therapy and would be, at that point, a *big* consumables hit. So, with these issues out, would we leave him in a suit for 2 hours?

PILMANIS: Well, again, if you look at the standard, nobody right now, at least in the Air Force, would ever dream of taking somebody back up to 3050 m (10,000 ft) after they've been bent. Even after 2 hours post-breathing. So, you're kind of locked in a situation where I don't know how you're going to get him out of there.

HAMILTON: You do have a person who's equilibrated at that pressure (3050 m) to start with once he gets into his EMU.

PILMANIS: True, but it's still going up 3050 m (10,000 ft).

HAMILTON: It is and it isn't, because that's where you started from.

PILMANIS: Well, it's still going back to altitude.

HAMILTON: We'd have to give you that.

PILMANIS: Summarizing, you pressurized to sea level for 2 hours, he has gotten better, and at the end of 2 hours you took him to 70 kPa, removed the suit, and remained at 70 kPa.

BOVE: I don't think you have any choice. You've got to get him out of the suit at some point; the poor guy will probably want to go to the bathroom at some point, after all. And so, after somewhere out of post-breathing, you've got to take him out of the suit. My guess is that, if you really denitrogenated the guy fully and oxygenated away the bubbles, you'd do okay at 3050 m (10,000 ft). If you didn't, you'd have to go back in the chamber and treat him.

NORFLEET: Let's break this into two scenarios very briefly. Let's initially take this one: MTC operation; the Station pressure is 70 kPa (10.2) psi all the time. Back in the airlock; recompressed back to 70 kPa plus suit pressure; pain is gone. Leave him in the suit for a period of time?

STEGMANN: Did his pressure resolve at 70 kPa (10.2 psi) or did it not resolve? When you had a complete pressure of 70 kPa (10.2 psi), was his pain gone?

NORFLEET: His pain resolved during repressurization.

WORKMAN: You have a combined suit and ambient pressure of 70 kPa (10.2 psi).

STEGMANN: And was it clear at that time?

WORKMAN: Then at the end of that period, you can take him out of the suit. You don't have to worry about decompressing him because you've only compressed him to a total of 70 kPa (10.2 psi).

NORFLEET: That's true. That *is* the scenario. You'd go from an ambient pressure of zero, with suit pressure of 29.6 kPa (4.3 psi). This goes on for 3 hours during EVA. You then recompress in the airlock. Ambient pressure goes to 70 kPa (10.2 psi). The pressure that this individual is experiencing goes to 24.6 kPa (4.3 psi) plus 70 kPa (10.2 psi), so that is 100 kPa (14.5 psi). And, there you are. Eventually, you're going to want to get back to 70 kPa (10.2 psi) so that you can get out of the suit. At this point, remember; there's 100% oxygen.

BOVE: The problem is, you've got to get out of the suit. You don't have a choice on that topic. There's a limit to the time you can leave the guy in the suit.

NORFLEET: This was 3 hours. And then a duration of 3 to 4 additional hours. So, an option would be?

BOVE: Post-breathe for 2½ hours.

REIMERS: What you might want to do is this: you go to 100 kPa (14.5 psi) or whatever is actually the pressure until the symptoms go away. I'd wait some reasonable amount of time, maybe 30 minutes, go back to 70 kPa (10.2 psi), and leave him in the suit. You can wait there for a while. If the symptoms don't come back, you

REIMERS: (Cont'd) begin to feel pretty good; "Hey, this is cleared up." If they do come back, you're still in the suit, you can go right back to 14-whatever. The name of the game is to stay out of the chamber.

BOVE: Yes, but you're losing time on the suit.

HAMILTON: I like the idea of getting the full benefit of breathing that cheap oxygen. You've got a good chance of avoiding a chamber treatment if you hold in this 100 kPa (14.5 psi) as long as you can. That's not a treatment pressure. But for the situation you're in, you do have a chance to resolve it completely.

REIMERS: That's your best bet, staying there.

SPEAKER: I have another question, though: What happens to the other EVA crew member when you're nearing the end of an EVA and this happens? The other crew member's going to stay and wait outside? Or, does he come in?

NORFLEET: He comes in.

HAMILTON: It wouldn't hurt to have the other crew member go through the same pattern all along if it doesn't matter. Can you get the other crew member out?

NORFLEET: Yes.

BUCK: When they come back in, they come into the equipment lock; that's standard procedure, to doff the suits. When you come back up to 70 kPa (10.2 psi), you just have one guy stay in the suit and the other guy can get out of it.

REIMERS: There's nothing to be gained by keeping a guy who's not bent in a suit. That's just making work for everybody.

PILMANIS: Why did you go to 100 kPa (14.5 psi) in the first place?

WORKMAN: Why not just go to a total of 70 kPa (10.2 psi)? Then you don't have to worry about going through that essential re-exposure back to 70 kPa (10.2 psi).

HAMILTON: That's something we don't know. Fred says, and I agree with it, that that extra 20 or 30 kPa (3 or 4 psi) is not going to do you a whole lot of good as a treatment. *But*, 2 hours of oxygen breathing at that pressure will do you some good.

STEGMANN: But, you can repressurize the chamber to 41 kPa (5.9 psi) and leave him in the suit, post-breathe him, and then depress the suit, bring up the chamber, and then you're at 70 kPa (10.2 psi).

HAMILTON: I see that algorithm. In other words, you don't use that little extra pressure and then you avoid the shock of taking him to altitude after he comes out.

WORKMAN: It's the oxygen that is your beneficial effect.

HAMILTON: Yes, the oxygen from the suit is available. You've already used the suit; you're going to have to recharge it anyway. So, take that extra 2 hours of oxygen as basically free. A chamber pressurization is certainly not free.

BOVE: Well, part of the message is that the chamber operator better learn to stop at a net pressure of 70 kPa (10.2 psi) and see what's going on first before he goes to the 100 kPa (14.5 psi). If he finds out symptoms are relieved at 70 kPa (10.2 psi) total, then you ought to stop there and go on and stay on the oxygen for an amount of time, depending on whatever is left in the suit.

WORKMAN: And, you can bring him out without penalty.

BOVE: That's right.

STEGMANN: A chamber pressure of 39.3 kPa (5.7 psi), I think, is what you're talking about.

WORKMAN: And that, combined with the suit pressure, comes up to 70 kPa (10.2 psi).

BOVE: Now the only other problem with that is your other guy is going to have trouble getting out of his suit at 35.8 kPa (5.2 psi).

WALIGORA: Bill, is that the way it really works? I thought when you repressed your suit, it was not pressurized anymore. At the normal repress, do you end up with a pressurized suit or not?

NORFLEET: On a normal repress, you end up with a repressurized suit to the best of my knowledge, yes.

WALIGORA: That's something we might want to check on, but I was under the impression that you didn't, and, if you didn't resolve the symptoms, then you could pressurize.

PANZARELLA: When you repress, you do go all the way to 29.6 kPa (4.3 psi); there's a 29.6 kPa (4.3 psi) differential, and then they'll drop it down to 8.3 kPa (1.2 psi) and go into the IV position. And then they'll talk and let the suit bleed down with the purge open.

BUCK: So, as a normal operation, the guys are always going up to 100 kPa (14.5 psi) and coming down.

PANZARELLA: Yes, the suit is tracking 29.6 kPa (4.3 psi) above whatever ambient pressure is. They're always going to be above ambient.

BOVE: The only concern here is, what to do with your other crew member, because he can't get out of the suit by that time. Wherever you go with this, it's a problem because, if you have two people in there, one of whom is bent and the other can't get out of the suit, you're going to have to put another guy in there at 41 kPa (5.9 psi), so you may be compounding the problem by trying to hold the lock at 41 kPa (5.9 psi).

NORFLEET: Would you resolve it to do essentially a test of pressure at a total of 70 kPa (10.2 psi) at the patient's surface, at the patient's skin? Repressurize the crew

NORFLEET: (Cont'd) lock to 70 kPa (10.2 psi) minus 29.6 kPa (4.3 psi) for a period of 10 to 20 minutes or whatever, and then call that your test of pressure; and then come back?

BOVE: The question is, what if he passes the test of pressure? Then you say, "Okay, we're going to keep the lock at 41 kPa (5.9 psi)." Now the other guy can't get out of the suit, and you can't lock somebody else in at that altitude. You're really getting yourself into a bind. I don't think there's any simple way you can solve that. The logistics solution is to put the one guy at 70 kPa (10.2 psi) plus 29.6 kPa (4.3 psi) and get the other guy out of the suit. If you want to, you can lock him out and bring another tender in to take care of the other crew member that's in there and let him breathe oxygen for the duration of the suit is remaining oxygen supply, take him out of the suit and take your lumps, whatever happens. If he gets bent again, you're going to have to treat him. If he doesn't get bent again, then you go back to 70 kPa (10.2 psi), and you're home free.

STEGMANN: What if you were to lock in a tender at 41 kPa (5.9 psi)?

SPEAKER: But, then you have to bring a tender at fairly significant altitude, and that guy is likely to get bent.

BUCK: You could bring one guy into the equipment lock and leave the bent guy in the crew lock. But, then what happens?

BOVE: You don't want to leave an injured crew member in the lock by himself. You need a tender in there.

BUCK: Right. How do you bring someone in at 39 kPa (5.7 psi), then?

BOVE: That's the whole question. You see, you get yourself into a very bad bind if you want to run that lock at 39 kPa (5.7 psi).

STEGMANN: Yes, but if you've got somebody in a suit, you're going to be doing precious little patient care anyway, aren't you? It seems that's kind of a moot point.

BOVE: Well, let me put it this way. If you were sitting in the suit and something happened to you, would you rather have somebody out there looking at you or not?

STEGMANN: But, you're going to have to repress the chamber to 70 kPa (10.2 psi) anyway instead of getting him out of the suit, so by then you can bring somebody in there.

BOVE: Well, it's not a good way to manage what we consider an injured crew member. Normally, if you have an injured crew member in a chamber you have somebody in there with them. The contingencies are such that things may happen too fast for you to get in there in time to do anything. I guess that's the way we think about it anyway.

NORFLEET: Okay. Can we move on? We've at least identified the issues there. Take the next scenario. Pain interferes with work; the crew returns, so we're at that phase. Thirty minutes after recompression to 70 kPa (10.2 psi), pain persists. For the purposes of this discussion, assume that you've decided to go ahead and take him out of the suit. He still has pain, and you have an unsuited crew member at 70 kPa (10.2 psi) in the equipment lock. The neurologic examination is normal,

NORFLEET: (Cont'd) and the hyperbaric airlock – that is, the crew lock – is ready to go. Is there anything you want to do prior to starting a treatment?

HAMILTON: Go to your bunk and get a comic book because you're going to be in there a few hours.

BOVE: You ought to give him two aspirin and all go out to dinner.

BUCK: I have a question. For a scenario like this, how do we consider the use of the CHeCS equipment – of all the portable equipment? Do you bring that into the work flow when something goes wrong?

HAMILTON: Isn't that embedded in the HAL being ready?

BUCK: No, it's transported in from the node. So if you wanted to put it in there prior to treatment, you could.

HAMILTON: So that follows, though. That's part of your HAL checklist, though.

BUCK: But, that's the question. In this case, is it? Do we need to bring in all that equipment, or is that just unnecessary in this case?

BOVE: No, I wouldn't bring it in. What I would do is put it outside. You've got a medical pass lock you can pass things through, so there's no use cluttering the thing up. You could have it standing by outside the hatch in case you needed something. A limb bend, as Bill said, means you get your comic books and you sit there and

BOVE: (Cont'd) read while you're breathing oxygen. Most of these people have no problems at all. You might want to make sure you have a liter or 2 of water for him to drink and a urinal so he can relieve himself, and maybe put some of that emergency equipment just outside the hatch. No use piling it all in there with him because you're going to get it through the pass-through lock.

HAMILTON: Hydrating him and things like that are part of the treatment.

SPEAKER: Is everything placed in that kit that's sized to go through the pass-through lock?

SPEAKER: Yes, it is.

NORFLEET: Point of information: When you do go over and look at the crew lock in the mock-up, just keep that scenario in mind and picture some EMUs and a bunch of junk piled in the equipment lock. It's not really confirmed by a full mockup yet, but my impression of the crew lock is that, especially relative to a lot of commercial chambers, it's actually quite roomy. And, when you put zero g in there with increased utilization of volume and fill this up with junk and people and a lot of activity, this might actually be a little bit more usable volume than you might otherwise assume.

BUCK: I guess my question was geared mainly toward the time. Do you want to take that time to bring all the stuff in, or do you just want to get the guy in there and pressurize?

SPEAKER: If you want an IV?

SPEAKER: No, you don't need an IV for a guy like this.

STEGMANN: Well, what if something goes wrong, though? The guy in the chamber probably is going to have a bad vein to go for and he's not able to help.

BARRATT: We've actually done some thinking that's established a need for placing an IV. Although the event of needing it is very unlikely, the difficulty in placing it is very high. We have found on the SLS-1 flight that it takes three people to do a simple phlebotomy effectively – one being the person who's donating.

HAMILTON: And two to hold him down, yes.

BARRATT: Somebody holds the needle stationary and they move the patient onto it. But seriously, we'll be doing a course of simulation studies and trying to discern this need a bit better; but I think that IV access is probably one of the things we would baseline, even for a simple case.

HAMILTON: Well, if it *is* really difficult, then you'd want to do it ahead of time. On the other hand, from my point of view the IV for a pain-only decompression situation is a complication that you don't need.

BOVE: The way we might do it would be to put what we call a heplock in – just put a little short needle in the vein, cap it off, leave it there in case you need it, and let them drink the fluid. People absorb better, and it helps to give them fluid orally and have the vein access available if you need it.

BARRATT: Yes, that's very similar to what we're planning. A very small, simple IV that doesn't use up a whole liter of fluid every time you place it.

BOVE: Well, you don't even have to hook them up. You can flush them with a little syringe sometime, once every 2 hours, and you don't even need to put a bag up there. Because once you put a bag up, you've got a complication of watching it and making sure its running or not running and all the rest of it. These little short heplocks just go in, they sit there, you tape them over, and the patient doesn't even know they're there. You flush them once every 6 hours, actually, to keep them patent; that's all you need.

NORFLEET: I think that this issue may end up being solved sort of by itself as scenarios are gone through during actual simulations, particularly regarding how long it takes to configure the crew lock for hyperbaric operations. We don't know that at all yet. Courtney, maybe you have some more recent information. But, if it takes 30 minutes to do that and you're sitting around? Well, sure, I think everybody would say, "Just throw in the heplock."

BUCK: The other thing is, there are certain items that we know we need in there; for instance, the masks have to bring those and they have to have them to breathe oxygen. But as far as crew restraints go, the one restraint that we're planning on having in there is the medical restraint where you have the guy in a supine position. Do we want that in there, or don't we want that in there?

BOVE: Again, not for a limited case. Most treatment is limited to what you do in a lounge chair.

STOLLE: A lounge chair is one thing you can't get through a medical lock.

REIMERS: There's been quite a lot of discussion about how to deal with oxygen-breathing time after a guy comes in. How do you do the oxygen pre-breathes? How are those done?

NORFLEET: There are two types of them basically. One of them is the 1-hour period prior to the staged decompression method, and that is done usually with a mask of some sort. On Station there probably will be a common mask that will be used for that purpose as well as, perhaps, for fire-fighting uses and non-respirable atmosphere uses. Now in the suit, just prior to decompression, the suit is purged.

REIMERS: But, my point is the following: Somebody is bent and has come in in a diving suit. The longer you think about it, the less likely you are to have anything to do with leaving him in that suit because, first off, you've got him in, and he's got DCS. Things *can* go from bad to worse fast in that kind of situation. You've still got him in his suit, and now you've got to get him out of the suit before you can think about repressing him in the chamber. So, I have this feeling that the thing you're going to want to do is get him out of that suit to where you've got access and, if something happens to him, you can deal with it. Part of the reason for keeping him in the suit is oxygen conservation, but if you're already set up for doing oxygen pre-breathes, that's just not an issue. You could use the same equipment that's used in pre-breathes for administering oxygen afterwards.

NORFLEET: Yes. Probably what would be used would be the BIBS mask. This would be one of the first things to be set up, because it has overboard dump.

REIMERS: What are you doing with the oxygen on the pre-breathe? Are you overboard dumping that?

NORFLEET: No. That's probably going to go into the atmosphere. But, the volume of the Station is such that it does not significantly impact the atmosphere gas mix.

REIMERS: It's no different here. In diving decompression sickness if you get bent, if you're at saturation, you go back to the depth of your saturations: 70 kPa (10.2 psi) is saturation depth here.

NORFLEET: That's right.

BOVE: Well, it's a little different, though, because the saturation depth in that case is going positive, which would compress the bubble. In this case it's going negative, which would allow bubbles to expand. The only difference in the two situations is this: Trying to return to your saturation depth, in this case, is going in the direction of more gas expansion rather than less gas expansion. So, there's a little difference. You'd like to give this crew member the advantage of 100% oxygen in a post-breathe and have him stable. I'm thinking of this scenario: If the pain was there at 70 kPa (10.2 psi) and you ended up at 100 kPa (14.5 psi) and you got control of his pain, you're going to give him oxygen to breathe. What do you do then? He's in the suit. The other thing he could do would be to bring the chamber to 100 kPa (14.5 psi) and put him on a BIBS mask. Now, you're still diving the chamber and you have to go through all the scenario. In a sense, you still have to get everything activated at that point. Maybe that would be the interim

BOVE: (Cont'd) solution: Bring the chamber to some small pressure that would get control and let him breathe oxygen as though he were on the surface.

PILMANIS: I guess I'm missing something here. When he comes in, he's been at 29.6 kPa (4.3 psi) and the Station is at 70 kPa (10.2 psi). As you're pressurizing, why can't you bleed the suit so he ends up at 70 kPa (10.2 psi) and then take the suit off?

NORFLEET: You could essentially do that.

SPEAKER: Yes, you could do that if you wanted to.

BOVE: The key is that, if the bends symptoms were there at 70 kPa (10.2 psi) and you could have them go away at 70 kPa (10.2 psi) plus 29.6 kPa (4.3 psi), what do you do then? That's the real question. Of course you get back to 1 ATA.

PILMANIS: I wouldn't look at it that way. If you take him out of the suit at 70 kPa (10.2 psi) and the symptoms persist, then you dive him.

STEGMANN: How long does it take for somebody who's incapacitated to get them out of the suit without their assistance? Can that be done in the crew lock, and can it be done in the equipment lock?

NORFLEET: Getting out of a suit is going to take the help of unsuited crew members. And so, that will be done in the equipment lock. The answer to that is known better by people who do EVA work, but it's essentially very fast to pop the helmet. To get somebody out of the rest of the equipment takes longer. To get to the airway is

NORFLEET: (Cont'd) pretty quickly. I believe that, in scenarios that involve getting around the limiting orifices and depressurizations, they get to a certain point and they pop a glove and then they pop the helmet.

BUCK: It can be done rather quickly. In documents, this will always be done in the equipment lock. There's really not room in the crew lock, and besides you're obviously going to need help. You've got to bring the equipment lock back to Station pressure to equalize and get your unsuited crew members there to give some aid.

NORFLEET: Can we move on? After 20 minutes at 285 kPa (60 fsw), pain is gone. Treatment Table 5 or 6? Do we use ancillary therapy or fluids? You can't do orthostatic tolerance test. I don't know what happens to people in microgravity when they get intravascularly depleted. I don't know if they just do fine until the ventricles suddenly are empty and then they just catastrophically go bradycardic.

BOVE: It rarely gets anywhere like that. Most of the fluid loss here is plasma loss with hemoconcentration. It might be 15% or 10% of the total plasma volume. We're not talking about that, unless he's frankly *bleeding* and could go into shock and there's no blood left to circulate. But, that's not what would happen here. What you're really trying to do is replace fluids to prevent sludging and hemoconcentration. So as I said, unless there was an obvious injury where there was blood loss, the fluid leak is not as much a problem of severe shock (unless it was a massive blowup) as it is of getting the hematocrit and platelets back to normal again. So again, with a plain old limb bend where the patient's awake and alert, you opt always to give him oral fluids. It's the easiest way out. In this situation, choosing

BOVE: (Cont'd) Table 5 or Table 6, well, I'm a Navy guy, so I would say, "Use Table 5 because as they just recently published that Table 5 still works for this kind of thing." There are a lot of people that are saying, "For diving, don't use Table 5 because you may be missing a subtle neurologic finding."

PILMANIS: But, it's 20 minutes. The cutoff is 10 minutes if you're a Navy guy.

BOVE: Sorry, I didn't see that. You're right.

WORKMAN: Once you're beyond 10 minutes, Table 5 goes out the window anyway.

NORFLEET: A point of information here is that more than half of the gas consumption is used in pressurizing the chamber, not in BIBS gas usage. So, in the decision between Table 5 or 6, it would be a *bad* thing to do a 5 and have a recurrence. With that information in mind, what are your recommendations?

BOVE: I think the 20-minute rule is, as Andy said, important. If it took that long to get rid of the pain, you probably had better use a 6.

WORKMAN: In our experience with the altitude cases that we've treated for a long time, we went through doing Table 5's, and we had a fairly high recurrence rate on those. Many of those recurrences were female (not to get into a discussion of male and female). But, we found ourselves back doing a retreatment at 2 and 3 o'clock in the morning, and we got out of that mode giving them a definitive 6 from the very beginning. However, now that I've said that I also want to say that, when our doctors have a chance to get by with a Table 5, they'll take it. But the overwrit-

WORKMAN: (Cont'd) ten criteria they use is resolution on descent. If they get pain resolution before we hit bottom at 285 kPa (60 fsw), they may go with a Table 5. But, if it's slow to resolve, they'll go ahead and do a 6. But, I think your comment about gas consumption is very real. I wouldn't even consider a Table 5.

HAMILTON: Nobody's going home.

WORKMAN: I would consider not even giving that as an option.

PILMANIS: I would go with a 6 right off the bat.

NORFLEET: I'd like to skip (in the couple of minutes that are remaining) to the following situation, which says that, "After first treatment table, all symptoms are still gone and neurologic examine is normal."

NORFLEET: Let's apply this to scenario number 1. You treated the person. After the first treatment table, all the symptoms were gone and the neurologic examine was entirely normal. We're now going to touch briefly upon return-to-duty issues. This was limb bends. He needed treatment with hyperbaric therapy. There appeared to be no sequelae, no complications. This is an EVA crew member. When can this crew member perform further EVAs? It brings up questions like: Does a history of DCS increase the risk of future DCS? Does Type I versus Type II really matter? Forty-eight hours, 1 week, never for a return EVA, and what?

BOVE: Well, the first question is a hard one to answer. There *are* individuals who are susceptible to decompression sickness – *individuals* – and no matter what you do,

BOVE: (Cont'd) they get bent under the simplest of circumstances. And, there are other people who get one bend, perhaps deserved because they did something beyond what they should've done, and they don't get it back again. So, I think the answer here is: If this is not a bends-susceptible individual, the history doesn't necessarily mean they're more prone in the future, unless they're that strange, occasional individual that seem to be bends prone.

WORKMAN: It's an occupational risk.

REIMERS: Back to the Navy experience: I can remember a series of dives where we were pushing tables to the limit; and we were bending somebody once a week, and not necessarily the same somebody. But, the fact that they got bent meant that you waited a day and you just forgot it ever happened. Now if you find here that one astronaut gets bent every time he goes out, maybe you'd better do something.

SPEAKER: You're going to know that before he goes EVA.

HAMILTON: Answering this question depends to some extent on what the mission is and what the resources are. If everything grinds to a halt and you've got a million dollars a day hanging up there, not working, then you're going to be a little *motivated* to go back to work sooner than you would otherwise. So, that has to be factored into it.

BOVE: Well, Bill Norfleet has carefully constructed these questions to ask about the person and not the mission. The main question is: When do you re-perform EVA? Well, if there's an emergency going on, everybody goes out and does it. But, I think that some questions are really based on the person. Those are more inte-

BOVE: (Cont'd) resting questions to ask because they reflect things in biology that we don't really know the answers to in many cases. The answer to the first question, though, I think is, *No*, except for those rare individuals that seem to very prone to get bent. And I think, basically, nobody would worry about somebody who got a limb bend and was treated today, cleared, and tomorrow could probably go back on a diving operation. That's normally the way they would treat divers, and I think that kind of scenario would probably be okay here. The only hook in this is the fact that it was a long treatment. The guy didn't resolve immediately and get better without a long treatment; and that might make the diving officer say, "Let's wait an extra day for this guy, just to make sure." But, that's all within the bounds of clinical judgment.

WORKMAN: As we had discussed with you in San Antonio at Andy's workshop, we do have some data where we went back and analyzed whether there was an increased incidence of recurrent Type II *diving* DCS, and we found no significant fact there. The Air Force policy on return to duty after treatment for DCS is 72 hours. Now, we will allow someone to fly back home, for example – perhaps in 48 hours. In some cases, they've slid by with 24 hours. It's rare. But, not as a crew member. Again, the defining factor is whether they are returned to duty, and that is 72 hours.

BOVE: The other thing that I think you need to think about is: When do you go back and do another EVA? Because, for these people, there are two questions: When do they return to regular duty? And when do they return to EVA duty? Those are different issues. The commercial people will take a limb bends person and put him back to work the next day, as long as he's cleared. There are limits of 1 week

BOVE: (Cont'd) from the Navy, 72 hours from the Air Force, and 1 day in most commercial practices. The recommendation from my standpoint would be, if this was a simple limb bend that was easily treated, no problem, no pain after 5 minutes, I'd go back to EVAs the next day if you really wanted to do it. This case was a tougher case; and I might say, let's wait an extra day, if you want to be sure. But, I don't think there's any reason not to consider him available for more EVAs within 24 hours. It's a simple treatment in a minor arena.

HAMILTON: Practical point: Don't put your time in hours. Put it in days. Because, if you say "48 hours," it throws your schedule off. Days aren't so important, maybe, when you're making your days every 90 minutes. On the schedule here, if you put a 24-hour delay, it means you can't work tomorrow on the same schedule that you worked today. So say 1 day or 2 days, rather than 48 hours.

REIMERS: There's a psychological side to this, too, that I think is important. And that's, the longer you make the return to EVA or the return to duty status, the bigger the penalty you would inflict upon a crew member for getting bent and the greater the incentive *not* to report getting bent.

NORFLEET: I'll wrap this up. I'd just like to say that I agree with you completely. A driving philosophy in life for me has been to try to decriminalize decompression sickness and make it as routine as possible. As in the diving world, it should be regarded as an inevitable part of EVA, almost nominal, to be expected. You treat it, fix it, and forget it.

SPEAKER: It's an occupational hazard.

REIMERS: I think the key there may be that it's something we expect to happen. It's no big deal. We treat it and we go on.

NORFLEET: That's right. Thanks.

BARRATT: Thanks a lot, Bill. I'm sorry we couldn't do this longer. It's been very helpful. Just to clarify a point or two: Do the astronaut rules preclude an EVA on consecutive days for other reasons? Isn't that still in effect?

WALIGORA: It's a kind of planning guideline that you don't do 2 days in a row of planned EVAs. But, it's not a mission rule. You can do 2 days in a row, and we have done 2 days in a row. On a recent flight, we had a payload contingency EVA; we did it, and then we had a planned EVA next day, so we went ahead and did it. They will plan 2 days in a row.

SPEAKER: There's a fatigue factor to consider.

BARRATT: That was my understanding. I had asked Mike Stolle from McDonnell Douglas and Stephanie Trausch from the NASA EVA section to give an update on development of airlock test items.

Hyperbaric Airlock Test and Development Items

STOLLE: I'll make this very quick. The Clear Lake Development Facility is being developed as we speak near Ellington Field (FIGS. 63 and 64). This is a picture of what

Scenario #1

- Three hours into EVA, crewmember reports moderate pain in left shoulder
- Actions:
  Is there anything else you want to know?
  Is there anything you want the crewmember to do?
  Do you abort?

Norfleet, 9/91

FIG. 61 Scenario 1

Scenario #1 (cont.)

- Pain interferes with work, crew returns
- Ten minutes after recompression to 10.2 + 4.3 psi, pain is gone
- Treatment options:
  1) no change in routine
  2) "hang on wall" at 10.2 + 4.3 psi for ?? minutes
  3) "hang on wall" at 10.2 + 8.3 psi for ?? minutes (disables suit for further EVA)
  4) oxygen by mask at 10.2 psia
  5) HBO
  6) others?

Norfleet, 9/91

FIG. 61 Continued

Scenario #1 (cont.)

- Pain interferes with work, crew returns
- Thirty minutes after recompression to 10.2 psi, pain persists unchanged; neurologic exam is normal and HAL is ready
- Anything else you want to do?

Norfleet, 9/91

FIG. 61 Continued

Scenario #1 (cont.)

- After 20 min at 60 fsw pain is gone
- TT5 or TT6?
- Ancillary therapy?
  fluids? (no orthostatic tolerance test; fill him until he voids?)
  drugs?

Norfleet, 9/91

FIG. 61 Continued

Scenario #1 (cont.)

- After 20 min at 60 fsw, pain is absolutely unchanged
- Knowing that almost half of gas consumption for a TT6 is used during compression, what do you do?

Norfleet, 9/91

FIG. 61 Continued

Scenario #2

- Three hours into EVA, crewmember reports mild but clear and continuous electric-like sensation along lateral aspect of left thigh and lower leg
  - He has never felt this before
  - It is not like having a leg "fall asleep"
- Actions:
  Is there anything else you want to know?
  Is there anything you want the crewmember to do?
  Do you abort?

Norfleet, 9/91

FIG. 62 Scenario 2

Scenario #2 (cont.)

- During recompression all symptoms completely resolve
- At 10.2 psia neurologic exam is normal
- Treatment options:
  1) nothing
  2) "hang on wall" at 10.2 + 4.3 psi for ?? minutes
  3) "hang on wall" at 10.2 + 8.3 psi for ?? minutes
     (disables suit for further EVA)
  4) oxygen by mask at 10.2 psi
  5) HBO
  6) others?

Norfleet, 9/91

FIG. 62 Continued

Scenario #2 (cont.)

- After recompression to 10.2 psia symptoms are not significantly changed
- Neurological exam is otherwise normal
- What do you do?

Norfleet, 9/91

FIG. 62 Continued

Scenario #2 (cont.)

- After 20 min at 60 fsw all symptoms are gone
- TT5 or TT6?
- Ancillary therapy?
  - Fluids?
  - Drugs?

Norfleet, 9/91

FIG. 62 Continued

Scenario #2 (cont.)

- After first treatment table, all symptoms are still gone and neurologic exam is normal
- When may he perform EVA?
  Does a history of DCS increase risk of future DCS?
  Does "Type I" vs "Type II" matter?
  48 hrs? 1 week? Never? Why?

Norfleet, 9/91

FIG. 62 Continued

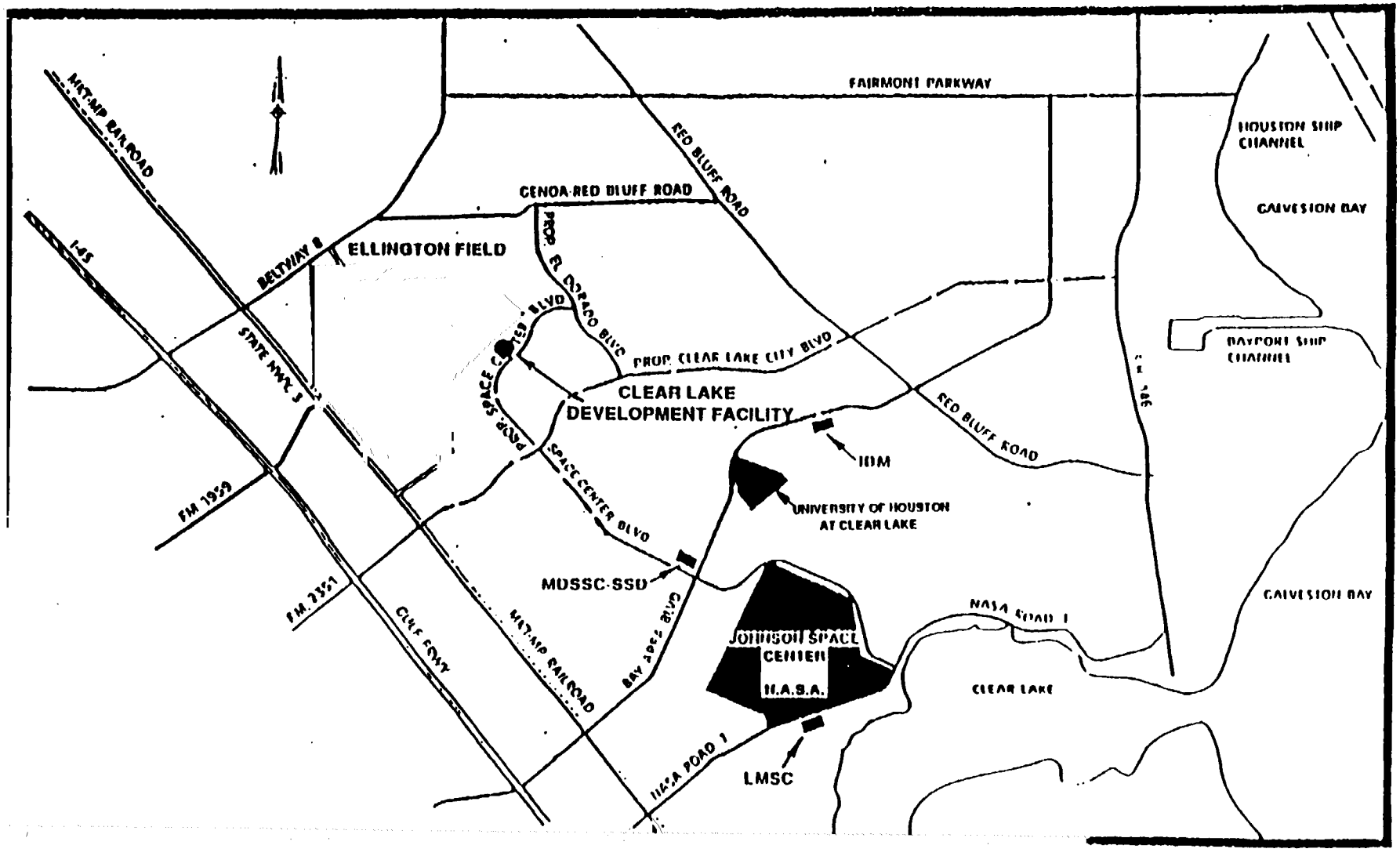
Scenario #2 (cont.)

- Post-flight would you screen for PFO?
- If so, what will you do with the results?

Norfleet, 9/91

FIG. 62 Continued

SSD HOUSTON FACILITIES LOCATION

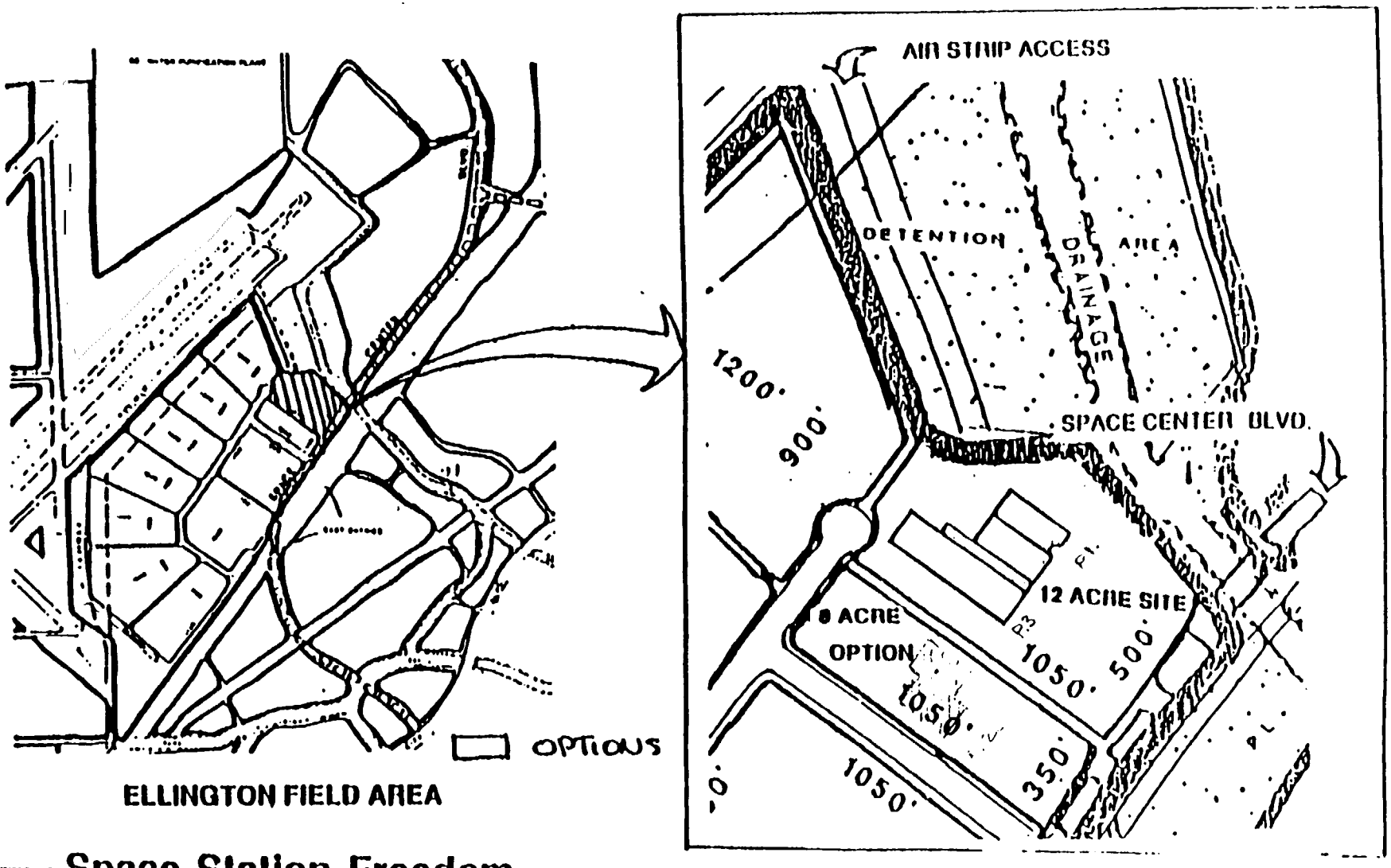


—Space Station Freedom—

McDonnell Douglas • GE • Honeywell • IBM • Lockheed

FIG. 63 Space Station Division (SSD) Houston facilities location

HOUSTON FACILITY SITE PLAN



Space Station Freedom

McDonnell Douglas • GE • Honeywell • IBM • Lockheed

FIG. 64 Houston facility site plan

WALIGORA: (Cont'd) we call Phase I (FIG. 65). And, I will be describing all three phases that are planned. The facility will include (in Phase I, which presently exists and is operating) a Light Manufacturing Facility and an Avionics Development Facility (FIG. 66). The Light Manufacturing will perform manufacturing of small equipment for Space Station, including development articles, test articles, and flight articles. The Avionics Facility of course will be used to develop the aviation electronics for each of these instruments. Power II, or Phase II, basically is another McDonnell Douglas office building. It will house about 700 engineers and a large computing facility. Phase III is the assembly and test building. This is where all of Work Package-2, which is McDonnell Douglas contract equipment for Space Station, will be assembled, put together, and tested in a fully integrated form. The sequence will be to put together our development test articles and then, as the flight articles come along, to substitute that test article for the flight article so that we maintain a fully integrated system and know that our flight articles are going to work the same way as our test articles.

Here's a drawing of the layout of the Light Manufacturing Facility (FIGS. 67, 68, and 69). I'll just quickly mention some of the features: It will have a paint shop, a welding shop, a machine shop, a wood shop, a clean room (a class 1000 or a class 10,000 clean room) – this, the clean room, will be where the CHeCS medical equipment will be assembled for flight. I mentioned that we are located near Ellington. Once the Space Station flight articles are fully integrated and tested and ready to be shipped to the Cape, we will only have to wheel them out the high-bay door to a waiting plane that is at the end of the runway at Ellington. So, it's all nicely situated.

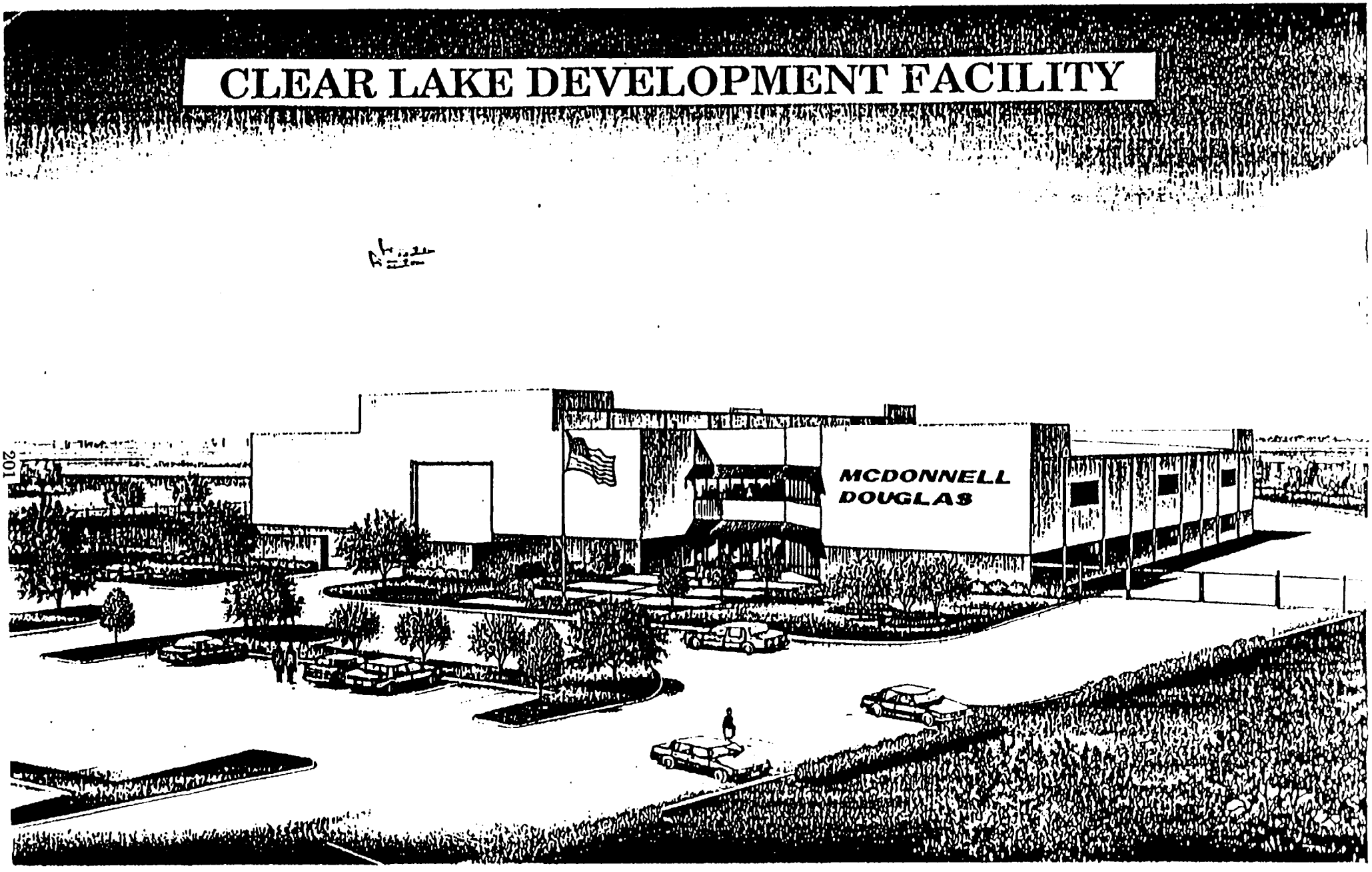


FIG. 65 Clear Lake Development Facility (photograph)

CLEAR LAKE DEVELOPMENT FACILITY (CLDF)

- Facility will be completed in three phases to support WP-2 requirements and other JSC needs
- Phase I was completed third quarter 1990 containing
  - A Light Manufacturing Facility (LMF) to provide a Houston capability to manufacture, assemble, modify and stage models mock-up, training devices and flight equipment
  - An Avionics Development Facility (ADF) providing office and laboratory space for the development of the Space Station Freedom power system and integration of the WP-2 software
- Phase II will provide a 175,000 square foot office building to consolidate program personnel
  - Building design is underway
  - The building will be operational in 1992

FIG. 66 Clear Lake Development Facility

CLEAR LAKE DEVELOPMENT FACILITY (Cont'd) (CLDF)

- Phase III will provide an 85,000 square foot high bay area for the verification of Space Station Freedom integrated system fit and function
  - Engineering requirements have been defined
  - Design will be undertaken in 1991
  - Facility will be available for tenant improvement late 1992

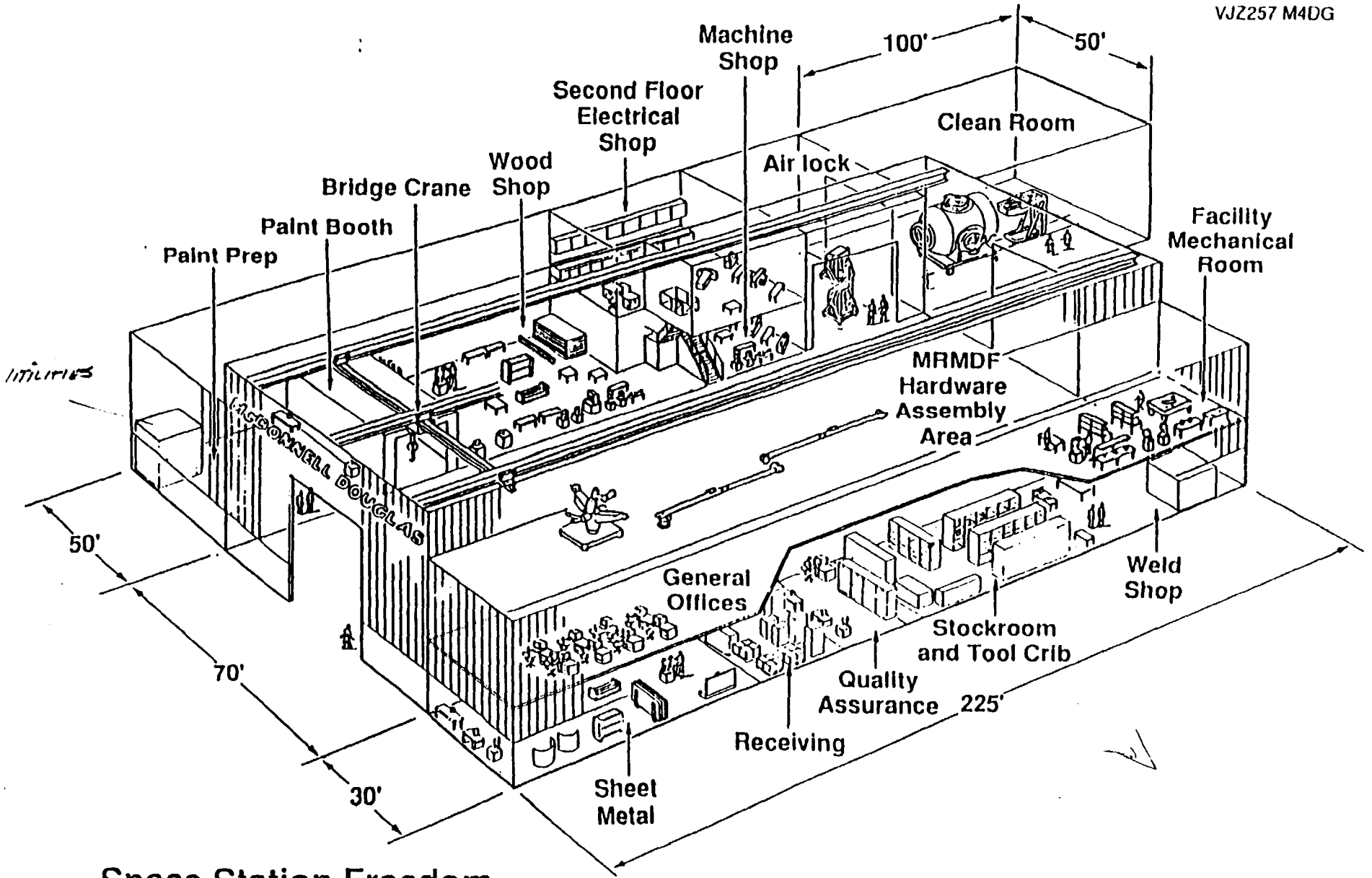
FIG. 66 Continued

CLEAR LAKE DEVELOPMENT FACILITY - PHASE I

- Light Manufacturing Facility (completed 8/90)
  - Designed for manufacturing modification, assembly and staging of equipment for:
    - Weightless Environment Training Facility (WETF)
    - Building 9 Astronaut Training
    - Mock-ups for engineering reviews
    - Crew Health Care System (CHeCS)
    - Work Package 2 Test Beds
- Facility contains
  - Central high bay area (225'x70'x35") equipped with bridge cranes
  - Shop areas connected to the high bay area
  - 100,000 class clean room (50'x100') with access through a 35'x50' airlock
- Machine, sheet metal, wood and welding shops are presently operational along with a large paint booth
- Future plans include electronic, tubing, plastics and fabric capability as specific requirements are identified

FIG. 67 Clear Lake Development Facility – Phase I

LIGHT MANUFACTURING FACILITY



Space Station Freedom

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FIG. 68 Light Manufacturing Facility

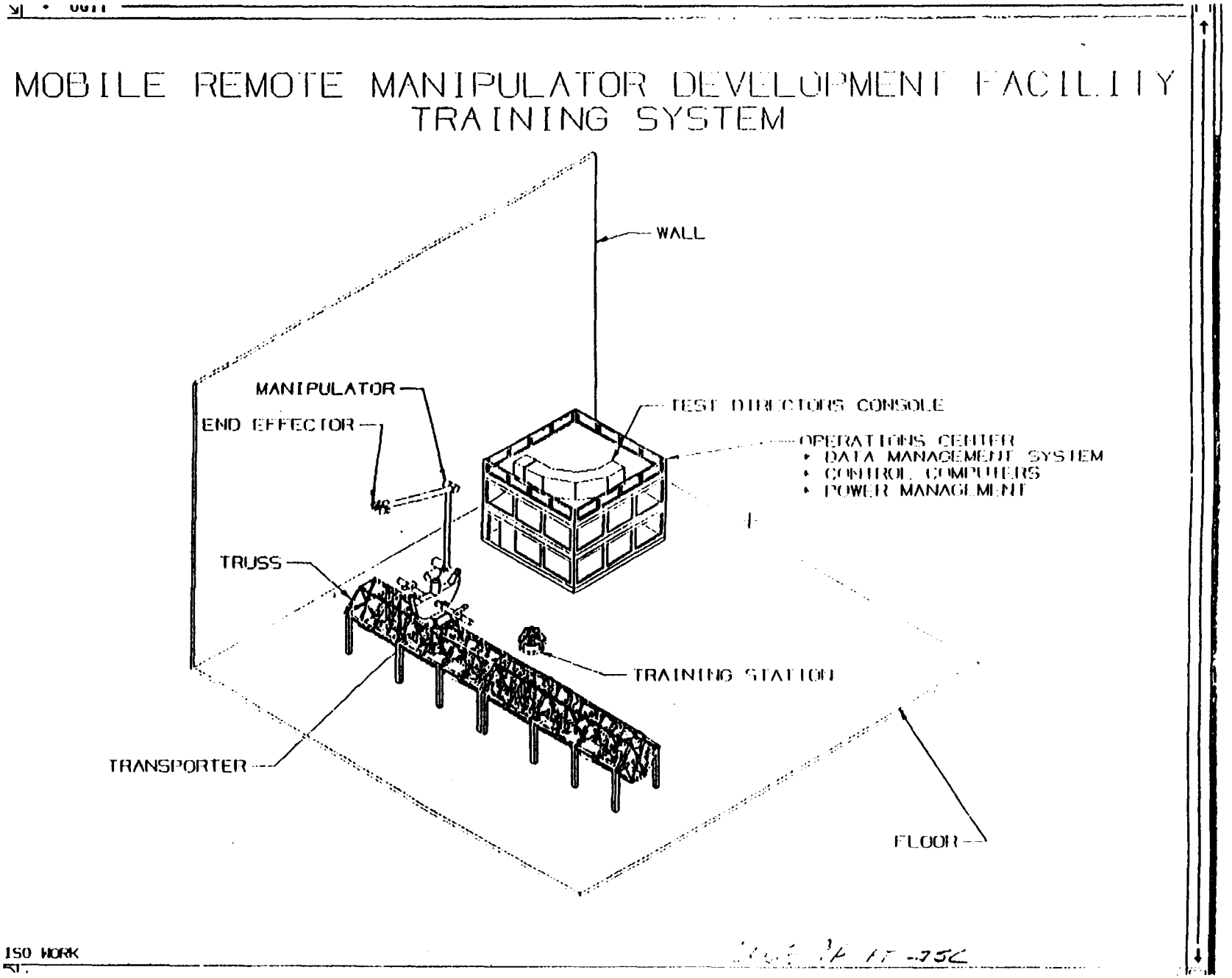


FIG. 69 Mobile Remote Manipulator Development Facility training system

STOLLE: (Cont'd)

Here is a little more information on the Avionics facility, called the ADF (FIG. 70). Just briefly: We will have a secondary power distribution facility. This is a working system that copies the Space Station power system so that we'll be able to take Space Station-type power directly and feed it into *our* equipment to assure that we're going to function properly off of Space Station power. A secondary capability will be to support Space Station activities after we're in orbit and operating to support the Space Station Control Center. Here's a little schematic drawing of the ADF (FIGS. 71 and 72). Basically, what it consists of is electronic benches and a computer system that allow us to fully test all of the avionics that are formed for Space Station, both for units of the dedicated test articles and the flight articles (FIGS. 73 and 74). Here's a little ground picture of how it will all be situated (FIG. 75). This is Phase I right here; this is what exists. This is the high-bay area where all of the flight manufacturing will be taking place. Then Phase II, which will come on board early in 1992, is right here; it's where all the engineers will be located (FIG. 76). And then late in 1992, we will begin operations in Phase III beginning our pre-integrated truss operations (FIG. 77). Just briefly on what the capabilities of that Phase III will be: As you can see, PIT means pre-integrated truss, and so that refers to our putting together each of these elements on the ground to verify, before putting them on orbit, that everything is going to talk to each other and work properly. And then, I described a little earlier how we're going to switch out our dedicated units for the flight units and do the same tests.

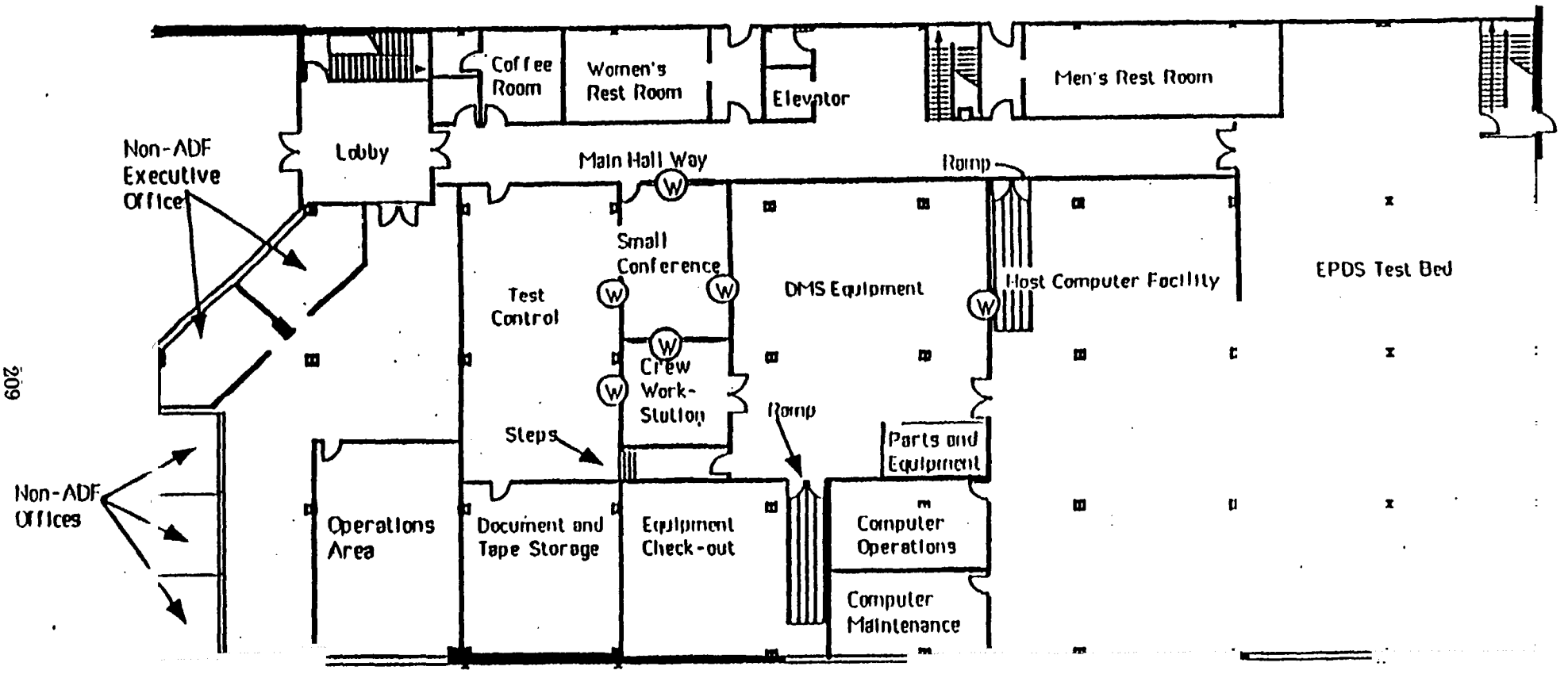
A little bit more on the ATD right here (FIGS. 78 and 79). We'll be able to do hardware and software integration so that, within a system, we can test integration in that way; and then the twin systems horizontally, we'll be able to test

CLEAR LAKE DEVELOPMENT FACILITY - PHASE I (CONT'D)

- Avionics Development Facility (45,000 sq. ft.)
  - Two stories of laboratory and office space are provided to support Space Station Freedom Work Package 2. The area will be utilized as follows:
    - Avionics Development Facility - The major portion of the building will provide laboratory and office space for the integration of the Work Package 2 systems software
    - The integrated Test and Verification Environment (ITVE) Equipment and personnel have been integrated into the ADF lab and office space
    - Electrical Power Distribution Systems (EPDS) Test Bed - Provides a development environment for the Work Package 2 portion of the EPDS.
    - Engineering Support capability (ESC) - will provide non real time engineering support to the NASA Space Station Control Center
      - Space has been reserved for the ESC per NASA instructions

FIG. 70 Clear Lake Development Facility – Phase I (cont'd)

ADF FIRST FLOOR



(W) = Wall containing window

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FIG. 71 ADF first floor

AVIONICS DEVELOPMENT FACILITY AND OFFICES

VJX815 M9AV

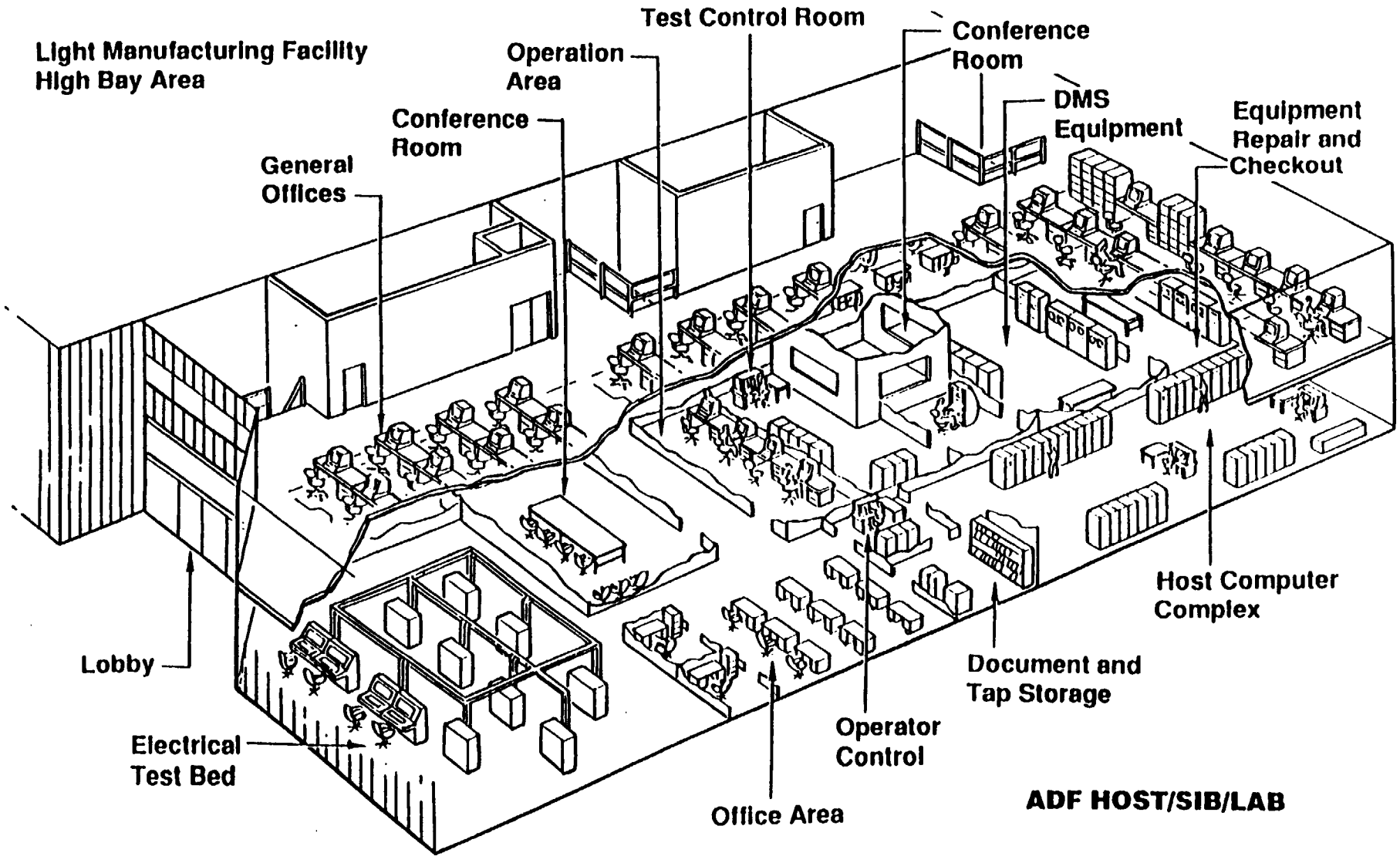

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FIG. 72 ADF and offices

SPDS LAYOUT

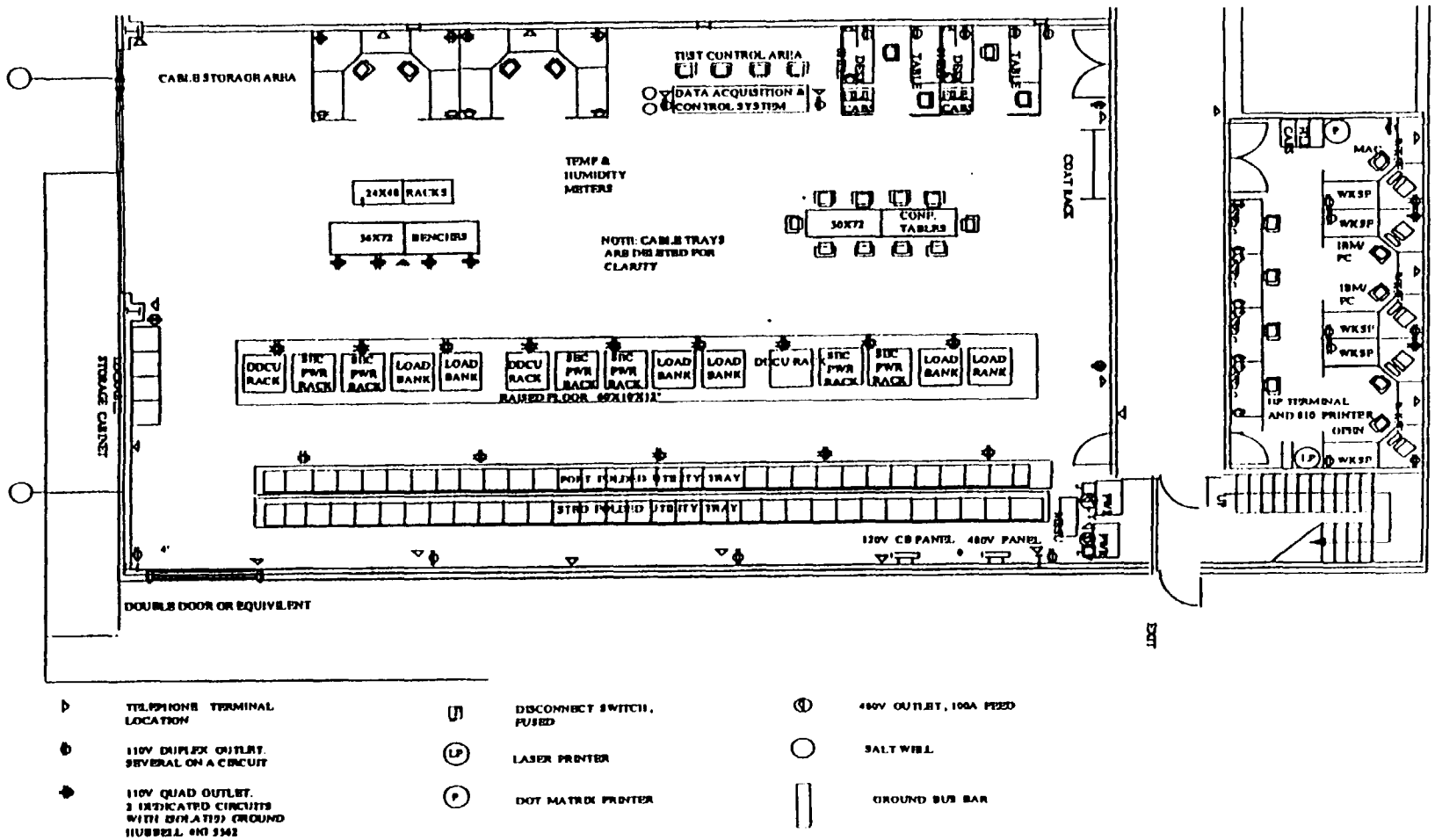

FIG. 73 SPDS layout

SECOND FLOOR LAYOUT

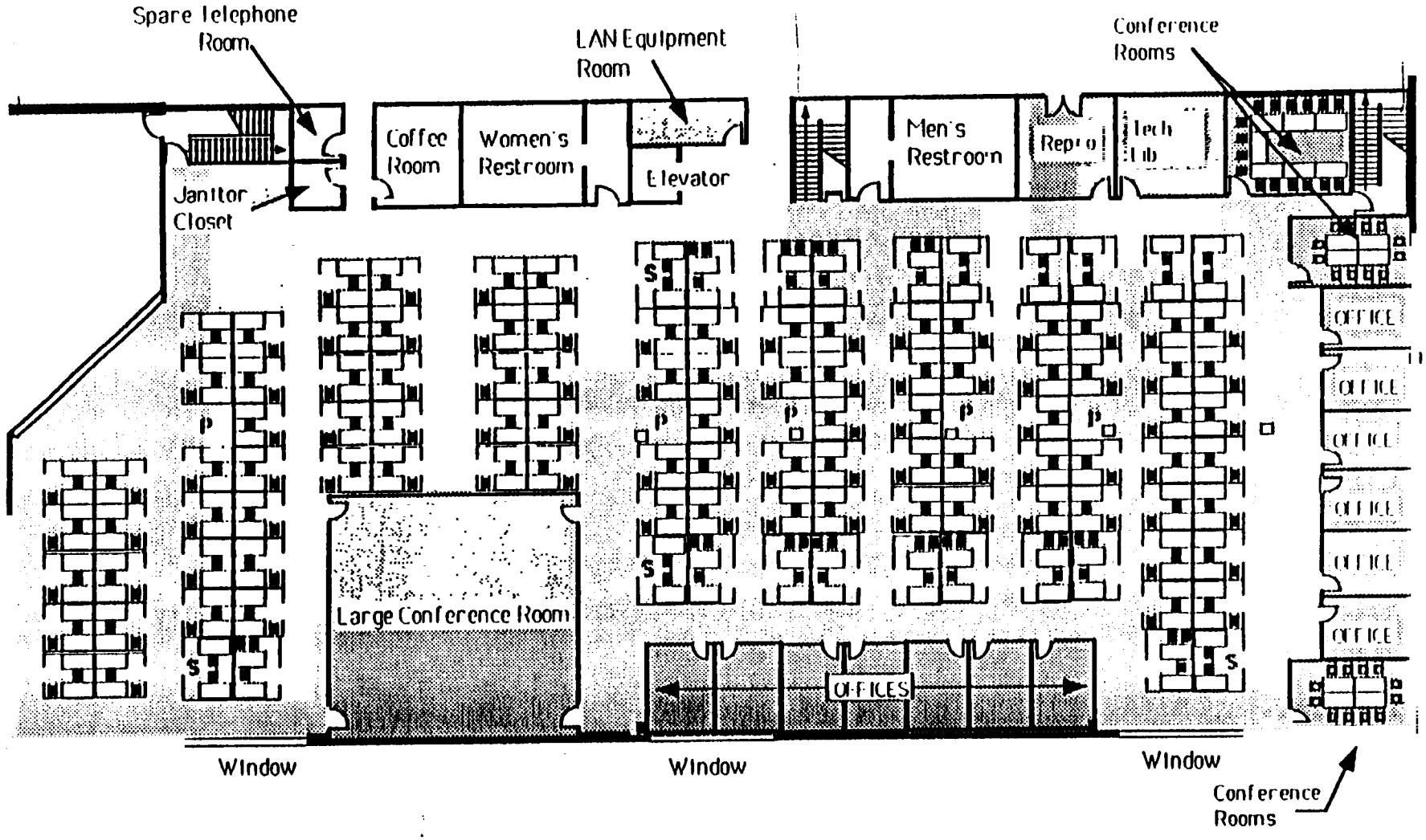

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FIG. 74 Second floor layout

MDSSC FACILITIES AT CLEAR POINT (ELLINGTON)

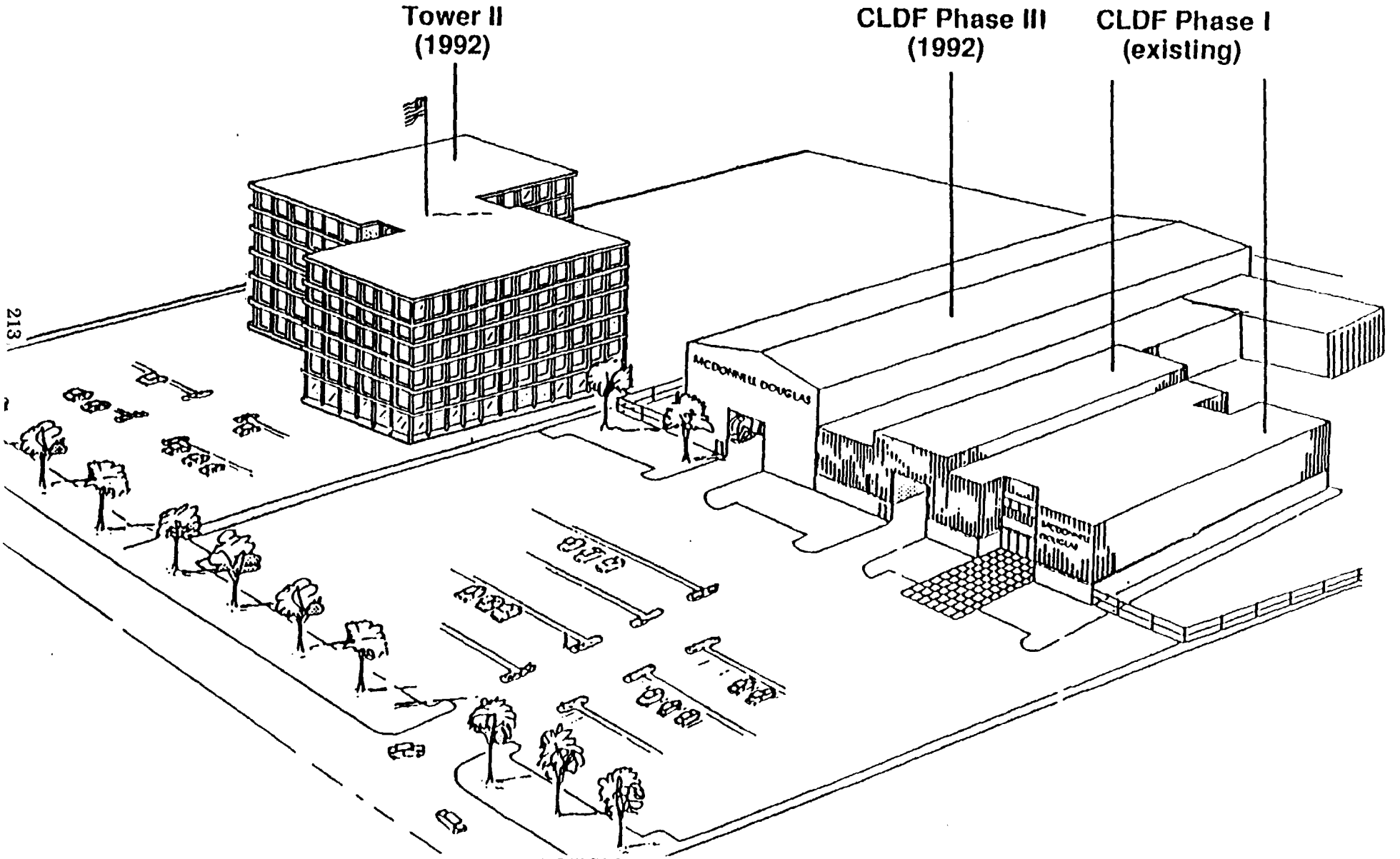


FIG. 75 MDSSC facilities at Clear Lake (Ellington)

CLEAR LAKE DEVELOPMENT FACILITY - PHASE II

- Location - 8 Acres contiguous to CLDF (Phase III) at Ellington Site
- Building design is in work
  - Six stories to include:
    - Computer facility
    - Approximately 700 engineering offices
    - Auditorium
    - Full Cafeteria
    - Etc.

FIG. 76 Clear Lake Develo ent Facility – Phase II

CLEAR LAKE DEVELOPMENT FACILITY - PHASE III

- Assembly and Test Building
  - PIT elements will be outfitted with high value systems equipment.
  - Pit elements will then undergo "stand alone" acceptance test.

    Note: Primary structure, secondary structure, electrical cables and fluid tubing will be assembled at Huntington Beach.
  - The "core station" flight elements and distributed systems will be physically integrated using DTA's.
    - Provides verification of form, fit, and function prior to on-orbit assembly
    - Verifies distributed systems will function properly in the flight configuration prior to decomposition for launch.

FIG. 77 Clear Lake Development Facility – Phase III

FEAT High Bay Layout

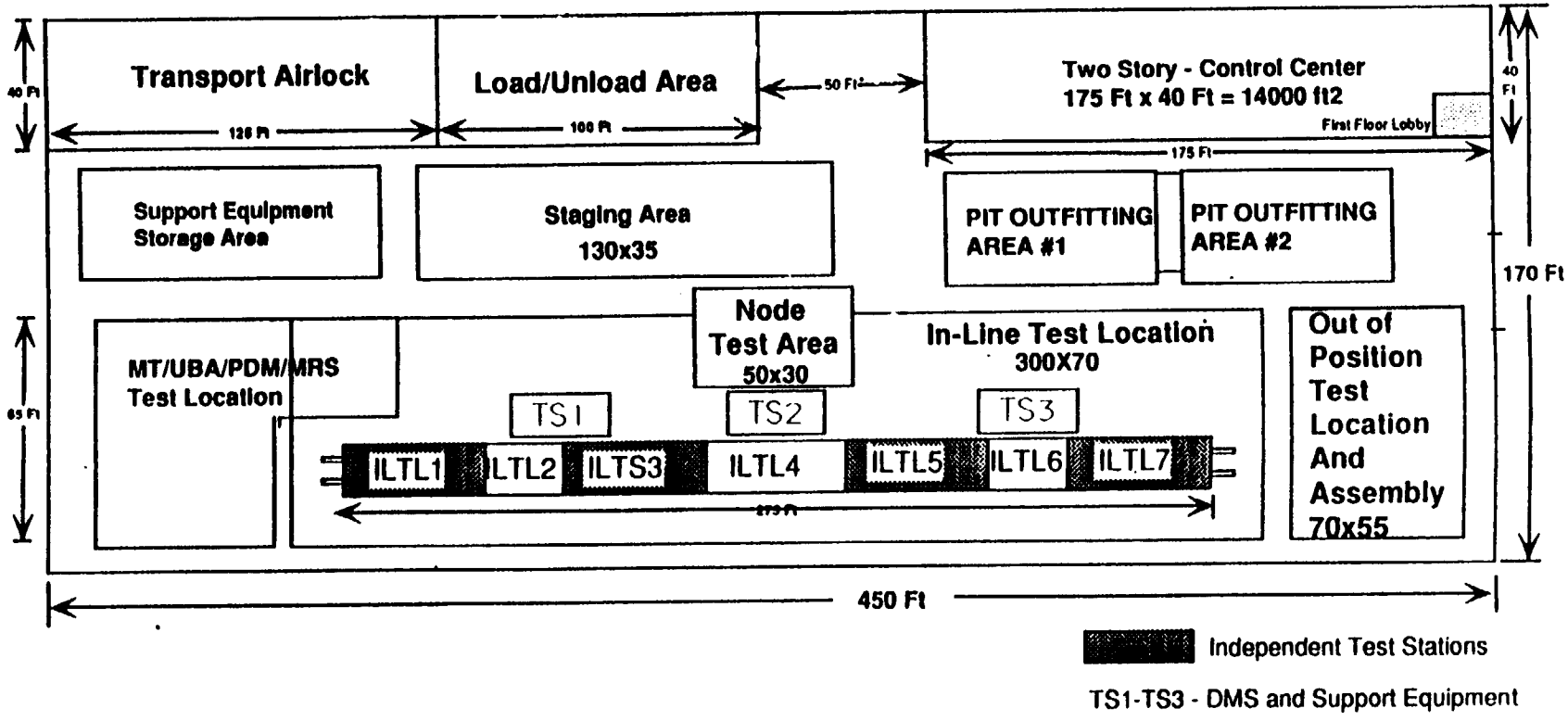


FIG. 78 FEAT high bay layout

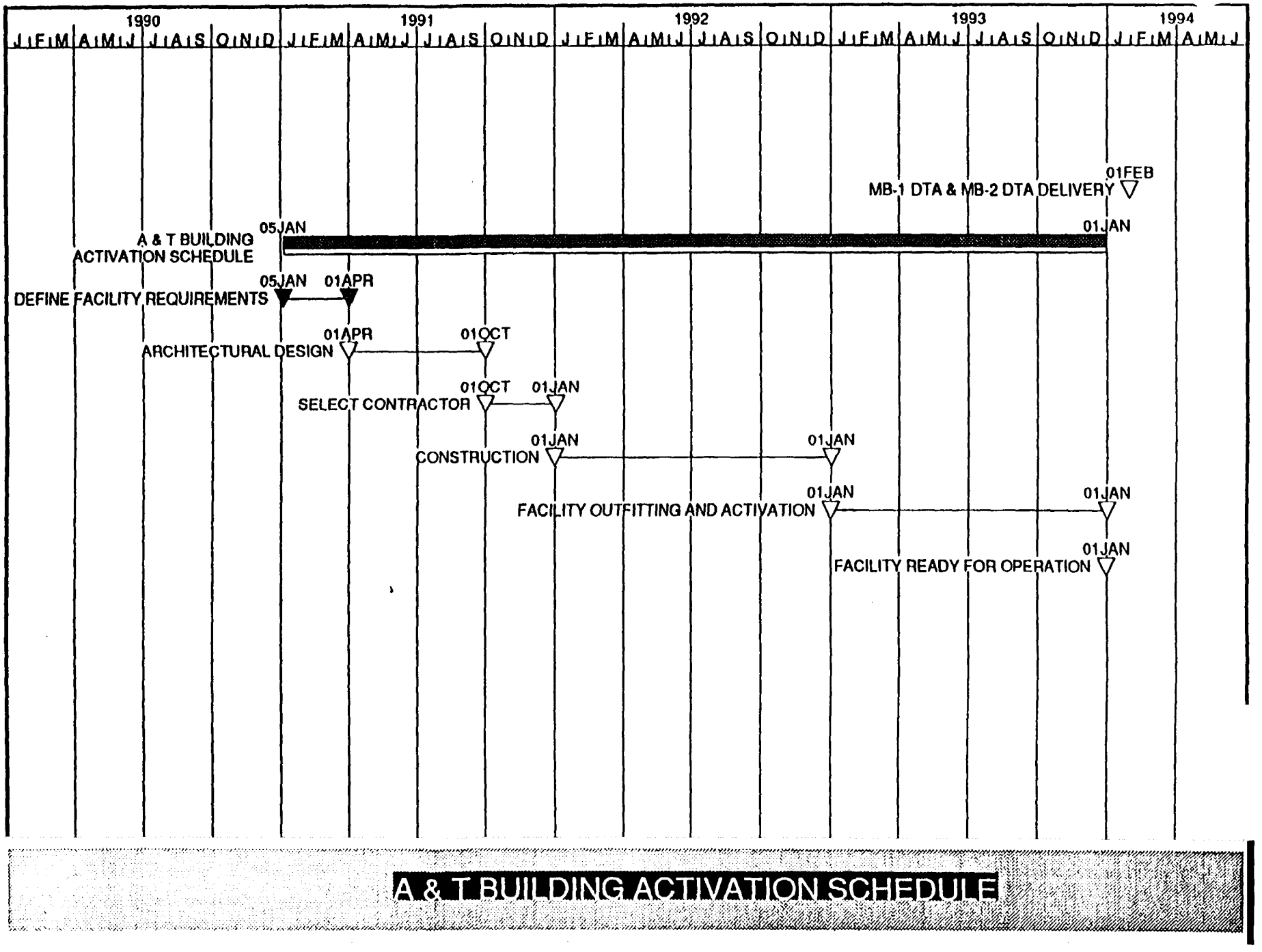


FIG. 79 A&T building activation schedule

STOLLE: (Cont'd) how the system integrates and functions properly horizontally between systems. FEAT is final engineering and assembly test. This is the area where the truss section will be put together. As far as elements go, we'll be able to hook them in and test our node integration in this area. We have a computing section to support DMS and electrical inputs to this truss. So, that's kind of how that's all laid out. The flight articles will then be, once they've been fully checked out, disengaged from their connection in the truss and moved out the high-bay door to be loaded on the aircraft for transport to the Cape (FIGS. 80, 81, and 82). Launch configurations for some of the early mission builds are shown here (FIGS. 83-86).

Finally, Mike has asked me to briefly go over what we plan for our one-g simulation to be conducted at Huntington Beach in early November. This is a hyperbaric simulation. We'll be looking at several different scenarios: One involves a DCS hit while on EVA, and then another scenario involves a DCS hit that's been delayed (FIG. 87). We'll look at CHeCS crew health care equipment to support a hyperbaric treatment, look at the interfaces, see how best they can be interfaced, what all is involved in a treatment, look at the wiring (the spaghetti mess problem) that is exacerbated by zero-g type environment, and look at things like that. We'll also look at being able to reach controls, see controls, how well our tender in the equipment lock can view what's going on in the crew lock, and vice versa.

SPEAKER: Mike, when did you say this was going to be?

STOLLE: In early November. Mike Barratt is going to be one of the conducting personnel; Courtney Buck is going to be supporting us; and I'll be there also.

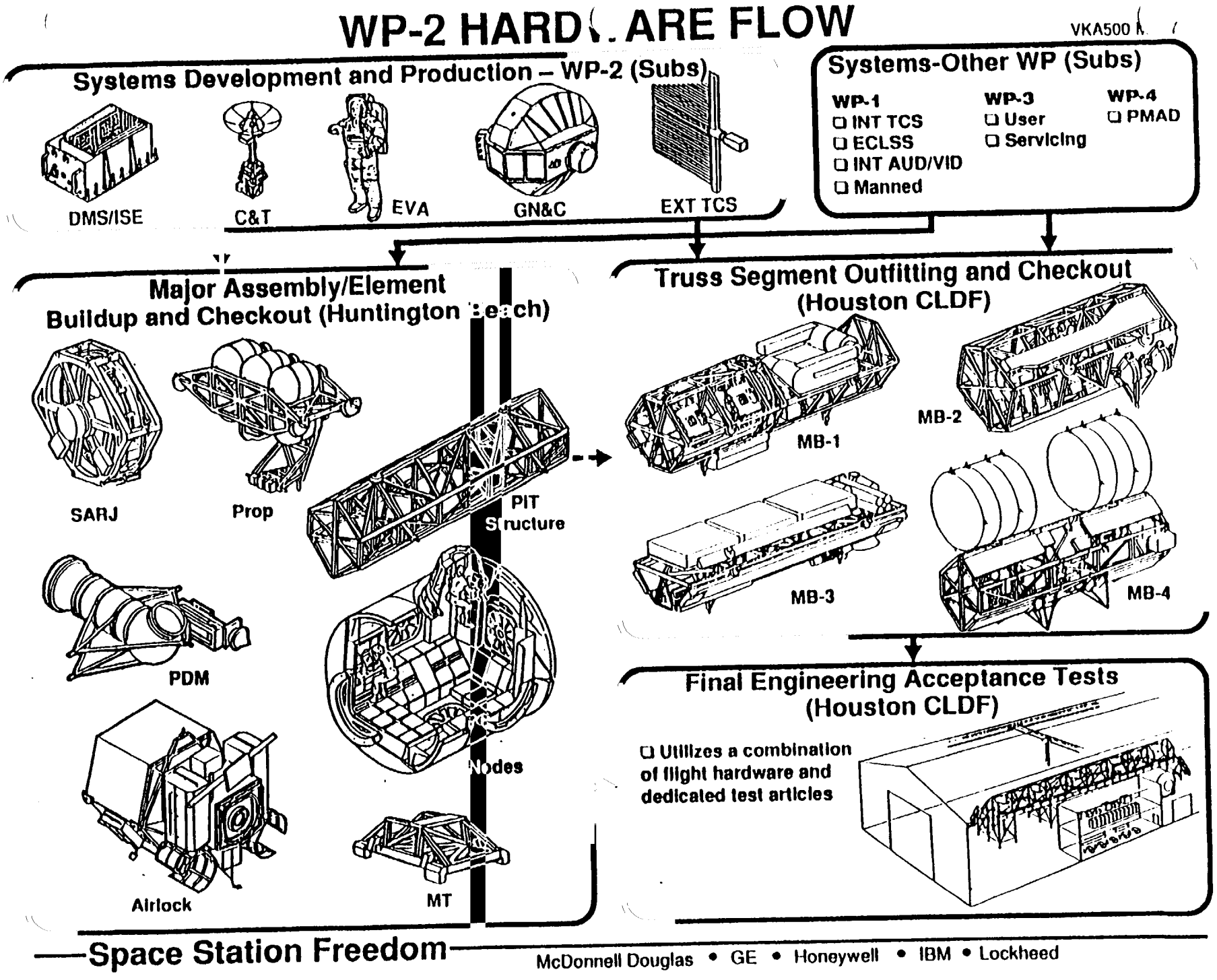


FIG. 80 WP-2 hardware flow

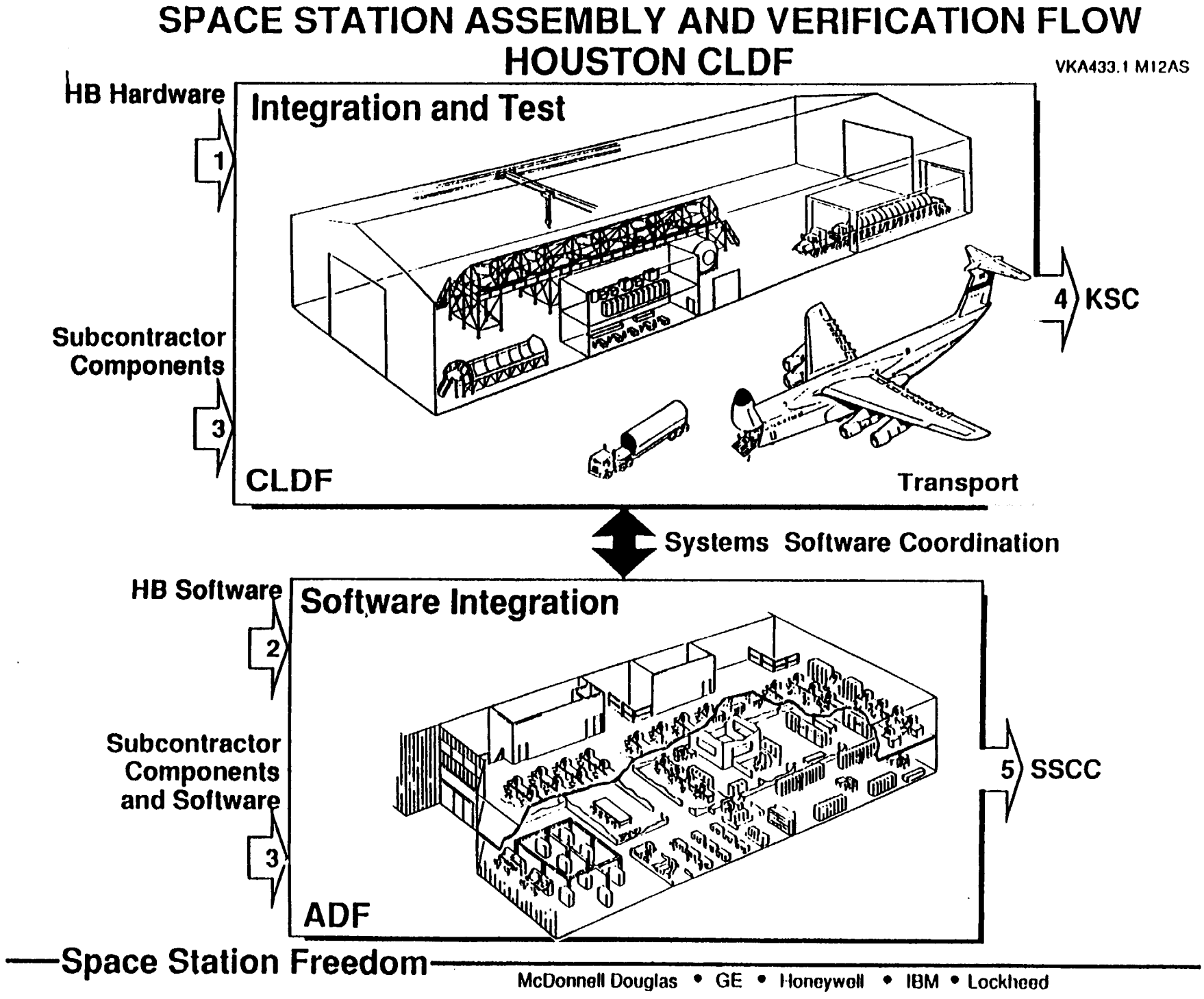


FIG. 81 Space Station assembly and verification flow Houston CLDF

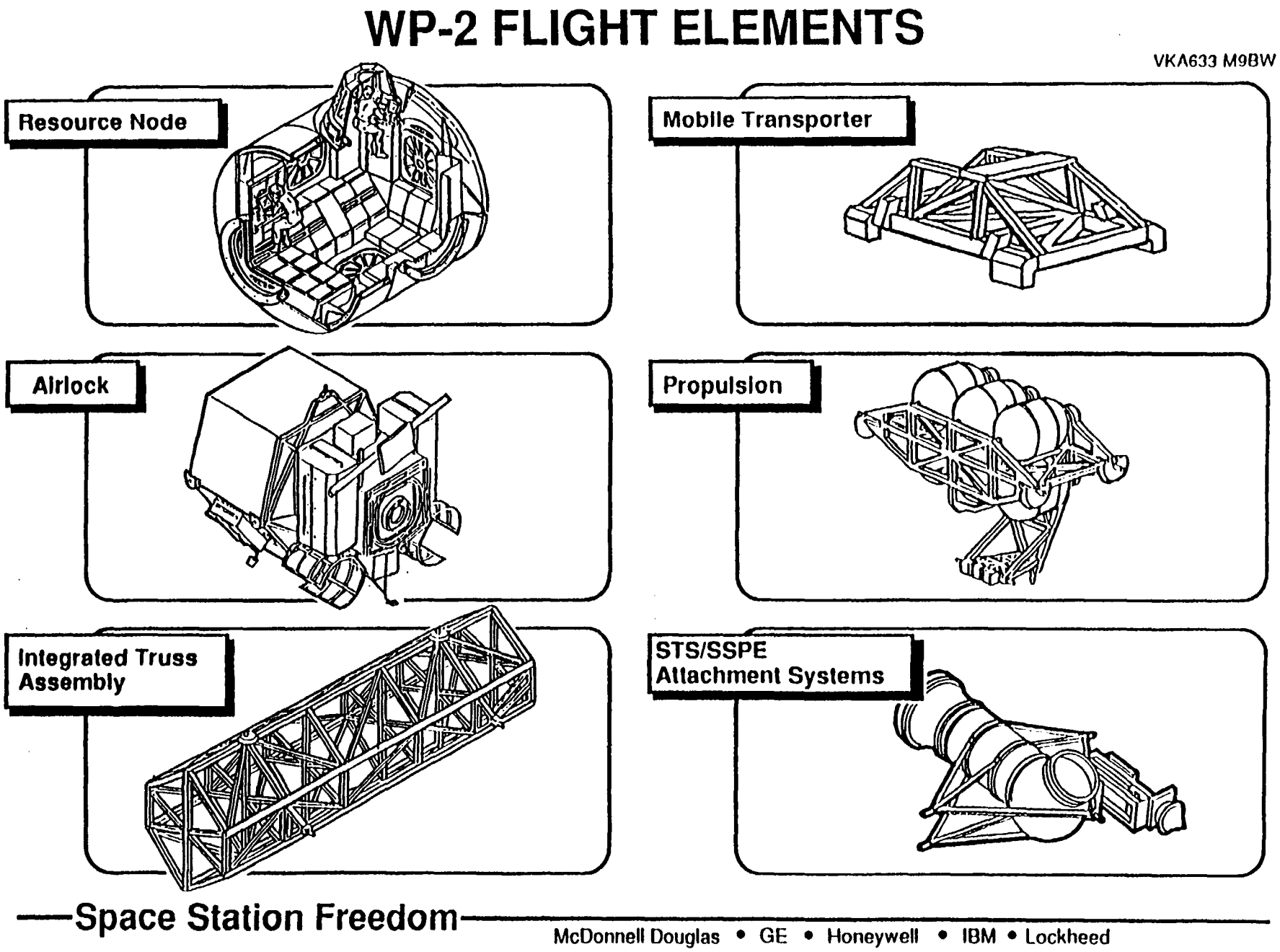


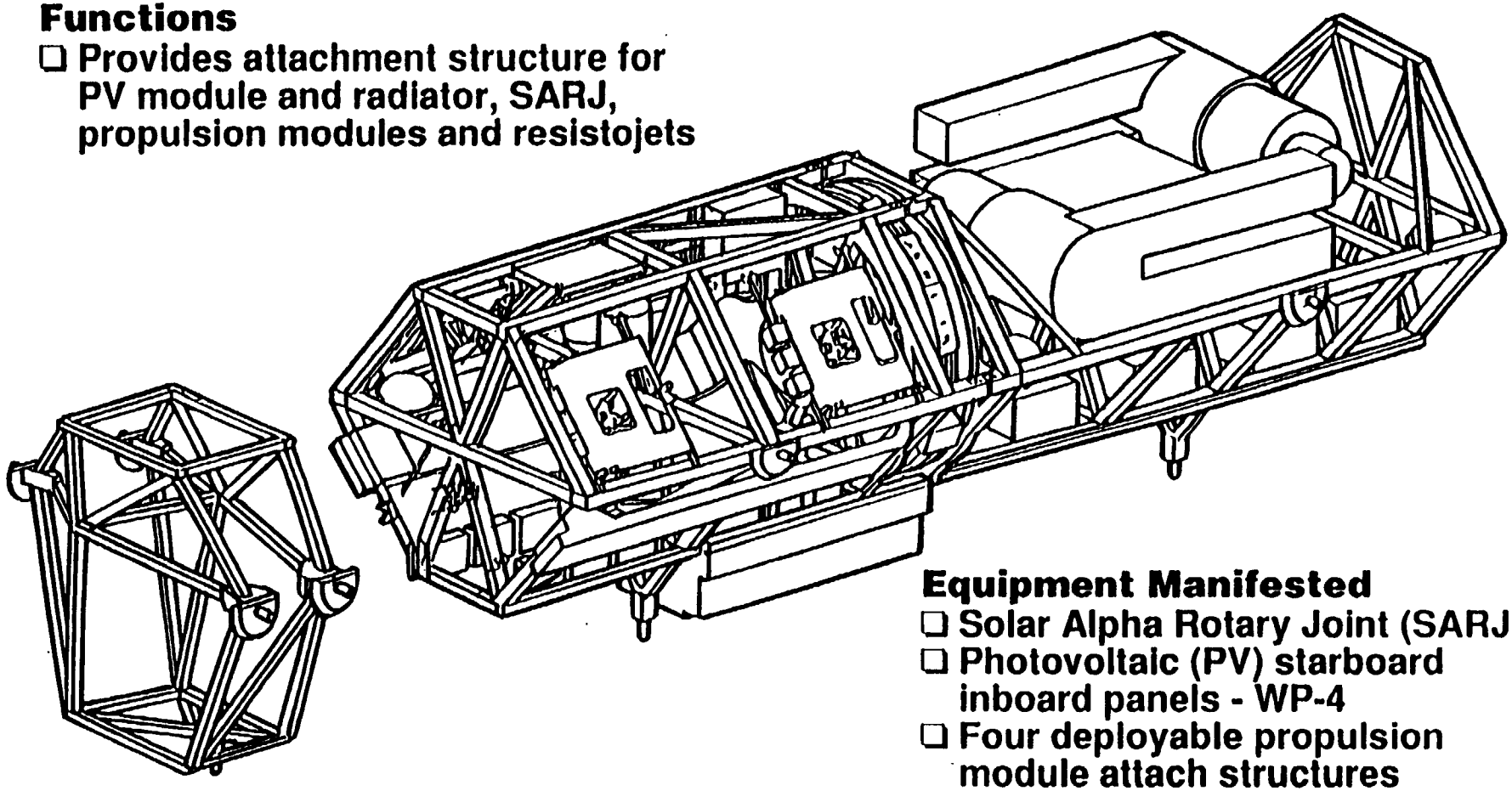
FIG. 82 WP-2 flight elements

MB-1 LAUNCH CONFIGURATION

VKA620 M9BW

Functions

- ❑ Provides attachment structure for PV module and radiator, SARJ, propulsion modules and resistojets



Equipment Manifested

- ❑ Solar Alpha Rotary Joint (SARJ)
- ❑ Photovoltaic (PV) starboard inboard panels - WP-4
- ❑ Four deployable propulsion module attach structures
- ❑ Mobile transporter
- ❑ Six passive dampers
- ❑ Two reducing waste gas tanks
- ❑ One resistojet attach structure
- ❑ Utilites and power distribution

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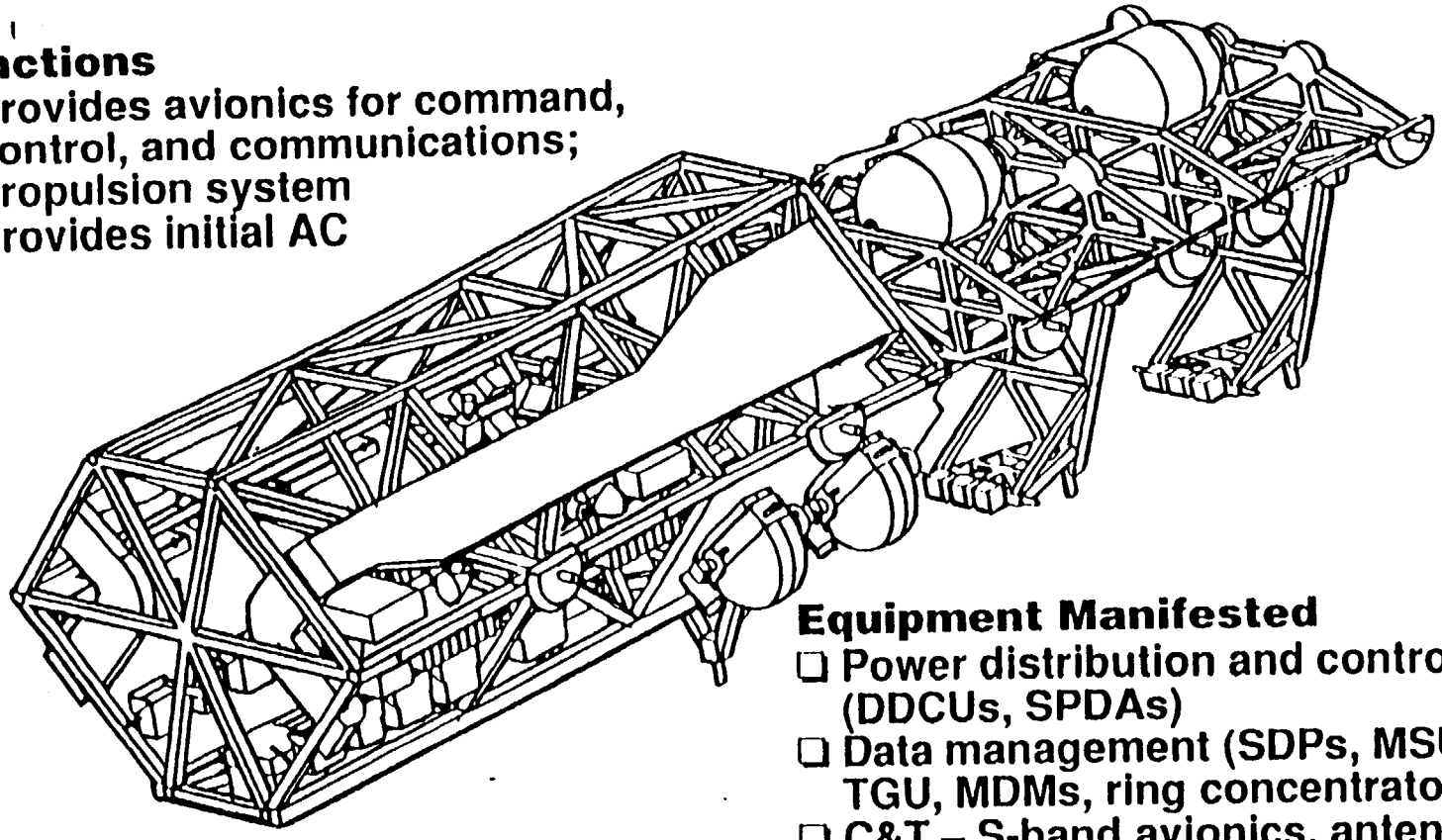
FIG. 83 MB1 launch configuration

MB-2 LAUNCH CONFIGURATION

VKA621 M9BW

Functions

- ❑ Provides avionics for command, control, and communications; propulsion system provides initial AC



Equipment Manifested

- ❑ Power distribution and control (DDCUs, SPDAs)
- ❑ Data management (SDPs, MSU, TGU, MDMs, ring concentrator, FDDI)
- ❑ C&T – S-band avionics, antennae (2 each)
- ❑ GN&C
  - ● Attitude reference (star trackers, inertial sensors)
  - ● Attitude control – (CMGs (4)
- ❑ Utility trays (2)
- ❑ Two propulsion modules (3000 lb of propellant each)

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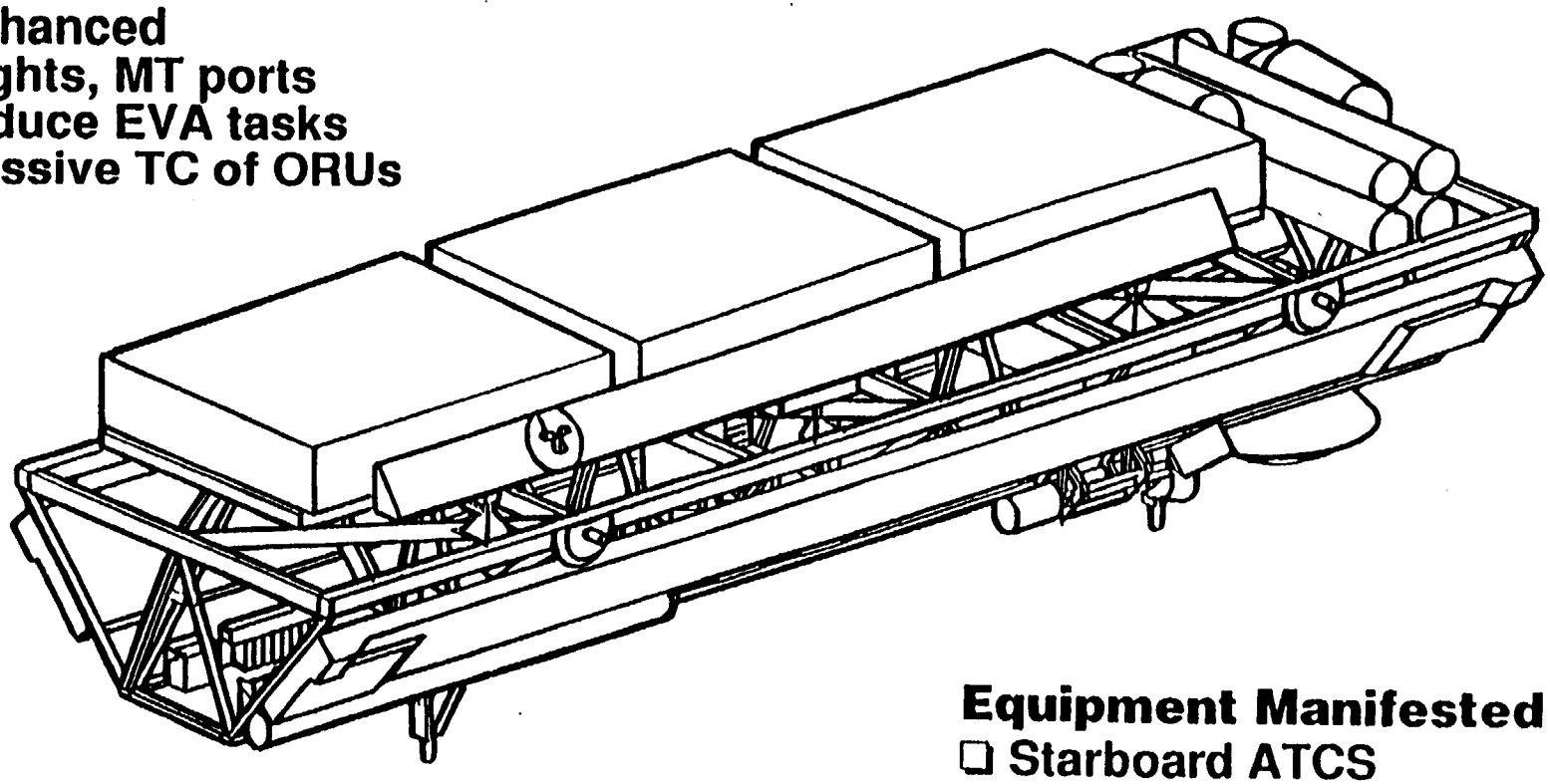
FIG. 84 MB2 launch configuration

MB-3 LAUNCH CONFIGURATION

VKA622 M9BW

Functions

- ❑ Utilities distribution enhanced
- ❑ Lights, MT ports reduce EVA tasks
- ❑ Passive TC of ORUs



Equipment Manifested

- ❑ Starboard ATCS
- ❑ UHF and Ku-band antennas
- ❑ 2 external video camera assemblies
- ❑ SSRMS

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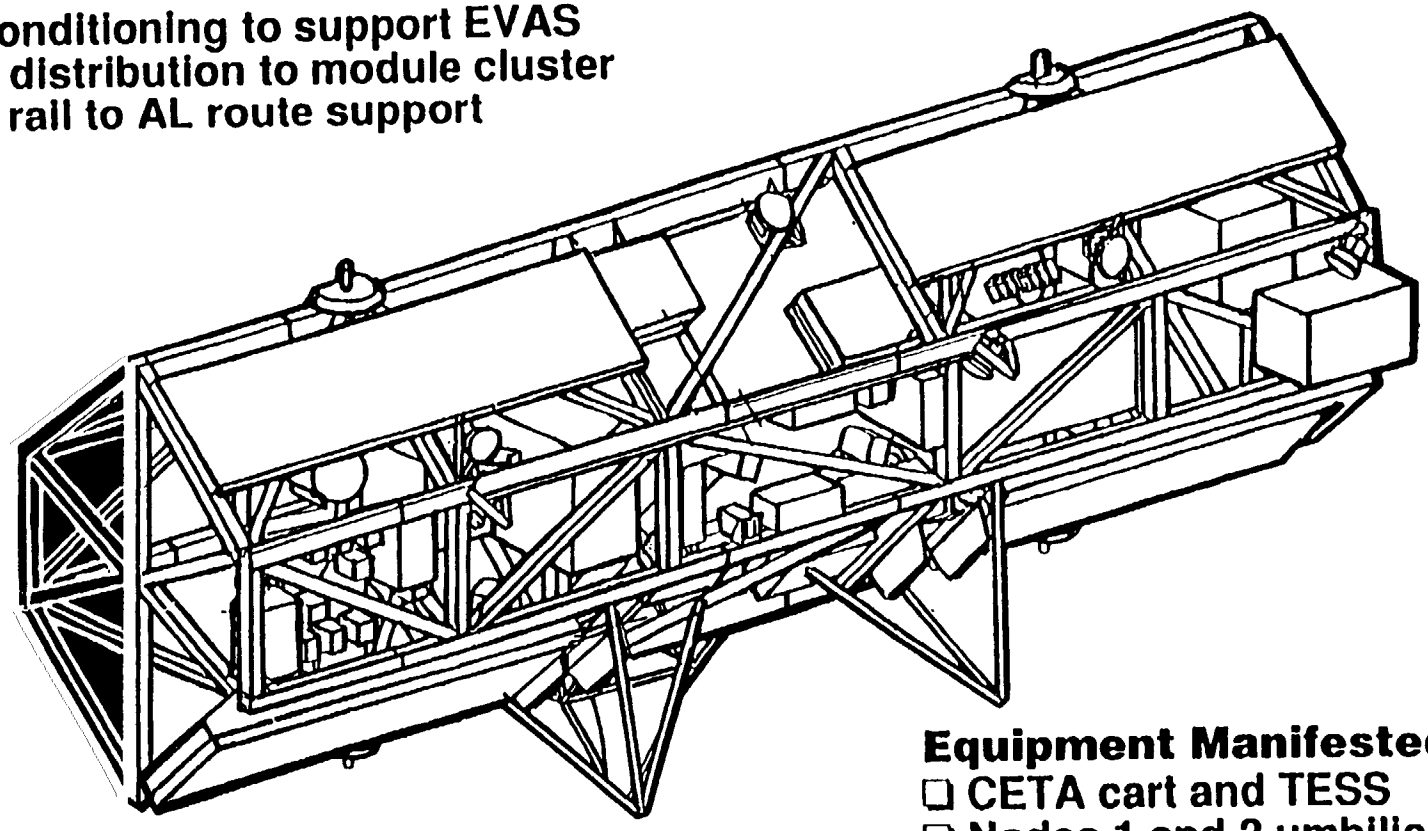
FIG. 85 MB3 launch configuration

MB-4 LAUNCH CONFIGURATION

VKA623 M9BW

Functions

- ❑ Gas conditioning to support EVAS
- ❑ Utility distribution to module cluster
- ❑ CETA rail to AL route support



Equipment Manifested

- ❑ CETA cart and TESS
- ❑ Nodes 1 and 2 umbilicals
- ❑ MT batteries
- ❑ Cryo berthing mechanisms (2)
- ❑ Gas conditioning system
- ❑ MTS, IUD, and IWGS
- ❑ Portable work platform

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FIG. 86 MB4 launch configuration

1-G SIMULATION

- **OBJECTIVES**
  - Evaluate time to perform hyperbaric treatment for selected scenarios
  - Evaluate CHeCS equipment interfaces and task light configuration
  - Evaluate equipment lock viewing/lighting
    - equipment lock itself
    - crewlock from equipment lock
  - Evaluate crewlock viewing/lighting
    - crewlock itself
    - equipment lock from crewlock
  - Evaluate restraints and handrails
  - Evaluate passthrough lock operations

FIG. 87 One-g simulation

1-G SIMULATION

- OBJECTIVES (cont.)
  - Evaluate accessability of controls, displays interface panels, equipment and patient
  - Evaluate disply labels and layout

FIG. 87 Continued

BUCK: Just to add to what Mike's saying; I think two of the biggest goals I see for this test are, one, maybe some timeline, even though we're not in a zero-g environment that is a definite factor for setting up equipment, etc.; second, for locating this equipment. I showed you some pictures of the airlock, in fact I have some pictures of our mockup up here if anyone is interested in looking before we go on over to see the mockup here. But, we've got an interesting problem in a worst case in getting all of that medical equipment set up in this chamber. So, we're trying to figure out some logistics here.

STOLLE: Lastly, we'll be looking at excessive loading of controls, access and volume limitation to do procedures like airway management and potentially CPR, and then the Station in layout. One thing I've not talked about in here is, we do also have some WETF simulations. The WETF is the Weightless Environment Training Facility, which is basically a big pool that you put your mockups in, and so we'll be doing some experiments and tests in there also.

BUCK: In January.

STOLLE: Any questions? All right, thank you.

BARRATT: Thank you.

TRAUSCH: Yes, those WETF tests are supposed to be in January. And, they're going to be looking at camera angles, so you're going to be able to see through it, to have your camera lined up and see the patient, etc. I am *not* Phil West, obviously, and it's not March 19th, but this has some pretty good information in it. I'd like to tell you about the Space Station airlock test article, or SSATA. What this is, is a full-scale, *working* mockup of the airlock. It's going to be both a hypo- and hyperbaric chamber, so we can simulate hyperbaric training operations, etc. The purpose of the SSATA, first off, is forward testing and verification of all our hardware and software for the airlock and hyperbaric chamber (FIGS. 88 and 89). In addition to all the verification, we are also planning on supporting flights and doing some crew training, both the airlock- and EVA-related equipment operations, servicing of the EMUs (you've got to train them how to do that inside that small area), and training in hyperbarics. This is still an issue. We believe that the outside operator of the chamber has to be trained in this SSATA, since it'll be set up exactly the same way. The question is about the inside attendant. We could train the inside attendant in the SSATA, but logistically this would make for quite a mess because of people available, because we want to be training for other things as well. Right now, we are suggesting that the inside attendant be trained in the other hyperbaric chamber at NASA; however, we haven't told them that we're suggesting that. There's a problem logistically with that because they have to support all WETF activities. Whenever we have a test going in the WETF, that hyperbaric chamber is on ready status.

SPEAKER: And for research activity.

PURPOSE of the SSATA

- Testing and Verification of development and/or qualification hardware and software
- Flight Support
  - Crew Training
    - EVA and airlock-related IVA operations
    - on-orbit EMU servicing
    - Hyperbaric operations
  - Hardware/Software trouble shooting
  - Final pre-flight checkout of EMU's
- Hardware Evolution
  - Future development and certification of Airlock and EVAS hardware and software

FIG. 88 Purpose of the SSATA

SPACE STATION AIRLOCK TEST ARTICLE (SSATA)	CREW AND THERMAL SYSTEMS DIVISION	
	PHILIP R. WEST	MARCH 19, 1991

FACILITY DESCRIPTION

- Only SSF ground-based facility for testing hardware and training crew in the actual pressure environment (from 0 to 2.8 atm)
- The SSATA will be as close to the flight airlock as possible while accommodating 1-g operations
  - Configuration - physical dimensions and layout
  - Functional hardware
- Will operate independently of the 20' chamber

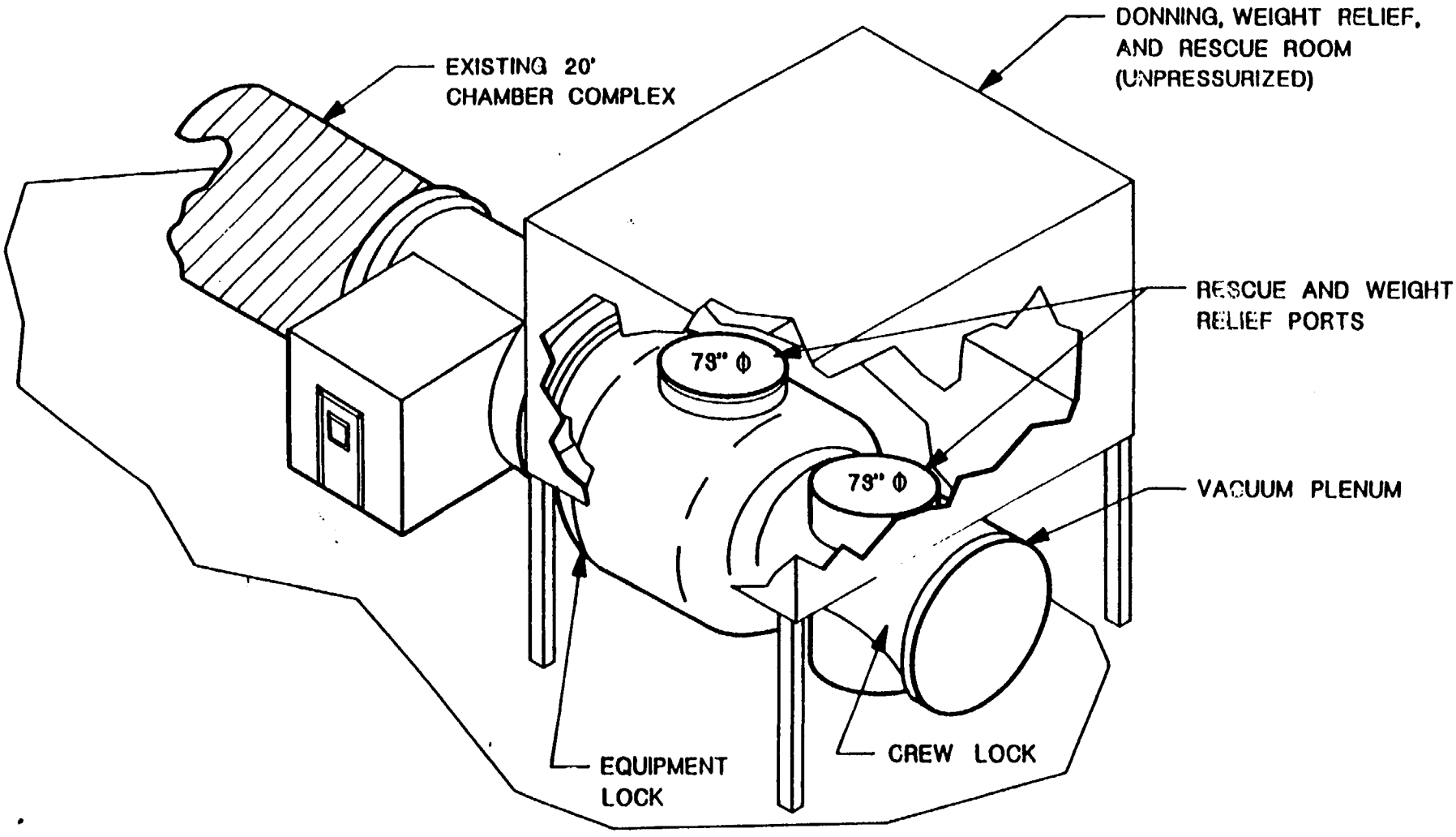
FIG. 89 Facility description

TRAUSCH: We're still trying to figure out where we are going to train that inside attendant. That's something that needs to be determined.

SPEAKER: Isn't the other thing logistically, too, that the crew lock is set on end in the SSATA?

TRAUSCH: Actually, the SSATA is *not* on end. It's on the normal configuration (FIG. 90). At one time it was on end, and I'll explain that in a minute. What we're going to do is, we have a 6.1 m (20 ft) chamber in building 7 and we'll just be tacking on to it. These little ports that pop are emergency escape ports, and that's why, at one point, we had the chamber turned sideways – so that, if there's an emergency (not during hyperbarics but during, say, EMU servicing or something) and something happens, you can pull the guy out. During hyperbaric training, we would lock this one down because it's a pressure port; and we would have to bolt it down so it didn't blow during hyperbarics. Right now, again, we are capable of having a man in there while it's pressurized for hyperbaric pressure. We haven't definitely determined that we're going to do so, and that's something that still needs to be determined. Anyway, we also want to look at some of the hardware evolution.

The facility itself is the only ground-based facility testing the hardware and training of the crew in the actual pressures. Again, it's a hypo-, hyperbaric environment, so we can go from vacuum up to 2.8 ATA. And, at times we will have both; for instance, if we want to train the guys in the equipment lock and then we want to bring the crew lock down to vacuum for simulating someone going EVA. Also, this area here could be at 70 kPa (10.2 psi) to simulate the node. So, we can do quite a bit there. As far as the differences, we want to make it as flight-like as



SPACE STATION AIRLOCK TEST ARTICLE (SSATA FACILITY)

FIG. 90 Space Station airlock test article (SSATA facility)

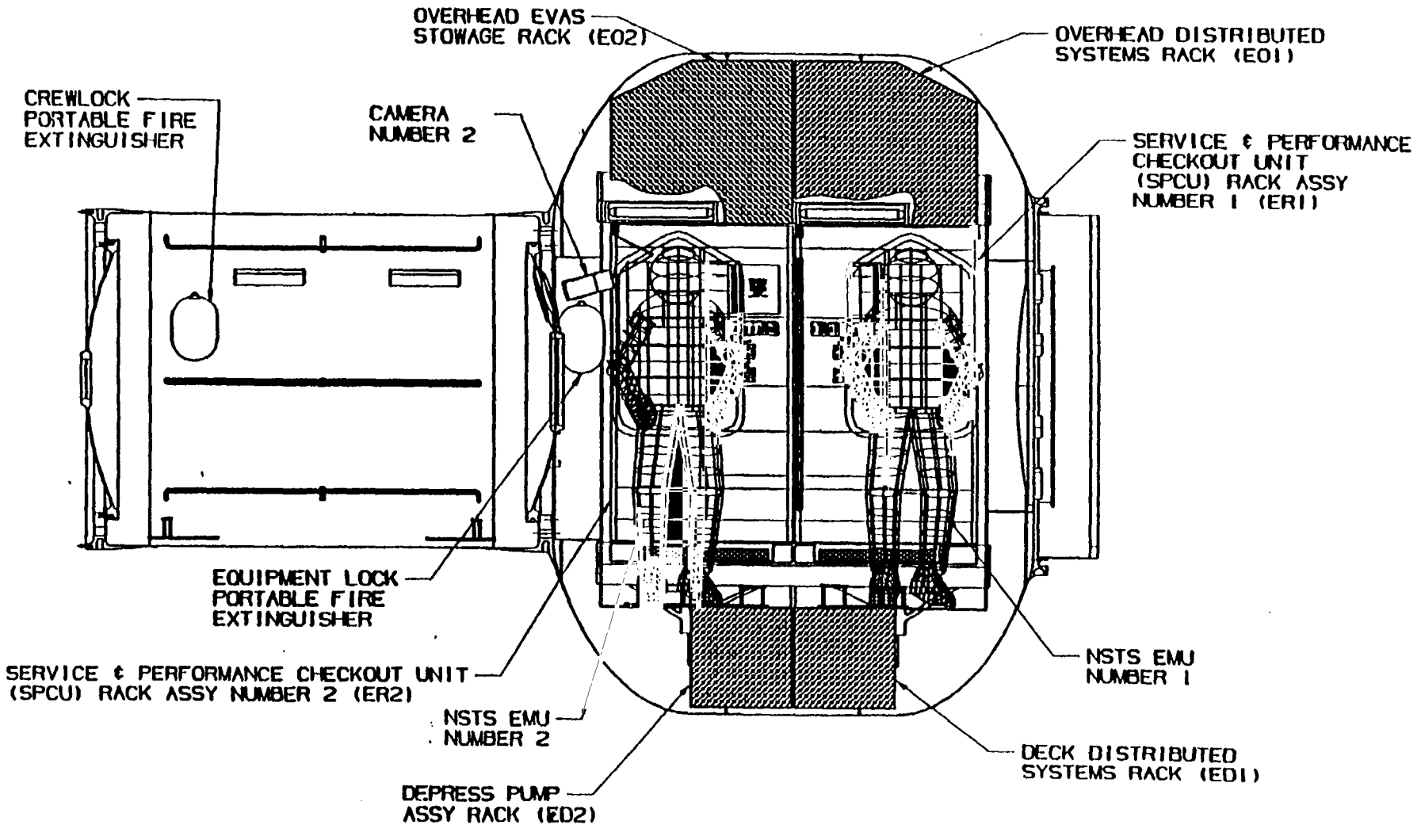
C007953C.ART;2

TRAUSCH: (Cont'd) possible, but there are some one-g limitations. For instance, fire suppression is going to be water deluge. The overhead exits are here; this one causes a small problem because of our rack in the crew lock. It does not just go up the wall, it also curves up a little bit. So, what happens is that it would interfere with this exit. So that rack is going to have to be a little bit different, and exactly how different is still being determined. But, that's going to be changed. Also, you may notice we have an extra port here that's not actually on the crew lock (FIGS. 91 and 92), and that's to create a flat floor; since you have one g, you need someplace to stand in your EMU. We *are* simulating the workstations for the node. That will probably be outside the chamber in the hallway, and we need to have some sort of simulation of flight controllers so they can talk to the flight controllers. Issues right now are: What sort of training will the inside tender have, and where do we do that? Also, there's an issue of medical certification. We're not really sure what that is. Do we want to do it in the SSATA? We need to figure that out. And, some of the interfaces between CHeCS and the hyperbaric systems themselves. At any rate, I was just going to give an overview of what this is and what we're trying to do. Does anybody have any questions?

BARRATT: Stephanie, will this be rated for the 345 kPa (50 psi) over-pressure limit?

TRAUSCH: I believe so. It's going to be set exactly like the real thing. And, we *are* going to need it to test the relief valves and such. That's about it. I also included some drawings that Courtney beat me to. You've seen these before. But like I said, inside it's going to be as flight-like as possible, so we're trying to make it exactly the same.

AIRLOCK RIGHT SIDE INTERIOR VIEW



CM-08.1 - MDC H6496 DWG. 1F03717

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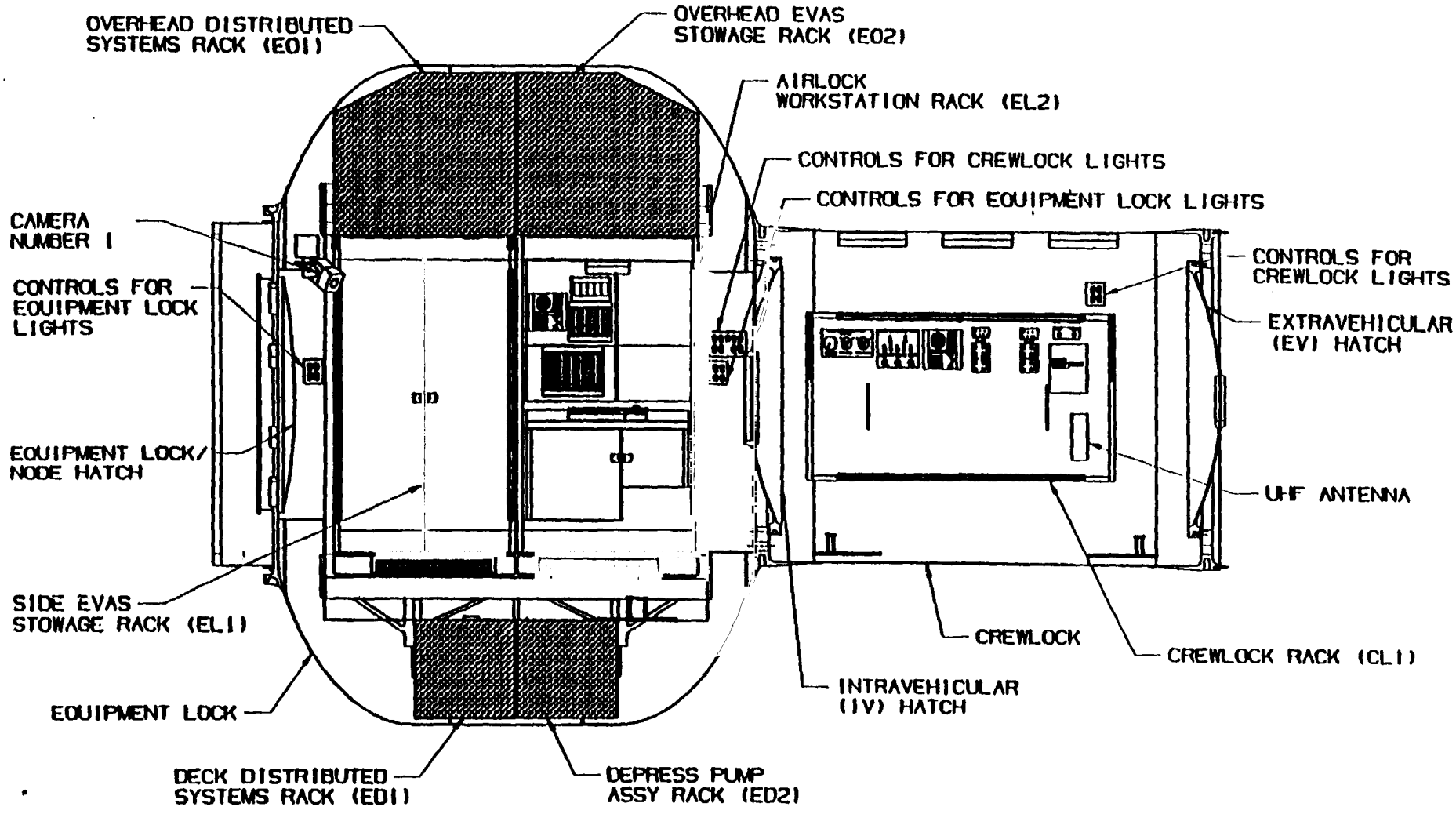
WONG 6/15/90

FIG. 91 Airlock right side interior view

AIRLOCK LEFT SIDE INTERIOR VIEW



CM-08.1 - MDC H6496 DWG 1F03717

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1-87

FIG. 92 Airlock] ·ide interior view

SPEAKER: You mentioned a workstation in the nodes. That's the first time that's really been addressed today that I recall. Could you elaborate on that a little bit? What type of workstation in the nodes?

TRAUSCH: I almost said for hyperbarics, but it's not.

BUCK: It's a general interface with the data management system. They have what they call an MPAC, which is an acronym for multipurpose applications console. It's a computer and it's the brains of the Station. There are several workstations around the Station. There's one located in node 2; in fact, we're lucky in that sense, because the airlock is attached to node 2. In terms of hyperbarics, except for the dedicated displays that were shown on some of my drawings, that's where you have to go to get the rest of your information. Someone was talking about trying to go with a laptop computer or something like that. Right now, our laptop is in the node, which is, as you know, right next to the equipment lock.

SPEAKER: But, you don't have a screen in the work area.

BUCK: No, we don't have a screen.

WORKMAN: If I'm reading you correctly then, there may be a situation where the operator of the airlock may have to go into the node?

BUCK: Yes, there probably will be times someone needs to be apprised of the information on the computer in the node. We've got a fourth crew member, and he's the one

BUCK: (Cont'd) that's basically driving the Station. You've got two people in the chamber and you've got one right outside.

WORKMAN: I didn't know until today that the crew member complement had been halved. So, you're going to have fewer people.

BUCK: And, then you've got your fourth person. He's the last guy who can go and check the computer console in the node.

HAMILTON: Not many hands.

TRAUSCH: Actually, as we were mentioning today, during the man-tended phase you can't get away with just four because who is your medical officer going to be? It can't be either of the EVA crew members, and it can't be the pilot or the commander. So you need five. So on that, well you're just going to have to hope that he's not the one that gets bent. That's why the medical officer can't be one of the EVA crew members; he may be the one that gets bent, then what do you do?

NORFLEET: There *were* workstation peripherals in the equipment lock, which were going to be an additional thing for log-keeping and chamber monitoring, and that were deleted for weight-savings reasons.

BUCK: I briefly alluded to that, and that's why we ended up working with the log and the tables, just on paper, on the worksheet right next to the controls.

STOLLE: We *are* tied to the computer system, but we have no computer outlet or control right there in the equipment lock. You have to go to the node, or somebody has to go to the node, to get that extra information.

NORFLEET: A possible solution to that, at least for a computer prompting of where you're supposed to be and what you're supposed to do next and a countdown for those events, would be a portable computer, like a laptop, which may be included in the program at some point. That could be taken into the equipment lock and wouldn't be connected to anything, but at least you could hit carriage return when you started the protocol and have it follow.

BUCK: The other thing is, you *are* in communication, or we're assuming you're in communication, with the ground.

NORFLEET: A problem, of course, is loss-of-signal periods.

BUCK: For the most part, you'll have printer help as well.

BARRATT: Some of these questions will no doubt come up as we go through the facilities at building 9B and get the dimensionality aspect of them. I'd like to go ahead and wrap up and get on to securing our badges. Thank you very much, Stephanie.

DAY 2

Review of Day 1

BARRATT: Today, we'll get some formal recommendations based on yesterday's orientation. I want to recap some of the concerns that came up as a result of the review and orientation session. There was concern voiced over the ALS pack and some type of seal was recommended so that we'll be able to know to check it if it had been raided for parts. There was some concern over the gas blender and the manual control capability of the gas mix to the airlock. I should mention that we do have a caution and warning amendment to the medical requirement that we're needing now to put back as a Change Request, but it will give us an alarm indication of a partial BIBS failure. The medical need for a camera in the crew lock was voiced yesterday while we were in the crew lock mockup. It was suggested to have a small state-of-the-art camera mounted on a gooseneck within the chamber. Defining the fidelity, resolution, and color saturation of a camera is something we're working on right now. But, the issue of having one in the crew lock is somewhat of an open issue, and we'll be discussing that further in the future. The treatment scenario that Dr. Norfleet was running was, I think, very productive. This is something we need to do in some form in the future – either in future reconvenings or, perhaps, via mailed scenarios to get the experience from people who've been doing a lot of treatment. It was emphasized during that time period that DCS is an expected consequence, that we should treat it and life should carry on for the crew members without an automatic stigma of increased risk of future events. We talked about the need for a pulse oximeter. I spoke with Dr. Bove about that a little bit more this morning. For the transport scenario, which

BARRATT: (Cont'd) is our MTC goal as far as medical hardware is concerned, we'll be looking into this also in the near future.

Today, the small task assignments are really geared towards addressing some of the issues that are now open for active discussion. Some of these are totally internal, some of them are between Work Package-1 (the Marshall folks) and Work Package-2 (at JSC). Some of the issues have some leeway in influencing now before their baseline, and some of them are rather controversial. There are a lot of intelligent opinions on either side and, of course, we're going into an environment that just has not been well characterized. We don't have the experience to draw on. So, it's very speculative, but we want the best speculations possible.

I'd like the sessions that are tasked to the individual people to actually be run by the person who is assigned to it. Each one, as you see, is scheduled for 20 minutes. You can fill the 20 minutes, or you can talk for 10 minutes and we can open up for discussion. I have some specific questions that I'd like to make sure we address; if you don't address them, I'll probably ask them. Some of the issues will take a short amount of time, some may take a little longer, and we'll try to be flexible enough on those. So with that in mind, I'd like to go ahead and open the first one up: "Training requirements for operators." Colonel Workman.

WORKMAN: I would like to take about 5 minutes before we get started. It might be helpful to all of us if we have about a 5-minute discussion on characterizing differences in altitude decompression sickness and diving decompression sickness. That may help frame today's discussions.

PILMANIS: I have some concern about the natural tendency that most people have to equate diving and altitude decompression sickness. There are some differences. By way of review, one of the main differences is that, in the diving field, DCS is "after the fact." The mission is over with, and time and performance are not big issues. In the altitude field, it occurs *during* the mission. This is an important difference; the impact is quite different. With altitude DCS is inherent recompression; you have to come down. For example, from 29.6 kPa (4.3 psi) back to sea level pressure *can* be characterized as going from sea level to 285 kPa (60 fsw) in tripling pressure change. So, it has a built-in treatment. In reality, about 90% of altitude DCS cases are treated that way. In most of these cases, 2 hours of oxygen post-breathing are added, but other times nothing is done *except* that recompression. That's quite different from the diving situation. The majority *do* resolve by coming back to sea level; that is, to 1 ATA or wherever the saturation level is. With altitude DCS, *treatment* is almost 100% successful. You *rarely* have residual problems. In addition, generally speaking treatment is easier. Table 5 can be used. Several years ago, there was even a suggestion of only going to 193 kPa (30 fsw), not 285 kPa (60 fsw). There were no data to support that approach, however, so it was not pursued; but I don't believe that it's a closed question. Do you really need 285 kPa (60 fsw) for treatment of altitude DCS? The Table 6 graphic has been transferred from the diving field to the altitude field.

The seriousness of the DCS symptoms with altitude is certainly less than with diving. The basic bubble composition is different; the proportion of water vapor and CO_2 is higher. In the diving field, you don't worry about those, because they're so small that they're of no consequence. In the altitude field, the higher you go, the greater that proportion is and the less nitrogen there is; and we don't

PILMANIS: (Cont'd) really know how that affects bubble resolution. Around 15,240 m to 16,764 m (50,000 to 55,000 ft), the bubble essentially has no nitrogen in it, or very little. It's all water vapor and CO_2, so there *are* some very basic differences in the bubbles themselves. Denitrogenation continues at altitude. There can be a situation where, if you stay up long enough, you're denitrogenated to the point where bubbles can't form.

We recently did a survey of U2 pilots who stay up 9 hours at cabin altitudes of 8535 m to 9140 m (28,000 to 30,000 ft). The symptoms generally occurred within an hour but didn't last much more than an hour; sometimes a little more, sometimes half an hour. All were asymptomatic at the end of the flight. So if you stay up long enough, you could resolve unless it becomes catastrophic, and there is always a chance of that. You have a finite amount of nitrogen, as you do in every situation, but more so with altitude. It's just a much, much smaller amount to deal with.

I'm sure some of you can think of other differences, but those are the ones that came to mind this morning. I don't feel that automatic transfer of information from hyperbaric to hypobaric should be done without some thought about these factors.

NORFLEET: I could inject *one* comment: And that's that, at least from what I've heard, in altitude exposures you seem to hear in Doppler monitoring a lot more bubbles than I'm used to hearing in hyperbaric work.

SPEAKER: Can you agree with that?

PILMANIS: I can't agree or disagree because I've heard Grade 4 plus in diving as well as altitude, and I don't know that anybody is ever really compared them. So, I wouldn't say one way or the other.

WORKMAN: Let's go ahead now and begin our discussion on the training requirements. This particular session is going to take more the form of an open discussion than anything else because, at least in the information that had been made available to me, very little in terms of writing has been addressed or focused on the training issue. Now, there may be other documents that are available that have addressed this, but I didn't have access to them. So with what I put up on the slide, if there's any discrepancy, please let me know because it certainly can help us in leading the discussion (FIG. 93). But basically, looking through a historical perspective in the involvement of our committee, there's been very little that has actually been discussed in our meetings and even less that's been addressed in writing. Looking at this to serve as a framework for what is currently available, I went ahead and just selected two Air Force training courses as a representative example (FIG. 94). There are other courses that are available that we all can go to for developing a representative curriculum for what you feel your individual training needs are to be. I also have copies of the individual training standards for these two courses. Again, I include them primarily so that you'll have an opportunity to see the specific topic areas covered in each of these particular courses. (Appendix at end of section.)

This course, which is taught by the Air Force, is oriented primarily toward the chamber technicians who are enlisted personnel, the people who will be actually operating the chamber. If you compare this course curriculum and the course

HYPERBARIC TRAINING REQUIREMENTS

JSC 31013 (14 JULY 86 TO PRESENT) - NOT ADDRESSED

HYPERBARIC MEDICINE AD-HOC COMMITTEE - 6 OCT 86

LIMITED DISCUSSION

AD-HOC SPACE STATION HYPERBARIC TREATMENT FACILITY DESIGN SAFETY COMMITTEE - 30 NOV 87

LIMITED DISCUSSION

COMBINED SPACE STATION FREEDOM HYPERBARIC AD-HOC COMMITTEE - 10 JAN 89

LIMITED DISCUSSION

Background

FIG. 93 Hyperbaric training requirements – background

HYPERBARIC TRAINING REQUIREMENTS

USAF COURSE B3AZY91150 002
HYPERBARIC CHAMBER ENLISTED TEAM TRAINING

USAF COURSE B30ZY9300 009
HYPERBARIC TRAINING FOR HEALTH CARE OFFICERS

REPRESENTATIVE CURRICULUM

Existing Courses

FIG. 94 Hyperbaric training requirements – existing courses

WORKMAN: (Cont'd)

training standard with the next one, you'll see a distinct difference in the amount of emphasis that's put on the medical side as opposed to the operational side. Again, this is primarily operationally oriented. Here, we're primarily interested in managing the DCS, including gas embolism and perhaps ebullism, so some of these topics would not apply. But, one of the things that we need to address – not necessarily today, but in the very near future – is what topics should be included in a training program for the operator or for the entire crew. In terms of background physiology, how much physiology do they really need? How much of the medical do they need? We talked yesterday about who the designated medical officer is going to be. Chances are he will *not* be an MD in many cases. And so, how much of a medical background do we think that we need to provide that individual?

Looking at the other course again; this particular course is oriented to the medical side of the house, and the difference in the emphasis will show up in level of training, knowledge levels, and proficiency levels. So again, this gives you a representative example of the types of topical areas that we often give our inside observers and medical team members that go out and operate Air Force hyperbaric facilities. Again, these are oriented primarily toward the treatment of altitude decompression sickness. Now, we could take a look at a course curriculum on diving, such as a diving medical officer's course, and there are a *multitude* of courses for which we can review the curriculum and determine what is good and what should be carried forward. Obviously, there will be some requirements to provide some orientation and training on issues that are unique to Space Station. Now, I do have some recommendations. These are to be used as a stimulus for further discussion (FIG. 95).

HYPERBARIC TRAINING REQUIREMENTS
RECOMMENATIONS

1. ESTABLISH MILESTONES FOR COURSE DEVELOPMENT AND IMPLEMENTATION
2. DETERMINE WHO SHOULD BE TRAINED
3. DETERMINE WHO SHOULD PROVIDE TRAINING
4. DETERMINE WHO SHOULD TRAIN THE TRAINERS
5. DEVELOP COURSE CURRICULUM
6. CONSTRUCT HIGH-FIDELITY MOCK-UP
7. DEVELOP PROFICIENCY TRAINING CRITERIA

FIG. 95 Hyperbaric training requirements – recommendations

WORKMAN: (Cont'd) We need to go ahead and begin paying attention to the milestones for course development, even though the schedule, as we heard yesterday, is somewhat slipping. But, at this point we need to begin developing a clear focus in that area. I think yesterday, Courtney, after your discussion, this is already ongoing. But, my thinking was framed, again, with our previous involvement in the documents that we were given. In determining who should be trained, I think that we have to focus our training on *all* the crew members; determine who should provide that training; determine who should train the trainers (I think that that's a big question); develop the course curriculum in terms of the specifics; again, we've got the construction of the high-fidelity mockup already on the way; and then develop a proficiency training criteria. One of the biggest issues that I see is in the region of proficiency training: What is going to be the requirement for proficiency training? What is going to be not only the depth of training but the frequency of training? That's really all I have in terms of overheads. At this point, it's probably appropriate to go ahead and open it up for general discussion.

NORFLEET: There have been some questions about whether, during the course of a 90-day mission, there should be proficiency training in flight. Would you care to comment on that?

PILMANIS: Can you afford it with the gas supply?

WORKMAN: I guess that's my first thought.

NORFLEET: Well, it depends on what you do. There's also discussion about how often this facility should have an engineering checkout and what that checkout would be.

NORFLEET: (Cont'd) It may just be a pressurization to half an atmosphere and a few breaths off a BIBS mask.

SPEAKER: Steve, would you like to say what you were going to say?

REIMERS: Yes, I would. First, about your training issue. One question I would like to raise: In the medical community now, there's a new hyperbaric technologist certification course that has just started. That may have something to offer in this department. I have not taken the exam myself.

WORKMAN: I took it a week ago, but I haven't counted the results yet either.

REIMERS: From what I'm told, it's *not* easy.

WORKMAN: No, it's not. Let me back up for just a moment. Several people in the room have already had an opportunity to go through the Air Force training program. Not to put you on the spot if you disagree or if you have any particular opinions about it, please feel free to speak to that because it's not my course. So, you can say what you want to about it. Do you feel that it was a worthwhile experience?

STOLLE: It was very helpful. We learned specifically how to operate the chamber from each position that a person has to watch and from the inside observer's point of view, also. So, it was very, very helpful to see how the chamber operates and how to *operate* the chamber.

WORKMAN: And, that was the primary orientation of that course. It was really targeted at the people who are going to operate the chamber; whereas the health care officers are the people who are going to be providing expertise as a medical specialist inside, with just a little bit of orientation to begin the operations side of things.

BUCK: It goes without saying that you're talking of a different beast here when you're talking about training. There were things, such as gas gangrene and the osteomyelitis and all that, that wouldn't apply. But, personally, I learned a lot. I gained an appreciation for the number of hands it takes to do something like that. And, we weren't even concerned with any of the medical operations inside; it was purely from an outside control standpoint.

TRAUSCH: When training on chamber operation, what struck me was the outside operations, because I know that several crew people are running it and we're trying to get away with one person.

SPEAKER: Well, the truth of the matter is, there's really no reason why one person can't run that chamber. The reason we don't is because of tradition.

HAMILTON: Tradition says, "One man, one valve."

WORKMAN: Exactly.

HAMILTON: Let me comment on your issue of training in flight. I've dealt in the past with saturation diving operations, where you have the task of training the dive crew in whatever they're doing and you have them trapped in there. You have decent

HAMILTON: (Cont'd) visual-aid capability and now it's quite easy with video. You can really give them whatever slides you want to; that's a good entertainment device. I would expect that there would be an ongoing training program for our astronauts all the time. In the missions that you have now that are so short and they're so busy, obviously there's no time to train. They don't have a minute to spare; there's no question about that. But, when they're up there for 90 days and have a work routine, there's going to be time when some kind of entertainment is needed.

WORKMAN: If they had a computer station at the hyperbaric controls, then they may have an opportunity of using interactive disks, with an interactive program where you can really do that proficiency training.

HAMILTON: But, you can have a human-oriented video presentation. In other words: you have a live teacher, they look at the teacher, they talk to the teacher, and they ask questions of the teacher.

WORKMAN: That is an option, and then you don't really go through the expending of the gas.

SUSAN SHIMAMOTO: There are no requirements for that right now. There are no time limits set aside for on-orbit training. But, we have some checklists we're developing.

BOVE: Going back to the analogy of the ship at sea: Most of the military ships at sea have always had emergency drills and damage control drills. It's one of the things that's *routine* for a ship's crew, to redrill for emergencies and contingencies. There are no drills built in to the Space Station at all for emergencies?

SHIMAMOTO: No, the hardware has not been set aside nor the time; and if this is a requirement, we need to know about that now.

BOVE: It seems to me that there ought to be some kind of emergency drill covering damage control drills and medical emergencies.

HAMILTON: The fact is, you are busy as hell getting up there, and the time is very precious in the months or days before the launch. Everybody is swamped. Once you're there, you can heave a little bit of a sigh of relief that at least you've gotten that phase over. *Training* takes more than one encounter. They have to have some, because they may have the problem the first day. But, *ongoing training* could very well be programmed into this thing, and it would reduce the intensity of the training required before you go.

NORFLEET: A point of information may be that, during Skylab-4, the last and longest Skylab mission, the problem there was that they were incurably behind the time line. They were *always* trying to catch up; it caused a lot of friction. I guess what you need to say is, "Determine whether or not it's necessary and a priority to do on-orbit training in order to get it inserted in what's probably going to be a very heavy schedule."

BOVE: Are there no training or drills at all to handle the emergencies of any space flights? Nobody thought through what's going to happen in the event of a disaster? Is there no training for that at all?

SPEAKER: It's all done beforehand.

BOVE: But, no drills in flight?

SPEAKER: None in flight.

BARRATT: No *formal* drills. In talking with Dr. Kerwin, they actually did a couple of drills during the Skylab-2 mission where they simulated a medical emergency. As you say, you breathe a sigh of relief, then it may be an on-orbit judgment call by the CMO to test the hardware, so to speak.

REIMERS: My own feeling on that is, we're beginning to talk about very long missions.

SPEAKER: That's right. I mean, it's different than the other missions.

REIMERS: The guys are there for 90 days. If something happens, there are lots of things that could cause that 90 days to stretch. If you're working steadily for 90 days, you begin to forget things that you did several months back. You might be well-advised to look at a certain set of basic emergency drills, not so much the training, because we're not training, but drills to reinforce what you've already been trained to do. They don't have to take a lot of time.

BOVE: But, there can be one medical emergency with a hyperbaric component as a drill and it will give you the training.

REIMERS: And, with a little creativity, because the chamber is being used as an airlock, you could probably maneuver this into some sort of scheduled activity. You're already using the thing anyway; everybody's physically already up there, and it could be

REIMERS: (Cont'd) made to take up a very little amount of time. It's generally an axiom in the diving world and in other things that, if you expect equipment and machinery to react in an emergency, it can't be 18 *months* since the last time you used it.

PILMANIS: I'd like to reinforce that. At the USC-Catalina Hyperbaric Facility we had, in some ways, a comparable situation to the Space Station. We did *not* have the medical personnel stationed there. For the crew, it was not their primary job; it was an extra activity. They were from different professions, different backgrounds – and they were only brought together for treatment in an emergency. They had a 1-week course to start with, and from there on it was proficiency training. I can't overemphasize that, if you drop your proficiency training, you *are* going to hurt somebody. This hyperbaric chamber can be lifesaving, but it can also *hurt* people if you do it wrong. The only time we had any accidents in our chamber, they stemmed from the simple lack of proficiency training and bad decisions. Something as simple as, "Oh, I forgot!"

WORKMAN: The majority of chamber incidents that have occurred throughout the world have been the result of operator error.

REIMERS: I would like to reinforce that. I've done lots of accident reconstructions, and there is one thing you typically find in any hyperbaric accident. It's not *one* thing that went wrong; it's not that *two* things went wrong; it's a series of eight or nine things that happened. Each one taken in isolation would've been just an irritation; but each one cut down your maneuvering room until finally there was no way out. In there, usually very early in the sequence, is an inappropriate operator response to what would've been just a minor aggravation had the operator

REIMERS: (Cont'd) responded correctly. But, the operator responded wrong, made it worse, and then usually by now people are starting to get a little bit in a panic, and they do something else wrong. After a while, you have a disaster.

BARRATT: I'd like to ask one other question and move on. It's very clear that we all agree that some type of proficiency or drill would be highly desirable in flight. I'd like the committee to reiterate or make a statement on some of the things we were speaking about at dinner last night concerning accommodation of international members, something perhaps as simple as addressing our units.

HAMILTON: The comment was made last night, and it's been made previously, and that is: At least, along with the psi on the gauge, put international units.

NORFLEET: It's a program requirement, as a point of information.

HAMILTON: Is it really? Okay; that's progress. May I put something on the record here that I'll embellish later? Within the treatment protocols, even though we're limited to pressure and we no longer have the 6A profile of the 6 ATA chamber, there is a myriad of possibilities. You'll see that later. A lot of this training time could be reduced by having a computer decision-tree. *That* would be something that could be done by someone who didn't have a lot of training in the treatment protocols.

PILMANIS: We found that proficiency training is most effective with "sham treatments", where you carry out all aspects of the experience, every step of the way, including pressurization. When we tried *not* pressurizing, it was much less effective.

COURSE TRAINING STANDARD
USAF School of Aerospace Medicine (AFSC)
Brooks Air Force Base TX 78235-5301

CTS B30ZY9300-009
(PDS Code 8H3)

HYPERBARIC TRAINING FOR HEALTH CARE OFFICERS

1. Purpose: This Course Training Standard (CTS) is:

a. To establish the tasks, knowledges, and proficiency levels of training to be provided by Course B30ZY9300-009, Hyperbaric Training for Health Care Officers.

b. To provide the basis for the development of detailed training objectives, instructional methods, training materials and training evaluation instruments for the course.

c. To provide a medium for discussion between training personnel and outside agencies with regard to the quality of course graduates and the training needs of the Air Force.

2. Course Description: The duration of this course is one academic week and is designed to provide education and training for officers assigned to duties as health care officers and medical specialists in USAF hyperbaric chambers. Instruction is given in hyperbaric physiology, medicine, chamber safety, and operations. Included are the physiological problems of diving, decompression procedures, dives to 165 and 60 feet of sea water, the etiologies and treatments of decompression sickness, air embolism and other entities, and the pharmacology of hyperbaric oxygenation. Laboratory sessions acquaint the students with hyperbaric crew duties and chamber operations.

3. Qualitative Requirements: The following pages contain the list of tasks, knowledges, and proficiency levels referenced in paragraph 1.

4. Recommendations: Comments and recommendations are invited concerning the quality of graduates and the training received at USAFSAM. Please use this CTS as a reference and address correspondence to USAFSAM/DA, Brooks AFB, Texas 78235-5301. Document comments on AF Form 1284 IAW AFR 50-38.

1 Atch
Qualitative Requirements

CTS B30ZY9300-009

TASKS, KNOWLEDGES, AND PROFICIENCY LEVELS

1.	HYPERBARIC PHYSIOLOGY	
	a. Department of Defense (DOD) Hyperbaric Therapy Program	B
	b. Compression Physics	B
	c. Mechanical Effects of Pressure Change	B
	d. Effects of Changing Partial Pressures of Gases	B
	e. Physiological Basis of Decompression Sickness and Hyperbaric Therapy	B
	f. Theory of Decompression Tables	B
	g. HBO Pharmacology and Therapeutic Procedures	B
	h. Hyperbaric Therapy Program - Future	B
	i. Decompression Tables	B
2.	HYPERBARIC MEDICINE	
	a. Management of Decompression Sickness and Air Embolism	B
	b. Patient Exam and Medical Support	B
	c. Hyperbaric Equipment and Administrative Procedures	B
	d. Tissue Oxygenation	B
	e. Management of Gas Gangrene	B
	f. Management of Carbon Monoxide Poisoning	B
	g. Management of Chronic Osteomyelitis	B
	h. Management of Osteoradionecrosis	B
	i. Management of Non-Healing Wounds	B
	j. Experimental Clinical Uses of HBO	B
3.	HYPERBARIC CHAMBERS	
	a. Chamber Systems	A
	b. Chamber Safety	A
	c. Emergency Procedures	A
	d. Demonstration Dive	A
	e. Crew Duties	A
	f. Perform Crew Position Orientation Dives	c
	g. Perform 165 feet Dives	2b
	h. Perform 60 foot Lock Dive	2b

REVIEWED BY:

COURSE SUPERVISOR: _____

DEPARTMENT CHAIRMAN: _____

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CHAIRMAN, DEPARTMENT OF ACADEMICS:

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Dean, USAF School of Aerospace Medicine

COURSE TRAINING STANDARD
USAF School of Aerospace Medicine (AFSC)
Brooks Air Force Base, Texas 78235-5301

CTS B3AZY91150-002
(PDS Code 44P)

HYPERBARIC CHAMBER ENLISTED TEAM TRAINING

1. **Purpose:** This Course Training Standard (CTS):

a. Establishes the tasks, knowledge, and proficiency levels of training provided by Course B3AZY91150-002, Hyperbaric Chamber Enlisted Team Training.

b. Provides the basis for the development of detailed training objectives, instructional methods, training aids, training materials and training evaluation instruments for the course.

c. Provides a medium for discussion between training personnel and outside agencies with regard to the quality of course graduates and the training needs of the Air Force.

2. **Course Description:** The course duration is 1 wk 3 days and is designed to provide education and training of enlisted personnel assigned to duties as hyperbaric chamber enlisted technicians in USAF hyperbaric chambers. Instruction is given in hyperbaric physiology, hyperbaric medicine management, chamber operations and safety procedures. Included are the physiological problems of diving, decompression procedures, the causes and treatments of decompression sickness, arterial gas embolism and other entities. Laboratory sessions acquaint the students with hyperbaric crew duties. One dive to 165 feet of sea water is required by AFR 161-21 and additional training dives to 120 and 60 feet of sea water are used for student practice and performance evaluations.

3. **Qualitative Requirements:** The following pages contain the list of tasks, knowledges, and proficiency levels referenced in paragraph 1.

4. **Recommendations:** Comments and recommendations are invited concerning the quality of graduates and the training received at USAFSAM. Please use this CTS as a reference and address correspondence to USAFSAM/DA, Brooks AFB, Texas 78235-5301. Document comments on AF Form 1284 IAW AFR 50-38.

1 Atch
Qualitative Requirements

CTS B3AZY91150 002

TASKS, KNOWLEDGES, AND PROFICIENCY LEVELS

1.	**HYPERBARIC PHYSIOLOGY**	
	a. Department of Defense (DOD) Hyperbaric Therapy Program	
	(1) Past	A
	(2) Future	A
	b. Compression Physics	A
	c. Mechanical Effects of Pressure Change	A
	d. Elevated Partial Pressure Gas Effects	A
	e. Decompression Physiology	A
2.	**HYPERBARIC MEDICINE MANAGEMENT**	
	a. Management of DCS and Arterial Gas Embolism	A
	b. Gas Gangrene	A
	c. Osteomyelitis	A
	d. Other Non-Healing Wounds	A
	e. Carbon Monoxide Poisoning	A
3.	**HYPERBARIC CHAMBERS**	
	a. Records and Reports	A
	b. Crew Duties	A
	c. Chamber Systems	A
	d. Inspection and Maintenance	A
	e. Chamber Safety	A
	f. Emergency Procedures	A
	g. Medical Equipment Familiarization	A
	h. Intravenous System Management	A
	i. Perform 165 FSW Dive	1a
	j. Determine Decompression Tables	2b
	k. Emergency Treatment Orientation	A
	l. Perform Crew Chief Duties	2b
	m. Compressor Operations	b
	n. Perform Chamber Operations	2b
	o. Complete AF Form 1354	2b
	p. Perform 60 FSW Dives	2b
	q. Perform 120 FSW Dive	2b

REVIEWED BY:

COURSE SUPERVISOR _____

DEPARTMENT CHAIRMAN _____

DAF _____

DA _____

_____
DEAN, USAF School of Aerospace Medicine

HAMILTON: Well, I'm talking about something different that I'll embellish a little bit later. But, I agree with that.

REIMERS: With pressurization in a Space Station, they can pressurize 14 to 21 kPa (2 to 3 psi), just enough to keep the door shut. They don't have to use that much gas. That's a little enough amount of gas to where you can bleed it back into the Station and not upset anything. So, in your long-term gas utilization it should not make any difference.

BARRATT: Okay. I'd like to move on. Dr. Stegmann has to leave relatively early. I'd like to move her participation and the ebullism discussion up. We'll go ahead and do that right now.

Ebullism

STEGMANN: Ebullism is a strange bird, and most people don't know what it is. It is not a misspelled word; it's not "embolism." I get that a lot. Ebullism by definition is the spontaneous boiling and off-gassing of body fluids and tissues as well as the evaporative cooling and loss of body water and heat and other materials. That's quite a mouthful. It occurs whenever the ambient pressure falls below 6 kPa (47 mmHg) – that's with a body temperature of 37°C. With a body temperature of 37°C, most of the body ebullizes at about 19,200 m (63,000 ft). There are local variations in that, depending on skin counter pressure and the local temperature of the body. It is an inherent danger in space flight. It *cannot* be engineered out of the system; you *cannot* make this danger go away, unlike air embolism and DCS, which you

STEGMANN: (Cont'd) can do a lot to get rid of. If you're exposed to a vacuum, you *will* ebullize. That's pretty standard.

EVAs obviously represent the highest risk for any kind of an ebullism event. It goes without saying, "If you lose a suit, you will ebullize." Cabin depressurizations: Depending on how fast they occur and where they occur, that can also lead to a loss of enough ambient pressure to cause the problem. Pressure suit failures: That's probably more Air Force oriented, but pressure suits and your EVA suits kind of go hand in hand. But, the other area that we need to look at is altitude chamber accidents. We'll talk a little bit about the altitude chamber accidents that have happened in the past.

When you ebullize, you have a very rapid loss of consciousness. The average length of consciousness is about 10 to 20 sec.

You get a condition known as cardiac vapor lock. You have large amounts of gas that form in the right side of the heart, which is the low-pressure side of the heart. When the gas forms, you can no longer move any blood. It's just like the vapor lock that occurs in a pump.

You have pulmonary collapse. In fact, the entire pulmonary tree reverses its pressure gradients. You get a positive pressure formed in the lining around the lung, which is normally negative, and you literally force the air out of the lungs and cause complete collapse. You lose all the air in your lungs; period. You have cerebral anoxia because of the inability to ventilate and the inability to move any gas. And, you will die if you don't recompress; that's the obvious outcome.

STEGMANN: (Cont'd)

People have been partially exposed. This was done in 1946 by Henry. He isolated a hand, put it in a box, and sucked out all the air. In about 5 minutes, the hand had doubled in size, and there was a large amount of subcutaneous gas that was noted. His subject didn't notice any pain. When it was repeated in 1959 by Ivanoff, his subjects *did* complain of some pain, and he also was able to analyze that vapor – and that vapor was mostly water, with little or no nitrogen. This indicated a water vaporization problem. The systems we are concerned about, if an ebullism occurs, would be the pulmonary tree (that is going to *probably* take the brunt of the damage), the cardiovascular system (strictly from the disruption that's going to occur from the vast amount of bubbling), and the central nervous system (because of the other two). The last area we're a little concerned about is the eye, because of corneal freezing. When you lose that much heat that quickly, things tend to freeze; and there's a concern that the surface of the eye may freeze and that may cause some blindness.

We have actually had some unprotected exposures to near-vacuum. In the 1960s there was a real concern with the Apollo Program of how long someone could be exposed to a vacuum, come back, and perform their normal functions. They had a total of 18 chimpanzees that were exposed between about 1965 and 1969. They were trained in baseline performance tasks. They were then taken to 36,580 m (120,000 ft), which has an ambient pressure of somewhere around 2 or 3 mmHg. Once they were at altitude, they were left there for up to 2½ minutes, a relatively long exposure. They were brought down and they were *not* treated; these animals were *just* brought back to ground level. Eight of the nine in the first group survived and were back to baseline levels of functioning within 4 hours and could perform their performance tasks that quickly. If you can survive the event, it

STEGMANN: (Cont'd) tends to be a pretty successful return to function. They repeated it, and none of the animals died in the last set. But, that is the survival exposure for chimpanzees. The thing that I want to bring out here is that they didn't take this out past 2½ minutes. They may have gone to 3½ minutes and still had survivors. So the common feeling that, if you lose a suit, you are immediately dead is *wrong*.

HAMILTON: Do you have information on how quickly they reduced the pressure?

STEGMANN: They were explosively decompressed in less than a second. They had very rapid exposure.

HAMILTON: That's going to make a big difference.

STEGMANN: Yes, it should cause more damage. The pathology on some of the animal work shows that that causes more damage to the pulmonary tree.

HAMILTON: And, they were not denitrogenated.

STEGMANN: No, they were just popped up. Bancroft at Brooks worked with dogs. At 2 minutes, 100% of his dogs survived. At 3 minutes, only 20% survived. So, he *did* take it out a little bit farther, and he had a very definite increase in mortality. Again, these dogs were not treated. They were just brought back to ground level. So that means, once they hit ground level, they started to breathe on their own and their circulation restored itself. This particular study brought out some of the concerns with the eyes: They noted transient blindness in the dogs that lasted in some up to 7 days. They aren't really sure what that was; they didn't pursue it,

STEGMANN: (Cont'd) but they did note transient blindness. I forgot to mention that these dogs and the chimpanzees were followed up for 2 years, and there was no neurologic damage out to 2 years out, so it was not a long-term problem.

HAMILTON: Excuse me. Who did the chimp work?

STEGMANN: Koestler. I've got the reference. As you go down the food chain, so to speak, smaller animals do worse. For most of the rats that were exposed, they had about a 40 sec, maybe a 60 sec, maximum survival time. This was the only group that had any kind of medical treatment afterwards. They were artificially ventilated. The investigators *were* able to increase survival time with artificial ventilation. But, without intervention, the rats survived about 40 sec. So, the higher you go up the body size of the animal, the trend is that they do better.

We had some humans exposed, too, and most people don't know about these. One was here at the Johnson Space Center in the 1960s. They had an individual who was at 29.6 kPa (4.3 psi) testing a suit and he lost the couple to his suit and was instantaneously, or relatively quickly, exposed to 36,580 m (120,000 ft). I've talked to the gentleman. He remembers the incident. He remembers the saliva boiling on his tongue, so he was in the ebullism range. He fell backwards over a railing and passed out. The chamber was recompressed immediately. When he passed 4270 m (14,000 ft), he woke up. He remembers the chamber technician calling "14,000 ft" on the way down to ground level. He completely recovered, got up, and walked out of the chamber on his own.

REIMERS: Didn't he pre-breathe oxygen for 3 hours? Was it 3 hours?

STEGMANN: We didn't talk about the pre-breathe, but he was doing suit protocols and I am quite sure that he did have a pre-breathe.

REIMERS: So, that certainly helped it.

STEGMANN: Surely. And, there is some evidence in some of the older work that the pre-breathe *does* increase the survival. We'll talk about that in a minute.

The second victim was an industrial accident victim. He was a very fortunate individual. This gentleman was cleaning an industrial vacuum chamber when his friend decided to play a joke on him and closed the door, which started an automatic cycle that they couldn't stop. He was taken to approximately above 22,560 m (74,000 ft) in a time span of 3 to 5 minutes. It was a very slow exposure and he was *not* denitrogenated. This gentleman had absolutely no protection from this exposure. We don't really know about the length of exposure or the absolute altitude because his friend, in a panic, went running around to find a supervisor and they ended up having to break through a window to get into this chamber. They reenacted the incident to approximate the time and altitude. When they opened up the chamber, they found a very sick individual. The man's lung had burst, and he was bleeding grossly from his lungs, which was not unexpected. He required intubation because he was not breathing on his own. He had an air embolism injury and DCS along with this injury.

That is the other point that I want to bring out. Ebullism is *not* an isolated state. When you ebullize, no matter how much you pre-breathe, unless you have absolutely no nitrogen in your body you're probably going to have some degree of

STEGMANN: (Cont'd) decompression sickness involved in this injury. And, you *will* have air embolism by virtue of the fact that you've now destroyed parts of your lungs; and it's very likely that, when you reinflate your lungs, you're going to introduce air into the vascular tree. This tearing may occur with even small pressure changes due to the pressure reversal in the pleural space, and this should be kept in mind when evaluating ebullism patients.

They waited 5½ hours to treat him. They had to put him in an ambulance to take him to the treatment chamber. They took him to Milwaukee, and he was treated on a modified Table 6A because, at that time, that was the standard. I guess it still is the standard. But, he was only at 6 ATA for about 2 minutes. When he got to depth, he woke up. He was combative and obtunded; but he woke up. And, he started to have some spontaneous respirations. He continued to bleed from the pulmonary tree, but he was able to exchange gas. He did require Valium to keep him down. I'm sorry. An obtunded victim is one who is awake but very combative, doesn't really know what's going on. They'll respond but the responses aren't appropriate.

HAMILTON: His mind is not clear.

STEGMANN: Right. Thank you. However, he was awake and alert at 24 hours. He was able to respond appropriately to the people around him, and he was taken off his ventilator at day 5. At 24 hours, there were no gross neurologic deficits; meaning, he wasn't paralyzed on one side. They couldn't evaluate his speech because he had a tube down his throat, but there was no definite injury that could be identified. He was just groggy. He had increased reflexes in the lower extremities on day 2.

STEGMANN: (Cont'd) They also noted he was more emotionally labile, but that's a very subjective finding. Two years before he had his accident, this gentleman was in the Navy and had psychological testing done, which they were able to pull out and use as a baseline; so he did us a real favor. On day 14, they repeated his psychologic testing and noticed about a 25% decrease in his overall mentation state, which isn't bad considering the exposure this gentleman had just been through. At 3 months, he had a normal neural exam and a normal electroencephlagram. And, the psychologic deficit had decreased to only 15%; it was up 10% from the earlier examination. He had his final battery of tests at 1 year, and he showed performance that was actually above his baseline level. This was probably a learning effect and *not* a result of the ebullism. I do not want to go on record . . .

SPEAKER: You don't recommend it.

STEGMANN: I do *not* recommend ebullism for increasing the mental capacity. But, at 1 year he was lost to follow-up. We also don't know about the ophthomologic aspects of this case.

What are we doing at Brooks right now? Brooks is currently involved in looking at what we can do for treatment for ebullism. I should say that "Brooks has maintained accreditation from the Animal Candidate Use Committee, and they have maintained this accreditation since 1967." These are approved protocols that have gone through numerous review profiles, so hopefully that alleviates anyone's worries. Please take my assurances that this has been a very closely scrutinized study.

STEGMANN: (Cont'd) We are exposing guinea pigs to 26,520 m (87,000 ft) for various times, looking for a couple of things. We are looking to define the pathology; we are expecting better than what's been defined in the past. We are also looking to see if we can treat this particular animal. Right now, we're treating with at ground-level air, ground-level oxygen, and hyperbaric oxygen on the straight Table 6A. Why are we doing this? There are some very good reasons. One of them is this: We need to develop some better protective measures to *decrease* the amount of damage we're seeing. That's a *long* way down the road, and we have a lot of groundwork to do before we can do that. But, we also hope to develop the medical treatment protocols because, as of right now, there are none. There are *no* recommended methods to do this; there's only been one real treatment. What we're hoping to do in the future is to look at different treatment tables and different methods of ventilation.

Bill Hamilton had asked me last night what we're finding in our studies. One of the big hurdles we have had to overcome is that we can't ventilate the guinea pigs when we get them down. We're having a lot of trouble inflating their lungs, and this may be a challenge in the future. We have some ideas on why this happens, but apparently the lungs have really undergone such dramatic changes that we just cannot get air into them.

PANZARELLA: Is there a reason why you are not looking further at chimpanzees?

STEGMANN: Yes. For one thing, if you want to justify the use of a primate, any kind of a primate, you have to have some very hard evidence that you are not just fishing in the wind. That's really one of the reasons you need to have some groundwork

STEGMANN: (Cont'd) done. No work has been done since 1967. We chose guinea pigs because we thought that they were not oxygen-toxic. However, we're not sure anymore. Rats are not a good model. Mice are really too small; you really can't get much to look at with a mouse.

PILMANIS: This was a preliminary study, really, before going to a larger animal.

STEGMANN: Yes. And, since no one has ever treated an ebullism exposure, we really didn't know what to expect.

HAMILTON: Can you state the results yet – currently?

STEGMANN: Preliminary. If you ask specific questions, I might be able to.

HAMILTON: What's your incidence of survival?

STEGMANN: The survival curves? That's really hard to say. There are some species-specific problems that we're having. Our survival curve right now for guinea pigs: They do well. At about 60 to 100 sec, we have about a 40% mortality. At about 110 sec, we got about a 60% mortality; and at 115 sec, we've had *none* of 10 survive, which was a little bit surprising because there's a very distinct cutoff between 110 and 115 sec. This is very much a learning evolution. We're learning a lot as we go.

REIMERS: In some of my work with underwater accident reconstruction, I found that, people that have been in underwater blast situations and have lung damage from it; you can kill those people by putting them on a ventilator. There are some lessons,

REIMERS: (Cont'd) considering the lung damage that occurs here. What does that tell you about trying to use a ventilator on these folks?

STEGMANN: Well, one of the problems that we have that blast injury doesn't have is that ebullism has a surfactant problem. We've apparently boiled off the surfactant. Surfactant is a detergent that the lung uses to keep the lung inflated; it overcomes the wall tensions so that you can actually expand the lung. It's an oil, but it rides on a fluid base. And, we may be boiling off that fluid base, which may make our surfactant ineffective. Because of that, the opening pressures that are required are very high. And, we have no air in these lungs. If we have animals that did not attempt a respiration and we couldn't get any air into them, when we take them to necropsy, their lungs are no longer normal. The lungs have a liver-like consistency and they sink when you put them in water, and that means that they have absolutely no air in them. So, if we don't ventilate the animals and they're not breathing on their own, they're dead. The other thing that we're finding is that, it is helpful if we can get the animals to self-initiate. When we started this, if they came down and didn't breathe, we attempted to ventilate them with Ambu Bags.

HAMILTON: The Ambu Bag is much bigger than the guinea pig.

STEGMANN: Yes. It does seem to be an exercise in engineering. But, we found that we actually did better just stimulating the guinea pigs, and, if they could self-initiate that first breath, they had better survival. We have successfully "Ambu'ed" and gotten two or three back. Of the two that we got back, incidentally, they were *both* in the 110-sec range and they were remarkably easy when I went to bag them.

STEGMANN: (Cont'd) I bagged them and the lungs immediately inflated, which had not happened before.

HAMILTON: You may be dealing with an airway problem rather than a lung problem.

STEGMANN: We thought about that, also. We don't think it's an airway problem for two reasons: Number one, we've tried intubating them. Guinea pig anatomy is very difficult, but we think we've gotten access into the airway. But, the other problem is that when we take them to necropsy and we try to inflate the lungs with saline, which is a standard procedure, they won't inflate there either. We are looking at different methods to inflate the lungs. What the research is showing right now is, especially in surfactant-depleted lungs, that high-frequency ventilation works really well because it can open the airways; it doesn't allow that repeated collapse. Once you get them open, they stay open. That's part of the reason we're looking at new ventilation techniques. Regarding high-frequency ventilators, I don't know how practical that would be in this situation. But, that may be the only way we can actually get a lung open and keep it inflated.

HAMILTON: May I make one point on the animal aspects? You really should use some other large animal before you go to primates.

STEGMANN: We're not going to primates now. We're going to monkeys.

HAMILTON: Okay. But, I would recommend *not* going to a ruminant or a rabbit, because they're going to have intestinal gas problems. Use pigs. They're very, very neat and they're a very practical animal.

STEGMANN: Well, there are problems with using pigs. They were one of our initial animal models.

PANZARELLA: I was just going to ask, I don't want to belabor the issue, but have you looked at birds that fly at very high altitudes to see what their bodies can overcome? What's different? There *are* some birds that fly at very high altitudes.

STEGMANN: Yes, but not above 18,290 m (60,000 ft). They fly above 12,190 m (40,000 ft). Some geese fly at 12,190 m (40,000 ft), but not above 18,290 m (60,000 ft).

BARRATT: The pulmonary anatomy is quite different in birds. Birds also have the ability to respire through their skeletal systems, which we don't.

BOVE: I was thinking about antifreeze. Antifreeze does two things: It lowers the freezing point and raises the boiling point. What you're doing is throwing more solute into the water to keep it from boiling. I guess the question is: Where does that thought lead you in terms of trying to protect someone from ebullism? Could you increase the solute concentration in their body water? The first thing that came to mind was alcohol, but that's also antifreeze. If you could add a hydrous group, for example, you could possibly reduce the amount of gases that are free because their boiling point was raised. It's a crazy thought, but it's just something to consider.

STEGMANN: Those are all issues we really would like to be able to look at, but this is such a new field. There's been so little done in it.

HAMILTON: I think this should be put on the record. There is a guy at Wright State who's working on the use of fluorocarbon injected into the circulatory system to remove inert gas. This was the poster that illustrated the issue of this thing. His name is John Simanonok.

BOVE: There is also a man at Temple doing that.

HAMILTON: Well, it's far out, but it's something that might be thought about. Actually, it relates more to the gas-loaded individual in decompression sickness than to the ebullism victim.

BOVE: Fluorocarbon has a vapor pressure that's, I think, lower than water. It would probably vaporize faster than water would. They can vaporize, I think.

HAMILTON: That may not be a solution. It certainly wouldn't be protected, is what you're saying.

BOVE: It's hard to say. Some little group at Temple has shown that you can absorb inert gas bubbles with fluorocarbon in the vascular system. In protecting guinea pigs from the lethal effect of decompression sickness, I'm not sure it would work the same way; but the idea of helping to introduce solute into a body of water is an interesting thought. You could do it with glucose or something like that.

STEGMANN: The possibilities are really wide open. But, for our purposes right now – that is, EVA – we can expect to have an ebullism event before too long. We've had two in chambers, and we may have had a third, although we don't have documentation

STEGMANN: (Cont'd) on it. It's more anecdotal. So far as we can tell, the humans that have had their exposures have lived. I think right now what we're looking at is, if and when this does happen, are we going to treat it? And, what do we need to treat it? Until we actually get people convinced that it is a survivable event, looking at protection isn't going to be particularly helpful. The chances of occurrence are always there.

PILMANIS: You should probably mention here that there have been at least five deaths from ebullism operationally; four Soviet cosmonauts and one Air Force pilot.

STEGMANN: The Air Force pilot had about 10 sec of useful consciousness. He may have been able to eject. But, he had been taught that he could not survive ebullism and, therefore, he gave up.

BARRATT: Okay. Thank you, Barbara. I'd like to move on. I think we can take home the fact that a rapid suit depressurization is not a uniformly fatal event, or automatically fatal, and that we do need some treatment protocols, or at least we need to address seriously the idea of treating one. Lou Panzarella's question brought to mind that there is a gentleman out at UC-Davis who's working on comparisons of birds, particularly high-flying geese and their physiology and their response to high-pressure altitudes. Dr. James Jones is very interested in developing that comparison.

REIMERS: One comment: The treatment of an ebullism has a training impact. In a DCS situation and in treatment of the DCS, it's going to be a rare day when you've got to do something really fast. You're better off taking your time and making sure you don't do something wrong. But, treatment of an ebullism is a genuine medi-

REIMERS: (Cont'd) cal emergency; there's got to be a rapid response with no thinking involved. It's not just reflex; you're done before you start.

SPEAKER: That's the one thing that really doesn't get drilled.

BUCK: Especially since you're talking minutes before you can return to the airlock and recompress to your Station ambient pressure. Depending on how far out these guys are on their EVA, you really are talking maybe 2½ minutes.

STEGMANN: That survival time may go up. There are a lot of things that may happen. They are going to be cold; they're going to be freezing. That may actually protect their heart and brain, so that may increase your chances. There is so much that needs to be looked at.

PILMANIS: There's more and more evidence that the brain can really survive longer than previously thought.

STEGMANN: And, there are a lot of drugs that can help. But, that is so far down the road I don't want to really speculate, except to say that, I'd like to look at it.

BARRATT: Thanks, Barbara. I'd like to move on to Dr. Hamilton. He'll be discussing some treatment and escape tables for our 70 kPa (10.2 psi) Station. If I didn't mention it yesterday, I'm trying to skirt the issue of the 90-day Orbiter; but, if that does come to pass, we would probably be looking at a 70 kPa (10.2 psi) Station for the duration.

Procedures for Hyperbaric Treatment Attendants

HAMILTON: There are two handouts (FIGS. 96 and 97). One is decompression tables and the other is the conversion tables. I was tasked with the problem of looking at the consequences, basically, of getting out of the chamber after parts of a Table 6 treatment; that is to say, if you've been through some parts of the treatment and need to return to cabin pressure for some reason. We don't have a pass-through lock, a transfer lock; the medical equipment lock is a little too small for most of us, and so we have to take the chamber to Station pressure. I will probably say "ground level" a few times, but this is all done with ground-based, diving-oriented techniques. I apologize for presenting the results in feet of seawater, but I just didn't have time to convert them to kilopascals – or psi, if you will; it can be done in psi. Most of us are more conversant with feet of seawater anyway, so that's what we have. What you have here is the Table 6 treatment. Basically, it consists of going to 2.8 ATA or 60 fsw for normally 3 periods of 25 minutes, of which 20 minutes is on oxygen and 5 minutes is on air. Now, the patient breathing all this oxygen doesn't have a decompression problem; it's only the attendant who does. We are looking at the attendant situation here. So, the task was to try to develop excursion procedures so that the chamber could be surfaced or taken to Station pressure and then taken back to the treatment pressure with a transfer of attendant, or a change of attendant or, perhaps, some equipment. I think all your equipment will go through the lock, but people won't. This study was based on an ambient Station pressure of 1 ATA so, except for the last line here, all of it is looking at that.

ep24 Date printed: 09/24/91 RWH File=ALTUNITS
nversion chart for various units and PO2 for air

swa	mswa	kPa	Atm	psia	mmHg	Altitude	PO2-air
7.787	2.391	23.91	0.236	3.467	179.329	35000	0.049
7.973	2.448	24.48	0.242	3.550	183.621	34500	0.051
8.163	2.506	25.06	0.247	3.635	187.995	34000	0.052
8.357	2.566	25.66	0.253	3.721	192.455	33500	0.053
8.554	2.626	26.26	0.259	3.809	196.999	33000	0.054
8.755	2.688	26.88	0.265	3.899	201.630	32500	0.056
8.960	2.751	27.51	0.272	3.990	206.349	32000	0.057
9.169	2.815	28.15	0.278	4.083	211.157	31500	0.058
9.381	2.881	28.81	0.284	4.178	216.057	31000	0.060
9.598	2.947	29.47	0.291	4.274	221.048	30500	0.061
9.639	2.960	29.60	0.292	4.293	222.000	30612	0.061
9.819	3.015	30.15	0.298	4.372	226.131	30000	0.062
10.044	3.084	30.84	0.304	4.473	231.310	29500	0.064
10.273	3.154	31.54	0.311	4.574	236.583	29000	0.065
10.506	3.226	32.26	0.318	4.678	241.955	28500	0.067
10.743	3.299	32.99	0.326	4.784	247.426	28000	0.068
10.985	3.373	33.73	0.333	4.892	252.996	27500	0.070
11.232	3.449	34.49	0.340	5.002	258.673	27000	0.071
11.482	3.526	35.26	0.348	5.113	264.439	26500	0.073
11.738	3.604	36.04	0.356	5.227	270.332	26000	0.074
11.997	3.684	36.84	0.364	5.342	276.301	25500	0.076
12.262	3.765	37.65	0.372	5.460	282.397	25000	0.078
12.531	3.848	38.48	0.380	5.580	288.594	24500	0.079
12.805	3.932	39.32	0.388	5.702	294.894	24000	0.081
13.084	4.017	40.17	0.396	5.826	301.320	23500	0.083
13.368	4.105	41.05	0.405	5.953	307.873	23000	0.085
13.656	4.193	41.93	0.414	6.081	314.502	22500	0.087
13.950	4.283	42.83	0.423	6.212	321.284	22000	0.088
14.249	4.375	43.75	0.432	6.345	328.168	21500	0.090
14.553	4.468	44.68	0.441	6.480	335.153	21000	0.092
14.863	4.563	45.63	0.450	6.618	342.290	20500	0.094
15.177	4.660	46.60	0.460	6.758	349.529	20000	0.096
15.497	4.758	47.58	0.470	6.901	356.895	19500	0.098
15.822	4.858	48.58	0.479	7.046	364.388	19000	0.100
16.153	4.960	49.60	0.489	7.193	372.008	18500	0.102
16.490	5.063	50.63	0.500	7.343	379.780	18000	0.105
16.832	5.168	51.68	0.510	7.496	387.654	17500	0.107
17.180	5.275	52.75	0.521	7.650	395.655	17000	0.109
17.534	5.384	53.84	0.531	7.808	403.809	16500	0.111
17.893	5.494	54.94	0.542	7.968	412.089	16000	0.113
18.260	5.606	56.06	0.553	8.131	420.522	15500	0.116
18.631	5.721	57.21	0.565	8.297	429.082	15000	0.118
19.009	5.837	58.37	0.576	8.465	437.794	14500	0.121
19.393	5.955	59.55	0.588	8.636	446.633	14000	0.123
19.784	6.074	60.74	0.600	8.810	455.625	13500	0.125
20.181	6.196	61.96	0.612	8.987	464.769	13000	0.128
20.583	6.320	63.20	0.624	9.166	474.040	12500	0.131
20.992	6.446	64.46	0.636	9.348	483.463	12000	0.133
21.409	6.574	65.74	0.649	9.534	493.064	11500	0.136
21.832	6.703	67.03	0.662	9.722	502.793	11000	0.138
22.262	6.835	68.35	0.675	9.913	512.699	10500	0.141
22.699	6.970	69.70	0.688	10.108	522.757	10000	0.144
22.906	7.033	70.33	0.694	10.200	527.522	10244	0.145
23.142	7.106	71.06	0.701	10.305	532.968	9500	0.147
23.592	7.244	72.44	0.715	10.506	543.331	9000	0.150

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fswa	mswa	kPa	Atm	psia	mmHg	Altitude	PO2-air
24.050	7.384	73.84	0.729	10.710	553.872	8500	0.153
24.515	7.527	75.27	0.743	10.917	564.591	8000	0.155
24.986	7.672	76.72	0.757	11.126	575.437	7500	0.158
25.466	7.819	78.19	0.772	11.340	586.486	7000	0.162
25.953	7.969	79.69	0.786	11.557	597.712	6500	0.165
26.447	8.121	81.21	0.801	11.777	609.092	6000	0.168
26.949	8.275	82.75	0.817	12.001	620.649	5500	0.171
27.459	8.431	84.31	0.832	12.228	632.383	5000	0.174
27.976	8.590	85.90	0.848	12.458	644.296	4500	0.177
28.502	8.751	87.51	0.864	12.692	656.412	4000	0.181
29.035	8.915	89.15	0.880	12.929	668.680	3500	0.184
29.576	9.081	90.81	0.896	13.171	681.151	3000	0.188
30.126	9.250	92.50	0.913	13.415	693.801	2500	0.191
30.684	9.421	94.21	0.930	13.664	706.653	2000	0.195
31.251	9.595	95.95	0.947	13.916	719.709	1500	0.198
31.825	9.772	97.72	0.964	14.172	732.942	1000	0.202
32.409	9.951	99.51	0.982	14.432	746.379	500	0.206
33.000	10.133	101.33	1.000	14.696	760.0	0	0.419
fsw	msw	kPa	Atm	psia	mmHg	Altitude	PO2-air
0.000	0.000	101.33	1.000	14.696	760.0	0	0.209
1.000	0.307	104.40	1.030	15.141	783.0		0.216
2.000	0.614	107.47	1.061	15.587	806.1		0.222
3.000	0.921	110.54	1.091	16.032	829.1		0.228
3.257	1.000	111.32	1.099	16.146	835.0		0.230
4.000	1.228	113.61	1.121	16.477	852.1		0.235
5.000	1.535	116.68	1.152	16.923	875.2		0.241
6.514	2.000	121.32	1.197	17.597	910.0		0.251
9.770	3.000	131.32	1.296	19.047	985.0		0.271
10.000	3.070	132.03	1.303	19.149	990.3		0.273
15.000	4.606	147.38	1.455	21.376	1105.5		0.304
19.541	6.000	161.32	1.592	23.398	1210.0		0.333
20.000	6.141	162.73	1.606	23.603	1220.6		0.336
25.000	7.676	178.09	1.758	25.829	1335.8		0.368
29.311	9.000	191.32	1.888	27.749	1435.0		0.395
30.000	9.211	193.44	1.909	28.056	1450.9		0.400
32.568	10.000	201.32	1.987	29.200	1510.1		0.416
33.000	10.133	202.65	2.000	29.392	1520.0		0.419
35.000	10.747	208.79	2.061	30.283	1566.1		0.431
39.082	12.000	221.32	2.184	32.100	1660.1		0.457
40.000	12.282	224.14	2.212	32.509	1681.2		0.463
45.000	13.817	239.50	2.364	34.736	1796.4		0.495
48.852	15.000	251.32	2.480	36.451	1885.1		0.519
50.000	15.352	254.85	2.515	36.963	1911.5		0.526
55.000	16.888	270.20	2.667	39.189	2026.7		0.558
58.622	18.000	281.32	2.776	40.802	2110.1		0.581
60.000	18.423	285.55	2.818	41.416	2141.8		0.590
65.000	19.958	300.90	2.970	43.643	2257.0		0.622
65.136	20.000	301.32	2.974	43.703	2260.1		0.622
66.000	20.265	303.98	3.000	44.088	2280.0		0.628

Definitions: 1 fsw = 1/33 atm; 1 atm = 760 mmHg = 101.325 kPa
Altitude in feet by ARDC Model Atmosphere, 1959. 1 bar = 10 msw
Altitude for 222 mmHg = 4.3 psi and 527.5 mmHg = 10.2 by interpolation.

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FIG. 96 Dec(ession tables

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Conversion chart for various units and PO2 for air; fsw=1/33 atm.

fswa	mswa	kPa	Atm	psia	mmHg	Altidude	PO2-air
7.787	2.391	23.91	0.236	3.467	179.329	35000	0.049
7.973	2.448	24.48	0.242	3.550	183.621	34500	0.051
8.163	2.506	25.06	0.247	3.635	187.995	34000	0.052
8.357	2.566	25.66	0.253	3.721	192.455	33500	0.053
8.554	2.626	26.26	0.259	3.809	196.999	33000	0.054
8.755	2.688	26.88	0.265	3.899	201.630	32500	0.056
8.960	2.751	27.51	0.272	3.990	206.349	32000	0.057
9.169	2.815	28.15	0.278	4.083	211.157	31500	0.058
9.381	2.881	28.81	0.284	4.178	216.057	31000	0.060
9.598	2.947	29.47	0.291	4.274	221.048	30500	0.061
9.656	2.965	29.65	0.293	4.300	222.387	30347	0.061
9.819	3.015	30.15	0.298	4.372	226.131	30000	0.062
10.044	3.084	30.84	0.304	4.473	231.310	29500	0.064
10.273	3.154	31.54	0.311	4.574	236.583	29000	0.065
10.506	3.226	32.26	0.318	4.678	241.955	28500	0.067
10.743	3.299	32.99	0.326	4.784	247.426	28000	0.068
10.985	3.373	33.73	0.333	4.892	252.996	27500	0.070
11.232	3.449	34.49	0.340	5.002	258.673	27000	0.071
11.482	3.526	35.26	0.348	5.113	264.439	26500	0.073
11.738	3.604	36.04	0.356	5.227	270.332	26000	0.074
11.997	3.684	36.84	0.364	5.342	276.301	25500	0.076
12.262	3.765	37.65	0.372	5.460	282.397	25000	0.078
12.531	3.848	38.48	0.380	5.580	288.594	24500	0.079
12.805	3.932	39.32	0.388	5.702	294.894	24000	0.081
13.084	4.017	40.17	0.396	5.826	301.320	23500	0.083
13.368	4.105	41.05	0.405	5.953	307.873	23000	0.085
13.656	4.193	41.93	0.414	6.081	314.502	22500	0.087
13.950	4.283	42.83	0.423	6.212	321.284	22000	0.088
14.249	4.375	43.75	0.432	6.345	328.168	21500	0.090
14.553	4.468	44.68	0.441	6.480	335.153	21000	0.092
14.863	4.563	45.63	0.450	6.618	342.290	20500	0.094
15.177	4.660	46.60	0.460	6.758	349.529	20000	0.096
15.497	4.758	47.58	0.470	6.901	356.895	19500	0.098
15.822	4.858	48.58	0.479	7.046	364.388	19000	0.100
16.153	4.960	49.60	0.489	7.193	372.008	18500	0.102
16.490	5.063	50.63	0.500	7.343	379.780	18000	0.105
16.832	5.168	51.68	0.510	7.496	387.654	17500	0.107
17.180	5.275	52.75	0.521	7.650	395.655	17000	0.109
17.534	5.384	53.84	0.531	7.808	403.809	16500	0.111
17.893	5.494	54.94	0.542	7.968	412.089	16000	0.113
18.260	5.606	56.06	0.553	8.131	420.522	15500	0.116
18.631	5.721	57.21	0.565	8.297	429.082	15000	0.118
19.009	5.837	58.37	0.576	8.465	437.794	14500	0.121
19.393	5.955	59.55	0.588	8.636	446.633	14000	0.123
19.784	6.074	60.74	0.600	8.810	455.625	13500	0.125
20.181	6.196	61.96	0.612	8.987	464.769	13000	0.128
20.583	6.320	63.20	0.624	9.166	474.040	12500	0.131
20.992	6.446	64.46	0.636	9.348	483.463	12000	0.133
21.409	6.574	65.74	0.649	9.534	493.064	11500	0.136
21.832	6.703	67.03	0.662	9.722	502.793	11000	0.138
22.262	6.835	68.35	0.675	9.913	512.699	10500	0.141
22.699	6.970	69.70	0.688	10.108	522.757	10000	0.144
22.906	7.033	70.33	0.694	10.200	527.522	9768	0.145
23.142	7.106	71.06	0.701	10.305	532.968	9500	0.147
23.592	7.244	72.44	0.715	10.506	543.331	9000	0.150
24.050	7.384	73.84	0.729	10.710	553.872	8500	0.153
24.515	7.527	75.27	0.743	10.917	564.591	8000	0.155
24.986	7.672	76.72	0.757	11.126	575.437	7500	0.158
25.466	7.819	78.19	0.772	11.340	586.486	7000	0.162
25.953	7.969	79.69	0.786	11.557	597.712	6500	0.165
26.447	8.121	81.21	0.801	11.777	609.092	6000	0.168
26.949	8.275	82.75	0.817	12.001	620.649	5500	0.171
27.459	8.431	84.31	0.832	12.228	632.383	5000	0.174
27.976	8.590	85.90	0.848	12.458	644.296	4500	0.177
28.502	8.751	87.51	0.864	12.692	656.412	4000	0.181
29.035	8.915	89.15	0.880	12.929	668.680	3500	0.184
29.576	9.081	90.81	0.896	13.171	681.151	3000	0.188
30.126	9.250	92.50	0.913	13.415	693.801	2500	0.191
30.684	9.421	94.21	0.930	13.664	706.653	2000	0.195
31.251	9.595	95.95	0.947	13.916	719.709	1500	0.198
31.825	9.772	97.72	0.964	14.172	732.942	1000	0.202
32.409	9.951	99.51	0.982	14.432	746.379	500	0.206
33.000	10.133	101.33	1.000	14.696	760.0	0	0.419
fsw	msw	kPa	Atm	psia	mmHg	Altidude	PO2-air
0.000	0.000	101.33	1.000	14.696	760.0	0	0.209
1.000	0.307	104.40	1.030	15.141	783.0		0.216
2.000	0.614	107.47	1.061	15.587	806.1		0.222
3.000	0.921	110.54	1.091	16.032	829.1		0.228
3.257	1.000	111.32	1.099	16.146	835.0		0.230
4.000	1.228	113.61	1.121	16.477	852.1		0.235
5.000	1.535	116.68	1.152	16.923	875.2		0.241
6.514	2.000	121.32	1.197	17.597	910.0		0.251
9.770	3.000	131.32	1.296	19.047	985.0		0.271
10.000	3.070	132.03	1.303	19.149	990.3		0.273
15.000	4.606	147.38	1.455	21.376	1105.5		0.304
19.541	6.000	161.32	1.592	23.398	1210.0		0.333
20.000	6.141	162.73	1.606	23.603	1220.6		0.336
25.000	7.676	178.09	1.758	25.829	1335.8		0.368
29.311	9.000	191.32	1.888	27.749	1435.0		0.395
30.000	9.211	193.44	1.909	28.056	1450.9		0.400
32.568	10.000	201.32	1.987	29.200	1510.1		0.416
33.000	10.133	202.65	2.000	29.392	1520.0		0.419
35.000	10.747	208.79	2.061	30.283	1566.1		0.431
39.082	12.000	221.32	2.184	32.100	1660.1		0.457
40.000	12.282	224.14	2.212	32.509	1681.2		0.463
45.000	13.817	239.50	2.364	34.736	1796.4		0.495
48.852	15.000	251.32	2.480	36.451	1885.1		0.519
50.000	15.352	254.85	2.515	36.963	1911.5		0.526
55.000	16.888	270.20	2.667	39.189	2026.7		0.558
58.622	18.000	281.32	2.776	40.802	2110.1		0.581
60.000	18.423	285.55	2.818	41.416	2141.8		0.590
65.000	19.958	300.90	2.970	43.643	2257.0		0.622
65.136	20.000	301.32	2.974	43.703	2260.1		0.622
66.000	20.265	303.98	3.000	44.088	2280.0		0.628

FIG. 97 Conversion tables

HAMILTON: (Cont'd)

The first thing to do was to find out what the decompression obligations are. I just took the normal Table 6, and this first run uses a typical Haldane approach to decompression computation with an algorithm that is a little bit more conservative than the one that would be used for, say, the Navy air decompression tables. I've used that because it's working in other situations. This will give us a more meaningful exposure; in other words, it will call for decompression in some situations where the U.S. Navy procedures would not but where, historically, the U.S. Navy procedures would not be very reliable.

What I did was decompress individuals or the hypothetical astronaut or diver after several situations. After a normal Table 6, you come out, according to the procedure, and end up with no decompression stop required. That is to say, the attendant breathes oxygen for the last part of the treatment procedure, just the 30 minutes from 30 fsw and 193 kPa (28 psi). If you breathe air from that point, instead of going on oxygen, however, we find that a 20-minute stop is required at 3.05 m (10 ft). This particular program will stop at 3.05 m (10 ft) because that's the way that most of our experience has gone. If you try and go to the surface from the 285 kPa (60 fsw) part of Table 6 without the 193 kPa (30 fsw) period, you find that you need 25 minutes of decompression.

These are not things we will consider doing in the Station at all; it is not appropriate to do decompression in this kind of situation, because your patient would have to go through that, too. But, this is to characterize the level of decompression required. So, these numbers here are the ones that tell us what we have. You don't really need to look at the details behind that – just that 25 is worse than 20. That's the message. I started adding the extra cycles; a cycle is a 25-minute peri-

HAMILTON: (Cont'd)

od of which 20 minutes is on oxygen, 5 minutes on air. If we add 2 extra cycles, it's 50 minutes, and you finish the table in the normal way with breathing oxygen in a linear ascent to the surface. So, the procedures that are in the book do in fact get you out. I never use the word "safe" to talk about the result of a decompression.

I always use "reliable," because it can never be considered really safe. While it's not safe, it's really not "unsafe" either; so, I don't use that word. Anyway, you get out quite all right if you continue the decompression on oxygen. Now if you use air, breathing air going to the surface from 285 kPa, you find a lot of decompression is required. It's a stop at 163 kPa (20 fsw) and a long stop at 132 kPa (10 fsw). So again, this is probably the worst one you have up here; that is, to go through two extra cycles.

For some reason, the procedure that's included with JSC-31013 only allows one extra cycle at 285 kPa (60 fsw). I think that's a mistake, and we've discussed it and haven't really found a reason for it. But, the Air Force does call for two. I think it's a small point, but I did all this before I noticed it only called for one. But anyway, if you put two extra cycles at 285 kPa (60 fsw) and then do the normal 193 kPa (30 fsw) stop, it calls for quite a long stop in coming up with air. These were all done at 132 kPa (10 fsw) or a third of an atmosphere per minute ascent rate. Now, I just picked it. It's a reasonable value. You can go faster than that, and there might be an incentive to do it. But here, we have the *slow* ascent that is called for in the table – 1 fsw per minute – or we have what I call the fast one, which is still not as fast as you can go, but it's just one used for this exercise.

HAMILTON: (Cont'd)

This is what happens when we extend the table at both 285 and 193 kPa (60 and 30 fsw). An interesting thing develops here; during the time 193 kPa (30 fsw) is more or less neutral. In other words, you take one extra cycle, you get a few minutes more required decompression; you take two, you get a few more minutes; you take three, you only get very small increases in the required decompression with additional time at 193 kPa (30 fsw). You don't get any help; you get a little bit more decompression required. But, extra time at 285 kPa (60 fsw) is very costly. It begins to build up rather quickly. Extra time at 193 kPa (30 fsw) doesn't have much effect one way or the other. So, then we put in some oxygen breathing here.

Now we've got to get the guy out. These were intended to characterize the scope of the problem. Now, we're going to have the attendant go on oxygen at treatment pressure until it's safe to go straight to cabin pressure because that's the algorithm we're trying to think about. We found that, after the normal 3 cycles at 285 kPa (60 fsw) but skipping the time at 193 kPa (30 fsw), it requires an 11-minute stop if she decompresses on air. So, that's to characterize where we are. In other words, it's really not as serious as coming out of the final table without oxygen breathing; at 60 minutes at 285 kPa (60 fsw), no stop is needed on the UW tables. This algorithm would allow a few minutes less than that. It's a little more conservative at that point; in any case, you are not in very bad shape. You could skip this most of the time. It wouldn't hurt anything. On paper, a few people would get bent, but it's not a serious decompression requirement to go ahead and just go to the surface. Add an extra cycle; now 18 minutes are needed; add two extra cycles, it calls for 25 minutes. I'm sorry, I misspoke. These are periods of oxygen breathing. These are not air stops at 132 kPa (10 fsw); these are oxygen-breathing periods at 285 kPa (60 fsw). I need two extra ones, but you can see that

HAMILTON: (Cont'd) that was what was required. I'm sorry I said the wrong thing a moment ago. These are periods of oxygen breathing at 285 kPa (60 fsw) or 2.8 ATA *after* the normal 3 cycles.

Again, where the attendant is breathing only air, he can breathe oxygen for 11 minutes and then pop to the surface – in other words, that's a clean decompression. If he extended 1 cycle, which is the one that was in the handout originally, he needs 18 minutes of oxygen breathing at the end of that time. Now, if he starts it sooner, the obligation is less. If you're breathing oxygen at 2.8 ATA, you have a toxicity problem, so we put the patient on oxygen in cycles. When the oxygen-breathing period gets above 20 minutes, we have to put it into cycles. That's what these last two lines are; they're the same situation as these, except we don't need an oxygen cycle for these because they can breathe it all in one period. But, when you break it down and have to breathe it in cycles, it takes that 25 plus 5 minutes of air breathing; so that takes it to 30, and it calls for 3 more minutes of oxygen breathing because of the gas you picked up during the air cycle. So, by breathing it in cycles – 20 on, 5 off – we have a 33-minute period here. This is 41 minutes if we have three extra cycles that are off the map, but it's one I thought we should look at. I looked at what happens if you breathe the oxygen during a stop at 132 kPa (10 fsw) to see what benefit the oxygen gives us. I think that's possible with this. In other words, if you breathe air, it takes 20 minutes; if you breathe oxygen, it takes only 5 minutes.

BARRATT: These are to get to the surface and stay at the surface?

HAMILTON: Yes, to the surface (1 ATA) and stay. Now, that was all basically for *my* information to get to the point of looking at the real problem.

BUCK: Just one quick question back on that straight set of analyses. You added one extra at 30 and you have 75 minutes there along all of those. What is that?

HAMILTON: At 193 kPa (30 fsw) or 28 psia, the extra cycles are 75 minutes – 60 minutes on oxygen, 15 minutes on air. Now, we add a little rumble here, a little confusion, because the Air Force continues with these 20 and 5 cycles and they break it into three 20-on/5-off cycles, whereas the Navy calls for 60-on/15-off cycles. But, it still takes 75 minutes the other way. To add a "single extension" at 193 kPa (30 fsw) is a 75-minute extension.

BUCK: So, two extra is 150.

HAMILTON: But, you can add these things one at a time, two at a time, three at a time. I hope one thing that shows through here is the fact that even this, looking at just one little part of this thing, is very complicated. I picked a rate, I picked certain times, I picked certain exposures, and I still got a whole bunch of tables. It would be silly not to be able to have the option of using all these possibilities. This thing should be put into a small computer; it can fit on a single disk. Really, this is not that difficult to do. And, you then can follow a decision tree. Obviously, you're going to have training and help from the ground, and so forth. But, this thing gets complicated really very quickly, and we want to be able to do the right thing for each individual situation. There are so many possibilities, it's going to be a book of tables that's going to weigh more than a laptop computer.

PANZARELLA: What's the surface in these? Is it 101 kPa (14.7 psi) or is it 70.1 kPa (10.2 psi)?

HAMILTON: The surface here is 1 ATA simply because the wheels roll slowly and that was the task. However, there are two other aspects of this: One is, what if we aren't going to come out forever? We only want to make an excursion to the surface to transfer and then go back – for example, open the door, put somebody in or out, and go back. Now, obviously the guy that's in can't go out unless he goes through this full decompression. So in order to do that, I took the data that Dr. Eckenhoff of the U.S. Navy had been doing in studies of submarine rescue in taking people to the surface. I'll try to explain very quickly what this is. For people saturated at different pressures. He was looking at how many times they can go to the surface and then go back to saturation without a problem. He calls this "latency," which is a pretty good word. In other words, if you are at a given pressure – say, we're at 285 kPa (60 fsw), 2.8 ATA – and we want to go to 1 ATA for a short period of time, how much time can we stay there? Well, he took people from four different depths of 45, 55, 65, and 75 fsw, and he measured three things. The triangles are the amount of time before they began to itch. This is a universal finding in a chamber; it always happens when you make this exposure. Nearly everybody gets it, and they usually get it fairly soon. It's *not* a big problem. It's normally not even regarded as requiring treatment if it happens from a normal dive, but still it is a signal that something is happening. This is the development of the venous gas emboli, the Doppler bubbles. This is what we determined was the threshold of decompression sickness. Now, he did a very nice curve that fits with a 0.99 R for these things; these are a simple power curve.

HAMILTON: (Cont'd) The problem is that although his curve fits his data very well, he chose these specific depths and the times of exposures to depth. The times he developed, but the depths he *chose*. The things he tried were also fixed ahead of time. So, these things could have been done very differently and the same physiology could have given us very different data had a different question been asked. Not to take those numbers as being too hard anyway; we took data but did not use his curve, which is done in ratios. The problem with ratios is, if you take it from, say, 75 fsw to the surface, we get a certain time; if we take it from 150 to 75 fsw, we get an infinite amount of time which we know is not the case. So, we felt there was a limitation in taking what he did and using it in all sorts of situations, and so we developed another curve.

Here are Eckenhoff data points. Now they're in a different perspective here. Time is usually on the abscissa but, here, time is the output; so, time is on the ordinate for a given differential pressure. And, we came up with this messy looking equation here. It's really not quite all that bad, and it's really only our method of doing a curve fit. Now, it doesn't fit the data nearly as well as Eckenhoff's little curve did, but we think it meets our needs better.

We have a couple of things that are important. Here is sort of the asymptote. This is the delta-P that you can tolerate from an infinite exposure. That's the "T nth", the delta-P for infinite time. Then there's an asymptote of a sort here; in other words, you can take almost any pressure for a short enough time. We don't really develop that into a clean asymptote. Because he used only short exposures, we don't think this approach is meaningful beyond, and probably not even mean-

HAMILTON: (Cont'd)

ingful up to, latencies of 60 minutes. Certainly, you can't rely on decompression sickness waiting for an hour before it comes on.

Now if you've got someone whose exposure is going to induce decompression sickness, you've got a certain amount of latency you can count on; but we do not think it is meaningful to trust latency beyond an hour. The problem that I was asked to solve called for a half hour maximum, which is reasonable. That's all we feel we need this excursion to do. But, we do have data that let us play with an hour. The delta-P for a 5-minute exposure is this end of the curve. We can vary this parameter here, which looks like a half time, and it changes the curvature, moving the curve up and down. This is not actually the curve I used. When I went back into the graphics program to try to get it to work, I was in a hurry and I think it may have exploded, so what you see is what I had already printed. So, this shows what we've done, but it doesn't show the actual curve we used. We took that curve, put it in the decompression program, and that gave us fixed time periods for given delta-P's. In other words, we could estimate what our latency or what our excursion period is from that. When we put that in at the end of the normal 5 cycles, which is the maximum treatment at 285 kPa (60 fsw), we could go to the surface for the full 60 minutes that the algorithm allowed without exceeding the latency.

Now, there's a problem with that. This formula calls for picking a compartment; we only used *one half-time* compartment to test against this curve. We chose in our model compartment 9, with a half-time of 385 minutes, because it matches the empirically determined 360-minute compartment that the NASA people have found to be effective. The problem is, *that* compartment doesn't load up

HAMILTON: (Cont'd) very much gas from the kind of exposure we're talking about. So, you've got gas peaks in the shorter compartments that don't play a role in the kind of exposure that Eckenhoff did; so we have to go back and take another look.

Johnny Conkin, who used to be here at JSC, is now a graduate student at Buffalo. He has put together, mainly from his work here, a huge database in which he has virtually every published altitude exposure. This is from the paper he gave at the UHMS meeting in San Diego a couple of months ago. Here we're looking at two things: First, we have to figure that this is a 360-minute compartment. We're going to have to take this curve and look at it for the compartments that have been loaded by this exposure and find out that there is some restriction there. We know you can't go straight to the surface and stay, so we have to figure out how to get the excursion on one of the slower compartments. We don't have much to go on there because the Eckenhoff work was all done on a square wave; you just go there and see if you can get away with it. What Conkin and Van Liow have learned is that this curve represents a change from one pressure to another that is presumably, as Conkin used the word, "safe." (I told you already I don't like that word.) Presumably, if you stay in this zone when you go from one pressure to another on this side of the curve you don't have any problems. The ending pressure is on the Y axis and the starting pressure on the X axis is converted to a partial pressure of nitrogen (pp N_2), and there's a little accounting for alveolar effects from what's expired.

This is supposed to be the safe side; we know it's bad over here. This side is supposed to be safe. But for these points, Conkin's data show that this particular P1, P2, delta-P ratio of pressures doesn't account for all this known decompression

HAMILTON: (Cont'd) sickness. So they say, "Let's draw another line." In fact, this line intersects with the other line up here and pretty well encloses the experience. That means that we now have a partial nitrogen pressure that we can have on board in all the compartments; for example, if we go to 8535 m (28,000 ft), you see where we are. We're right in the middle of this. But, with this much gas on board, this is as high as we can afford to go and still miss this zone, which is high risk. So, we ought to take these numbers and, again, adjust for the fact that we're dealing with a faster compartment. We can't rely on the 360-minute compartment where we're loading and unloading both. We have to use a faster compartment for that. So, that's the next step with the thing.

Again, I think we're going to find that there are some restraints on how much time we have for the excursion when we look at the shorter compartments. Now what this is for, though, is not for that; it's to allow us to go to altitude. We will convert this where it fits into our algorithm now to take the people *back* to 70 kPa (10.2 psi). That's the next phase of the project. This is about where we stand.

PILMANIS: Have you looked at comparisons with escape tables in the Air Force manuals? There is a set of escape tables.

HAMILTON: I haven't look at them in the manual. What do they say?

PILMANIS: Well, I don't have it here in front of me. I would just mention that we used *those* tables to escape for many years successfully. All this experience was at 6 ATA rather than 2.8 ATA. There is a 2.8 table; we just didn't have occasion to use it.

HAMILTON: It's a much different thing.

PILMANIS: But, they were calculated the same way. So from that sense, there's a common thread there. We used them mainly to get our tenders out in cases where the patient was pronounced at depth successfully; no bends whatsoever. When we switched to the DCIEM tables, which appeared to be more conservative, we had tenders bending. I also tried Carl Huggins' escape-from-treatment tables, a whole book of escape-from-treatment tables. The first time we tried it I bent my wife, so I did not continue. There is some experience on escape from treatment.

HAMILTON: I think I should make one comment. Perhaps you've got it, but I want to make sure it's understood. We have these formulas, we use these algorithms, but everything has to be related to data for it to have any meaning. This is true for diving decompression; it's also true for altitude. We have a bit of work yet to do to bring all the data in and make it so that we can apply this particular task. We're going to have to go to 70 kPa (10.2 psi). Let's face it: This is helpful as an analysis, but it doesn't really solve our problem. I don't think it's going to be a horrendous additional problem, but I think we've got to press on with it, and we've got to get the data to do that.

BARRATT: Thanks very much. So, we need some new, creative tables that Dr. Hamilton is helping us to develop. I'd like to give the floor to Dr. Bove at this time. He's going to be discussing something we touched on briefly yesterday, and that is time to return to duty after DCS treatment.

Return to Duty Following Hyperbaric Treatment On Orbit

BOVE: We'll talk about two different things in the return-to-duty issue. I've put together a very brief review; and this is really a review, because I'm not sure there are enough data to make clear statements.

[NOTE: Text out; ~5-minute gap at the beginning of Dr. Bove's presentation.]

BOVE: Issues that come up are, if somebody is out on EVA and gets bent, the question is: What are the times that will allow him to return to normal duty working in the Space Station? And, the other is: What are the times that one would delay before allowing that individual to go back and do more EVAs and return to the exposure? This was addressed at a workshop that the Undersea Medical Society held back in 1980 – actually Dr. Hamilton was there and a number of other people. And, the issue was raised then because the United States Navy had declared a 1-week delay after a pain-only bend. That caused a lot of havoc with the commercial diving industry, particularly because, for some reason or other, the Navy diving manual turned out to be a standard of care; and it was of great concern to have a standard of care saying "1 week" when most of the people in the commercial business had been putting people back to work in other sectors after 24 hours with a simple pain-only bend that cleared readily. That workshop brought out a number of issues, and they made some recommendations at the end of it, which, I think, were at least considered to be reasonably valid, useful recommendations. But, that's where we have most of the basis, in the decompression from diving relationships.

BOVE: (Cont'd) The Air Force has its rules regarding return to work, and I guess the Navy has rules regarding return to work (the Air Force for altitude and the Navy for diving). But, let me just show you what the consensus of this workshop was because this is a little more in keeping with the kind of environment that we'd see in Space Station. Remember that the Navy and the Air Force have a lot of people; so, if they have an operation going on – in particular, a diving operation – and there are 10 divers, there's no problem with putting one diver on deck duty or surface duty for a while and replacing him with somebody else. So, they're relatively conservative because they don't have any pressing needs to have one person back to dive again. And, to some extent the Air Force is in the same situation. There are enough personnel that, if you have any doubts at all, just put somebody else on the job.

This is *not* the case in the Space Station. The crew is quite limited, and there may be need to help people go back to duty on a very short notice. But, let me just go over the way things have been broken down before. I've turned them into what we might think of in terms of Space Station environment. You'll notice also that I've got pain-only and neurologic decompression sickness (FIGS. 98 and 99). The other sheet that I handed you is the next talk, but you'll notice in here that we're still talking about pain-only bends and neurologic bends. That kind of falls back into this ancient categorization of Type I and Type II decompression sickness, which is always challenged. Everybody wants to make it better or different or a little more precise in terms of the clinical findings. But, at least for today I'm going to stick with simple pain-only bends and neurologic decompression sickness with our understanding of it. They're anatomically different and, clearly, they have functional implications that are different.

DCS treatment in Space Station Freedom

A. A. Bove
27 September, 1991

In spite of arguments regarding the accuracy of discrete staging of DCS, there is still merit in classifying DCS into two types: minor and serious.
Minor DCS (type I) involves the bones and joints, usually is manifest by pain in an extremity, and is not associated with systemic involvement. Pruritis, localized edema, and skin mottling may be found under this classification.

Serious DCS (type II) involves the spinal cord or brain, the systemic circulation. In its most serious form it causes massive gas embolism to the lungs. and pulmonary circulatory failure.

All forms of DCS should be treated with pressure, oxygen and fluids. Mild type I DCS can be treated at 60 fsw (26.7 psig). There are two protocols which have been proposed by the US Navy, described as table 5 and table 6. These are 60 fsw intermittent 100% oxygen treatment tables. For simple limb bends, table 5 has been recommended, however standard of practice in the US is to use table 6 for type I DCS. Neurologic DCS is treated with table 6. This is a 60 fsw treatment table which provides longer treatment time at both 60 and 30 fsw.

Treatment provided within a few hours of the onset of DCS is successful in 80-90% of cases. If the subject does not improve or deteriorates while under treatment at 60 fsw, then treatment at a deeper depth or for a longer time at 60 fsw can be provided. Return to the surface after the deeper excursion can be accomplished by following USN table 7 which is a prolonged 60 fsw oxygen table requiring 36 hours to return to the surface. Other tables requiring deeper depths are also available.

Adjunctive therapy

In cases of severe DCS, there are several acute inflammatory systems activated. Blood clotting, platelet activation, complement activation, direct tissue injury, and capillary leakage all result from serious DCS. These effects are amenable to treatment with medications. Platelet inhibitors, steroids, antihistamines, crystalloid fluids, and plasma replacements all have a place in the treatment of serious DCS.

FIG. 98 DCS treatment in Space Station Freedom

Return to duty after DCS

A.A. Bove
27 September 1991

SITUATION	TIME TO ALTITUDE EXPOSURE	TIME TO DUTY	MEDICAL EVALUATION
Pain only, cleared	24 hours	24 hours	none
Pain only, prolonged treatment	24 hours after relief of symptoms	24 hours	discuss with medical officer
Neurologic DCS, rapidly resolved	1 week before altitude exposure	48 hours?	Medical officer exam before altitude
Neurologic DCS with residual effects	no further altitude exposure	when able	Medical officer exam to return to duty

Adapted from the workshop on Post Decompression Sickness return to diving, UHMS, Bethesda, 1980.

These data relate to diving related DCS, and have been extrapolated to the space station environment. Return to duty is likely to be an easier decision that return to altitude exposure, since most subjects will be able to perform routine duties after treatment for DCS. Subjects with residual paralysis, or weakness after neurologic DCS may require physical rehabilitation before return to full duty. All cases which are in question should be reviewed by a medical officer.

FIG. 99 Return to duty after DCS

BOVE: (Cont'd) So, we start out talking about pain-only decompression sickness. This is the common type of decompression sickness you see when you take a person that's "saturated" and take him to a lower pressure. That's known in diving and it's also known in altitude – altitude is basically decompression from saturation. So, here we get pain-only bends; that is, a pain in an elbow, wrist, knee, ankle, or foot. The situation here would be that you have pain-only bends and you bring the person back in, bring him to the surface, and it clears. Or you bring him to the surface and there's a small amount of residual pain that clears very quickly upon treatment with a hyperbaric exposure. Here, we're talking about 285 kPa (60 fsw) hyperbaric exposure. One of the things that would be interesting to discuss would be, "Do you have to go to 285 kPa (60 fsw) for a very simple pain-only bend?" If this pain disappeared at 193 kPa (30 fsw), could you develop some 193 kPa (30 fsw) table that probably would be effective for that type of treatment?

PILMANIS: There is a Table 8. That is a 193 kPa (30 fsw) table.

BOVE: There is a Table 8? I haven't seen it.

But the point is, in this kind of environment where gas conservation is a major issue, it never comes up in running a treatment table. You have plenty of air and you usually have enough oxygen. But, for a pain-only bend that 80 or 90% of the time clears just be going to the surface, for the small amount of those patients left over that have to go to some depth, it's not clear that you ought to go to 285 kPa (60 fsw) in this environment. We have to throw that out at some point. I'm not ready to do it now, but you ought to throw it out at some point. It's quite revolutionary, and yet this is the perfect application for that kind of a treatment.

BOVE: (Cont'd) So you have a pain-only bend. It either has cleared on the surface or you treat the patient with some kind of table and it clears very quickly. You don't extend the table. There's no other residual. This person is out of the chamber or on the surface. The kind of approach that the commercial diving industry and most other people now would take is, that individual can go back to *diving* in 24 hours. I think, for the most part, one could say, if it was absolutely necessary, you could probably allow that individual to return to altitude exposure within 24 hours as well. And clearly, they could return to regular duty – that is, 70 kPa (10.2 psi) atmosphere work – within 24 hours and probably less than that. So I think, the simplest case is simple to deal with; that is, that individual *could* go back to doing EVAs in 24 hours. Schedule-wise, it sounds like they wouldn't be required to do that, but for emergency purposes, they probably could. Clearly, that person ought to get back to his work tasks within the day of his diving or of his EVA exposure – simple work.

The next issue would be a similar case where it took a while to get the treatment; that is, it didn't clear on the surface. You went to chamber depth – let's call it 285 kPa (60 fsw) at this point – and it was a bit of a struggle. For instance, the pain lasted 15 to 20 minutes. You went through to Table 6. But, at the end of the treatment, the patient came out with no pain.

HAMILTON: One has to be careful about how rules are worded. Once we set an arbitrary waiting period of 24 hours for the next dive. This sounded reasonable and was printed in the rules. But, the effect it had was to require that the dives start later each successive day. And, once it was written into the rules we could not change it.

BOVE: Bill brings up a very interesting point.

HAMILTON: This is an operational point.

BOVE: In the same 24 hours, somebody is sitting there with a stopwatch waiting for the second hand to cross the 12. You don't want to imply that, but that's kind of the way things fall together. When you say "a day," you really mean that you get up at 8 o'clock in the morning, the day begins; and the next day, somewhere between 6:30 and 9:00, is the beginning of the next day – not necessarily exactly when the clock crosses zero.

PANZARELLA: I know that, at one point in time, we were looking at evolution of the Station and talking about possibly having two shifts – like a Blue shift and a Red shift. So a 24-hour period might take you into a shift where you would be able to pick up duties on that shift instead of waiting an entire two shifts.

HAMILTON: That's what I'm saying. If you make the delay exactly 24 hours, it throws him out of the next shift, whereas if you make it 1 *day*, he can go back to work on his next shift.

PANZARELLA: Well, it doesn't have to be like that. If he started on a Blue shift (let's use that terminology) and 24 hours takes him into the Red shift, he might be able to do that – go into the Red shift and perform some of the tasks. In other words, he waits 24 hours and then waits till the next Red shift comes up.

HAMILTON: But to do that, somebody else has to take an extra shift early.

PANZARELLA: It depends on the workload.

HAMILTON: But we've had this problem that, if you say "24 hours," people are going to write it down and they're going to wait for the second hand to cross the 12. Whereas, if you say, "1 day," physiologically and medically, it's more or less the same thing. Especially when it's *more* than 1 day. In 24 hours if you've got an 8-hour mission, that means you're talking 16 hours. That may *not* be enough. It's a question.

BOVE: We could almost make the recommendation in terms of shift duties, or something like that, rather than in days of 24 hours.

HAMILTON: In other words, the question is: Do you go to work the next day that you're up, or do you skip a day? That's really the question. We could perhaps refine this.

BOVE: Yes, that's basically right. I'm sure they're using what's been established; and, depending on how the work cycles are designed in the Space Station, you could design your entire recommendation based on the shifts, which might be a better way.

HAMILTON: In fact, we were told yesterday that they would not be scheduled the next day for an EVA, but it might happen. And so, we would want to make our rule as little restrictive as we can, knowing that normally it will be a 2-day break.

BOVE: The one comment I'll make about this is that, there are an awful lot of data that are being presented among the diving meetings now indicating that people that get this problem actually have anatomic injury that's permanent in the spinal

BOVE: (Cont'd) cord. It's apparently small enough and not focal or localized enough, but diffuse, so that the injury doesn't show up clinically. But in postmortem examinations, at least in the small numbers of people that have been examined when the opportunities arise, clearly these kind of people have permanent anatomic damage to the spinal cord that's not evident clinically. So, I think that's sort of part of the driving force about treating these people different from others. If you have an anatomic permanent injury to a ligament, it's not going to bother you the way you do arithmetic. But here, if you have a permanent injury in an area of the spinal cord that's not detected, I think there's a little more conservatism injected into the recommendation. Part of it's now being based on this fact. We get strong evidence that, even when these are fully treated, that's not getting us all the way back to totally normal at the anatomic level. That's relatively new in the last few years, but it's raising a lot of important issues.

BUCK: Are those people that are prone to another neurologic hit? More so than others?

BOVE: It's not clear. The way I would say it is, as we discussed yesterday, there are some people that, if you look at them wrong, they get bent. That's one group of people. It's not clear that somebody that's had a spinal cord decompression accident who is fully recovered is more prone to get another spinal cord decompression accident. The thing that they may be prone to, though, is if they get another accident, this little bit of residual permanent damage added to the next set of permanent damage makes the clinical result much more severe. In other words, the spinal cord is capable of hiding small amounts of injury; it has what's called "plasticity"; it rebuilds the circuitry around the damage. But, if you keep damaging it, it's harder and harder to rebuild the circuitry. So these people may not necessarily

BOVE: (Cont'd)

be prone to another decompression accident, but if they get another decompression accident, they may be more prone to severe injury from a case. So, it's a little different issue, but that again builds in more conservative thinking here than if there was no permanent damage.

Now the other endpoint would be neurologic decompression sickness that has been treated and the individual comes out of the treatment with permanent residua. This could be after one treatment, two treatments, whatever it is you do; but, at the end of it all, there is weakness of a leg, there are pins and needles in the foot, there are problems with urination, there's some permanent residual effect. These people, in the diving business, are taken out of diving; commercially, they can't dive unless they burn their records and lie about it. They're basically recommended not to dive anymore. I think the reasoning is not necessarily that they're prone to more decompression sickness, but if they get it, they're going to have massive defects of the cord if they get more cord damage, because this would imply much more anatomic danger to them. These people may need rehabilitation. They don't necessarily have to be sent home; a lot of these are minimal defects, and they could stay on board and do their normal tasks. They might end up having to get rehab'ed if they have a weak leg or something like that; but I don't think they would require an emergency evacuation because they're hemodynamically stable. Overall, their general physiology is quite stable. And, there's not much else that you can do for them at that point other than rehab; and presumably, you'll have some sort of exercise capacity that can actually rehab these people on the Space Station and put them back to work.

BOVE: (Cont'd) Then again, that would be a very complex discussion amongst a lot of people on the ground and with the representative Medical Officer on the Space Station on exactly when to return this person to duty and how to manage that person on Space Station. Clearly, they would not go back to EVA, so you lose a crew member for outside work. But return them to duty when they're able, and again this might require rehabilitation. I would think that these people would have to wait at least 2 or 3 days after all this before they went back to any kind of duty.

So this is a guideline; this is based on what we've seen as a relatively carefully discussed consensus from a group of men in 1980. Again, I think we have to break down the relationship, if you just go on back to the regular task of Space Station and any part of EVA to a reexposure to attitude. These I think are only recommended guidelines and need some further discussion. But, I would make the point that individual cases are going to have to be decided upon by the Medical Officer in conjunction with whatever consultation is available, and it's not reasonable to try to make a case to cover every possible contingency.

BUCK: Just a question on the last case then. You say "no further altitude exposure." What if, hypothetically, you've lost this crew member as a potential EVA person. So, say, the next crew goes out EVA and you get someone bent and you have to bring them in. Could this guy go in the chamber as an attendant?

BOVE: Well, I guess I have to live with the rules the way we've lived with the Navy. The commanding officer decides what has to happen as the bottom line. If there's an emergency, and this is the only person left, then the commanding officer assigns duties to save the Space Station and doesn't worry about the individual. So, yes, I

BOVE: (Cont'd) think that guy could go back and do anything he has to do, even an EVA if necessary, for emergency purposes.

BUCK: But is that defined? If he were to go into a chamber for a treatment or as an attendant of another patient, is that defined as altitude exposure?

BOVE: Well, it would be the same problem. You're giving him a gas load and trying to decompress him from it, so he basically has the same problem. Again, if everything was fine, you'd recommend, "No, he doesn't get exposure."

HAMILTON: You mean, no further altitude or pressure exposure.

BOVE: But, I think the bottom-line rule for any operation like this is, the commanding officer of the Space Station, whose interest is survival of the Space Station, can make anybody do anything if necessary to save the station. So, this person could go back to anything he has to do if it was ordered.

PILMANIS: I'd like to address another emergency situation. We all feel that there's a very low possibility of serious DCS. If you go back to the original pre-breathe work back in World War II or post-World War II, they found that what pre-breathing really did in those studies was to reduce or eliminate the very serious symptomatology. It didn't do much for the pain-only type. If you increase the pre-breathing, it probably does something for the pain, too, but the primary interest was the neurological or circulatory type of serious symptomatology. I'd like to ask the question, is there a scenario in which pre-breathing would be skipped for EVA?

PILMANIS: (Cont'd) In this case, the possibility of a neurological hit climbs rather dramatically. Is that something that has been discussed, or is it even a possibility?

WALIGORA: There's a mission rule that says that, in a contingency situation, we should have a minimum of 2½ hours pre-breathe. That means that, if you have the need, you have to evaluate why you want to break that mission rule. You may need to, in which case you make that decision. But at least you have that mission rule, and that's still a substantial monster.

PILMANIS: That's still a lot of pre-breathing.

BARRATT: So you're asking about a possible scenario where something requires immediate decompression?

PILMANIS: Such as, 1 ATA to 29.6 kPa (4.3 psi) with no pre-breathe.

STOLLE: What about your 70 kPa (10.2 psi) to 29.6 kPa (4.3 psi)? That's better from a pressure excursion standpoint.

PILMANIS: I would say it's dramatically better.

BOVE: Yes, I think the point to be made is that the risk of no pre-breathing is more neurologic decompression sickness, where you can run the risk of very long-term disabilities. That is, you could put everybody out of business up there. Then everybody needs to know that pre-breathing is not only expedient from the

BOVE: (Cont'd) standpoint of general health, but it's expedient for preserving the operations of the Space Station.

PILMANIS: Because you raise your risk of serious symptomatology dramatically.

BOVE: That's right.

PILMANIS: Pain, you can tolerate in emergency situations.

BOVE: Well, I'm sure there will be a lot of bottles of aspirin up there. That will take care of it. But, it won't take care of neurologic deficits. So, that's the problem. I agree with that. I think, somehow, the concept ought to be fostered that pre-breathing is an essential component for long-term function of everybody and the whole unit. It ought to be done unless there's absolutely a dire emergency where things have to be done quickly.

PILMANIS: Survival is basically the main priority.

BOVE: Well, yes. You get to where, if you have a bunch of disabled or partially disabled people at the end of it, you're better off surviving with partial disabilities. But, I think on average if we have to treat anything, we certainly would like to be dealing with Type I patients for the most part, not any kind of major neurological event.

WALIGORA: When we looked at emergencies in Shuttle, at least – and I'm speaking for other areas – it's been hard to identify a scenario where you have to get out with zero breathing.

TRAUSCH: That was one of the baselines for the 57 kPa (8 psi) suit.

PILMANIS: Yes, but was that for emergency reasons or for practical reasons?

TRAUSCH: That was for practical reasons, because we didn't have any emergency scenarios.

WALIGORA: Most of the emergency scenarios really give you a certain amount of time to decide how you want to deal with them. In most cases, you want to take some time to prepare.

BOVE: Let me go on now. The other thing I was supposed to talk about is treatment of decompression sickness. As I mentioned at the beginning, there is an awful lot of discussion in the diving area to get rid of the Type I/Type II classification. There are a lot of in-between cases that don't quite fit, and there are a lot of things that people would like to have that are a little more detailed. In fact, there are some efforts going on right now at developing a new classification scheme that is much more complex; it's almost like hospital codes for diagnoses. It's a very long, complex list for diagnoses, but one that is more accurate for the diving medical or other medical officer in terms of the way he deals with the patients. But, I think we're still in the era where we look at minor and major, or Type I and Type II, or limb and neurological, or whatever you want to call it. There are still two kinds of classifications that we deal with; and, no matter what I do or what anybody else does, this thinking still evolves into everybody's approaches to things. So, I made this long excuse up here, but the fact is that I still have to talk about Type I and Type II decompression sickness because I think it still helps us to understand where we go with it.

BOVE: (Cont'd)

Remember, what we normally define as Type I is considered to be nonsystemic decompression sickness. It's usually considered to be involvement of a component of an extremity, and I'm not sure yet we know where it is, but at least probably involving a joint in the area of the tendons or ligaments that produces pain and occasionally a little swelling or some swelling of the joint. The pain can often at times limit motion of the joint, but it's local. It does not get into a major systemic involvement. Now, if you go back with Doppler and look at people with Type I decompression sickness, you usually hear precordial bubbles on your Doppler; but they're not of significant magnitude to demonstrate any major systemic reaction. And the concept there is that the body can handle a certain amount of air, or gas, before it starts to demonstrate a systemic reaction. There's a reserve process in there that allows it to handle that. What you usually call Type I is pain of a bone or a joint – usually a joint – and it's often in the joint that's being used a lot during the exposure, which is interesting; and it's usually, in fact, I think by definition, *not* associated with any evidence of systemic involvement.

There is sometimes itching, and there are sometimes cases where skin mottling may be found. The skin mottling is an interesting issue because some people feel that skin mottling goes beyond Type I and starts to bring us into Type II decompression sickness, so there's some controversy about this sort of bluish, patchy mottling of the skin. I think most people would consider that more than just plain old Type I.

Serious decompression sickness is anything else. It's commonly manifested by injury to the spinal cord in, let's say, the air-diving community, which most of us see because it's the largest amount of diving. I think people are beginning to

BOVE: (Cont'd)

characterize spinal cord decompression sickness as the short bounce-dive type decompression sickness, whereas limb bends is the long, shallow exposure, almost saturation-type of decompression sickness. When it gets very severe, there's a whole progression that appears to be related to the amount of gas that's released. This goes from a small focal injury to the spinal cord to enough gas in the systemic circulation to start showing abnormalities of lung function, which has classically been called "the chokes." Here, there's gas embolization to the lung that is obstructing pulmonary vascular flow. The patient begins to get short of breath and cough and has some other things that show evidence of the lungs being embolized.

Total circulatory failure can occur as massive amounts of gas get into the circulation. We're beginning to understand now that, whenever we see this spinal cord syndrome, we'd better look hard for brain abnormalities. There's more and more evidence coming that there are several brain abnormalities that aren't often seen clinically. The reason we don't see them clinically is most of us aren't clinical psychologists; we're used to doing things like rapping on knees with rubber hammers and testing for sensory abnormalities. And to find brain injury in its subtle forms, you often have to do complicated behavioral testing. Many places now in fact are doing behavioral testing as part of the routine analysis because it's showing up that there is more brain injury than we used to think. This is another conflict that's more or less evolved over the past probably 3 or 4 years in diving.

Now in altitude, there has been this sudden unconsciousness syndrome that's been considered decompression sickness for many years that I think is probably

BOVE: (Cont'd) brain involvement. I'm not sure I understand it, but there's been more of a propensity for the brain to be involved in decompression sickness from altitude exposure. The point is that, Type II is neurologic or systemic injury, including devastating shock-like syndromes and, at the other extreme, pins and needles in one toe. So, there's quite a spectrum of Type II. But, it's clearly beyond what would be called "something just in the joint."

Now, the classification of these two goes beyond clinical identity, because the treatment of them has been, to some extent, divided up based on the classification. In the environment of Space Station, I think we're going to end up recommending pretty much the same treatment for all of these; that's the 285 kPa (60 fsw) air-oxygen treatment table. But, I would still throw out at least the possibility that, for pain-only, one might consider a radical change in the approach to treatment; that is, using something less than 285 kPa (60 fsw), even a 193 kPa (30 fsw) table that obviously would have to be developed. I can tell you that the radicalism is not unwarranted, because we're doing that in air embolism in diving right now. The old Table 6A, a 165 fsw table, is slowly being challenged with 285 kPa (60 fsw) treatments for air embolism, and that appears to be working. So, I think it's reasonable to challenge 285 kPa (60 fsw) for an uncomplicated limb bend.

NORFLEET: Just one point interjected: Since this is altitude DCS, would you like to fit oxygen breathing at cabin pressure into your comments as well? Is there any role for that in treatment?

BOVE: You mean, as far as treatment of pain-only that resolves with just return to cabin pressure? Yes; but again, I'm not ready to make a rule about that. But, Andy and the Air Force group are saying that, it's common to do post-breathing even though the symptoms have gone away. And in the diving industry, we commonly would treat a limb bend that has no symptoms if it was documented. A lot of times somebody may get a limb bend, and by the time you get to the chamber the pain is gone, but we still treat them. Now we don't treat them with oxygen, because the diving business is a chamber: you put them in and squeeze them. That's one of the times somebody might use Table 5 in particular with no symptoms. So, some sort of active treatment on return to cabin pressure without symptoms is warranted. The question is, what is it? I'm not ready to say what it is. But, obviously it would be oxygen-breathing for some period of time.

HAMILTON: How do you guys feel about that?

WORKMAN: The procedure that we use in the Air Force, especially if we do not have a chamber on site and we've got simple pain-only bends, is to administer 100% oxygen at ground level for 2 hours. I don't know the percent resolution on it now, but it's been very successful. We still go ahead and make arrangements for transportation; if the pain is resolved within that 2 hours, the transportation is canceled. If he's still symptomatic at the end of the 2 hours, we go ahead and transport and treat. We *do* have some experience in using a 193 kPa (30 fsw) treatment depth for simple pain-only bends, that is reported within a 2-hour period. I don't remember the N of it, but it was 100% resolution.

PILMANIS: Eight or nine cases.

WORKMAN: Yes, it's not a huge number; but, again, it was used very successfully.

BOVE: I would at least throw out for discussion the idea that an entirely new approach to simple altitude limb bends be considered. Particularly in the environment where your gas supply is limited and the operational aspects of running the chamber at 285 kPa (60 fsw) are more complicated, you could propose that a depth-of-relief table or a 193 kPa (30 fsw) table would be quite reasonable for an uncomplicated altitude like limb bend where you had to go beyond just breathing at cabin pressure. I don't know where you'd go to do that. I think probably the most likely place to do a clinical trial would be in the Air Force where you've got a lot of altitude bends. I think it would be quite justified to develop a protocol for randomizing a group of people to treatments and looking at the results. I don't think NASA could do it at this point, because there are not enough cases, but I think you guys could do it.

PILMANIS: Well, as I think I mentioned yesterday, we *do* have a chamber immediately next door. These are research subjects, not operational situations; but last year, we studied 77 DCS cases. Six were treated with hyperbaric treatment; 71 were treated with 2 hours of post-breathing; none of them had any problems. Not *all* of those 71 cases had resolution of symptoms at ground level. Now the rule is, if they don't have resolution, they should be treated with hyperbarics, but that didn't happen in all cases. I don't know what your numbers here are on post-breathing; how many times you treat with hyperbarics and how many times you post-breathe.

WALIGORA: We haven't had very many folks with pain that's been extended past sea level, and I think we've treated them unless it was only a minute or two.

PILMANIS: You treated them all with hyperbarics?

WALIGORA: In fact, that was a small number.

WORKMAN: As Andy said, in the majority of the cases where there is chamber on site, we'll go ahead and treat them.

WALIGORA: You see, we've only treated about eight people, and about four of them were for simple limb bends and four for presumed Type II.

PILMANIS: It is not clear whether the 2-hour post-breathing is technically called a treatment or not. Obviously, it *is* a treatment; but procedurally, some people view it as a medical treatment, some people do not.

WORKMAN: In our interest, to capture those data in our reworking of some policies, we are going to be classifying that as a medical treatment.

BOVE: Yes, I think you should.

PILMANIS: It has not been classified?

BOVE: No.

HAMILTON: Can this be done in the Station without dumping the oxygen overboard?

NORFLEET: You can do it in the suit.

HAMILTON: Do you have to do it in the suit? Can't you just unplug the thing and expire into the Station? Because that much oxygen in the whole Station, if you had a way of keeping it moving so it doesn't pocket, would not be a problem and you'll breathe it down in 2 hours.

NORFLEET: In reality, when you do the calculations and assume uniform mixing and the like, that is true. It's not a problem. However, procedurally it would probably cause an institutional fire storm.

HAMILTON: If you have to throw that oxygen away, you might as well go ahead and give them a definitive treatment with pressure.

BOVE: If you can sit inside the chamber and put them on the BIBS at cabin pressure, it seems to me that's a heck of a lot easier than running a treatment dive.

HAMILTON: It isn't going to be needed very much. Maybe we're not talking about a big loss of storage.

BOVE: The ideal thing would be to have a BIBS setup so we can run at cabin pressure with an overboard dump and have the ability to treat from cabin pressure up to 285 kPa (60 fsw) above cabin pressure.

STOLLE: That exists right now. And also, the pre-breathe masks and the emergency-breathing masks are all dumped to cabin.

BOVE: They all dump to cabin? The pre-breathing masks dump to cabin, is that right?

STOLLE: Yes.

BOVE: Well, that's the way you should do it. It seems to me that you're just using procedures that are already built into the system as part of the spec now, which I think is really the best way to do it. I'd still at least raise the issue of doing a shallower table or even a depth-of-relief table for limb bends that would be sort of an interesting thing to do for the diving industry as well. Let me go on so we can get done quickly.

The statement here is: "All forms of decompression sickness will be treated with pressure, oxygen, and fluids." And, I think that, as a good general statement, return to whatever pressure gets rid of the pain is probably useful. A return to cabin pressure may be all you need. Oxygen should always be injected into the treatment as well as fluids. Now again, there's no need to start an IV in somebody that's got no pain and you're going to put him on an oxygen post-breathe for 2 hours. But, you certainly should give him a jug of something and say, "Drink this liter of water between now and the end of the treatment," because dehydration is one of the things that sort of augments the problem of decompression sickness. This is the simplest triad of treatments that one can go through. There are many cases of ground transportation where oxygen and fluids were applied and the individual became asymptomatic during that time.

BOVE: (Cont'd) So, I think the bottom line always should be pressure, oxygen, and fluids. Those are the three things. Where you go with pressure really depends on the individual. Again, pressure in this case could be just return to cabin pressure.

Type I, at present, is usually treated at 60 fsw, or 285 kPa (41.4 psi). I still challenge this approach in this environment. I think you could probably get by with some new ideas on this, but right now that's the standard treatment. We've already discussed the idea of this Navy Table 5 and Table 6. Table 6 is becoming standard treatment, as I think yesterday it was mentioned, and we probably ought to do that if we make the decision to treat because of the possibility of occult neurologic problems that we at least make an effort at treating during this time. For anything beyond simple limb bends, neurologic decompression sickness is still treated with the same table; that is, the 285 kPa (60 fsw) air-oxygen table with the possibility of extensions. The outline of the table was drawn in the first handout we got from yesterday morning. This is again at 60 fsw or 285 kPa (41.4 psi) above cabin pressure. It's got the ability to prolong the table because of response to treatment or prolonged symptoms, and it has a break breathe from the 193 kPa (30 fsw) and can be extended out. Bill was talking about the problems with the tenders in particular; the subject being treated doesn't have a problem because, by the time this is done, I don't think he has any free molecules of nitrogen left in the body, but the tenders obviously have the problem with prolonged exposures to 285 and 193 kPa (60 and 30 fsw), as Bill has been working on.

I think we can still say that, if you can get to the person within a couple of hours, you can get 80 to 90% recoveries in the treatment of decompression sickness. In

BOVE: (Cont'd) this case, it's going to be much sooner than that because you've really got a very nicely captivated audience here, so it's likely that you're going to be treating these individuals within 25 to 30 minutes of the accident unless there's a delayed onset; that is, the person comes back and starts to show symptoms 10 to 12 hours later. But from the onset of decompression sickness, if you have short periods of time before treatment begins, the recovery rates here are very, very good; they should be above 90%.

If the person deteriorates under treatment, this would be a fairly serious case most of the time. The strategies for the most part are to go deeper or stay longer at 285 kPa (60 fsw). Going back to the surface on these deeper excursions, etc., is complicated and there are some protocols to do that. But, in the environment in Space Station it's not going to be easy. You'll probably go to 70 fsw; I think the chamber specs will allow you to go deeper.

HAMILTON: We can go to 345 kPa (80 fsw), actually.

BOVE: Eighty feet? Okay, 345 kPa (80 fsw).

HAMILTON: Not that it's going to do any good.

BUCK: At 80 fsw, which is equivalent to 345 kPa (50 psi), your relief valve is fully open. So it cracks at something actually less than that.

HAMILTON: So, you won't even be able to get to 345 kPa (80 fsw).

BOVE: What I'm saying is that the common strategy of the diving medical officer follows this: Somebody either is not getting better or deteriorates under treatment. The common strategies are to go deeper and stay longer. That is *not* to bring the patient out of the chamber, but to go deeper and stay longer and try to control the symptoms.

HAMILTON: The situation we *could* find, especially with a horrendous embolism situation is, we really can't leave 285 kPa (60 fsw). There's not going to be a lot to be gained by that little additional pressure.

PILMANIS: No, you need the oxygen, 100% oxygen.

HAMILTON: Well, you could still breathe 100% oxygen. You'd have to use something like 15-minute cycles to reduce toxicity, and you wouldn't know where you are because we don't have any experience of that sort.

BOVE: No. I'm just stating that that's the common strategy, to go deeper and stay longer.

HAMILTON: But we do need to have in our protocol an ability to stay, because we may get somebody there we just can't get out.

BOVE: Twenty-four hours to stay?

HAMILTON: Or maybe longer, at 285 kPa (60 fsw). It's not likely to be beneficial to stay much longer than that. But then you've got a tender problem, too.

BOVE: I'm bringing up the issue because that's the common way we would treat somebody that's either getting worse under treatment or not getting better. Now, this raises some interesting issues. The environment here is not the same as on the ground with the hyperbaric chamber. The environment is much different; and the question is, what is the diving officer's decision? Now again, there is going to be a lot of conferencing before any decisions are made about somebody who's already been in the chamber for 4 hours and is not getting better or is deteriorating. There's going to be an awful lot of talk about what to do about it. But, the standard strategy is to stay there. In any treatment where you're trying to control bubble growth or get rid of bubbles, one of the things not to do is to come toward the surface, because that will clearly make the person deteriorate.

Many times, if you really can't get a diver to come to surface, you could basically write that diver off because, if he's already getting into trouble at 285 kPa (60 fsw), he's going to get into bad trouble coming to the surface. So somehow that discussion needs to be thrown in the soup. What do you do if you have a bad case of something where you get the person to 285 kPa (60 fsw), get a little bit of control, but not as much as you want, and you're waiting things out at 285 kPa (60 fsw)? You're kind of soaking at 285 kPa (60 fsw) in a sense, and you don't have control of that person at the end of all the prescribed cycles. Where do you go from here? You've come to 193 kPa (30 fsw), and the guy deteriorates clearly. I think it's been tried many, many times.

There *are* protocols. The Navy has a Table 7 that gives you a way to come out of the chamber after you've been there for 8 or 12 hours at 285 kPa (60 fsw). The key is: It's easy to sit at a given depth for as long as you want. The trick is: How

BOVE: (Cont'd) do you get out of it? That's the real trick, to get out of there safely with an injured person and get your tenders out. There are protocols for coming back out of long exposures. Maybe Table 7 is one.

HAMILTON: But we also have the possibility of being able to dial up the particular situation on electronic format and deal with that. And that's really what we should go for.

BOVE: I don't know what the answer to this is. If you have somebody that was in big trouble and you got some stability at 285 kPa (60 fsw) and ran out of all your extensions, the question is: What do you do? If you start up toward 193 kPa (30 fsw) and the person gets worse; and, as soon as you go back to 285 kPa (60 fsw), you're better again, you're sort of stuck there. And, the standard strategy is to stay for what we call a "long" soak or a "saturation" and then try to come back out.

HAMILTON: What you do is you stay at that pressure. You're not breathing oxygen now for a period of time, because you've used up that individual's lungs. So you need a 12-hour break, and then you go on oxygen. It's somewhat as it is in here for your maximum worst-case situation, except that you don't have the reduction of pressure and then go back; you stay there. You wait 12 hours, then you breathe another regime of 6 cycles of oxygen.

PILMANIS: There is the other option; you can extend at 285 kPa (60 fsw) out to eight 20-minute oxygen periods and out to 18 20-minute oxygen periods at 193 kPa (30 fsw). We've done that for 12 years very successfully. It is *not* a standard Air Force-, Navy type of procedure, but it's done in a lot of civilian chambers very

PILMANIS: (Cont'd) successfully. We chose that over any kind of saturation or any kind of *increased* depth because we didn't feel that increasing depth was going to do anything except bend the tenders ultimately. And, we did not want to leave the 100% oxygen. You can continue 20-minute oxygen periods and 5-minute air breaks for a total of 12 hours.

HAMILTON: And, then you need a break off of oxygen.

PILMANIS: We used a 12- to 24-hour break and then went to Table 5's.

BOVE: In fact, the Navy has a formula for running a 36-hour Table 6 in a sense and on how to come out from that. It's Table 7.

BUCK: When you're talking about a long exposure like you were just speaking of, is your treatment completed after that long exposure? Or do you follow it up with further treatment?

BOVE: The answer to your question is that, in this kind of situation, if you get the diver to the surface, by the time you finish this long treatment, you've got him stable on the surface. You may have residual, and that's what you would treat. But, basically, hemodynamically, he's not in shock anymore; he doesn't need a ventilator; and you've got him to the surface talking and breathing on his own so that you don't have to keep him at pressure. The decisions of going back to re-treat, to try and improve the residual deficits, are different issues.

PILMANIS: And, that's where your oxygen toxicity enters.

BOVE: Yes, that's right.

PILMANIS: We had about 10% pulmonary oxygen toxicity on those patients. Ten percent isn't bad, and you can deal with it.

BUCK: The reason I asked is because, we'll have a certain amount of consumable and how we budget that may be flexible. We could potentially go for a long exposure; the only thing I can think of is problems with that the HECA and the molecular sieve bed can't handle. They build up residual CO_2 and humidity that *they* can't get rid of. That's why these rest periods that are right now in our worst-case scenario are needed. We need those rest periods to get rid of residuals in the molesieve bed, etc.; so there are some reasons, aside from just consumables, that a long exposure like that might be problematic.

BOVE: Well, I don't think there's any way to plan for a long exposure. The likelihood of that is very, very low. It seems to me that, if a person required that, there would have to be a lot of discussion amongst the engineering people on the Station and the ground on how to accommodate all of the factors, because obviously, air-rest periods can be built in here. You actually *do* have the ability to lock back and forth, although that consumes air whenever you do that, to move people back and forth. But, if the chamber were held at pressure with the initial gas compression, it seems to me that your major consumable would be the oxygen that's being breathed. If your HECA system is working well, basically these folks could stay on at that pressure for quite a long time.

STOLLE: There is no man lock.

BUCK: Only medical equipment, through that small pass-through lock.

HAMILTON: That's why we're developing excursion exercises.

NORFLEET: You've got a crew of four, limited consumables, and the option, at some point, of transporting to get help on the ground. The line for planning purposes in terms of consumables needs to be drawn somewhere. We drew the line philosophically this side of saturation therapy.

BOVE: The consumables here would be mainly the HECA and the oxygen. But, somebody would be making a very tough decision if every time you came from 60 to 50 fsw, the victim went into shock and stopped breathing. The question is, who's going to make that decision if you're going to kill the person when you start to come to the surface?

Nitrogen Elimination At Altitude

BARRATT: I'd like to move on to Dr. Pilmanis, who will present some of his work in nitrogen elimination at altitude.

PILMANIS: I was asked to address the issue of nitrogen elimination at pressures lower than sea-level ambient. First, in response to the question of reducing the pressure on station. Resetting the thermostat to 70 kPa (10.2 psi) gives me a warm feeling as far as DCS hazards for EVA, because it's going to reduce the risk. The work was done here at JSC to verify this, both experimentally and mathematically, and I

PILMANIS: (Cont'd) think Jim Waligora covered this somewhat yesterday. I might add a couple of things on the first part of the procedure; i.e., going directly from sea level to 70 kPa (10.2 psi) and the production of microbubbles or any bubbles. Using echo images, we've recently done this on 100% oxygen. No DCS was seen in any of this. The exposures were 4570 m (15,000 ft) to 6100 m (20,000 ft) for 6 hours. Figures A and B show a nice curve for VGE limits. At 70 kPa (10.2 psi), it's unlikely that you're going to get any circulating detectable bubble. Figure C shows the comparison with breathing on a 50% oxygen/50% nitrogen mixture.

Another question that could come up is whether denitrogenation at a higher altitude or a lower pressure is as effective or different somehow than at ground level. Almost all databases that we reference this information to are at sea level; e.g., saturation at sea level. We have very little information on resetting the thermostat to a higher altitude, as far as the basic processes are concerned. We recently completed another study that verified what a lot of people thought was probably true; denitrogenation at altitude is as effective as at ground level. The endpoints were VGE with echo imaging and clinical DCS. We used 1 hour of pre-breathing and 2 hours of pre-breathing. As you can see in FIG. D, the incidence of venous gas emboli is around 80% for 1 hour pre-breathes and 53% at 2 hours of pre-breathing. The pre-breathing was done at 2440 m (8,000 ft), 3660 m (12,000 ft), and 4880 m (16,000 ft). It appears that we actually had a decrease in DCS with the 1-hour pre-breathing at 4880 m (16,000 ft) versus ground level. It was not statistically significant. There's no change at 2 hours and I wouldn't expect any change with the 4-hour or the longer pre-breathe. I think the bottom line here is that pre-breathing at altitude is probably just as effective as at ground level, up to 4880 m (16,000 ft) That principle can be used at this point.

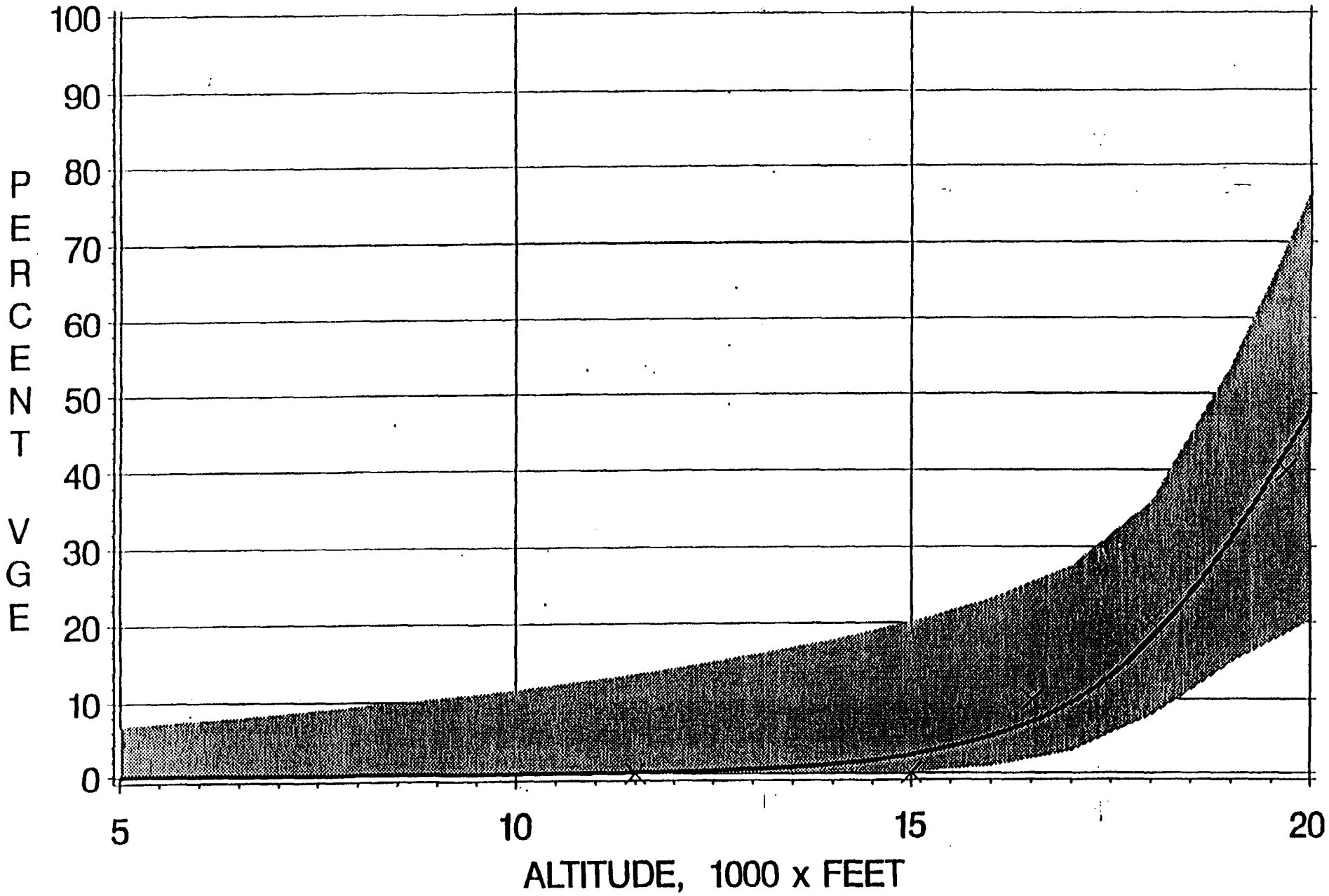


FIG. A Percentage of subjects with incidence of severe VGE (Grades 3 and 4) while breathing 100% oxygen

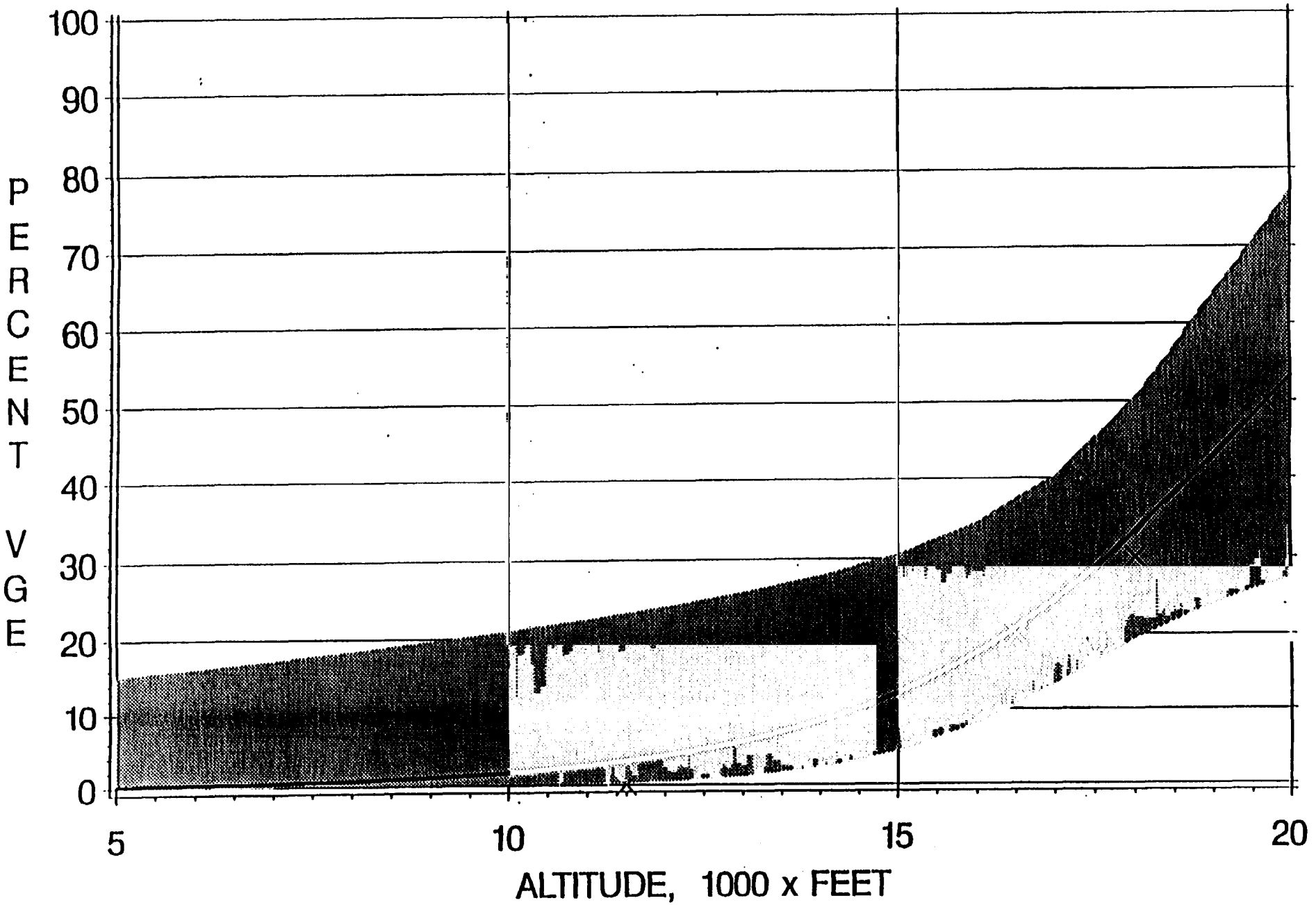


FIG. B Percentage of subjects with incidence of any VGE (Grades 1 through 4) while breathing 100% oxygen

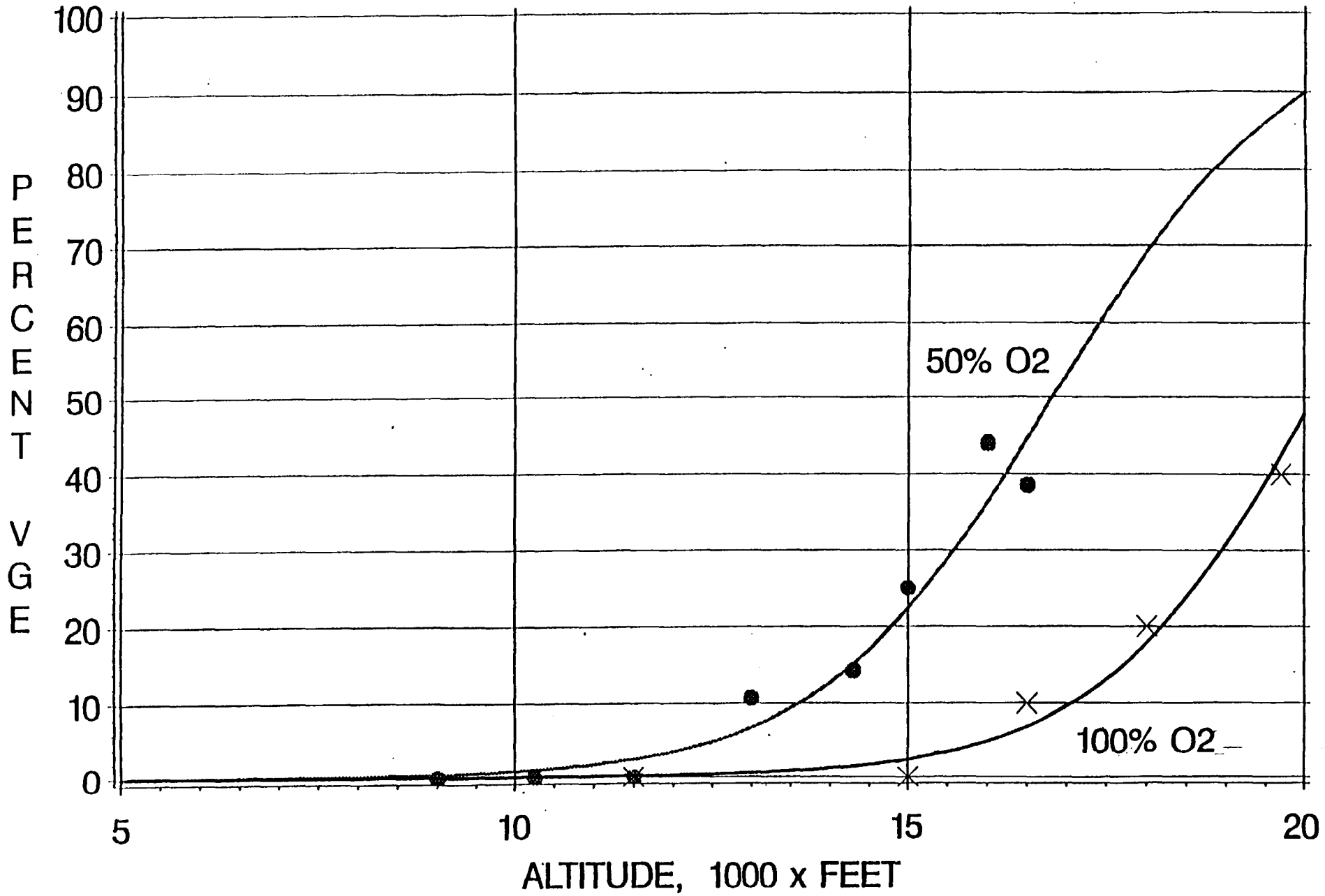


FIG. C Severe VGE incidence during exposures with a breathing gas of 50% oxygen/50% nitrogen versus 100% oxygen

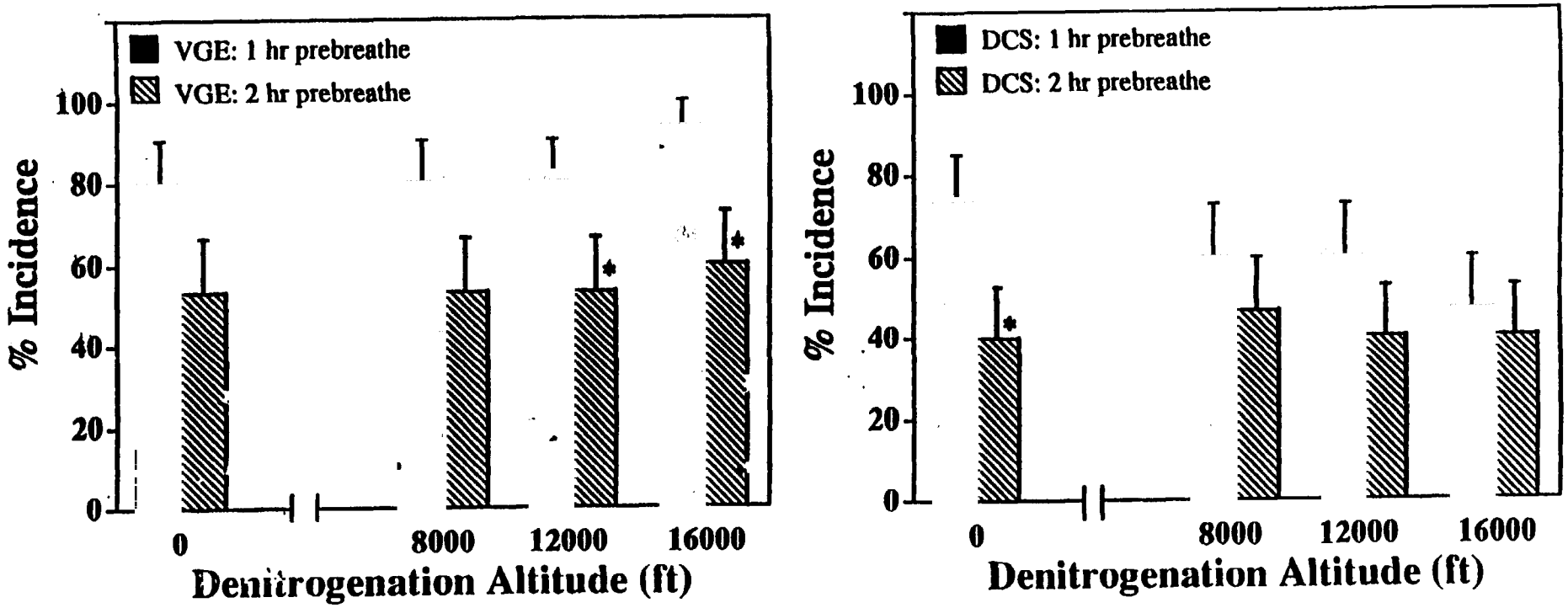


Figure 4

VGE and DCS incidence for a 4 hr exposure at 29,500 ft.

* denotes significant difference ($p \leq 0.05$) between 1 and 2 hr prebreathe at the same altitude.

(Values are mean ± SD)

FIG. D The effect of in-flight denitrogenation (pre-breathing) on altitude decompression sickness risk

BARRATT: Is it any more effective at 4880 m (16,000 ft)? You said that you had some decreases. Is this representative of the data that you have thus far?

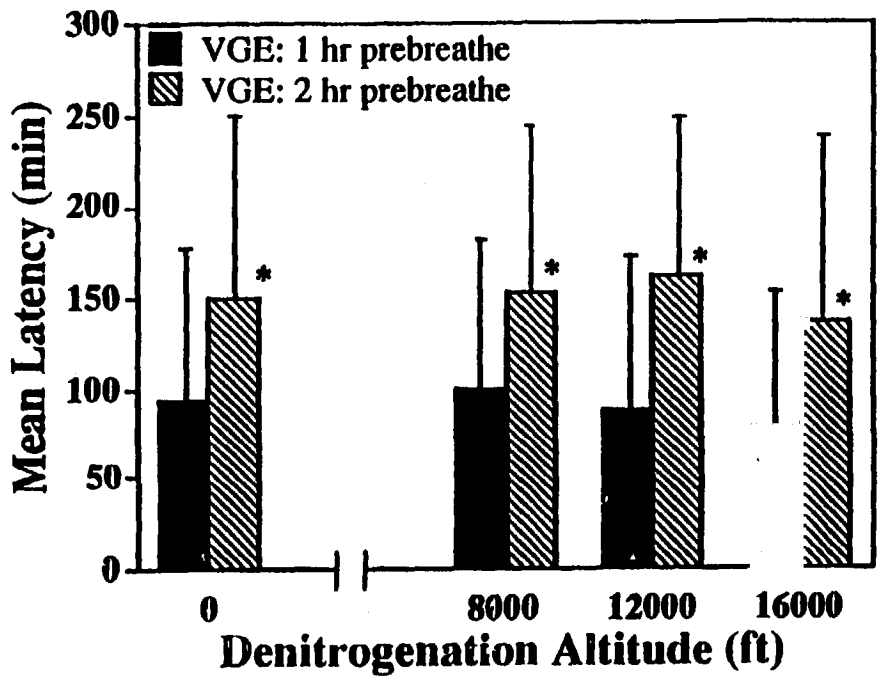
PILMANIS: Again, it appears to be, but it was not significant. In FIG. E, we can look at it in another way. This is from what Eckenhoff defined; this is onset of time symptoms or latency. That was statistically significant between ground level and 4880 m (16,000 ft); that is, at 4880 m (16,000 ft), you pushed back the onset of symptoms significantly. We are reactivating the study. It's important enough to try and find out if, indeed, you get a better picture by pre-breathing at altitude. At this point, I wouldn't want to state that; but, if that's true, that could be very useful, at least for the Air Force.

HAMILTON: Are you going to go a little higher with this pre-breathing?

PILMANIS: Yes, we're doing 5490 m (18,000 ft). Preliminary data show a large increase in DCS and VGE incidence; 4880 m (16,000 ft) may be optimal.

HAMILTON: Because I remember some earlier work that MacGiver or at SAM did, particularly pre-breathing at 6100 m (20,000 ft).

PILMANIS: That was Marbarger. He used 6100 m (20,000 ft), 6700 m (22,000 ft), and 7620 m (25,000 ft), I believe; but he didn't use very many subjects. However, the trend was there. Actually, you can go back to World War II and find some very good data to verify this concept. The trend was there, but obviously they didn't have echo imaging. This is very useful for certain air operations. It allows an airplane to get off the ground without sitting on the ground pre-breathing.



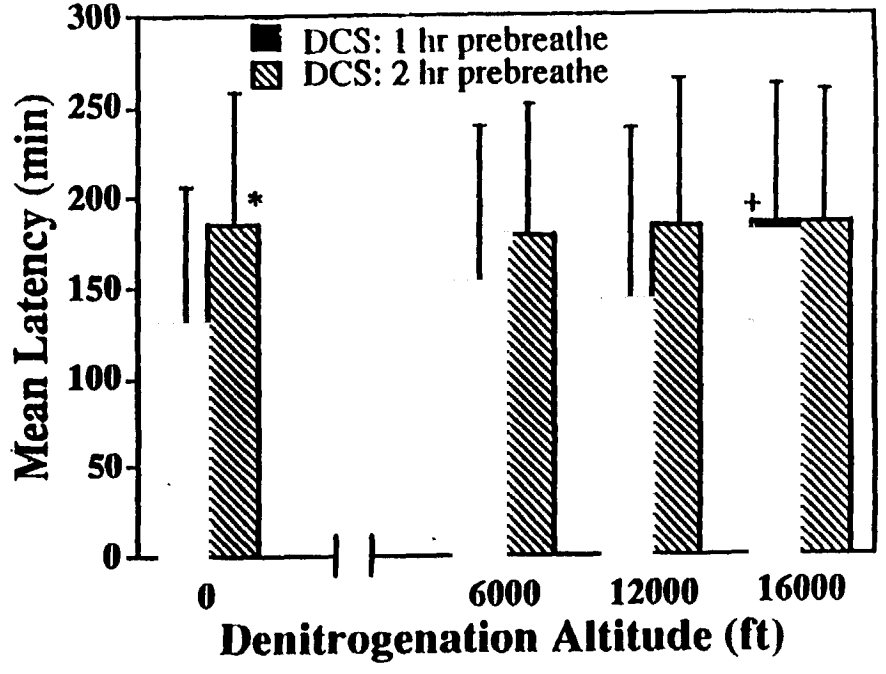


Figure 5

VGE and DCS latency for a 4 hr exposure at 29,500 ft.

* denotes significant difference ($p \leq 0.05$) between 1 and 2 hr prebreathe at the same altitude.

+ denotes significant difference ($p \leq 0.05$) between 1 hr of prebreathe at altitude and 1 hr at ground level.

(Values are mean $\pm$ SD)

FIG. E The effect of in-flight denitrogenation (pre-breathing) on altitude decompression sickness risk

BARRATT: Okay, thanks very much.

It seems safe to conclude then that pre-breathe is as effective at our ambient Station pressure as at sea level.

Hyperbaric Treatment Mask Issues

WORKMAN: This is really going to be more of a a show-and-tell for the first part, and then we'll open it up for general discussions. Was anybody able to bring some of the examples of masks that are currently used or planned?

BARRATT: I could not get hold of the person who's holding the Magic mask.

WORKMAN: Okay. What I'm going to throw out here quickly are just some representative examples of some mask types that we use in our program. Some of you may be familiar with some of these; perhaps some of you are not. I'm not necessarily going to talk about the relative merits of these mask types, because we all have our favorites. But, I did want at least to give you an opportunity to see some that, perhaps, you might not have seen in the past. Scott overboard dump: There are two types, but this is pretty much standard. You can see that it is an overboard dump mask. Quite a heavy assembly; and, my personal opinion is, it's not very user-friendly, even though I said I wasn't going to comment on the pros and cons.

HAMILTON: It will take a lot of beating. Those things are made out of stainless steel beer cans and you can't damage them.

WORKMAN: At shallower depths, you have to have vacuum assist on these, however. It works strictly off the delta-P; and, if you get to the shallower depths and do not have a vacuum assist, then your overboard dump is going to be a tremendous amount of work.

HAMILTON: Those are demand valves just like a scuba valve, with one of them turned around backwards.

WORKMAN: Yes. This is an old Air Force MBU-5P face shield, double-sealed oral-nasal mask used in the aviation community for many, many years. We took it; and we adapted it for hyperbaric use by adding an oxygen overboard dump assembly and head strap assembly. Again, it's worked well. It's got its limitations as well.

HAMILTON: What's the black?

WORKMAN: That's your collection bag for your venturi for overboard dump. Your exhalations go first into the bag.

HAMILTON: So, it can go out slowly? You don't have to have a big hose and high pressure?

WORKMAN: Yes.

REIMERS: With respect to that mask that's going around: Several years ago in our shop, when they were still dealing with the single hole in the front, we found it possible to take those two regulators and combine them into one, make the whole thing out of plastic, and have it work just as well and weigh almost nothing. I have a working model of that, that we use for a paperweight. You can take a lot of the weight out of that thing if you have a mind to.

WORKMAN: The Air Force has come out with an MBU-12P that is an integrated hard shell, but again another double seal on the oral-nasal mask used in the fighter community. It has also been modified with a slightly different version of the overboard dump, but it also has again the same basic performance characteristics. It's a little more comfortable because of the difference in the design of the face form itself and the restraining assembly. This was modified at Wright-Patterson and is used in the hyperbaric chamber at Wright-Patterson. One thing that is common to all the masks that I have here is that, there is – with the exception, perhaps, of the French mask – no built-in intercom. We have sacrificed the mike port for the overboard dump in these modifications. Now, there is another mask that's in use at several research labs, and this is the French Intertechnique mask. And I guess, Mike, this is similar to the MAGIC mask.

STOLLE: That's the hood that's used. The major difference is that the restraint is a quick-donning type of restraint, where you grab the nasal section and press in some levers, and this restraint inflates. You slip it over your head and then you release them, and it clamps down on your head. It's a very quick-don type of mask.

NORFLEET: One hand, quick-don?

STOLLE: Right. But, it's got no overboard dump right now.

PILMANIS: This is not a quick-don mask.

STOLLE: No.

WORKMAN: That is not, and that does not have overboard dump capability, I'm sure.

HAMILTON: What is in this overboard dump rig here? Or does it matter?

REIMERS: It's just a venturi.

WORKMAN: A very expensive venturi, I might add.

Now I know this really is not in the running, but it was discussed earlier and, again, for those of you who've not seen what a Sea-Long hood assembly is, I brought one for you. Very comfortable for long-term wear; but, again, you pay a penalty with your consumables here. An awful lot of gas is required to operate this system. However, there's nothing that says that it has to be this big.

HAMILTON: Well, you could also recirculate the gas.

WORKMAN: Yes, as we had discussed before. Now, I don't have a complete prototype with me, but this is the new face form that the Air Force did not adopt, but it was a clear close competitor to it for the new advanced tactical fighter system; the Combat Edge mask, as it's commonly called. Now this particular mask has again a

WORKMAN: (Cont'd) different profile: very comfortable for long-term use. Right now, we're beginning to modify it for hyperbaric applications because we can do away with that overboard dump assembly. We've got the overboard dumping that can be integrated into this without the venturi, and you maintain your intercom capability. We are even interested in this perhaps to be able to incorporate both the oxygen supply and the overboard dump into a single hose so you can eliminate one of the hoses from that.

HAMILTON: It's not concentric?

WORKMAN: Yes.

STOLLE: So what you're saying is that, your patient or other person breathes in and out of that one hose?

WORKMAN: Yes.

STOLLE: And so the overboard dump part of it is actually enclosed in your gas system?

WORKMAN: Yes. I've got a test plan and I'll make additional copies. This is a test plan just for your information that our folks will be using in the very near future to do a little further work on this mask. Now the interesting thing about this particular system is, with the exception of combining the oxygen and the overboard dumping valve, all of the parts are existing in the inventory right now. It's just a matter of assembling them together into a workable system.

HAMILTON: This has a relief valve on it. It looks like this was made for aircraft with two hoses. Why did they need two hoses?

WORKMAN: I was not involved in that. I don't know.

HAMILTON: Have you looked at the British mask?

WORKMAN: No, I have not.

HAMILTON: They have one thing, just looking at the mask, that looks attractive to me; that is, that the hose comes off to the side. It's not on a long lever arm sticking out in front trying to pull your head down and disrupt and seal. It may be something to think about if you're actually getting to the point of designing something.

WORKMAN: One of the reasons that we started trying to go with this modified Combat Edge mask was again to eliminate the requirement for that overboard dump assembly. Because, to replace those, it's about $1000 a copy for that little piece. Anyway, basic functional requirements of the mask as presented in JSC-31013, are a mask with the ability or BIBS ability to provide 21 to 100% oxygen, overboard dump capability, and an issue that is only addressed by the MAGIC mask or, at least, the French mask that we have here in the *hood*, is the element or the requirement for eye protection. I have to be honest; I don't recall us discussing that when we met a couple of years ago, as that being one of the requirements. Was that recently added?

NORFLEET: Yes, that was. That was added in Rev. C of JSC-31013.

WORKMAN: Now, some of the other issues, of course. Fit: One size fits all. Long-term comfort. Again, weight: In-use weight is not necessarily the problem; but, of course, the overall weight of the mask is, I'm sure, of vital concern for just the overall contribution to the weight of the airlock itself. Are there any other issues that anyone would like for us to discuss on line right now?

BARRATT: Where you have a question mark, we are to design to accommodate the 5th percentile Oriental female to the 95th percentile Caucasian male.

WORKMAN: Have fun!

NORFLEET: Individually fitted masks, preflight, in the absence of facial hair.

BUCK: How are you going to use individually fitted masks, though, when we have a requirement for three masks? We stow those three masks in the equipment lock; you don't know which three crew members those will be unique to.

NORFLEET: You're probably going to have to bring up a shell, a subassembly, because it takes two to make a mask seal. You've got the mask and you've got a person's face, and realistically now I'm talking budget talk; but it seems to me that realistically there is no way that you could get one mask to fit everybody from the 5th percentile Japanese female to the 95th percentile American male. If you can, that would be a great seller.

WORKMAN: That's a very difficult thing because, in many of our female flight nurse DCS cases, we've had to jury-rig the mask. We've had to pad here and pad there, and

WORKMAN: (Cont'd) build up the nose bridge. That's one reason we really like the Combat Edge mask because it is more adaptable to facial contours than are the earlier generations of the mask. With it being a semisoft shell as opposed to a hard shell, it's really much more advantageous for us to make those modifications. Personally, in our program I'm excited about being able to go to this type of system.

NORFLEET: So it's almost like the oral-nasal cup to a Draeger; what is it, the Aga Divater?

HAMILTON: What's this story on eye protection?

WORKMAN: For contaminated atmospheres.

HAMILTON: But is it going to be there? We don't meet that requirement with this mask.

STOLLE: The only requirement for eye protection is in the eventuality that the environment comes down into the eyes and you can't see. If we don't go with the MAGIC mask, we plan on also transferring with the masks a pair of goggles that you could stow somewhere.

WORKMAN: That didn't come across in JSC-31013. It came across to me as an integrated unit there. It is, perhaps, a more reasonable approach to come in with a pair of goggles. The overall weight is going to be reduced significantly.

STOLLE: Right.

WORKMAN: So, with that in mind, then, you've got a full range of options.

NORFLEET: Maybe I could bring up an issue for Mike. Those are our requirements; you're quite correct. But, there's a Station-wide effort, which makes sense, to try and come up with common masks for all purposes – pre-breathing, fire fighting, and supplemental oxygen, as well as hyperbaric use.

WORKMAN: I think you can understand that that would be a question that would be asked.

REIMERS: That's going to be a little bit difficult. I think you're going to find for long exposure, like pre-breathing or hyperbaric treatment, people aren't going to want something over their face. It's going to be hot and sticky, rather uncomfortable. They're going to have a tendency to take it off and throw it at you.

PILMANIS: Wee use this French mask routinely for 6 to 8 hours, sometimes 10 hours. Never a complaint from our subjects; it's very comfortable. And, we know it's 100% oxygen because there's a slight over-pressure. In fact, the reason we went to it was for the comfort, to use for prolonged periods of time.

NORFLEET: It does incorporate the eye protection, and it fits around. As was mentioned, it's easy to make a seal with this kind of a mask. Because all you've got to deal with is the neck.

WORKMAN: That's right. And it's got your built-in intercom with it.

STOLLE: Is it any more gas hungry than, say, your facial mask?

PILMANIS: Well, we have an unlimited supply, so for us it's not a problem.

WORKMAN: Again, we have not looked at this mask in an overboard configuration. I can't answer that question.

HAMILTON: Can it be *made* to be overboard? Do you use it overboard, Tom?

WORKMAN: No. I'm sure it *can* be modified for it.

NORFLEET: It's got a one-way valve on the exhalation port that we've actually modified to collect expired gases for pulmonary measurements. So, yes, it can have that. It's got kind of a wimpy oral-nasal cuff, so, perhaps, the dead space in the thing is a little bit bigger and the gas consumption would go up a little bit more.

WORKMAN: Not nearly as much as it would on the hood.

NORFLEET: Oh no; no way.

REIMERS: How deep did you use that thing?

WORKMAN: They go to altitude.

PILMANIS: We go to altitude.

HAMILTON: I've not had that MAGIC mask.

REIMERS: I would guess it would flunk in the hyperbaric chamber because the regulator capacity is awfully small. The reason I say that is, when we built that chamber at Conroe, we said, there's got to be a better way for a mask in a chamber that's got a mask. There are all kinds of little operating room scavenger masks with overboard dump capability. There are several of them out that look real attractive: nice, small, and what have you. We dragged three or four of them out and, by the time we got to the 60 or 70 fsw, they just couldn't cut it. Most disappointing. There was a supply regulator made by Sierra that was small, light, and had very nice performance; this was several years ago.

HAMILTON: Is this intended to be an aviation mask? Why do they make them like that?

WALIGORA: Bill, it was originally designed for submarine escape, I believe. So it may have been actually designed originally for a higher pressure.

HAMILTON: But see, the submarine escape profile actually doesn't have very much high pressure. There's a momentary spike, but not much high pressure.

REIMERS: The mechanics of adapting a regulator with hyperbaric capacity and overboard dumping in something like that is manageable. You have to be a little bit careful about CO_2 retention. I have a suspicion that could get to be a problem really fast.

BOVE: Well, actually, a device that like that, almost by definition, has to have some free flow in it for it to scrub CO_2.

PILMANIS: We over pressurize by about 2 mmHg.

HAMILTON: But does it flow continuously when they're not inhaling?

PILMANIS: Very slight.

REIMERS: Has anybody done any definitive studies on that thing in terms of inspired CO_2 levels; e.g., dead space?

PILMANIS: We periodically test for all gases. I can't quote you the exact numbers; but, it has been fairly thoroughly tested for gases. I believe it's 99% oxygen and very little, if any, CO_2.

NORFLEET: We put a mass spec probe in the oral-nasal cup to try and get end tidal CO_2's. I can't give you a lot of information on that because we've only gotten it fixed in the last couple of weeks. But, we do get a nice alveolar plateau, and we do get a drop to very close to zero inspired PCO_2 with that oral-nasal cup. Was that your question?

REIMERS: What oral-nasal cup?

HAMILTON: You don't get to that cup because the mike's in the way. This has a valve; so, when you open that, you're breathing from ambient. Is that a safety valve?

WALIGORA: There are two controls on there. One of them, you can divert the oxygen inflow with. One of them is to the cup, and the other one is to give you some constant flow.

HAMILTON: Okay. That's probably what that is, because there doesn't seem to be any place where you can inhale through it without a gas supply.

WALIGORA: The basic setup is a demand regulator.

HAMILTON: If you haven't drilled for it, when the gas supply fails, you'll learn to take it off very quickly.

BOVE: Both of those masks have an override on the mask for when people get tired of sticking their face in the oral-nasal and they want back out of it. But, if the demand isn't being demanded and you're stowing the mask, you've got to have a free flow to breathe through; so usually they have an override so you can free flow the thing. These things generally require more gas supply.

WORKMAN: Depending upon the type of mask that's selected and used, we have enduring factors that you need to be concerned with. One is the oxygen delivery. Obviously, you are in a tricky situation. You want to be able to maximize that oxygen delivery. I tried to look for the data but was not able to find it. We have done some work at Brooks that showed that, even with a very slight leak in the face form of the mask, you can reduce oxygen delivery by as much as 50%. So, obviously we want to be able to try to meet that challenge of the full spectrum of being able to

WORKMAN: (Cont'd) fit, and I don't think that it's going to be easy to come up with "one size fits all." I really don't.

Another area that we're concerned with, of course, is the increased oxygen build-up in the airlock. Some mask options have no overboard dump. Obviously, if you have an improperly fitted mask, you're going to have an outboard leak of oxygen and, without the ventilation, that's going to increase. Without a way of dealing with that increased oxygen buildup, you're going to increase the risk of fire. Regarding increased CO_2 buildup, you have pretty much the same criteria, except we're dealing there with perhaps the adverse physiological response with the increase in CO_2. Steve, do you have anything that you want to add to this?

REIMERS: Yes, a couple of things. In our experience testing various kinds of masks, we generally find inspired CO_2 performance on masks with oral-nasals to run about 1% surface equivalent and kind of get worse from there as the oral-nasal goes away. This is doing a little different measurement technique. This is volume averaging, pneumatically homogenizing the inspired gas and then moving the CO_2 over there. Now how that translates into end tidal CO_2 is unclear; there's some timing involved there. Doing this sort of thing with mass specs can give you really bizarre results if your timing is off a little bit. In fact, one of the things we tried to do at one time was develop a procedure for the NFPA for measuring inspired CO_2 in fire fighter masks and correlate the results of that procedure to a mass spec timing type approach the Europeans are trying to use. The difference in the price of the test equipment that you had to do this with was about 5:1. The pneumatic drawing averaging procedure is one that I've used for 20 years, and

REIMERS: (Cont'd) maybe used it for a long time until I got to where they felt I could afford mass specs and computers.

We found that the inspired CO_2 levels that we were getting on the same mask with the volume averaging technique tended to be consistently about 0.5% surface equivalent (50 kPa) higher than what the Europeans were reporting on the same mask under the same metabolic conditions. So far, based on the limited amount of work we were able to do at the time, we were not able to explain the difference. If you like, I could fish some of that stuff out and send it to you. It was work we did for Interspiro, and the idea was to submit to the NFPA procedures and criteria for doing this prior CO_2 testing on this kind of stuff. But, so far the committee in its infinite wisdom has decided not to address that subject.

BARRATT: I think we'd certainly like to look at whatever you have.

REIMERS: Okay. I'll fish that out.

There's a society called the International Society of Respiratory Protection that deals with masks for miners, fire fighters, and general industrial applications. Those people are really big into this quantitative fit testing business. They've got procedures, and you can go buy a machine now that allows you to put a hood over the guy, sort of half a body sack, and you put some chemical in it and then they sniff for it. I brought with me copies of the journal they put out for the first several years. If you want, Bill, I could leave those here and you could go through them and glean out what you want and send them back to me.

BARRATT: One somewhat unrelated question. We're looking at the MAGIC mask primarily from a commonality standpoint, as Bill said. Do people feel that the quick-don feature is important in our hyperbaric airlock given two things – the masks will be destowed and out there; on the other hand, the chamber is going to be the more hazardous volume from a fire standpoint on the Station.

WORKMAN: The quick-don feature is going to be more of a concern for your inside tender. I don't necessarily see a requirement for a quick-don feature for the patient unless you're in an ebullism state.

BARRATT: Primarily for the tender who will be off the mask himself.

PILMANIS: The ebullism situation is going to be difficult; I don't know that you're going to be able to use that full head because of respiratory problems.

REIMERS: Another issue, too, is that it's quick-don when someone is putting it on their own head; but how about when you're trying to put it on a patient who can't help himself?

PILMANIS: I'm not sure you want to cover the whole patient's head in that situation, because he'll be intubated and the oxygen will be delivered that way.

STOLLE: Right now, we *do* have a medical requirement to treat ebullism. And, so what you seem to be saying is, to treat ebullism would rule out even the possibility of using a full-face mask.

PILMANIS: No. You're not going to need any mask if you're going to intubate the patient, and that's very likely. However, during the course of that treatment, you may or may not have to extubate him and then go to the mask. You might keep them on intubation; it just depends. But one thing I would stress is that, there has to be an oxygen connection to the trachea.

WORKMAN: And you've got to have overboard dump.

PILMANIS: And that is not something you buy off the shelf. We could jury-rig something in the chamber, but we used it all the time in intubated patients.

STOLLE: So, what you're saying to me is that some of your treatment does not involve the use of a ventilator but it does use an endotrach tube with oxygen being supplied to it.

PILMANIS: And with the Ambu Bag, you need to have a connection for the oxygen, too.

STOLLE: Right. Now that's something that we'll have to work out.

WORKMAN: In my personal experience of patients that we've had to intubate, we've always had them on a ventilator. But again, we have made accommodation to be able to provide the oxygen plus the overboard dump.

STOLLE: I guess one possibility is to remove the demand regulator from the mask if it exists as a detachable unit and make it attachable to your trach tube or something like that. There were two questions that I wanted to ask regarding mask leak. One of

STOLLE: (Cont'd) the things is that we may be forced into purchasing three different sizes of mask – small, medium, and large, being able to interchange oral-nasal sections. But, that's going to require a time factor in there to exchange those oral-nasal sections. Assuming that we have a good fit, does a mask under positive pressure normally leak due to head movement, movement down, or anything of that sort? What I'm getting at, is it reasonable to expect a *no* oxygen leakage requirement to that mask?

PILMANIS: Leakage out is fine; leakage in is the problem.

WORKMAN: It depends on what size your leak is, though, Andy. If you've got a substantial leak, then you're significantly degrading oxygen delivery to the patient.

STOLLE: Right, and the concern is oxygen buildup within the chamber. We don't have a lot of resources to purge that chamber.

WORKMAN: I would say that probably, looking at all of the potential negative implications of a leaking mask, you'd be better off just to not have it leaking.

STOLLE: So it's reasonable to say that the mask should not leak?

WORKMAN: I would say so, yes. The mask should not leak.

STOLLE: Okay.

PILMANIS: It's very important, and maybe we should go on record as saying it, that they truly get 100% oxygen.

NORFLEET: With a conventional Scott-type mask, not a hood-type mask but a conventional Scott aviator mask, is monitoring of expired gases for percent oxygen or percent nitrogen as a detection for occult mask leaks advisable?

REIMERS: Let's compartmentalize the question. We've got several scenarios here. One is oxygen pre-breathe, and the other is DCS treatment. The answer may be different.

WORKMAN: Well, if you've got a pulse oximeter on board, you can monitor it.

BOVE: You have the arterial. There are two concerns at least. One is you raise the PO_2 in the chamber, and the other is the crew doesn't get enough oxygen. The pulse oximeter on the fingertip tells you if you're getting the proper oxygen, although most of them are designed to measure oxygen saturation of hemoglobin. It seems to me that there's another major concern. The thing is very tight, so you're pretty comfortable with delivery, but a small leak is still going to contaminate the chamber environment. And there, we'll be testing on the outside of the mask, not the inside.

WORKMAN: I think I would probably agree with that. Yes.

STOLLE: One of the other mask fit problems that we have is that we can fit and verify easily that a particular mask fits properly on the ground. But, facial morphology

STOLLE: (Cont'd) changes in zero g, and so now we have a completely different person up there to fit those masks. And, there's no way to test it.

BOVE: Actually, it's usually in favor of improving the seal. I think a little bit of swelling will cause it to seal better. Most of the time, it ought to improve or enhance the seal. Not too many people get gaunt and thin while they're up there.

WORKMAN: You should be able to have enough adjustment on the mask that would compensate for that, I would think.

STOLLE: Okay. In what mask? In a particular mask that was properly fit on the ground?

WORKMAN: I would think so, yes.

REIMERS: Another aspect of that is the emergency nature of particularly the MAGIC mask. You're only going to use these things if there's some sort of incident going on. Chances are, the reason you're putting them on is you want to put them on in a big hurry. Now given that you've got four crew members up there, suppose you've got four different face sizes? Unless a crew member is trained to go around with his little cup on a string around his neck, how do you have any sort of realistic assurance that, when this drill comes and everybody has to drop whatever they're doing and go run for their mask, he's going to be able to find that mask that has his fit on it? You may wind up covering a worse situation than if he had a universal one and just tolerate the leaks you get.

STOLLE: Yes. Well, a lot of people here have said that there's no way we're going to fit a 5th percentile Oriental female with a 95th percentile American male.

REIMERS: I know, but the question I'm asking is; you've got a mask up there. You get in an emergency situation. I see you've got them colored red, green, yellow, blue, you're going to go for the first mask there. If you're the 95th percentile American male and the mask you pick up is fitted for the 5th percent Japanese female, you've got a problem, my friend.

HAMILTON: Are these things going to be distributed here and there throughout the Station? Are there going to be more than the number of crew members?

STOLLE: Yes. Every 4.6 m (15 ft), they have to be able to get to a mask.

HAMILTON: Okay. So that's the reason for commonality, then. One could make a case that each person should have his own mask, but to carry the mask around with you all the time when you're trying to work around the Station, when you may not ever need it the whole time you're there is a little bit of a problem operationally.

STOLLE: I would suggest that we size for the oral-nasal section for the hyperbaric type of situation, where a mask fit is very important.

WORKMAN: Mike, where does that leave us? Can we have a summary?

BARRATT: It leaves us with the points that: Form fitting is going to be very difficult, there probably will not be a universal mask, and that seems a solid recommendation of

BARRATT: (Cont'd) the committee. The quick-don feature kind of got a soft response as far as looking at the MAGIC mask; commonality is going to remain our major issue. And, Mike, do you have any other things?

STOLLE: No, you summarized it quite well.

WORKMAN: I'll keep everyone informed on how we're coming along with our development testing with this.

REIMERS: I would encourage you to consider the possibility of using basically a universal mask and then using customized masks only when you find you have to. Otherwise, the confusion factor is likely to be a little bit hard to manage.

BARRATT: One thing we didn't address was shelf life. Obviously, that's going to be an issue for us. Comments on the newer ones that are developed here? This one in particular.

HAMILTON: That's not much of an issue. But, if you put them in there and expect them to be there 30 years later, you might have a problem.

WORKMAN: You're going to need to incorporate some periodic examination to see if there's a degradation of the rubber or whatever.

BOVE: Just to raise a question. Having walked around with a gas mask at my side for 10 weeks: How far out is it, the idea that you have a custom-fit part of this thing relatively small and compact? Somebody is in a special jacket in the flight suit or

BOVE: (Cont'd) whatever people wear, and they actually do carry the little custom-fit part of it with them all the time and just hang it on the wall; the fitting that it snaps into is universal. I was just wondering whether that idea is possible? Then everybody just carries it all the time.

WORKMAN: I guess the answer that we would expect to hear is, that hasn't met the materials testing; right?

REIMERS: My own feeling is, if you have to go to custom, that would be the way to do it. Well, Steve, even if you had four sizes, you could imagine all the size A's suddenly converging on one size A mask in a certain spot; you still have a problem even if there are only four sizes. You fit it and make sure it works; you stick it in your pocket and carry it with you. So, everybody has one that fits. It doesn't have to be customized.

HAMILTON: There's something to be said, also, from a weight point of view if each person has one mask, and you have maybe one or two spares in the whole Station, you don't have to have nearly as many masks up there. But, it's a burden to carry it around.

BOVE: Unless it's really small. That little thing there could be tucked in a pocket in a suit without any problem at all if there wasn't much more than that. And, that's snapped into a retainer that supplied the gas for it.

WORKMAN: Well, you could have the hard shell portion being resident at the site. I'm sure there would be a way that you could do that. You could just roll this up and stick it in your pocket.

SPEAKER: That's what I used, that little special pocket there.

REIMERS: The notion of carrying something around just seems awkward. I realize there's a vacuum out there. But, are you going to take it in the potty with you?

HAMILTON: It might be the time you need it. Just don't flush, right?

BARRATT: Mask selection will be an issue with us for awhile, and Mike Stolle is one of our main men there. So, any further input would be welcome.

Hyperbaric Chamber Fire Suppression On Orbit

BARRATT: I want to move on to one of the more important topics for us right now, one of the focal points of a lot of ongoing discussion on several fronts, and that is fire suppression. I've asked Mr. Reimers and Dr. Hamilton to address this issue. Before we get started on it, I want to mention two things I think I mentioned to some of the folks individually. A recent study that was released to some of the folks at JSC, especially the materials science people, somewhat preliminary of the actual data being released described a comparative trial between nitrogen and CO_2 as fire suppressants that was done at the White Sands Test Facility. In this test, it was demonstrated that CO_2 was more effective than nitrogen. However, nitrogen and CO_2 were equally efficacious in extinguishing the most flammable materials at 2.8 ATA. By "equally efficacious," that meant that both put out the fire within a second.

BARRATT: (Cont'd) The second point to mention is, there is some ongoing microgravity combustion research. The team is centered at Lewis and they have discerned in a series of three Shuttle flights – and there will be seven more in this series – that, because of the lack of convective forces in microgravity, fires don't burn very well. Below an oxygen concentration of about 35%, it's not a threshold valuate by any means; but, as you go below there, the fires become much less capable of propagating. They speculate that, at 20% in a totally quiescent microgravity environment, even at our pressures, they do not think that the fires would actually burn. However, a little bit of convection goes a long way. I think it's been mentioned at previous ad hoc committees meetings that there was some concern about the convective front of a wave of fire suppressant actually causing a fire to flare. They have indeed found that to be the case, although they have not done a comparative trials of fire extinguishants. So some experiments are ongoing in that area, but we're finding again that a little bit of convective force can actually increase the flammability beyond the point of one-g combustion.

BOVE: Is this microgravity at 1 ATA?

BARRATT: These are microgravity studies between 0.5 and 2 ATA, and they haven't really seen a lot of pressure difference.

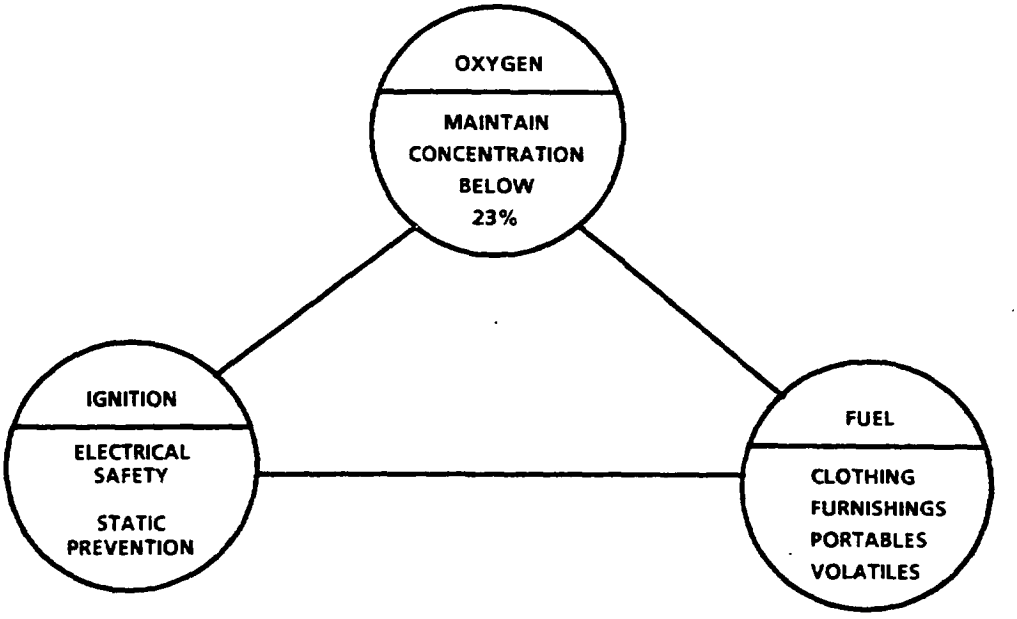
BOVE: That's different than the hyperbaric data.

BARRATT: Right. But again, under microgravity conditions, the picture changes.

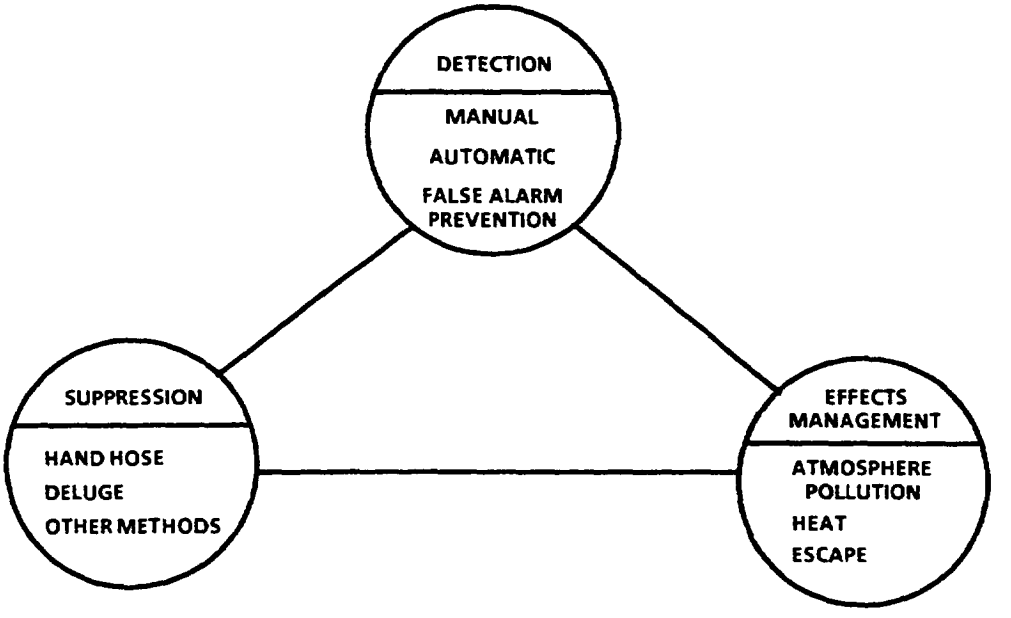
HAMILTON: You should have three handouts from me. One on CO_2, and a two-part thing from the NOAA diving manual – the old manual and the draft of the material for the new one; "new" being written in 1985, but they're just getting the thing out this year. It's actually gone to the printer. But, the material hasn't changed a lot. (Added at end of section.)

REIMERS: We'll spend a lot of time on it. The top part of these (FIG. 100) is the usual fire triangle: oxygen, ignition, fuel. Several years ago, I cooked up a similar thing for how you deal with it: detection, suppression, and effects management. Effects management is management of both the fire and the suppression agent. Oftentimes in a closed environment like this, the suppression agent is worse than the fire. Enough said on that. There's a paper I wrote some time ago on operational safety in hyperbaric environments. It's being copied, and the paper has a copy of this in it. It has some other useful things, too. That particular paper was written for people operating clinical HBO chambers. There's not a lot in it other than motherhood that's applicable here, but there are some things. In the back are two references that are in published literature in atmospheric control.

In terms of discussion of burning rates, as you can see, for constant oxygen concentration as the pressure goes down (FIG. 101), burning rates in standard tests tend to go down. This is according to a one-g environment. This is a fairly standard chart that's now in back of the NFPA 99 standard on fire protection in hyperbaric facilities that's widely available.

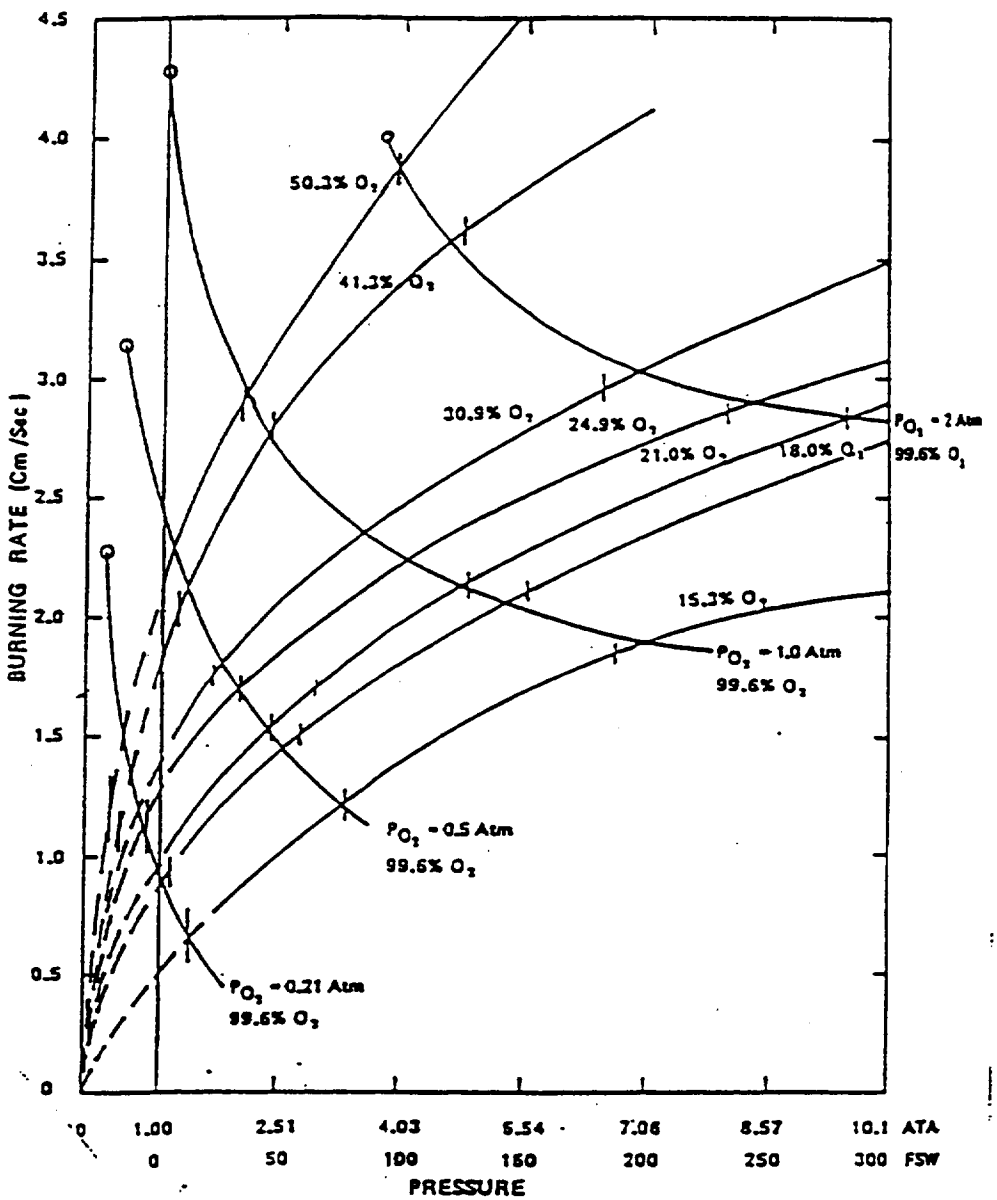


(a) Fire prevention.



(b) Fire management.

FIG. 100 Triangles for hyperbaric chambers



The curves show the relationship of partial pressures and percentages of oxygen, using empirically determined rates of burning of filter paper strips in various mixtures, with derived rates (vertical bars) at various partial pressures.

(Shilling, Werts, and Schandelmeier 1976)

FIG. 101 Burning rates of filter paper strips at an angle of 45° in N_2-O_2 mixtures

REIMERS: (Cont'd)

In a hyperbaric chamber, it's a different story. If you get 30% oxygen in your hyperbaric chamber, you've got a very dangerous situation on your hands if there's any gravity or convection going around.

I've done a lot of fire risk management stuff over the years. One of the more interesting ones was fire risk management in about a 4-story high, 9.1 m (30 ft) wide, 1 ATA undersea well head enclosure which was supposed to be manned and occupied whilst handling live petroleum.

That was a bit interesting. But, this is a different ball game. What it keeps coming back to, in terms of suppression procedures, is that the best thing to do is cut off the oxygen. Translation: Use microgravity to our advantage. It makes it very easy to cut off the oxygen supply, which means the first thing you do in any fire event is turn off the ventilation. Still the atmosphere as much as you can. In the hyperbaric chamber, that means the first thing you do is turn off the HECA. Instantly. That basically means anywhere else in the Station, if you get a fire alarm, the first thing you do is turn off all the ventilation. Now that does a lot of things – all good. You cut off the oxygen supply to the fire. And, probably equally as important, you contain all the bad gases and the heat. You don't go spreading the combustion products all over the place; which, among other things, means you don't go ruining the visibility. If people are going to manage a fire situation, they'd better be able to see what they're doing. In a fire that's making any smoke at all, it doesn't take much smoke to fill up a confined space. It happens very quickly.

REIMERS: (Cont'd)

Once the area is isolated, then afterward, if needed, add some agent to the isolated area. What I'm suggesting in terms of fire risk management is, once you turn off the ventilation, it may very well be a simple fire blanket is all that's needed. I don't know what they make these things out of. They've got some sort of flame-inhibited chemical built into the blanket. Just put that on and say "Okay, we'll wait for you to go out." That cuts off the oxygen supply, contains the pollutants, and, if you've got something nasty, you can squirt a little Halon or some other sort of suppression agent under the blanket.

Other ways of dealing with fire, of course, are to cool the source, primarily in microgravity just to prevent reignition. And, now you've got time. If you've got the oxygen cut off you can take your sweet time cooling the ignition source, and one way to cool it is just simply to wait. As long as whatever the initial heat source was, is gone. Other possibilities in terms of fire extinguishers: nitrogen, CO_2, and Halon maybe. Now, if you're going to use nitrogen, rather than thinking in the usual terms of fire extinguisher, the fire's over there and you stand here and you blow at it, I think what's going to be appropriate here is something with a great big, long wand. You stick the wand in the middle of the fire, you bleed in nitrogen, CO_2, or whatever you want. But, you stick it right in the fire, do it slowly, and again the idea is to push the oxygen out. Any atmosphere movement that you purposely create should be basically from the flame source *out*. This is sort of 180° out from what we do down here. A little bit of Halon there likely would work very well; in terms of fire suppression, a little bit of Halon goes a long way. Now, the down side of this is the stuff you get when it pyrolyzes. There may be a situation where you'd want to think about this stuff. Any questions here?

HAMILTON: At some point, we have to address the fact that we turned the oxygen supply off. And, we all have our masks on. What are we going to breathe?

REIMERS: Bill's right. Coming down here a little bit further, in talking of automatic and manual-type actions, the first one is detection, such as an ultraviolet detector; you've probably got those up there already. However, I think your first line of defense is going to be the combustion products detectors. Now, the ones we were talking about yesterday I found very interesting. We tried them in hyperbaric chambers years ago and threw them out because the typical combustion products detector, or home smoke detector, is an ionization device. It measures the amount of radiation, whatever kind it is, that gets to the sensor. But, there are two things that decrease that: large molecules getting in there, even smoke particles, or just more smaller ones; e.g., increased ambient pressure. So, those kinds of detectors in a hyperbaric environment don't work very well because you have to turn the sensitivity down so far they don't false-alarm beep; that shallow, they're sort of useless. But, the device we saw yesterday should be fairly immune to that. It wasn't using that process.

There's another thing here that's very useful to keep in mind, in that there are two types of fires. There are two very different types of ignition. The fire risk management response to those differs. One is a high-temperature diode that was used for instance, to do this kind of work, where you get a piece of clothing and take a match or blow torch or something, stir it in the bottom, and see if you can quietly watch it burn. The other one is where you have some sort of mass of combustible material that's slowly heated. That's a much more dangerous situation because, as NASA research from years gone back has shown, with most

REIMERS: (Cont'd) materials when you do that, somewhere a few degrees below autoignition you lose 10 or 20% of their weight. This represents volatiles going out in the atmosphere. So in a slow-heating environment, by the time there's actually an open flame to be detected by anything, you've got a fair bit of fuel released into your environment. And, if the combustion products detector is working right, it should pick that up.

There have been some efforts to do this in hyperbaric chambers. The problem is there's very little – and to my knowledge, there's no – definitive research in how this works. It might be something that your R&D people want to look at. With some sort of atmospheric sniffing device up there, if you take typical fuels and slowly heat them up, determine what appears in the environment before you actually see open flames.

BARRATT: What's the experience so far with hyperbaric fires? What's the distribution of those two types of fires that you tend to see?

REIMERS: The test fires tend to be made with little high-temperature igniters. In my experience with those, you take a little bale of excelsior wood chips and ignite it, and it sits there inside the chamber like a nice little Boy Scout bonfire and quietly waits until you come pour water on it. Operational fires have been more like, "Ooh, there's a fire – one, two, three, blooey!" Those are usually the slow-heating kind. For instance, with the EDU fire they had some sort of CO_2 scrubber that apparently had a kerosene trace in it next to a motor that overheated and, you've got to know, by the time that thing caught fire there was a ton of fuel in the environment. Furthermore, they had 35% oxygen in there and did everything wrong.

REIMERS: There's a guy down in Taylor Diving where they had lights inside the chamber. Outside people wouldn't turn them off, and he took his T-shirt off and hung it over the light. You've got to know by the time that T-shirt went, there was a lot of fuel in the environment.

WORKMAN: Most of the fatal fires have been a result of something that's volatized. But, there have been hyperbaric chamber fires that have been survivable because they have been more isolated events.

REIMERS: In that regard the one at Geissinger probably fits the second category, where they microwave-heated a blanket; they were locking it in to cover up an infant. They had it in a pass-through lock, and when they took it out and it hit the compressed air, the thing burst into flames. But, in that case there was clearly no pre-release of fuel into the environment because it came out of a medical lock. And, there, the inside attendants moved the infant first rather than tending to the fire, which probably they ought not to have done; but the people outside saw what was going on, turned on the deluge, and put it out.

WORKMAN: We're putting together a report now looking at chamber fires, trying again to pull together all the data that we can find internationally and get that published. We're not ready yet to get that out, but that certainly will be available soon.

REIMERS: In a hyperbaric environment, one of the things we do as a package response to a fire alarm in that situation is turn off the oxygen. We're talking about fires here that started from the slow heating of some sort of combustible material. For instance, an electronic device has overheated or what have you. The one real

REIMERS: (Cont'd) nasty up there that doesn't follow any of these rules is if you get oxygen fire. You get oxygen getting out of something, either in the line itself or you've got somehow a line that's ruptured and oxygen is pouring in on something, that doesn't obey any of these rules. About the only thing you can do there to put that out is to turn the oxygen off. Now one question is: Once you do that, what does that do to your masks? The question there, particularly on the MAGIC masks that are distributed around the Station is: Are those being fed with oxygen and nitrogen mixed on site, or is it being mixed someplace else and sending air around? That's an extremely important question.

STOLLE: Our present system takes O_2 and N_2 and mixes them at the chamber, via the HGPCA.

TRAUSCH: But, if you're turning off the HECA you can still use HGPCA vents.

REIMERS: Right. If the fire is *inside* the hyperbaric chamber when you turn off the HECA, what we're sending into the chamber, at least for the attendant, is going to be something that approximates air. For the patient that's in there, he's getting oxygen. You somehow have to turn that oxygen off. The way the system is designed right now, that's not going to happen automatically. The tender outside is going to have to control this.

BUCK: Or turn it to air; he could go on air.

REIMERS: Turn it to air, yes. One thing you don't want to do is turn it to nothing.

WORKMAN: In all of our emergency procedures for our operations, the first thing we do is to switch to air.

REIMERS: The question I was addressing more was the general Station, the MAGIC masks around the Station. How much oxygen is actually piped around internal to the Station? That's an issue that someone needs to have a peek at; because, if that ever got loosed, there's just no way you can put it out by turning it off.

Suppression mechanisms: Whether or not they're automatic or manual depends a lot on the mechanism that you use for doing it. It would appear, in microgravity, that a manual response seems to be much more appropriate, whether it's in a hyperbaric chamber or somewhere else. It would appear that the most effective suppression technique is simple containment. For instance, a fire in a little bay out in the Station. If you could somehow isolate it, turn off the oxygen supply, and maybe then squirt a little suppressant of your choice in, that may be a very effective way of managing the fire risk. In the hyperbaric chamber, the same idea is likely to apply: A little fire blanket on a fire someplace and cover it up! That buys you time. Now you've got time to deal with it. It's going to have a finite amount of oxygen. It's not going to get away. And, if you've got either nitrogen, CO_2, or a little Halon in there, you just squirt it in under the blanket, I would think it would probably be very effective.

HAMILTON: Blankets may not sit on a fire very well in zero g. You'd have to put a blanket there and hold it.

REIMERS: You don't have to. Oxygen transport to the flame front is lousy to begin with. All we're trying to do is make it a little worse. Now, we don't want to make it better in the process. This is an area where we're all just speculating, really.

BOVE: Steve, what do you think is going to burn? Assuming there will be a lot of equipment and racks and stuff like that, they might catch on fire.

HAMILTON: The racks are going to have extinguishant dumped into them, aren't they? The electronic racks and avionics?

NORFLEET: Are you talking about Station-wide? Yes. CO_2.

HAMILTON: And, if you've got a confined space like the space behind the rack, that's pretty easy to put a suppressant into. It's going to work fairly well.

REIMERS: Let's move on to the next one. The $64 question, I think, in this airlock is: What happens if you've got some hydrazine in there? In the traffic pattern, people are going to be bringing in debris both from the Station and from EVA. Up until just yesterday, the notion of them tracking some propellant in and leaving little bits of it behind hadn't entered my thinking. But, it changes all the rules if that's a serious possibility. That means a couple of things, particularly for Courtney's work. There will be a big premium on designing the interior of the airlock so it's very easy to keep clean – sort of like surface cleaning now in clinical hyperbaric chambers. One of the things we've tried to do is keep it so we can wipe the whole thing down with a cloth; we don't have exposed pipes. That may be a very important consideration there, that it's just easy to keep it clean. I'm not familiar

REIMERS: (Cont'd) with the flammability characteristics of these fuels, but considering what they're being used for, I suspect they're excellent.

HAMILTON: Aren't we talking about a rather small amount of fuel that would be likely to be tracked in?

BARRATT: Hopefully that would be detected and removed before they actually hit the airlock. There is an outside station for detection of hydrazine and removal.

HAMILTON: If there's a large amount, they're going to be aware of it. And they have to deal with it.

REIMERS: Yes. But, there may very well be a situation where someone has been out, an ebullism for example, and somehow got himself contaminated, brings it in, tracks up the airlock, and now you've got to treat him. You don't have time to clean it up.

HAMILTON: You've got to live with it. It's a pretty unlikely event.

REIMERS: Maybe it is. But, that's a question a lot of people have to decide. You may wind up with that as a serious possibility but no way to deal with it.

BUCK: Why not something like CO_2?

REIMERS: It takes too much. And, it's too slow. Regarding Halon in an environment like this, the only bad thing about Halon is getting rid of the stuff afterwards.

HAMILTON: Well, there are three bad things: the breakdown, cardiac anomalies, and getting rid of it. You've really got a few problems there.

REIMERS: It was looked at in hyperbarics several years ago, and we elected not to use it because it takes about 5% by volume Halon to put a fire out. Physiologic reaction to it starts at about 8% surface equivalent, which means that, at 1 ATA, it's a fairly fine agent. You've got about a 15-minute exposure to it before you start having physiologic responses that are typically cardiac problems. But, as the atmospheric pressure goes up, obviously the onset of those physiologic responses becomes much more, much quicker. And, at 2.8 ATA, you're looking at about 15% surface equivalent. A couple of minutes' worth of that's not going to get your people in serious trouble. But again, whether or not this kind of headache is even worth considering depends on how big a problem, you deem the fire to be.

WORKMAN: I think we crossed that bridge a couple of years ago, didn't we, with the issue of Halon?

REIMERS: Two years ago we discussed it. But, we weren't talking about propellants in the chamber.

PANZARELLA: Well, is Halon still ruled out by the Program?

BARRATT: Yes. Our requirements for a physiologically acceptable fire suppressant preclude that.

REIMERS: I understand all of that, but that depends on how big a problem this is. If that's potentially significant, those other things won't handle it.

HAMILTON: Well, there are going to be Shuttles around everywhere – one or two maybe. How big a problem has it been? Is there any propellant out there? Is that a realistic concern?

SPEAKER: We've done this in the past, where we've exposed the spacecraft to questionable status as far as propellant containment, but we've never had a real problem with it.

HAMILTON: I should think if any of it is loose out there, it's going to disappear fairly quickly. It'd be a bizarre situation, like opening up a compartment or something, that would allow a real contamination.

SPEAKER: During EVA you can stay away from those areas that are susceptible to propellant contamination. When we are there, we don't stick our face in the thruster or RCS areas.

HAMILTON: Is it reasonable then to assume that we don't need to be concerned about this rather peculiar combination of things; namely, a contamination with hydrazine or something and a fire, both?

PILMANIS: And, the hyperbaric treatment? All three at the same time?

SPEAKER: Yes.

HAMILTON: That's sort of like a double or triple failure, and maybe it's not something we need to worry about. We may make more problems than we solve by mentioning the word "Halon" in this room.

REIMERS: Enough said. This is just something that came up, at least in my consciousness, over the course of the past couple of days.

BARRATT: In some prior proceedings of this committee or others, it has been posited that a single traumatic event could involve the rupture of a propellant-containing vessel that also involved a rupture of suit and loss of pressure. So, perhaps it's possible, without a bunch of isolated events.

REIMERS: It may very well be that the way you deal with this is, when you have a contamination question, you just declare the hyperbaric chamber out of service until you can clean the thing up.

BOVE: My perception is, if you had hydrazine and you started to pump up the PO_2, it would spontaneously ignite. After all, there are no spark plugs in rockets, are there?

BARRATT: Most of the RCS fuels are hypergolic.

BOVE: Yes. If it was exposed to high partial pressures of oxygen, it would just spontaneously flash. So, if you have a little blob of it somewhere and start pumping up the chamber, I think you'd start to have fireworks in there.

REIMERS: It used to be, years ago, that they cleaned oxygen systems by slowly adding oxygen and then slowly raising the pressure.

WORKMAN: They called it a traumatic pressure purge.

Carbon Dioxide Physiologic Issues

HAMILTON: I'd like briefly to present a physiological perspective of one of the possible extinguishants: CO_2. And, I'll say at the beginning and I'll say at the end, and it's written at the beginning and at the end of this handout, that I'm not advocating it. On the other hand, I want to make sure, from my personal point of view, that at least the people who are making this decision understand what they're dealing with. So, I thought I'd review the situation with CO_2 quickly. I don't think it merits a detailed discussion.

First, the perception of the hazard of CO_2 is influenced by the standards that are set almost anywhere you look at gas purity standards, and we've talked several times here about the standards for the Station and for the chamber. They are set so low that the implication is that something a little above that is dangerous. There are lots of cases where it can be undesirable, and in some diving situations it actually is dangerous. But, it's not as bad as one might believe by looking at the limits that people have set for it. The real danger of CO_2 is as an asphyxiant, and this is how it kills people in breweries, fire extinguisher factories, and other various places. Oil fields use CO_2 to treat oil wells. When you have the possibility of it layering in a confined space and a person getting down in there, there's *no*

HAMILTON: (Cont'd) oxygen down there. It replaces the oxygen, and that's deadly. When people have been killed by CO_2, it's almost always been as an asphyxiant.

The stuff has been used for a lot of different things. A high level of CO_2 in a working diver can cause them to go out. This has been documented many times; Bill Norfleet saw it happen at Buffalo. It's a well-known problem. It tends to be worse in some people who have an unusually low sensitivity, respiratory response sensitivity to it. But, I don't think that's really a concern here. CO_2 as a respiratory stimulant or even as a hormone is very interesting physiologically.

I want to talk about CO_2 at the high levels. Let's work up the scale here. At 1%, you're not aware that it's there. And, I'll talk in sea level equivalent because that's something we can all deal with most quickly. At 2% to 3%, people will begin to increase their ventilation; they'll be aware of it, and it can be measured in acid-base shifts and in other biochemical reactions. Now at 1%, you can't really measure it. The body compensates for it by increasing ventilation well enough that you don't get much in the way of changes. The body looks at CO_2 this way. The computer inside says, "I see that we have a load of CO_2 and I'm going to have to increase the ventilation in order to get rid of it." The only way to get rid of CO_2 is to increase the ventilation of the lungs. So, the body compromises between the amount of CO_2 it's willing to accept and the amount of effort it's willing to expend to get rid of it. Now that's oversimplified, but it's really what happens.

As the level goes up, the body allows CO_2 to build up because the cost of getting it down is too great. And, when you're breathing through a restrictive system such as the BIBS, with dense gas, the body faints; that's why people go out. In the

HAMILTON: (Cont'd) situation where you're in a room and there's CO_2 building up (like in a submarine, there's plenty of experience with that – not much of it good because there are other problems), at 5% you're going to be uncomfortable. You can work hard, however; and you can tolerate it more or less indefinitely. It requires a shifting of the buffer system of the body. At levels above that, it's going to get downright uncomfortable. I've breathed it at 10%, and it feels awful when you start; you can tolerate it for a while, and then it's awful again when you go off. You experience nausea and dizziness and just a real sick feeling. But, it gets better rather quickly, even while you're on it. You sort of stabilize after about 10 or 15 minutes. Enough time to change some kind of parameter and have a blood sample taken.

REIMERS: May I add something to that? When I was in the Navy, we were testing various devices and little tanks. One night we went home and left the CO_2 line running all night. I came along the next day and went in to work and inadvertently stuck my head down in this thing and I came back out of there really fast.

HAMILTON: Well, you can taste it. It tastes like soda water.

REIMERS: In whatever concentration that was, it felt like I had just inhaled NO_2. It burned like fire.

HAMILTON: That's right. You got a bigger dose than 10%. You can taste it at that level, but you don't get this burning feeling. We're really not likely to experience it that way; it will be abrupt but not that abrupt, whatever happens.

HAMILTON: (Cont'd) At higher levels, it's going to become narcotic or it's going to become anesthetic, if you will. And, somewhere in the neighborhood of probably 15, 20, or 25%, most people are going to go unconscious. They will not die; they will become unconscious. Now, at levels even higher than that – 25, 30, even 40% – an animal and, in some rare cases, a person can tolerate this for a matter of an hour or two. They're all right up until the end of that time; but if it's taken off abruptly, they go into ventricular fibrillation and die. This has happened in many operating rooms when people leave the valves out of a closed-loop anesthesia machine. The patient has oxygen; he's not supposed to be moving or doing anything anyway or responding, because he's anesthetized. He stays pink and everything seems fine, except the CO_2 has been building up because they forgot to put the valves or the adsorbent in the system. He looks okay, and then all of a sudden they realize what's going on, and they take everything off and the patient fibrillates. If they're not able to deal with it, they've got a big problem. They found out that this is due to an acid (actually potassium) shift in and out of the heart muscle. If this situation does occur then, as anesthetists may or may not be taught, you don't take them off abruptly.

BOVE: Ever hear of this before?

NORFLEET: Well, no. Never.

HAMILTON: Well, this does say it's *not* much of a problem.

NORFLEET: These days with capnography, that's pretty well prevented.

HAMILTON: Yes, that's true. You now measure the CO_2 in most anesthesia systems, and that's the reason. But, from this it's been learned that, in fact, the exposure to high CO_2 itself is not dangerous; it's the shift in electrolytes that you get when you take it away. The reason for belaboring this is that it's something that needs to be known if we are going to use CO_2; if we create this situation, somebody could get exposed to an anesthetizing dose of it. Now, you're not going to get the pockets that you do in one g; it's not going to settle to the bottom, because there isn't any bottom on the Station. But, in a confined space, if you are going to use CO_2 as an extinguishant, you could get enough that you might need to reduce it. One other point: the exposure has to be fore some time – many minutes to hours – in order for the effect to appear.

To give another example of why or how the human can tolerate CO_2: Emphysema patients can allow their CO_2 to build up to 80 mm of Mercury (10 kPa), which is the equivalent of breathing about the 10% we were talking about on a long-term basis. They make buffer shifts to accommodate it; they're not very comfortable, and they can't do much exercise or anything. But, it's because they can't ventilate their lungs. The point is, they *can* adapt to this long-duration CO_2 load without anything fatal or startling coming up. So, we need to program somewhere, if we are going to use this gas, to train somebody in the system on this possibility. If you do have CO_2 anesthesia and total unconsciousness is the result of it for more than a couple of minutes, it's really unlikely that you'll have a long enough exposure to get this shift. But, it's the only real risk, other than anesthesia.

PANZARELLA: When you talk about concentration, are you talking mainly by volume?

HAMILTON: Well, I was speaking in terms of sea level equivalent and volume percentages, but the effects are a function of *partial pressure*. That's volume percent. And, I have tried to translate it in a hyperbaric situation or the low-gravity situation of the Station.

PANZARELLA: Another question is: The percentages that you talk about; are these for a healthy person?

HAMILTON: A lot of these are for a healthy person, but of course the emphysema patient who can't ventilate his lungs very well is a very sick person.

BOVE: Just a question for the two of you. Steve, I was involved with a work chamber test as well. One of the strategies there was to flood it out with nitrogen, since at a pressure above 1 ATA, you can actually go to smaller percentages of O_2. If you want to suppress a fire in a microgravity environment, you can compress and just add nitrogen and let the O_2 concentration drop to suppress the fire, couldn't you?

Fire Suppressant Agents and Atmospheres

REIMERS: You can do that. The Navy has, for the submarine fleet, done a lot of looking at fire suppression by nitrogen pressurization. The problem with that – and I think here it would be a big problem – is that it takes a lot of nitrogen delivered perhaps very quickly. You've got to drive the oxygen concentration by volume down to a 10, 11, or 12% range that, in a hyperbaric chamber like this means, in the course of a few seconds, almost doubling the chamber pressure. That's why

REIMERS: (Cont'd) for this kind of thing, I was suggesting something I've never done before; that is Halon, which in this case only adds 21 kPa (3 psi). If you were at 30 fsw gauge, and all of a sudden you're at 90 fsw and the relief valve is going off, it's going to be a problem.

BOVE: I think you'd have to be venting the chamber itself.

REIMERS: Yes. The likelihood in a Space Station environment being able to deliver that much nitrogen in that amount of time is probably not very high.

HAMILTON: If you had cryogenic storage, unless you've got a buffer tank of some sort, you're not going to have enough capacity to do that.

BOVE: Let's say you wanted to drive the O_2 concentration down from 22% to 12% with nitrogen. That's a lot of nitrogen. How much equivalent CO_2 do you need to accomplish the same thing?

REIMERS: In that situation, I would expect that the CO_2 rule is going to be the same. It's going to take just as much CO_2 to put the fire out as it's going to take nitrogen in this kind of environment. That's just going to be a volume-driven amount.

HAMILTON: Is that what the White Sands study showed?

BARRATT: They compared local concentrations. Nitrogen was 20%, CO_2 was 15%.

REIMERS: Okay. So, it takes a little bit less, but still a lot.

HAMILTON: Basically, it's a bulk effect. You're diluting the O_2, whereas Halon acts chemically, doesn't it?

REIMERS: Halon interferes with the flame front itself. That's why it doesn't take so much.

PANZARELLA: You're talking about quantities of nitrogen and CO_2. That's going to depend upon your chamber size, though, and how much gas is in the chamber. You might need a lot to suppress the entire volume, but you might need much less in the hyperbaric chamber. Or in the rack itself.

REIMERS: That's true.

PANZARELLA: The words "a lot" bother me a little bit, because they're dependent upon the size of the space you're inerting.

REIMERS: Yes. The chamber volume is about 7 m^3 (250 ft^3). Even at 2.8 ATA, to effectively nitrogen-pressurize the chamber you're talking about dumping three times that – say, 20 m^3 (700 ft^3) – in there, which is three standard size bubbles. Not a lot. It's not a gigantic quantity of nitrogen in the overall scheme of things. But, it does require that you have it in a form where it can be delivered quickly. Even that much nitrogen, in a form where you can deliver it at that kind of speed, I suspect is going to cost a lot of weight because it's going to have to be in gaseous form under pressure.

BOVE: And, the CO_2?

REIMERS: Well, no. There are a couple of subtle differences here. CO_2 stores in liquid form. CO_2 at room temperature liquefies at about 4820 kPa (700 psi). So, for a typical CO_2 fire extinguisher and any other CO_2 tank that you buy – e.g., with the gas company you buy CO_2 – that's liquid in that cylinder, and you could store a lot. It comes out very cold, which is sometimes helpful. In this environment, one aspect of using CO_2 in that form that has to be considered is the fog it's going to generate. Very quickly, it's going to make it so that people in there can't see. That's because of the cold. It's foggy. Whatever water vapor is in there, it's going to turn into fog and obscure your vision. Nitrogen won't do that to you. But, it's going to take a lot less weight to hold the same amount of CO_2 than it will to hold the same amount of nitrogen.

BOVE: Now, CO_2 being a nonideal gas, I assume a given volume of CO_2 going into the chamber wouldn't raise the pressure as much.

REIMERS: It would because, at the kind of pressures you're talking about for a hyperbaric chamber here, you're down in the regime where CO_2 behaves as an ideal gas. We do a lot of work with CO_2 and, for normal engineering purposes, it is a perfect gas up to about 500 lbs dilution.

BOVE: I have trouble figuring out why CO_2 has a real advantage over nitrogen, particularly when you've got a large nitrogen store on the Space Station to start with.

REIMERS: I've come to that same feeling. The other aspect of all this that has to be considered is this: Once we've got all this wonderful extinguishant up there, what happens someday when it all gets loose by accident?

HAMILTON: That's why you should try Krypton. I'm really not joking. Krypton has properties very much like CO_2. You can store it the way you store CO_2, and you can fill a fire extinguisher with it. It's going to cost a bundle, but you only have to do that a couple of times.

PANZARELLA: A lot of people are talking about the volume going in the mask in case of a fire inside. One of our concerns is, if something should happen to the line that's going into the chamber that provides the air to the mask, as long as you have a fire and you start dumping CO_2 into the chamber, you're just making that environment really hazardous as far as toxicity is concerned.

REIMERS: In that environment, you probably just ran out of options.

PANZARELLA: Whereas, if you use nitrogen, you would lessen the effects of toxicity.

REIMERS: In the case of a nitrogen pressurization, you have done *nothing* to spoil the atmosphere as far as people are concerned. You've raised the total pressure, but you have not lowered the partial pressure of oxygen – unless, of course, while you're doing this, the relief valve is blasting away.

WORKMAN: Let's go back to the partial pressure of oxygen and the conversation that we had when we last met. We are assuming that we are operating with 21% O_2 environment, are we not? Didn't we say yesterday that that concentration was variable? Why can't we operate at 16 or 17% chamber environment? You minimize the risk of fire, and you're still at a physiological equivalent for your inside tenders. Even at 18%, you still have a little ambient risk of fire, but the

WORKMAN: (Cont'd) outlook is improved. The lower you can make the oxygen concentration in the environment, the better in terms of fire prevention.

BARRATT: Agreed. This should always be a real-time option for us.

SPEAKER: As we discuss bringing someone in from outside, what is the time line involved? How fast can we get an unconscious astronaut in and get the chamber up and pressurized? It seems like they could go no further than the crew lock and pressurize while they doff their suits.

PILMANIS: The only problem is that, if you haven't intubated him, you're going to have problems ventilating.

HAMILTON: You've got to intubate him. But, you can pressurize at the same time.

BUCK: Well, I don't know where you'd put the suit. I don't know how you'd fit the suit in there, the medical restraint, and all your medical equipment once you did get it in there. With one person doing all of that: setting up the restraint, trying to get the guy on the restraint, trying to intubate, and trying to set up the medical equipment.

BOVE: Would the suit go through the medical lock?

BUCK: No.

BOVE: Even without the guy in it?

BUCK: No. Not with the upper torso. I'm sure you could put the glove through or something like that. But I'd say, you'd probably waste more time doing that, trying to have one guy set up the whole thing.

HAMILTON: Well, you've got several levels of response, and getting intubated and on oxygen and at pressure are all important. And, I don't know that one is ahead of the other one.

PILMANIS: You need people, and one person just can't do it all.

BOVE: No. Somebody will have to be the chamber operator and somebody will have to be inside. But, how long does suit doffing take? Have they drilled in trying to get the suit off fast? The helmet and the upper shell?

TRAUSCH: As soon as you reach the pressure and equilibrate, you can pop that helmet off in a matter of seconds.

BOVE: Let's say you wanted to get a guy under pressure, so you want to get the upper torso off. Because it seems the pants could go through the lock.

TRAUSCH: Not really, because it's got a hard ring that you have to turn.

NORFLEET: I wish Dr. Ziegelschmidt was still here, because they do these runs for WETF operations, getting somebody in. They do have a requirement to have the patient under pressure in 5 minutes.

BOVE: Out of the suit?

BARRATT: The suit can be doffed in under a minute for WETF operations.

TRAUSCH: That's in one g also.

HAMILTON: It may be easier in some ways and not so easy in other ways in zero g. It's going to take you some time to get him back there; but that additional time, if it's a minute, then it's worth it.

REIMERS: Well, you've got to consider that, if the guy has an ebullism, he's probably some way away from the Station.

BUCK: That was something else I wanted to bring up. He could be as much as 10 minutes even getting in the airlock and up to Station pressure.

PILMANIS: If it's a frank rupture or a tear, then that's one situation. But, where it's a small hole, for example, you have make-up gas available. There are all kinds of other variables and time factors that could stretch the exposure to 10, 15, 20 minutes, and still the person may be salvageable. It's not a pure all-or-nothing situation. Does the suit provide any containment to the body?

BOVE: If it's intact.

PILMANIS: Doesn't it tighten up? I'm talking about physical containment.

HAMILTON: No, it's not tight. It's not in the nature of the space activity suit.

PILMANIS: What I'm getting at is that the body will double its physical size unless something holds it in.

NORFLEET: A very interesting comment, I think, that an astronaut made is that he cannot take a vital capacity inspiration in the suit.

PILMANIS: Okay. That's very important because, if the suit prevents the body from doubling in size or at least to some degree, survival would be extended.

BOVE: Let me clarify this. The equipment lock does not go under pressure and is not hyperbaric. So, it's really a single lock. Basically, you don't have a double lock.

PILMANIS: That's another thing that's very important. Whoever goes in at the start is in for the duration, and no one else can be locked in or out.

NORFLEET: Well, that's basically right. I mean, it's a monolock, multiplace chamber.

PILMANIS: The reality is, in very hyperacute patients, that we often had four to five people in at the start and we locked people in regularly; it was a regular elevator.

NORFLEET: And that's why, with multiple extensions, you're just going to kill your staff. You've got to come down at some point, hopefully prior to the point where everybody is so exhausted that they can't even manage to do the transport scenario.

Hyperbaric Chamber Duty Station Requirements

BARRATT: To continue on then. We're going to defer the communications equipment discussion. Mr. Reimers will probably be discussing that privately, along with some of the open issues that have come up between Work Package-1 and -2. We're going to go on to Duty Station requirements. We touched on it briefly yesterday in Courtney's presentation and during our tour of the mockup that the workstation has been removed from the equipment lock and moved to the node nearby. I have asked Colonel Workman to discuss Duty Station requirements partly with that in mind: Who should be monitoring what, for how long, dedicated positions, etc.

WORKMAN: With that in mind, using yesterday as a kickoff point, here is a listing of what I gleaned out of JSC-31013, which is what the existing document says in terms of requirements (FIG. 102). There's nothing new in terms of personnel requirements. There will be a minimum of one inside attendant and one outside operator. I think at this point, we're looking primarily at evaluating what impact removal of the workstation to the node is going to have. Also, as we discussed yesterday, the ability to maintain an adequate visual contact with the existing camera that we currently have needs a close look. It goes without saying, from the gist of the conversation yesterday and a lot of what we've talked off line about, that we as a committee are *not* comfortable with removal of that workstation back to the node.

There are so many "what if's" that will require that the individual who's operating the chamber be there, with direct line of sight, and have all that information available to him. Whether it be the additional database we've been talking about, having immediate access to that, or other tasks. It's even more critical

FIRE PREVENTION IN HYPERBARIC CHAMBERS

R. W. Hamilton

A hyperbaric chamber poses a special fire hazard because of the increased flammability of materials in compressed air or an environment otherwise enriched in oxygen.

Fire safety in hyperbaric chambers requires basically the same practices as in other locations. The chamber, however, involves two special considerations--the atmosphere will be an "artificial" one, and people may be confined in a relatively small space with the fire. The traditional fire "triangle" of conditions necessary for a fire are a source of ignition, combustible materials, and an oxidizer. To these can be added four additional steps in chamber fire safety in case a fire does start: Prompt detection of the fire, a means of extinguishing it, a mask for breathing, and--if possible--a means of escape.

The conditions discussed here are those of a typical undersea habitat or diving-related hyperbaric chamber. An additional chamber situation not considered explicitly is the hospital hyperbaric therapy chamber used for treating a variety of patients and conditions; although their objectives are fundamentally different, these chambers have many common factors with those used in diving.[1] A special situation in diving is the underwater welding chamber, where there is a guaranteed source of ignition and possibly restrictions on the control of the atmosphere.[2] Another aspect of fire safety related to diving but not limited to chambers is the handling of high-pressure oxygen, which is a specialty area in itself.

A safe chamber begins with its design. Various codes and design handbooks deal with this complex subject, and it can only be touched on here.[3] Given a safe design, the way a chamber is used is just as important. This section reviews chamber fire safety, covering both basic principles and operational techniques. For a more thorough treatment of the subject and additional references consult the section on fire safety in the Underwater Handbook.[4]

1. Ignition

Possible sources of ignition in a hyperbaric chamber include:

- Electrical wiring or apparatus
- Cigarettes and other smoking materials
- Adiabatic compression
- Electrostatic sparks

The most common sources of previous chamber fires have been smoking and faulty electrical wiring or electrically powered devices. Electrical fires can start from either overheating such as might be caused by a defective component, short circuit, or jammed rotor in a motor, or from sparks due to making or breaking a load-carrying circuit or from a device such as a motor with arcing brushes.

The safe use of electrical devices in a chamber is primarily a design factor in that it requires proper installation of the supply wiring and properly designed devices. Wiring should be insulated with mineral materials or Teflon® and shielded in mental conduit (which can be flexible). The housings of electrical devices such as instruments can be purged with an oxygen-free inert gas during operation, and may or may not be pressure proof. Lights may be enclosed and purged, or they may be external to the chamber and the light directed inside with a "light pipe" or fiber optic cable. Even an enclosed light can put out enough heat to start a fire, a fact to be considered at both design and operational stages. As part of the fire protection plan it should be possible for both inside occupants and the "topside" crew to disconnect all inside electrical power instantly; lights of course must not go off.

Some installations control the electrical hazard by allowing no electricity in the chamber at all. When it is used, it requires good knowledge of the hazards and safe procedures by all personnel, and good operational discipline. The use of electricity in a chamber also requires protection of the occupants from shock hazard, which may be done with such things as ground fault detectors and interruptors. Use of low voltage (e.g., 12 or 24 volts) avoids this hazard, but it is a dangerous misunderstanding to think such voltages cannot start a fire, if high current flow is possible. Devices tolerant of pressure and qualifying as intrinsically safe may be used, and low-current, low-voltage devices such as headsets and microphones are generally safe.[5]

There is a fundamental difference between the concepts being "intrinsically safe" and "explosion proof" devices and those required for chamber safety. These devices are made to defend against sparks igniting flammable gases or vapors, which is not the expected problem in a diving chamber. Junction boxes and other equipment made to "explosion proof" standards may provide the kind of protection afforded by mechanical housings (mentioned above), but because this equipment is designed for a purpose different from the hyperbaric, enriched-oxygen environment, they may in fact be inadequate.[6] Also, most explosion proof boxes are much too large and heavy for efficient use in the crowded conditions of a chamber; there are better approaches.

Static sparks are of course to be avoided if possible, but their hazard in the diving chamber is probably overrated. For one thing the atmosphere usually has humidity sufficiently high to suppress sparks. Also, static sparks are only a hazard with vapors or gases or dry, finely divided materials, none of which should be present in a chamber with proper housekeeping. To prevent static sparks conductive materials can be used, and everything possible should be grounded. In some medical hyperbaric chambers the patient is grounded with a wrist strap.

Adiabatic compression is more of a problem in the piping of oxygen-rich gases, but it is also a factor in chamber safety. The problem is that gases heat up when compressed, and sudden opening of a valve allowing an oxygen mixture to compress in the pipes can cause an explosion. A different but related hazard is the gas flow through a filter or muffler in the air supply. If the air is produced by an oil-lubricated compressor some oil may collect on the filter or muffler and be ignitied by compression or sparks generated by flowing gas.

Incredulous as it may seem, a major source of chamber fires has been smoking. This is less of a hazard now than before the risks were widely known, but constant attention still need to be given to its prevention.

2. The chamber atmosphere

The primary factor that makes a diving or hyperbaric chamber a fire risk is the increased combustion due to the enriched oxygen atmosphere. An "enriched oxygen atmosphere" is one which has either a partial pressure or oxygen percentage greater than those of air at sea level pressure. Thus compressed air is an enriched atmosphere as far as fire is concerned. Burning rates (determined in a laboratory with paper strips) when the pressure is equivalent to 75 fsw is twice that of sea level air, and it is 2.5 times as fast at 165 fsw.

A still worse situation ensues when the gas mixture in the chamber also has an increased percentage (i.e., fraction) of oxygen. These relationships are complex and non-linear, but show a consistent trend toward faster burning with increased oxygen percentage, or with an increasing pressure at the same oxygen percentage; these relationships are shown in Figure 1. The nature of the background gas is important, too, with helium causing higher ignition temperatures to be necessary but allowing faster burning.

Figure 1 about here. This is Fig. VIII-12 in the U/W Handbook, p. 655. Title: Burning rates of paper strips in N2-O2 miixtures. Caption: The curves show the relationship of partial pressures and percentages of oxygen, using empirically determined rates of burning of filter paper strips in various mixtures, with derived rates (vertical bars) at various partial pressures.]

Because of the greatly increased risk when oxygen is added to compressed air, it is now considered essential to use an "overboard dump" for exhaled gas when divers are breathing oxygen by mask during a decompression or treatment. This is a device to vent the exhaled oxygen to the outside of the chamber. It is also considered acceptable if a low oxygen level can be maintained by ventilating or purging the chamber with air, but this is a losing proposition from the start since the gas use for purging (air) is itself fairly rich in oxygen. It takes high flows to keep the oxygen below an accepted limit of 23%, and these are accompanied by excessive noise and compressor wear and tear.

One helpful aspect of atmosphere management in fire safety is the "zone of no combustion." While changes in pressure at a constant oxygen percentage affect burning rate, the more prominent effect is when changes in the percentage of oxygen. The result is that there is a "zone" of pressure and oxygen percentage that provides adequate oxygen for respiration but that will not support combustion.[7,8] This is illustrated in Figure 2.

An important consequence of the zone of no combustion is that the chamber environment in most saturation dives is fire safe except in the latter stages of decompression. It also allows for controlled combustion such as welding to be performed safely at pressure. Along with the zone where no combustion is possible is a broad zone of incomplete or reduced combustion. The zones of partial and noncombustion can be used operationally (as in welding), but care must be taken that the mixtures are correct, and particularly that all personnel are well acquainted with the fire risk and that discipline is maintained when the safe conditions do not prevail.

[Figure 2 about here. The same as Fig. 16-4 in the second Edition, but the one used as VIII-15 in the U/W Handbook has better graphics. The caption of 16-4 is good as it is. Title: Combustion rates in O2-N2 mixtures showing the zone of no combustion.]

3. Materials

The third element required to make a fire is fuel, something to burn. Chamber fire safety requires that all combustible materials be kept to a minimum, and that where possible materials be used that are not flammable in enriched oxygen. Some materials regarded as "non-flammable" in air will burn in a high oxygen mixture, so it is best to rely on materials known to be safe or relatively safe in oxygen.

Metals (unless finely divided) are safe, as are ceramics. For wiring insulation TFE (Teflon) is probably the best all around material, but there are mineral insulations and fiberglass as well, and some hard plastics like bakelite (sp?) and Melmac are usable in some circumstances. Some fluroine-based elastomers are relatively safe in high oxygen mixtures, but their properties are poor and they are expensive. For clothing the popular choice is Durette, but Nomex is virtually as good. Beta fiberglass is suitably flameproof but has undesirable wearing properties.[9]

These materials were selected and tested some years ago, and where special needs exist some of the more modern polymers may be superior, but there is little research literature available. At the design stage of a hyperbaric facility or chamber system the best approach is to consult someone experienced in this technology.

While design is important, even the well-designed chamber needs to be used properly to be safe. Good housekeeping is mandatory; all loose clothing, papers, and other flammable materials must be stowed, preferably in metal boxes, or removed from a chamber when out of the fire safe zone. Particularly important are fuzzy or powder or finely divided materials, and flammable liquids and gases.

One gas that may come into use in diving but that cannot be removed at certain times is hydrogen. This gas is being explored for deep diving because of its physiological properties (mainly low density resulting in low breathing resistance). Hydrogen can be used without danger of explosion (one it is properly mixed) when a mixture contains less than 5% oxygen,

making it suitable for diving deeper than 100 fsw or so where such a mix would have a breathable PO_2. Most safety problems with hydrogen as a diving gas are in handling and mixing it.

4. Dealing with a Fire

The preceding sections deal with preventing a chamber fire. Another component of fire safety requires that the people involved are able to deal with a fire once it starts. Although some past chamber fires have spread rapidly, many others (most of which never make it into the literature) have been extinguished without loss of life.[10] It is well worth the preparation needed to be able to control a chamber fire.

a. Detection

Numerous fire detection mechanisms are available for routine fire protection. Many of these systems are usable in a pressure chamber, particularly ones operating at the low pressures used with compressed air. The detection mechanisms most suitable for chamber use are those with infrared or ultraviolet sensors. Ionization or smoke detectors may also be of value.

There are two problems with fire detection systems, false alarms and failure to detect a fire quickly enough. Any detection system needs to be thoroughly studied in light of the uses and needs of the particular installation. In particular, it should be decided whether it activates an alarm or a deluge system when a fire is detected. Most experts feel, for example, that a clinical hyperbaric chamber treating patients with open wounds should have an alarm system only rather than one that automatically deluges the chamber; a preferred approach is to have both a hand-held directable fire hose inside, and switches to activate a general deluge system easily available to both chamber occupants and the topside crew. Whatever system is used it should be thoroughly tested on installation and periodically checked therafter.

The best protection is an alert crew backed up by detectors. During certain welding operations in compressed air the only dependable detection system is another person standing by watching the operation. For a couple of reasons this system works better if the fire watch is inside the chamber rather than relying on what he or she can see through a viewport.[2]

b. Fire extinguishment

[Sect. 16.3.5 ok as it is, with changes:

1. Delete short paragraph beginning "The mode of . . ."

2. Three lines from end add after "chamber": "; lights must of course remain on"

c. Breathing masks

Most fire fatalities are due to smoke inhalation rather than actual burns, and this no doubt applies to chamber conditions as well.

Accordingly, the first thing the occupants of a chamber with a fire should do unless immediate escape is possible is to don a breathing mask. The masks should be handy, and should have a breathable gas on line or be controllable by the occupants at all times.

d. Escape

If it is possible for occupants to flee quickly to another chamber or lock that can be sealed off from the fire, this is the preferred method rather than going on mask and trying to extinguish it. In an underwater welding chamber this might involve escape into the sea, in which case breathing and thermal requirements must somehow be met.

5. Summary of fire protection procedures

[First 6 points of 16.3.6 are ok. Continuing:]

- The extinguishing system should involve a water deluge spray that can be activated by either occupants or topside operators, and a hand fire hose that can be controlled and directed by the chamber occupants.

- A detection system should warn when a fire has started, and when appropriate should activate the water deluge spray.

- A mask with an appropriate gas that can be immediately put on line should be available for each chamber occupant.

- Where escape to another chamber or directly into the sea is possible this should be a primary option in the operations plan.

6. References

[Details to follow in next mail]

1. Davies and Hunt, 76.

2. Hamilton, Schmidt, Reimers, CADC2, 1983.

3. Some design handbooks (can SDR supply the latest?)

4. Shilling, et al. 1976, pp 646-664.

5. RWH has book on intrinsic safety.

6. Anybody got anything on explosion proofing?

7. Cook, Meierer, Shields, 1968.

8. Rodwell, Moulton, 1985.

9. Dorr, 1971a.

10. NFPA 53M, 1979.

16.3 FIRE PREVENTION

The key to fire prevention in hyperbaric chambers is the elimination of any material that can burn or cause a spark. For this reason divers, patients and attendants should wear fire-retardant clothing and remove any articles that might cause high levels of static electricity or sparks. Shoes, along with any clothing that is greasy, must be removed prior to entering the chamber. Other items presenting potential fire hazards include: watches, rings, jewelry, jackets, and other articles of clothing that have metal buttons or zippers.

16.3.1 Ignition

Possible sources of ignition in a hyperbaric environment are:

- Sparks—electrostatic sparks; frictional or impact sparks; sparks or arcs caused by interrupting the flow of electric currents
- Hot surfaces—heating by shear rates; heating of wires by electricity; incandescent carbon wear particles from electric motor brushes; friction
- Hot gases—gas flames and shock waves; adiabatic compression

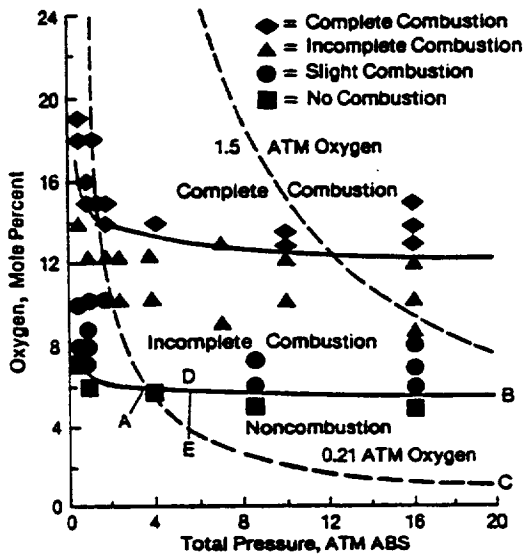
The most probable source of ignition in a hyperbaric chamber is its electrical system. Malfunctions in such systems often supply the heat necessary to ignite flammable materials.

Electric motors, such as the type used in scrubbers or fans, are potentially more hazardous than short-lived sparks. Locked or jammed rotors may cause sufficient overheating to start a chamber fire.

Sparks generated by occupants may possess sufficient energy to ignite combustible gases and powders in both air and oxygen, but these sparks have a very low probability of igniting solid materials such as cotton or nylon. Appropriate procedures should be followed, nevertheless, to minimize the likelihood of static spark generation by either personnel or equipment. Electrostatic sparks may be avoided to a large extent by having as many materials as possible conduct electricity, and keeping the humidity high.

The Navy Clothing and Textile Research Unit has developed clothing and textiles for use in oxygen-enriched atmospheres. These items were selected based on results of extensive tests of the flame-retardant ability of more than 100 materials. As a result of these tests, the Navy concluded that a commercial fabric, Durette, is the best material to use in flame-retardant clothing (Higginbottom and Silvia 1944). Durette fabrics are used in mattresses, sheets, towels, and most types of clothing required in decompression chambers.

Figure 16–4
Combustion Rates of Paper Strips in Mixtures of N_2 and O_2 as a Function of Pressure and Gas Composition



Combustion zones are defined by solid lines and normal respiration by dashed lines. The area A-D-E is compatible with respiration but is in the zone of non-combustion (Cook, Derr, and Shields 1968)

16.3.2 Combustion

The hazard presented by fire in a chamber filled with compressed air increases as the air pressure increases (to about 300 fsw) for two reasons:

- The higher the pressure, the greater the ease with which combustible material ignites (see Figure 16–4)
- The higher the pressure, the greater the rate of combustion

The risk of fire is not always increased in hyperbaric environments; for example, this is not true in saturation diving chambers. At high pressures, the oxygen percentage in a mixture of oxygen and inert gas normally is reduced to lessen the danger of oxygen toxicity. This decrease in the oxygen percentage also may render the atmosphere incapable of supporting combustion. However, whether this fire-safe condition exists must be calculated carefully.

16.3.3 Materials

When it is impractical to maintain the hyperbaric environment within the region of non-combustion, and

Table 16–3
Fire-Resistant Materials

Category	Material	Class	Comments
Fabric	Teflon-Coated Beta Fiberglas (4484)	9	Teflon coating increases comfort and durability.
Fabric	Beta Fiberglas (4190B)	9	Completely non-flammable under all conditions; chief disadvantages are possible skin irritation and low abrasion resistance (resulting in poor durability).
Fabric	Teflon	8	Heavy, low moisture regain, lack of wearer comfort.
Fabric	PBI	7	Suitably flame resistant in compressed air; comfortable as clothing and bedding, however, is not commercially available at present.
Fabric	Durette	6	Available (at relatively high cost) and suitable for use in compressed air in terms of flame resistance and comfort. Appears to be the best compromise choice of fabrics at this time.
Elastomer	Fluorel 1071	8	Significantly increases fire safety of breathing masks and hoses.
Paper	Non-Flammable Paper (Dynatech)	9	Writing quality inferior to Scheufelen paper.
Paper	Scheufelen Paper	9	Good choice for all paper articles that are used in chamber.
Electrical Insulation	Kapton	9	Generally unavailable as pre-insulated wire.
Electrical Insulation	Teflon	8	Teflon insulated wire commercially available; wires should always be enclosed in additional mechanical protection and should be protected from overheating.

if all possible sources of ignition within the chamber cannot be eliminated with absolute certainty, materials to be placed in the chamber should be selected carefully.

Recommendations for material applications in oxygen-enriched hyperbaric chambers are given in Table 16–3; the class numbers in this table correspond to those in Table 16–4.

16.3.4 Fire Detection

Because of the rapidity of fire development in oxygen-enriched atmospheres and the consequent extreme hazard, reliable detection techniques should be mandatory. Detectors for this application should provide volume surveillance and permit early and rapid detection of incipient combustion as well as flame. Table 16–5 indicates the various types of detectors currently available for fire detection (Schmidt et al. 1973). In general, these detectors rely upon either the temperature rise, radiation emission, or combustion products of the flame process for activation. Certain of these detectors, such as the overheat or rate-of-temperature-rise detectors, are not acceptable for oxygen-enriched environments because of their inherent slow response and limited volume coverage. Flame radiation, ultraviolet (UV), and infrared (IR) sensors and smoke detectors in combination appear to be ideally suited for this application.

The chamber operator also should obtain special sensors to detect the slower, smoking, smoldering type of fire that can occur in environments where the percentage of oxygen is reduced. Such sensors are now available on the commercial market.

16.3.5 Fire Extinguishment

Fire extinguishment is accomplished by physical or a combination of physical and chemical actions involving four basic mechanisms:

- First, the combustible material can be cooled to a temperature below that required for ignition or the evolution of flammable vapors
- The second mechanism involves smothering the fire by reducing the oxygen or fuel concentration to a level that will not support combustion
- A third mechanism involves separating the fuel from the oxidizer by removing one or by mechanically separating the two. This is the major

Table 16–4
Scale of Fire Resistance

Class 0. Burns readily in air at atmospheric pressure.
Class 1. Has an appreciably higher ignition temperature and/or burns at an appreciably lower rate in air at 1 ata pressure than cotton cloth or paper. An example of a Class 1 material is wool.
Class 2. Non-flammable or self-extinguishing in air at 1 ata pressure.
Class 3. Self-extinguishing or burns slowly in air at a pressure of 100 feet of sea water (4.03 ata).
Class 4. Self-extinguishing or burns slowly in air at a pressure of 200 fsw (7.06 ata).
Class 5. Self-extinguishing or burns slowly in a mixture of 25 percent oxygen and 75 percent nitrogen at a pressure of 1 ata.
Class 6. Self-extinguishing or burns slowly in a mixture of 30 percent oxygen and 70 percent nitrogen at a pressure of 1 ata.
Class 7. Self-extinguishing or burns slowly in a mixture of 40 percent oxygen and 60 percent nitrogen at a pressure of 1 ata.
Class 8. Self-extinguishing or burns slowly in a mixture of 50 percent oxygen and 50 percent nitrogen at a pressure of 1 ata.
Class 9. Non-flammable in 100 percent oxygen at a pressure of 1 ata.

mechanism of mechanical protein foam on jet fuel fires and is often referred to as "blanketing" action

- A fourth mechanism involves chemical interference or inhibition of the reactions occurring in the flame front or just before the flame front.

The mode of action and effectiveness of several extinguishing agents are shown in Table 16–6.

At the present time, the best fire extinguishing agent for use in hyperbaric chambers is water. Water extinguishes primarily by cooling and works best if it strikes the flame or wets the fire in spray form. The pressure at the spray nozzle must be about 50 psi above chamber pressure to produce the desired degree of atomization and droplet velocities. Simultaneous with the discharge of water, all electrical power to the chamber should be shut off to prevent shorting and electrical shocks to personnel in the chamber. A manually directable fire hose will permit occupants of a chamber to control small localized fires.

16.3.6 Summary of Fire Prevention Procedures

A summary of fire prevention procedures follows:

- Maintain oxygen concentration and partial pressure as low as possible, preferably within the region of non-combustion. Use an overboard dump system whenever pure oxygen is breathed by mask in a chamber.
- Eliminate ignition sources.
- Minimize combustibles, with the complete exclusion of flammable liquids and gases.
- If combustible materials must be employed, the type, quantity and arrangement in the chamber must be carefully controlled.
- Firewalls and other containment techniques should be utilized to isolate high risk fire zones.
- A fixed fire extinguishing system should be utilized that incorporates automatic initiation by flame and smoke detectors as well as manual initiation, and provides rapid and sufficient agent discharge.

An excellent source for additional information on fire hazards related to hyperbaric chamber facilities has been published by the National Fire Protection Association in the form of a standard (1976).

16.4 CHAMBER MAINTENANCE

Proper care of a compression chamber requires both routine and periodic maintenance. After every use or once a month, whichever comes first, the chamber should be routinely maintained in accordance with the Post-Dive Maintenance Checklist (see Table 16–7). At this time, minor repairs may be made and used supplies restocked. At least once a year, the chamber should be inspected both outside and inside. Any deposits of grease, dust or other dirt should be removed and the affected areas repainted.

Only steel chambers are painted. Aluminum chambers are normally a dull, uneven gray color and corrosion can be recognized easily. Painting an aluminum chamber will hide and further encourage corrosion.

Corrosion products are best removed by hand-sanding or by using a slender pointed tool, being careful not to gouge or otherwise damage the base metal. The corroded area and a small area around it should then be cleaned to remove any remaining paint or corrosion products. Steel chambers should then be painted with a non-toxic, flame-retardant paint. If it is not known whether the chamber has been painted previously, all old paint should be removed and the chamber repainted, as described above.

Upon installation and at five-year intervals thereafter, chambers should be pressure tested. The date of every inspection and pressure test must be noted in a conspicuous location on the outside of the chamber's shell near the hatch ring. Notations should

OPERATIONAL SAFETY IN CLINICAL HYPERBARIC CHAMBERS

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ABSTRACT

Hyperbaric medicine is rapidly becoming an established therapy modality. However, hyperbaric chambers present their operators with a complex set of structural, functional and procedural considerations which must be properly managed if acceptable levels of operational safety are to be achieved. The major considerations are (1) structural integrity, (2) atmospheric control, (3) mask breathing system performance, (4) fire safety, (5) system safety, (6) crew qualifications and (7) operational procedures. The principal factors affecting each area are discussed along with the operational procedures and principles which have been found necessary to achieve safe, trouble-free chamber operation.

INTRODUCTION

Hyperbaric medicine is rapidly becoming an established therapy modality. However, hyperbaric chambers present their operators with a complex set of structural, functional and procedural considerations which must be properly managed if acceptable levels of operational safety are to be achieved. Indeed, some people regard hyperbaric chambers as potential bombs waiting for the correct set of miscues to set them off. To be sure, hyperbaric chambers have seen their share of accidents. However, technology advances by learning what does not work as well as by learning what does work. Thanks largely to past misfortunes, there exists today a body of well established principles in the design, installation and operation of hyperbaric chambers which, if followed, will provide a level of operational safety quite sufficient to satisfy even the most skeptical observer. With respect to clinical hyperbaric chambers, the major considerations are (1) structural integrity, (2) atmospheric control, (3) mask breathing system performance, (4) fire safety, (5) system safety, (6) crew qualifications and (7) operational procedures. Those considerations are the subject of this paper. Note, however, that chambers used in support of diving operations are subject to additional considerations which are beyond the scope of this paper.

RELEVANT CODES AND STANDARDS

The principal codes and standards affecting clinical hyperbaric chambers are the following:

National Fire Protection Association (NFPA)

NFPA 56D: Hyperbaric Facilities

FFPA 53M: Fire Hazards in Oxygen-Enriched Atmospheres

American Society of Mechanical Engineers (ASME)

PVHO-1: Safety Standard for Pressure Vessels for Human Occupancy

Boiler and Pressure Vessel Code
Section VIII, Division I: Pressure Vessels

Naval Facilities Command (NAVFAC)

DM-39: Design Manual, Hyperbaric facilities

A third ASME document, PVHO-2 "Piping Systems for Pressure Vessels for Human Occupancy" is in preparation. However, it is not expected to be through the necessary approval cycles until sometime in 1984.

Of the documents listed above, the most important one in most non-military chamber installations is NFPA 56D. It is not a large document, and all chamber operators and facility supervisors should become thoroughly familiar with its contents.

STRUCTURAL INTEGRITY

The purpose of a hyperbaric chamber is to permit the exposure of patients to pressures that are in excess of normal atmospheric pressures. Loss of vessel structural integrity can result in a very rapid loss of pressure in the vessel. Depending on the rate of pressure loss and the original pressure exposures of the occupants, severe injuries such as pneumothorax, gas embolism and compression sickness can occur.

Most chambers constructed in recent years have been built to the requirements of the ASME Boiler and Pressure Vessel Code as amplified by ANSI/ASME PVHO-1. Vessels built to that standard are quality vessels that can be expected to give good service as long as due attention is given to necessary maintenance. There are also many vessels in service which were built before the appearance of ANSI/ASME PVHO-1. These vessels can normally be continued in service as long as the window designs employed meet the requirements of PVHO-1 or other recognized standards. However, any chamber using acrylic plastic windows which were built before 1978 should have the window designs checked for conformance with ANSI/ASME PVHO-1.

The windows in human occupancy pressure vessels are normally made from acrylic plastic. Acrylic is preferred because it is easily formed and it normally gives ample warning of any impending failures. However, acrylic plastic is susceptible to attack by several chemicals commonly found in hospital environments. Experimental work on the tolerance of acrylic plastic windows to common hospital chemicals is still in progress. Table 1 lists presently available data. Alcohol based solutions have been found to be much more troublesome than water-based solutions and should be avoided. In Table 1, for example, alcohol-based Lysol spray attacks acrylic whereas a water-based Lysol solution does not. As a matter of operation of procedure, all chemicals except mild soaps mixed with water should be considered potentially harmful to acrylic plastic unless evidence to the contrary is available.

Acrylic plastic is also subject to damage due to excessive heat and nuclear radiation. Heat damage is easily avoided by keeping heat sources such as powerful lamps well removed from the windows. Many monoplace hyperbaric chambers, however, are used in conjunction with radiation therapy. That is one

of the reasons for which they were originally developed. Radiation damage is cumulative, but is predictable and occurs slowly. Most monoplace chamber manufacturers now give a radiation exposure limit for their windows. As long as these exposure limits are observed, the chambers can be used quite safely.

Acceptable

Tergisyl	1:100 water solution
Lysol	1:100 water solution
Sani-Bactol	1:100 water solution
Amphyl	1:128 water solution
O-Syl	1:128 water solution
Sani Jet Spray	(As received)
Cidex	(As received)

Not Acceptable

Viro-Tec Spray	EPA Registration No. 11525-30-36171 American Hospitex, Div. of American Hospital Supply Corp., McGraw Park, IL 60085
Staphene Spray	EPA Registration No. 1043-19-AA, Vestal Laboratories, Chemical Corp., St. Louis, Missouri, 63110
Lysol Spray	EPA Registration No. 777-20-AA, Lehn and Fink Products Div. of Sterling Drug Inc., Montvale, NJ, 07645
Amphyl Spray	EPA Registration No. 665-25, Lehn and Fink Products of Sterling Drug Inc., Montvale, NJ 07645
Mikro-Quat	(As received)
Vesphene	(as received)
Ethyl alcohol	(98 percent)
Windex	(As received)
Chlorothene Spray	

Table 1

Cleans/Disinfectants Which Have Been Found Acceptable and Unacceptable for Use Where They May Come in Contact With Acrylic Plastic Pressure Vessel Windows. Unacceptable agents initiate stress crazing/cracking of acrylic plastic windows and must not be permitted in contact with acrylic plastic windows.

ATMOSPHERIC CONTROL

Atmospheric control is a general term used to describe the creation and maintenance of a safe atmosphere inside the chamber. Contamination of that atmosphere is possible with products carried in with the pressurization gas, by pollutants carried into the chamber by using personnel and by fire within the chamber.

A hyperbaric chamber is pressurized by one of three methods: compressed gas provided directly from a compressor, compressed gas from a pressurized accumulator or gas from a cryogenic supply system supplied through a suitable vaporizer. Monoplace chambers are usually pressurized from either gas stored in an accumulator or from a central cryogenic supply system. Large multiplace chambers are usually pressurized by compressed air from a compressor supplied through a large accumulator that acts as a buffer in the event of compressor failure or less of electrical power.

The pressurization air, regardless of the source, should be periodically checked for composition and purity. See Table 2. Gas supplied from central cryogenic supply systems are generally free of contaminants. However, liquid supply tankers have been known to inadvertently put liquid nitrogen into a liquid oxygen storage tank.

Gas supplied from compressors will normally have adequate oxygen. However, it is subject to possible pollution from several sources. The first potential source is pollution in the intake air. This is normally avoided by locating the compressor intakes in areas well removed from areas where atmospheric pollution is likely to occur such as areas near engine exhausts, sewage manholes, potentially leaky gas mains and locations where toxic or noxious gases may be released. Further protection from intake pollution can be provided with suitable absorbers. The second potential source of pollution is the compressor itself. Compressors used for handling medical gases are normally required by Codes to be of a type that does not permit contact between the gas being compressed and the compressor lubricating oils. However, this requirement is not universally observed. Where "oil lubricated" compressors are used, special care must be taken to prevent oil carry-over into the output gas and to prevent the partial oxidation of such oils with the resultant production of carbon monoxide in the event of a compressor overtemperature incident. The

third source of intake air pollution is the piping system. This system must be thoroughly cleaned of all oil, grease and loose particulate matter before being placed in service. Clearly, many types of intake pollution can occur, but the probabilities are usually very low. Monitoring methods and frequency must, therefore, be tailored to the specific conditions most likely to occur in each situation.

Contamination of the chamber atmosphere from within is possible by several means. CO_2 from the occupants must be somehow removed. Chamber CO_2 levels should not be allowed to exceed a partial pressure equivalent to a 1.5% concentration at surface pressure (11.4 mm Hg). In a ventilated chamber, CO_2 control can be maintained by ventilating the chamber at a rate equivalent to 4 cubic feet per minute at depth pressure per occupant. In non-ventilated chambers, CO_2 control is effected by circulating the chamber atmosphere through a suitable bed of CO_2 absorbent chemicals. Note, however, that in non-ventilated chambers attention must also be paid to the oxygen level, especially during prolonged periods of air breathing. Anoxia is not usually a threat in clinical chambers since the oxygen concentration is usually elevated. However, it is also insidious and deadly. Thus, the operational team must be aware of its possibility, especially if there exists a possibility of flooding the chamber with an inert gas. Contamination from within is also possible from chemicals or volatile medicines which may be deliberately or inadvertently introduced into the chamber. There have been several cases of atmospheric contamination due to bottles of freon cleaning solutions inadvertently left inside of chambers. There is also one known case of paraldehyde poisoning due to a paraldehyde vile which crushed in a physician's case during pressurization. One chemical that should be banned from any chamber installation is trichoroethylene which is a common cleaning agent. In its normal form, it is relatively harmless. However, it can break down on contact with common CO_2 absorbent chemicals to form highly toxic dichloroacetylene. Contamination from within can easily be prevented. However, doing so requires constant attention to all items which may be introduced into the chamber either deliberately or accidentally. Consideration should also be given to the management of any noxious odors that may be encountered.

Temperature control in a clinical hyperbaric is not generally a safety related item. Nonetheless, care must be taken to keep the patients comfortable, especially during pressurization and depressurization. Humidity control is another matter. Relative humidity levels below about 50% promote the formation of static electricity. Very high humidity levels are uncomfortable and can produce a thick fog in the chamber during depressurization. Both extremes should be avoided.

Contaminant	Maximum Level
Oxygen concentration	20 to 22% by volume
Carbon dioxide	0.05% by volume (500 ppm)
Carbon monoxide	0.001% by volume (10 ppm)
Gaseous hydrocarbons (e.g., methane, ethane)	0.0025% by volume (25 ppm)
Halogenated solvents	0.00002% by volume (0.2 ppm)
Oil and particulate matter	0.005 mg/liter, weight/volume
Total water	0.3 mg/liter, weight/volume
Odor	None

TABLE 2

Maximum levels for contaminants in air supplied to hyperbaric chambers. (Adapted from Hamilton and Sheffield (6)0

MASK BREATHING SYSTEM PERFORMANCE

A reliable mask breathing system, often referred to as a BIBS system or "Built-in Breathing System", is an essential part of a multiplace chamber. It provides a safe and secure source of breathing gas in the event that contamination of the chamber atmosphere is suspected. Also, since for fire safety reasons the oxygen content of the chamber atmosphere must be no more than about 23% by volume, oxygen delivery to patients must be by means of masks or hoods. These masks or hoods are normally supplied from the mask breathing system as are the masks used to supply oxygen to the inside medical attendants when required for decompression purposes. The number of available masks in a chamber must always be equal to a greater than the number of occupants and any masks routinely used for oxygen breathing should be fitted with an overboard dump system which directs the exhaled gases out of the chamber. The supply system for the masks must contain adequate reserves of oxygen, compressed air, and, when appropriate, other mixed gases. In the event of activation of the chamber fire suppression system, the supply system should automatically switch from oxygen to compressed air or another suitable mixed gas.

For effective oxygen therapy, it is essential that the masks fit well. A properly fitted anesthesia or aviator's mask will deliver essentially 100% oxygen to the patient. However, other types of hospital masks may deliver only about 40% to 80% oxygen (9). The difference is often enough to render a treatment ineffective. Masks must also be comfortable. For patients who cannot tolerate masks, there are several types of hoods that can e used to achieve the same effect. Note, however, that hood arrangements require careful attention to CO_2 removal and the prevention of excessive humidity accumulation. Masks often have the opposite humidity problem; the nearly complete absence thereof. To avoid potential respiratory irritations due to airway dehydration, the oxygen supply to masks should be humidified.

Monoplace chambers are generally not equipped with a mask breathing system since the chamber atmosphere is normally pure oxygen and the fire safety precautions that are required virtually preclude the possibility of atmospheric contamination.

FIRE SAFETY

In clinical applications fire in the chamber is, without question, the most significant operational hazard. Fire in an enclosed space can be an awesome event even at one atmosphere. Add pressure and extra oxygen and the hazard potential increases still further.

Between 1962 and 1970, there were nine known fires (seven fatal) in hypobaric and hyperbaric chambers. As a result, strict fire safety guidelines were developed and promulgated through the vehicle of the NFPA 56D Code. The early editions of that Code were so strict that compliance with their provisions nearly prevented useful operations. However, the 1982 edition of that Code has been extensively revised. It is still rather intimidating on initial examination. Nonetheless, it is now compatible with practical operations at reasonable cost. The author has designed three clinical systems where NFPA 56D was the governing Code. Compliance with the provision of NFPA 56D in these systems proved to be neither particularly difficult nor outrageously expensive. The biggest problems are becoming familiar with the rules and getting used to the idea that they must be followed.

The fire safety record of clinical hyperbaric chambers since 1970 is excellent. The author is aware of only one non-injury producing fire since that time. However, just as one does not smoke while filling the gasoline tank of one's automobile, there are certain precautions in hyperbaric chambers that simply must be understood and adhered to. Fire safety is a matter of both taking all practical preventive measures and establishing a practical fire management procedure to be used in the event that a fire should occur. Figure 1 shows the classic fire triangle and the preventive measures associated with each of the three elements. Figure 2 shows a "fire management triangle" and the management methods normally used.

The principal purpose of a clinical hyperbaric chamber is usually the administration of oxygen at elevated pressure. In multiplace chambers, this is accomplished with the patients breathing 100% oxygen by mask while the chamber itself is filled with air. In monoplace chambers, this is usually accomplished by filling the entire chamber with 100% oxygen. Consequently, the fire safety considerations in the two situations are substantially different.

Multiplace Chambers

Combustion rates increase rapidly with rising oxygen concentrations (12), and oxygen leakage rate the chamber atmosphere from the patient masks is inevitable. Consequently, the oxygen concentration in the chamber must be constantly monitored and should be kept below 23% by ventilation with either air or pure nitrogen. Oxygen concentrations above 25% warrant securing the oxygen supply to the chamber until the cause of the leak can be found.

Combustible materials must be restricted to the bare essentials. The complete combustion of as little as one pound of celluloid type material can raise the temperature in a medium sized chamber several hundred degrees. Greases and oils must be special types approved for use in oxygen service and then used only where necessary. Patient garments and linens should be of a fire retardant material such as Durette. Combustible medical necessities should be kept in metal containers, always vented lest they crush on pressurization of the chamber, until needed for use. Potentially volatile or flammable liquids such as alcohol should not be permitted in the chamber except in very controlled circumstances and in very small amounts. Note, however, that fire safety rules should not be so rigid as to keep needed medical supplies out of the chamber. With adequate planning and preparation, almost any needed material or equipment can be taken into the chamber without compromising necessary fire safety.

Potential ignition sources must be reduced to an absolute minimum. Matches, cigarette lighters and any items likely to generate sparks must be excluded from the chambers. Communication equipment should be fitted with intrinsically safe isolation amplifiers so that the energy levels deliverable to the components inside the chamber are not high enough to produce sparks. Electrical power items such as motors should be avoided. If necessary, however, they can be used with suitable precautions such as ground fault sensing circuit interrupters and inert gas purging of all components. Static electricity generation can be avoided by careful material selection and by keeping the relative humidity level above 50%.

Fire detection may be manual or automatic methods. When automatic methods are used, due regard must be given to false alarm prevention. Pouring stale water on a critically ill patient is not likely to improve his condition. When manual methods are used, care must be taken to ensure coverage; e.g., that someone is always watching.

The only currently accepted extinguishment methods consist of pressurized water supplied by a built in deluge system augmented with hand-held hoses. Care should be taken to not block the deluge nozzles and to keep the water in the system clean. Extinguishment systems should also be periodically exercised. It is foolish to expect a high performance water deluge system to sit undisturbed for several years and then function perfectly on a moment's notice.

Effective management consists of avoiding injury due to the effects of a fire even if it is one the deluge system successfully extinguished. Breathing masks must be available for immediate use and some procedure for escape to the exterior or to another chamber should be established in advance.

Particular care should be given to the prevention and detection of combustible atmospheres in the chamber. Such atmospheres can be created by spilling volatile chemicals inside the chamber, pollution of compressor intake air or by the slow heating of celluloid type materials (such as occurs if a cotton shirt is placed over a light bulb). Such atmospheres are difficult to produce, even when on purpose. However, if ever produced, they represent a fire hazard that is not likely to be manageable even with a very good suppression system.

Monoplace Chambers

In monoplace chambers, a 100% oxygen atmosphere is usually a standard operational condition. Thus, oxygen level control is meaningless and fire suppression is impractical. Fires occurring in pure oxygen environments cannot be readily extinguished. Some combustibles are also always present in the forms of patient garments and a mattress. Consequently, the only effective fire safety technique is to absolutely eliminate all ignition sources. This is usually possible in monoplace chambers without hampering their use, and monoplace chambers today have an excellent fire safety record.

When pure oxygen is used, however, the fire hazard does not end when the chamber door is opened. The patient's garments and bedding that have been exposed to oxygen under pressure will still be saturated with oxygen after the chamber is decompressurized and the patient moved back out into the room. Oxygen saturated fabrics ignite easily and burn quickly. Consequently, such fabrics must be treated with extreme care until the trapped oxygen has had time to diffuse out and be replaced with room air. The one fire since 1970 referenced previously involved the apparent spontaneous combustion of an oxygen saturated mattress that had just been removed from a monoplace chamber.

SYSTEM SAFETY

System safety is a term used to refer to the ability of the chamber and its support systems to continue to provide essential services in the event of one or more component failures and to the arrangement of the operator controls. System safety is not always as well appreciated as it should be and is one of the areas that should be examined closely in both existing and proposed facilities, especially when a supplier comes in with an unusually low price. Some of the more important aspects of system safety design are:

- Operator controls that are clearly labeled, sensibly placed, and organized so that they do not promote operational errors. Two divers died of compression hyperthermia in an offshore system because the pressure gauge that the system operator was monitoring was not connected to the chamber he was pressurizing.

- Single failure points should be minimized. The mask breathing systems and pressurization supply systems should be able to complete a treatment despite the malfunction of any one component, compressor or supply bank.

- Essential controls and monitors should be provided with emergency power sources for use in the event of loss of normal mains power and the transfer from normal to emergency power should be automatic.

- The chamber exhaust and exhaust from relief valves should be piped outdoors so that opening an exhaust or relief valve does not over pressurize the surrounding room. An operator of a hypobaric chamber (altitude chamber) on a test dive once opened the emergency compression (return to surface) valve just to try it out. The valve worked fine. However, the operator emerged from the chamber to find his laboratory collapsed inward onto his chamber.

- The system operators must understand their facility and be well trained in emergency procedures.

- System maintenance should be performed in a planned manner.

CREW QUALIFICATIONS

Like any piece of medical equipment, a hyperbaric chamber should only be operated by fully-qualified personnel. Chamber operators must be knowledgeable in all pertinent operational and safety requirements and should be required to demonstrate that knowledge. Physicians and inside medical attendants should also be trained in the medical aspects of diving as well as chamber operating and emergency procedures. Emergency response drills should be carried out on a scheduled basis. A number of major emergencies have been caused by improper responses to what would otherwise have been relatively minor problems. No matter how well designed a chamber system is, a lack of crew proficiency can result in serious danger to the inside occupants and operating personnel.

OPERATIONAL PROCEDURES

There is no room for procedural sloppiness in the operation of a hyperbaric chamber. Clearly defined supervision is essential. The chamber supervisor must ensure that all personnel understand their assignments and are proficient in them, that repairs and maintenance are performed as required and are duly recorded in an equipment log and that an accurate operational log is maintained. Wherever possible, operational history data for the operational log should be gathered with automatic methods such as pressure recorders, etc. In any accident investigation, the operational log is a critical item. However, one of the first effects of most emergencies is that the log keeper, who usually also has other responsibilities, is distracted by higher priority responsibilities and entries into the log cease at the time when they are most needed. The supervisor should also ensure that a complete operations manual and written emergency procedures are available in a location where they can be referred to quickly. Treatment schedules and responses to all likely attendant medical emergencies should be established in advance of any treatment dives.

Patient handling procedures must also be carefully planned. Many chamber interiors are cramped. Also many patients now being treated with HBO are not ambulatory and must be assisted by chamber personnel. Moving litter patients into and out of a cramped hyperbaric chamber requires careful planning if lifting related injuries to chamber personnel are to be avoided. IV set-ups must also be carefully handled so that they do not run or ingest air as a result of changes in chamber pressure.

SUMMARY

Clinical hyperbaric chambers have achieved a very fine safety record over the past several years. Hyperbaric medicine can be both safe and effective. However, the following considerations must be kept in mind.

1. Hyperbaric chamber installation, operation and safety are highly complex, expensive and require careful planning.

2. The use of shortcuts to operate a hyperbaric chamber with substandard, low-cost materials or without adequate system safety designs is dangerous and should not be permitted.

3. Attempts to operate a hyperbaric chamber without a well-trained and experienced crew invite disaster and should never be made.

4. Safe chamber operation requires:

   - A physical plant that is designed, built and maintained in accordance with accepted principles
   - operating and emergency procedures that are understood and adhered to
   - a trained and experienced crew that understands all aspects of proper patient selection, decompression procedures and chamber safety

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1991 September 24

CARBON DIOXIDE: THE REAL HAZARDS

Opinion by R. W. Hamilton

Because carbon dioxide is a candidate for the extinguishing agent to be used on Space Station Freedom, it is pertinent to review the physiology of this gas as a toxic agent. This in no way is intended to indicate my support for this choice, because I do not know the issues well enough at this point to make a decision. What I do know is that the toxicity of CO_2 is often poorly understood, and a fair choice can be made only if the basic facts are generally known.

The physiology of carbon dioxide is exquisitely complex at the tissue level; this gas is a hormone as well as a metabolite. It has been around throughout evolution, and the body is well equipped to deal with it. While an imbalance of CO_2 can be disturbing to cellular function, respiration, brain function, and even digestion, among others, most of these effects are easily and completely reversible if exposure is for only a short time. The situation here suggests that a short exposure—a few to many minutes—is what should be expected, and this memo addresses that.

Toxic limits

Because CO_2 is relatively easy to detect, even easier to remove or "scrub," and apt to be troublesome when it builds up for a diver, gas purity standards allow relatively low levels of CO_2 in breathing gas. The limit often set is 0.5% by volume at sea level. This is a practical limit and one easy to attain, but it may create an impression that levels a little higher than this are toxic; in fact, much higher levels than this can be tolerated without serious consequences.

CO_2 is an asphyxiant

The most hazardous property of CO_2 is as an asphyxiant. Because it is heavier than air and can collect in low places and thus exclude oxygen, it is frequently fatal to people falling down into a concentration of CO_2. Asphyxia, from whatever cause, implies a deficit of oxygen, and this is surely the fatal element in almost all cases.

Pooling of a dense gas is not likely to be a problem in microgravity, but pockets that do develop might be very slow to diffuse unless there is forced convection.

Unconsciousness in working divers

CO_2 can cause unconsciousness in divers doing hard work, especially if there are restrictions to breathing. This is especially true for certain individuals whose respiratory response to CO_2 is abnormally low. The consequences for a diver, of course, can be serious or fatal due to drowning.

Respiratory stimulation

The only way CO2—which is generated by metabolism—can be reduced in the arterial blood or eliminated from the body is by means of ventilation of the lungs (i.e., breathing). CO_2

builds up when respiration is reduced, and is lowered when ventilation is increased beyond the level commensurate with the current metabolic rate or activity level. Thus the body's physiology regulates CO_2 by controlling alveolar ventilation.

As ambient CO_2 is increased in individuals without breathing restriction, a linear increase in ventilation volume (above a threshold) is normally seen with increases in end-expiratory or arterial PCO_2. At somewhere between 1 and 2% at sea level, which is a partial pressure of 1 to 2 kPa, most people will be aware of an increased desire to breathe. At 3 kPa (or 3 percent) up to about 5 kPa (5 percent at sea level) most individuals will begin to notice labored breathing and an increase in respiratory minute volume. At 5 kPa (5%; the reader should be weaned from percentages now) it begins to get uncomfortable but can be endured indefinitely.

Carbon dioxide is the primary stimulant to normal respiration and the main element in the feedback loop that controls breathing. The target "set point" is probably not a CO_2 level at all, but rather the intracellular pH in the cells of the respiratory center in the brain stem; CO_2 crosses the membrane easily to get
inside the cells.

When under stress to remove CO_2 the body compromises between the amount of CO_2 buildup it is willing to tolerate and how hard it is willing to work to get rid of it.

Incidentally, a lowered CO_2 level from hyperventilation reduces brain blood flow and simulates the symptoms of hypoxia. Divers breathing dense gas with inadequate breathing equipment have been known to "hyperventilate" (as they may call it) in the sense of increasing respiratory frequency at the expense of depth. This amounts to a rebreathing of dead space and a net hypoventilation, and can probably lead to unconsciousness.

Higher levels

When the inspired level of CO_2 builds up toward 10 kPa partial pressure the stimulus to respiration is reduced, as the narcotic properties of the gas supersede the stimulatory processes. CO_2 at 10 kPa is uncomfortable to breathe, especially during the transition periods (on and off) if they are abrupt, but it is certainly not fatal in itself. Emphysema patients with restricted ventilation are often able to acclimate and carry on with levels this high. Consciousness begins to be clouded as the level is increased, so that at probably between 15 and 20 kPa most people can expect to become functionally unconscious.

Levels to 30 and even 40 kPa can be tolerated, for tens of minutes to hours, but this is not all there is to it. When CO_2 is abruptly reduced after such an exposure it generally leads to heart failure due to fibrillation. The mechanism of this has to do with release of potassium from cells; the details are not important, but the management of such cases could be. If the reduction is slow, over a fraction of an hour, the problems can be averted. Actual experience with humans has come from closed-loop anesthesia machines with valves inadvertently left out; these well-oxygenated victims were already unconscious, but suffered heart failure when the problem was discovered and the CO_2 abruptly removed. Since this was worked out, others have survived this experience.

Long duration low-level exposures

Studies on submarine atmospheres have shown that up to about 1.5 kPa the crew is not aware of the presence of increased CO2, and it is difficult to detect much in the way of biochemical

changes. At slightly higher levels, 3 kPa, it is felt and detected, but is tolerable for many weeks. At still higher levels to perhaps 5 kPa it can be uncomfortable, but still can be tolerated and people can perform exercise. Higher levels have not been studied over time, but as the level and duration increase the consequences will probably become more severe. When people so exposed would be unable to function is not known, but the emphysema model suggests at least 10 kPa should be endured with more or less normal function. Psychological failure is perhaps more of a threat than physiological.

Mechanics

An important aspect of CO_2 is that it can be removed from the atmosphere with the existing scrubbing equipment. If stores of necessary consumables are available this might be an easy "cleanup" compared to some of the alternatives, but as has been explained, it will not be without cost.

Conclusions

The use of carbon dioxide as a fire extinguishing agent should be decided on the basis of its fire fighting and other operational aspects, along with a valid consideration of its toxicology and physiology. The levels of CO_2 that can be tolerated are probably higher than is generally assumed, given the body's ability to acclimate to such a familiar stressor. This is not meant to be an argument in favor of carbon dioxide, but is inteded to help prevent inappropriate rejection should it turn out to have other important operational advantages.

HYPERBARIC AIRLOCK
DUTY STATION REQUIREMENTS

HAL COMPOSITION
- EQUIPMENT LOCK
- CREW LOCK (TREATMENT)

PATIENT MONITORING
- ALL PARAMETERS AVAILABLE TO INSIDE/OUTSIDE ATTENDANTS

VIEWING
- DIRECT /INDIRECT VIEW OF PATIENT CARE AREA BY OUTSIDE ATTENDANT DURING TREATMENT OPERATIONS

ENVIRONMENTAL CONTROL
- ALL DISPLAYS SHALL HAVE DIRECT PRESENTATION TO OUTSIDE ATTENDANT DURING TREATMENT OPERATIONS

FIG. 102 Hyperbaric airlock duty station requirements

HYPERBARIC AIRLOCK
DUTY STATION REQUIREMENTS

ALL PRESSURIZATION/DEPRESSURIZATION CONTROLS LOCATED IN EQUIPMENT LOCK TO MAINTAIN DIRECT VIEW OF PATIENT CARE AREA BY OUTSIDE ATTENDANT DURING ALL TREATMENT OPERATIONS

REQUIRED PERSONNEL

1 - OUTSIDE ATTENDANT WITH DIRECT VIEW OF PATIENT CARE AREA DURING TREATMENT OPERATIONS

1 - INSIDE ATTENDANT TO ASSIST IN PATIENT TREATMENT

FIG. 102 Continued

WORKMAN: (Cont'd) now, as we learn that the crew complement size has been reduced from eight to four; you don't have any "gofers" left.

Regarding that camera: We would like very much to be able to see a significant enhancement of that capability, to perhaps the extent of actually putting the camera inside. The technology available should allow us to do that; I understand the difficulties. As with the mask, items have to go through testing, etc., and whether or not we are already behind the power curve and time line to get something new, I don't know. All we can do is make good recommendations. It is our recommendation to take a very *strong* look at the camera, and to be able to provide for enhancement in the patient monitoring capability, and do anything that is possible to get that workstation back, or at least have some added capability given back to that operator who's going to be adjacent to that hatch.

REIMERS: I would like to lend some support to that. If you look at the scenario, let's say you're talking a 6-hour treatment, the hyperbaric chamber operator really has very little to do but sit there and mind valves and pressure gauges. The other guy, who's now the Station commander, is the only guy who can run errands to support the three people who are in this chamber, but he's also supposed to be the Station commander. What you're really going to want is to have the guy there at the controls of that chamber be able to do whatever is necessary to run the Station at the same time, leaving that other guy free for whatever happens. If you leave it like it is now, you have everybody pinned down.

STOLLE: I would like to mention that one of the areas here was to have all of the physiologic parameters available to the inside *and* the outside attendant. With the

STOLLE: (Cont'd) workstation gone, those physiologic parameters are only available to the inside attendant and to your "gofer," who's in the node looking at the computer over there.

BUCK: Except for what may be able to be viewed directly.

WORKMAN: That is going to compound the ability of the ground-level personnel to effectively advise the medical officer.

STOLLE: They will have that on the ground, though. They'll have the same information as the workstation in the node.

WORKMAN: Yes, but there's something to be said about talking to the regular crew chief. And, the regular crew chief is the guy who's got his head at the site, not some guy who's relaying information third or fourth hand.

BOVE: You see, the basic rule we worked on, too, is the inside tender is not the one who makes the logistic decisions. He's the one who carries out the orders from decisions, and that's been a standard rule of hyperbarics for a long time. It's the outside people who make the decisions; the inside tender is the purveyor of the decisions. The situation now is, the inside tender has the data.

HAMILTON: But, that comes from a situation where you often have a level of narcosis. That's a situation we should not see.

BOVE: It's more than that, because the guy's got a lot of manual tasks to do at the same time as the integrated thinking, and normally you would leave the committee outside to do the thinking and tell the guy inside to carry it out.

BARRATT: To add to that briefly: We're positing, as Courtney has mentioned, that the CMO would not be an EVA crew member. However, we do have the requirement to deliver advanced cardiac life support in the chamber during a treatment, and that implies that one of the CMOs would actually be in there.

BOVE: Then everybody has to learn that. A 2-day course is not that big a deal.

BARRATT: Your trainee may be an astrophysicist with no medical background.

HAMILTON: Suppose you haul somebody in, you've got two suited people – one of them is a casualty. Does the one casualty suited person go in and unsuit and stay inside, and then you put another fresh person into the chamber with the casualty? Or has that been thought about?

BARRATT: If I'm following you, we're assuming that somebody who's in a suit is automatically not a CMO because we've baselined two CMOs for a complement of four.

HAMILTON: In other words, if a person's a CMO, he doesn't get to go on EVA?

BARRATT: That's correct.

HAMILTON: Will you take turns being CMO? I would think that all members of the crew would share the EVA duties, but you're saying that's not the case.

BARRATT: That's not our plan.

BUCK: But, if there are two CMOs, then at least one could EVA at a time.

HAMILTON: You have to have an inside, a non-EVA CMO whenever you've got somebody out. So, then that person would be the person who jumps in. That bucks the trend a little bit.

BOVE: It raises another question, too: What happens if you have to go EVA consecutively for 2 or 3 days to do something? Are you saying that the first two guys would do the next-day EVA, too? And, for the third day or whatever? What happens if you have a 3-day EVA that you need to do?

BARRATT: Three days in a row would represent an unusual contingency, and then of course you might consider breaking protocol. But, as far as our baseline goes, to my understanding CMOs would not perform EVA.

HAMILTON: But, what you're hearing from us is the tradition we've grown up in, if you will.

BARRATT: Well, my understanding was that was primarily due to narcosis of the tender, which should not be a problem for us.

HAMILTON: But, that is *an* issue.

NORFLEET: Just another point of information. Isn't that tradition also based on a multilock system where, if you needed, you could readily interchange crews?

HAMILTON: It is based on a different set of rules. That's the old rusty barge, and yet, there's still some merit to this idea. If you're *always* going to put the highest ranking, best medical person inside, you may be compromising your decision-making power.

PILMANIS: Yet, you need the skills inside.

SPEAKER: Well, the point is, you've got skills and you've got decision-making. And, they may not be the same.

WORKMAN: You make your call based on the severity of the event. If it's pain-only bends, there is no problem.

HAMILTON: Right; that doesn't matter. There's no manipulation. But, putting in a trach tube is not easy; and putting in an IV in zero g, that's terrible, because you don't have any vein.

PILMANIS: Then you consider the outside back on Earth.

HAMILTON: Well, that seems to be what we're going to be doing.

PILMANIS: If you make the communication good enough, video and otherwise, then the medical support can be on Earth and not in the Space Station.

WORKMAN: That's why it's really important to have that camera inside.

NORFLEET: Just for the record, there's been a suggestion to delete some or all of the pan, zoom, and tilt capability from the outside camera that presently exists. Would you think that that would *not* be a good idea?

HAMILTON: If it's looking through the window, it doesn't much matter whether it pans or not. You have a wide-angle lens on it and you can't do much with panning.

BOVE: You might want to zoom, though, if you want to get a closeup.

HAMILTON: If you zoom it, then you can use pan. Or again, you'd have to jam the victim up against the window.

WORKMAN: Yes, we talked about that. Just press your patient up to the window.

BOVE: If taking away pan, zoom, and tilt in that camera would give you another camera, that would be a good deal.

WORKMAN: That's a good trade. If you had to have some horse-trading material, I would consider that.

REIMERS: As the other members of the committee said, just trade the camera out there in its entirety for one you can tilt.

HAMILTON: That's a surveillance camera; that's assumed. You will find out what's going on if you look at the patient closely. You've got to have a camera inside.

STOLLE: I think what sparked all the moves to try and do away with the pan and tilt capability of the portable is, the Station portable camera itself does not have pan-tilt. So, Courtney's group was actually working on a sight attachment mechanism that would provide manual pan-tilt to this portable camera. So actually, the camera that we're planning on using presently does not have pan-tilt, which means we're not trading anything.

BOVE: Then we have to ask for it and, when it gets there, we have to say, "We'd rather trade it off."

REIMERS: The point is that communications are going to count for a lot. With this shortness of people, you're going to have to be able to communicate with ground. Even with pan, tilt, and zoom, the placement of that camera in terms of viewing angle is less than superb. You're going to be trying to look at this patient from somewhere up there, and unless you remember to send a mirror in with the inside attendant, there's no way to get a good look at that patient's face with that camera the way it is.

WORKMAN: You're always going to be in the same orientation to the visual display. You may be closer to the patient, but you're always in the same orientation. You've always got the same angle of view.

REIMERS: And, that angle of view, in my opinion, is always a rather crummy one.

STOLLE: We do have some periods of no communication capability. What's the lowest time for those?

NORFLEET: It's 85% coverage; 15% loss of signal or something like that.

REIMERS: If you have to leave the camera where it is, I think you're going to find that you need to turn the patient around and put his head towards the block to space. That way at least, if ground wants to see a patient's face, the attendant can lift his head up, you can zoom in on it, and you can see him square out. You can see something.

PILMANIS: Assuming it's a 70 kPa (10.2 psi) Station, if you get a severe patient, one person really cannot do CPR, intubate, etc. Prior to hyperbaric compression, does the Station, even though it's at 70 kPa (10.2 psi), have the capability to go to sea-level pressure?

BARRATT: I would say that the logistics in increasing the pressure on the short term are overwhelming.

BOVE: What about the two locks opening together? Could they go to sea level, the equipment and crew locks.

BARRATT: Right, sealing off the equipment lock from the rest of the Station.

PILMANIS: Then how are you going to get the other people out?

BARRATT: You could lock them out.

BOVE: Well, then you have a double-locked chamber. When you're ready to go, you'd go in the main chamber and bring the other one back down to Station. If you ran the thing at 70 kPa (10.2 psi), you'd have a double-lock chamber. If you could go to sea level, you'd essentially have a double-lock chamber that would run out to sea level. After that, it's a single-lock chamber. But, it's conceivable you could leave the door open between the two locks and put the two locks down to sea level while you did everything, and then put the crew member into the hyperbaric part of it and close the door.

HAMILTON: You'd be that much better off doing the undressing and intubation during that.

NORFLEET: I think you'd have to take the node, too, because didn't they delete the hatch between the equipment lock and the node?

BUCK: No, we still have that. The hatch on the node side was deleted. But, we have an airlock hatch at that location.

WORKMAN: So, that scenario *perhaps* is feasible.

BOVE: In other words, you only have a vacuum hatch, not a pressure hatch.

NORFLEET: You would have to take the node, too, because you couldn't have a pressure-assisted seal between the node and the equipment lock. So, you'd have to take the crew lock, the equipment lock, and the node.

BOVE: The thing is designed to connect all three. I mean, you'd have a nice, big hyperbaric chamber there.

PILMANIS: I guess it isn't clear in my mind but, what are you designing to – the pain-only bends patient or the severe, critical ebullism patient?

BARRATT: I'll try to answer this, and Bill Norfleet can back it up because there's a lot of history here. We have a chamber capability evolving on the one hand and medical capability evolving in parallel with it. We started out with a 6 ATA chamber, for instance, and we started out with a lot more medical capability. Both of those have evolved upward or downward, however you want to say it, and not necessarily in step. We still have the capability defined to deliver ACLS in the chamber. That, of course, implies a critically ill patient who's bent. On the other hand, we have a monolock 2.8 ATA chamber to work with; that's all we have.

PILMANIS: But, can you deliver ACLS with one person?

BARRATT: That's a very good question.

PILMANIS: I don't believe you can.

BARRATT: Part of this is reflective of future capabilities in that we are eventually to have a cardiac compression assist device – a mechanical device that would be one-handed that a single CMO would be able to operate. If a patient has deteriorated and has had the appropriate orifices tubed, cannulated, etc., and then is translated into the chamber, all I can say is that the founding fathers believe this is possible.

NORFLEET: And, I would comment that, in an ideal world, form would follow function. You'd have clearly defined goals and then facilities to meet them. This has been much more of an iterative process – trading equipment, and the like. So, the point is well taken.

HAMILTON: Last time, you didn't even let us talk about any of this. We've gotten somewhere.

NORFLEET: The flavor I get from the Program Manager's discussions is that, when we start talking about blowing a glove or catastrophic failure of a suit, the phrase "It's a bad day" comes up a lot. It's hard to get those scenarios taken seriously as being really survivable. The probability is seen as being so remote that it's not worth devoting hundreds of pounds of resources to that.

PILMANIS: Yes, and they may be right. If you're half a mile out and you blow a glove, it's a good chance that it's a bad day. But, what about the in-between situation? I believe they are underestimating astronaut survival. Exposure to vacuum does not have to be automatically fatal.

NORFLEET: We do the best we can.

REIMERS: The most likely time it's going to happen is right after you go out, right after you put the thing under stress. That's the most likely time, just like car accidents happen closest to home.

PILMANIS: Wasn't there an EVA incident in the last Shuttle mission involving a damaged suit?

SPEAKER: Yes. That was plugged, but it came close.

PILMANIS: Now that wouldn't have been catastrophic, even if there had been a larger leak.

SPEAKER: It did leak.

TRAUSCH: During the last EVA, when the crew members got back, they noticed there was blood in the glove. And, when they looked at it, they found a pinhole in the glove. You know, the astronaut didn't even notice it. The only way they found it was because his blood was on the glove.

HAMILTON: Was it a meteorite or something?

TRAUSCH: No, it was the palm bar restraint.

BOVE: Maybe, Tom, you can verify this. I thought when we met there were to be two committees. One was to have been the serious, the Type I, and the other the Type II committee.

HAMILTON: I understand the common one was engineering.

BOVE: I thought we were the Type II committee, because we started out with the premise that we were going to be treating the possibility of air embolism or ebullism and Type II decompression sickness, and that's where we started with the 6 ATA chamber. And, that was in the discussion from day 1, as I recall, in that group that we had together.

STOLLE: If you look at JSC-31013, which is our requirements, it says, "treat full range of DCS and ebullism." So, it depends on how you interpret that; but all you have to work with is 2.8 ATA.

BOVE: That's okay. It gives us the task. We have to figure out how to deal with it. I don't think there's any problem interpreting what that says. It basically says, "treat everything." As we know, the risks or the probability of the really serious ones are low, but we ought to have some way of dealing, at least to some extent, with the possibility.

Hyperbaric Treatment Capability for Lunar Base

BARRATT: I'd like to move on to the next presentation, which is Dr Bruce McKinley's, who's going to discuss Lunar Base. We're going to take a major turn here and ask a major question, and possibly define the future thereafter of what we'd like to see done with the committee. I'd like to get a little bit of feedback from you folks on that as well.

HAMILTON: We are going to build a concrete chamber on the Moon, aren't we? I don't know whether there's limestone on the Moon or not. Then you could cook some Portland cement.

POWELL: You know, historically speaking, the first science fiction story released recently was Edward Everett Hale's "Brit William," and that was a concrete space station.

DR. BRUCE MCKINLEY: I'd like to address the evolving Lunar Mars Program, the hybrid program that, at this point, is an initiative. It's engendered quite a bit of interest throughout the Agency and contractors, but there are a lot of things that happened in the past couple of years. So, although I thought it would happen and become a program, at this point it hasn't yet. However, a lot of design efforts have been going on.

I don't know how many have seen this picture (FIG. 103) – it's been around for a year and a half or so. It shows a lunar outpost with a spherical inflatable habitat, starting with an initial habitat and a whole lot of infrastructure and emplace-

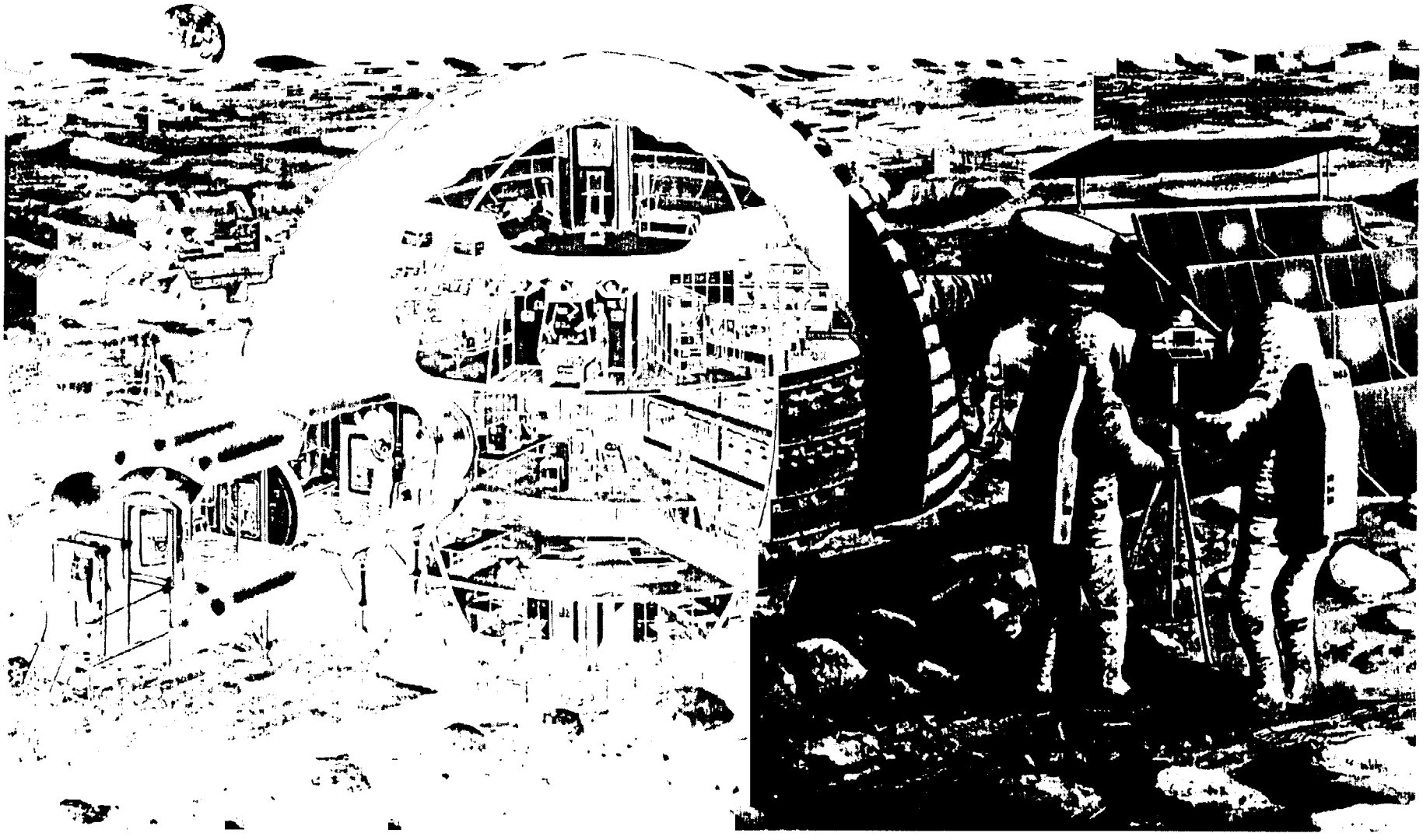

FIG. 103 Propos nar outpost

MCKINLEY: (Cont'd)

ment. The idea is that people would be able to live on the Moon indefinitely. This emplacement would handle a crew of 12. The idea is for a permanent emplacement headquartered as one possibility, with the ability to use resources that are found on the Moon. What those resources are and how they would be used would take a lot of study, but one example would be to obtain oxygen derived from Moon rocks. Another possibility is to use the lunar rocks themselves as a building material to construct habitats. I'm going to show you a few pictures of some of the things people have in mind. One is living in habitats. Another is rovers – this is a so-called pressurized rover. The idea here with the rover is that there would be extended missions from a habitat lasting weeks, with radius of exploration from the primary habitat of 100 km having been mentioned. Also extensive EVA with a surface suit. The suit is something that doesn't exist at this point, but a lot of ideas are being formulated as to how to design a suit that would function on the lunar surface. They're also talking about EVA for a Mars mission. So, this illustrates the idea of remote EVA. The idea here is exploration and science, but there is a lot of concern about what might happen if something goes wrong with this EVA suit, which is something that a few of us have discussed also – Bill Norfleet, myself, and others.

Vehicles are being described; space transfer vehicles. This is just an illustration of a lunar transfer vehicle. Something for a Mars mission would probably be much bigger and much more complex for a very long-duration mission, on the order of months to a year in this vehicle en route to Mars, depending on the type of mission. A point here is that EVA from one of these vehicles as presently stated is planned only for a remote contingency. Possibly what's going on here is trying to avoid the Space Station controversy that was brought up earlier this year about

MCKINLEY: (Cont'd) the amount of EVA it will take to maintain a Space Station. There's also a lot of consideration as to whether this vehicle for an extended Mars mission would require artificial gravity and how to provide that. The only feasible method that has been discussed is a rotating Space Station. EVA from a rotating Space Station could bring new meaning to the word "spinoff."

So this is, perhaps, a more realistic habitat design. It's actually the first part of one of the first pictures I showed of the lunar base. It's called a construction shack, and it might have some resemblance to a Space Station module, which maybe some of you are familiar with. The idea is that this would evolve from the Space Station module. The idea is that this would accommodate a crew of six.

These are some of the health care facilities that were designed into this habitat. These designs, by the way, are being done by space architects, and they're incorporating some really interesting methods of design. There's a lot of detail that goes into the design, but I want to emphasize that there is no one habitat, there is no one mission; it's all just preliminary planning at this point.

Another design is for a larger, inflatable habitat; horizontally inflatable. This would accommodate a crew of 12. Another view shows some shielding that would be erected over that. A view of the inside shows a space suit maintenance and preparation area. In working with one of the architects doing that horizontal inflatable habitat, he offered to do some work in providing some concept designs for health care systems. What we've done is try to carry forth the Space Station analogy to provide some pictorial representation of what might fit in this fairly large habitat. What is shown here are some countermeasures; an analytical

MCKINLEY: (Cont'd)

laboratory section and a medical care section. A starting point for a design, at least in our minds, was work volume. I think that's one important concept that really wasn't involved in early Space Station medical care system designs. That's a question I have that I want to put to you folks.

One thing I just want to point out here, on that medical care system, is the hatch. This will provide a hyperbaric airlock or hyperbaric treatment capability as part of the medical care system. The idea here is to use the hatch, but that's as far as it's gone. And, even the hatch isn't quite right here. We ought to have that elongated to accommodate the partial gravity and try to eliminate the big stopovers that aren't really a big problem in lunar gravity.

So, that is an introduction and at least an assumption, that there will be exploration of the Moon and Mars by crews and surface exploration using permanently emplaced habitats, lunar rovers, and EVA suits. Vehicle EVA for contingency only. Maybe the most important issue here is that the respirable atmosphere composition and pressures are to be determined. A further assumption is that the habitat and EVA technology – say, 10 or 20 years from now – will be able to accommodate any required combination of pressure or composition that will be necessary to make the transition from a habitat to space suits.

We have a little project ongoing now that actually addresses airlocks and airlock designs for some of these habitats. Although it's very preliminary and the actual construction of such a habitat is quite far off, we're really getting down to some of the details. I want to review some of the assumptions for this design project that are ongoing. Basically, the assumption is a crew of six, with a surface stay time

MCKINLEY: (Cont'd) on the planet of 45 to 180 days. The outpost description would include two habitats, two nodes, a laboratory, the lunar LOX production plant, a vehicle fueling pallet, and a pressurized rover. EVA could involve three missions per week, with at least two crew members per mission, but the idea is not to have a mission repeated on consecutive days.

I would like to get from you folks an answer to the first question. Ideally, I could get a "yes" or "no" answer with the little information and the planning so far and be able to take that back to a meeting on Monday. The first question is: Assuming there would be no need for pressure transition from the habitat to EVA, is hyperbaric treatment capability needed for exploration missions?

WORKMAN: Have you worked out what your failure scenario would be with what you anticipate in the EVA suit?

MCKINLEY: No. I think the main point in asking this question here is that the focus for Space Station activities has really been on the operational design of the pressure transition from the Shuttle or from the Station to a lower pressure suit. So, there is a built-in risk of decompression sickness or pains or bubble evolution.

BOVE: What are the assumptions? That the entire habitat is maintained at 29.6 kPa (4.3 psi)? Or, are you going to run the suit at sea level?

MCKINLEY: The assumption is that we would have the ability to transition easily between either the habitat or the suit. Combinations of pressure and/or atmospheric composition would be chosen to address that transition. Ideally, the pressures would

MCKINLEY: (Cont'd) be the same; I should say 55 or 60 kPa (9 psi or 8 psi), maybe going from a nitrogen mix in the habitat to oxygen in the suit.

PILMANIS: There are two reasons for a hyperbaric chamber. One is the problem of going from habitat to EVA and the associated pressure transition. The other is failure of the EVA suit. Or, not necessarily the suit, but perhaps a part of the Station, which is inevitable sooner or later. You then have two choices: You either treat the people or you write them off. I don't know of any other choice.

BOVE: I think the first answer is that it would not be a problem if the pressure doesn't change, unless you change the breathing gas. I would strongly suggest that, if you're going to keep all the pressures the same, you leave the breathing gases the same as well. If they breathe whatever the mixture is in the habitat, they could probably breathe the same in the suit.

HAMILTON: Even if you changed it, you could work that out. And, you could certainly have the Station at 70 kPa and the suit at 50 kPa and jump back and forth between them, or something like that. We're assuming that a hard suit, or a suit that would run at those pressures, would be available. I think that's a reasonable assumption.

BOVE: Yes, that's true.

MCKINLEY: Whatever the design is, the assumption is, at least for our design project, that the technology is available.

HAMILTON: But, that doesn't eliminate the fact that there's a vacuum out there. All the time.

POWELL: That question is the one that's going to haunt you, since most of the Moon is outdoors. You're not going to get around it. You know, in truth they tried making a ship without lifeboats once, and they haven't done it since. History shows you it's a bad place to put all your money.

REIMERS: And, the more industrial your operations become, the more likely it is that something is going to go wrong.

MCKINLEY: My intent in showing some of these pictures is that there *are* a lot of activities assumed. By the way, if you're interested, one of the most recent documents that's publicly available is the so-called synthesis report. It was published earlier this year. This is available, and it's probably the most comprehensive compilation of the exploration initiative within the program.

HAMILTON: I'd read it if you sent it to me. That's the highest compliment I could pay.

BARRATT: We will send copies to the committee members. It may take a little while, but you'll get them.

MCKINLEY: Bill, in terms of an introduction to this, this has been going on at a fairly high pace for 2 years now and at a lower level, a slower pace, for several years within NASA. Any major facts that I've overlooked here as an introduction?

NORFLEET: No. I would emphasize that cabin atmosphere selection is going to be an extremely interesting process, trading off physiologic concerns against material safety. But, basically, exactly what you've highlighted are the issues.

WORKMAN: I think for the purposes of your meeting Monday, the answer is: Yes, the committee would recommend inclusion of a hyperbaric chamber.

MCKINLEY: If nothing else, the possibility of traumatic suit rupture and ebullism drives this need.

PILMANIS: Let me comment on that. We are currently doing research on ebullism and hyperbaric oxygen. But, all this time we do not have any data whatsoever that prove that HBO is the treatment for ebullism. Until that kind of research is completed, I intuitively would use it if confronted with it, but the data are not there at this moment.

MCKINLEY: So ebullism is the major concern, but hyperbaric therapy may not be the definitive treatment.

PILMANIS: We don't have a medical protocol for ebullism; that's the bottom line.

POWELL: Whatever would be an addition, though, I'd think would be adjunctive. I don't know how you would restore the circulation when it's filled with gas bubbles.

BOVE: Well, I think the data suggest that, if you get back to your source pressure, you can recover a lot of functions. Just going back to your source pressure may be

BOVE: (Cont'd) enough. And, the question is: Would we be gaining a whole lot with hyperbaric treatment beyond that?

HAMILTON: There aren't many cases, though, where altitude decompression sickness hasn't resolved and has needed aggressive treatment.

BOVE: That's right.

MCKINLEY: But, that's not ebullism.

HAMILTON: No, but there are a lot of similarities. Now, if you've got a person with no inert gas on board, then that's okay. But, these people, there's going to be at least a half an atmosphere of inert gas in there; 50%, more or less.

REIMERS: Yes. I think it's fair to say that we don't know yet, from a medical point of view, what's the best way to deal with ebullism. However, at this point, some plans have to be laid on the basis of the best available guesses; and that's what they are. The best available guess is, it's likely that some sort of recompression facility to something in excess of Station pressure will prove to be required. But, the medical research may show that all you've got to do is get back to Station pressure.

MCKINLEY: A couple of other obvious things here are that this is more remote than Space Station; the Moon, by current technology, is 3 days away, and the idea again here is to be able to go to stay. For a Mars mission, it would be just impractical to return en route; depending on the particular mission designs, these are on the order of

MCKINLEY: (Cont'd) 3 years for a total Mars mission. There are more activities; there's partial gravity involved also. The types of activities involve trucks and rovers and high energy and compressed gases and pickaxes and everything else. So, there may be more hazard than is being envisioned.

WORKMAN: Now, we're looking at a situation where you've got a risk of trauma in addition to just the released pressure scenario.

SPEAKER: In a vacuum.

MCKINLEY: I should also say that, a lot of the assumptions or working concepts that you have been talking about for Space Station appear to be able to carry right on into some of these exploration missions. Such things as the buddy system for EVA. One problem has been the idea of extended rover missions. One place mentions a 100 km radius for the rover; and the person involved with EVA suit design pointed out that, if you got a flat out there and you couldn't fix it or the engine quits, you wouldn't be able to get back.

HAMILTON: It's a long way back.

MCKINLEY: You couldn't walk back. There wouldn't be enough oxygen in your tank.

WORKMAN: Then it's a bad day.

MCKINLEY: Yes, it's a bad day. Another extension of these concepts with this rover with these extended missions involves EVA from the rover. You've also got the potential for

MCKINLEY: (Cont'd) a hypobaric accident from that rover. So, that's a related question here: Is hyperbaric treatment capability needed?

HAMILTON: We could probably build a rover without much extra effort so it could be sealed off and pressurized to 1 ATA, which is what we like.

MCKINLEY: Well, that's a related question then. With a hyperbaric chamber at the habitat, would it be necessary to have a chamber in a large rover as in the picture I showed?

HAMILTON: With the rover itself, we're looking at obviously some help at 1 ATA, certainly if you see a problem with your suit. If your suit is going to fail, you've got a place to go. You've got a place to hide. And, you want to get out of the suit. If you're going to go that far away, it's going to take a long time.

REIMERS: The other thing, too, is that when you start talking about a rover, now you're talking about a vehicle that's going to have to be stiff enough to withstand being jostled around and banged and whatever.

HAMILTON: So, the structure has got to be there anyway.

REIMERS: You're going to have structure enough there to have a fairly reasonable pressure vessel just to keep the thing from falling apart.

WORKMAN: Well, my first thought when you put the slide up was, "A mobile hyperbaric chamber."

BOVE: This thing could dock right up against the outer door of the Station chamber, and you could just pass people through with relative ease.

REIMERS: Hyperbaric chambers are frequently much thicker than they need to be for reasons of pressure, just for reasons of being able to build the thing and handle it without destroying it.

MCKINLEY: Well, I think I'm pretty close to a "yes" on the first question. The other questions are more along the lines of design and more detail. This is not something that's going to be solved this year, obviously; and the idea here, Mike, is to have you folks involved and be able to respond to some of these questions. If you felt inclined to think about them and get back with some response, I'm certainly available to feed that information in and use it over the next months to years. I think a major thing here for you folks also is to be able to carry forward some of the good things from the Space Station Program and also, maybe, think about some of the things that aren't exactly right and be able to work them in at an early date.

[*EDITORIAL COMMENT*: Let the record reflect that the Committee was in complete agreement that there should be hyperbaric capability for both lunar and Mars bases.]

PILMANIS: I think I would just reiterate what Barbara Stegmann said yesterday; that you can engineer out DCS. I'm sure it can be done. But, you can never, never engineer out exposure to vacuum.

MCKINLEY: That's my approach here also, and I think it's common sense to follow it.

WORKMAN: We're in agreement with that. Strong agreement.

HAMILTON: I predict that the first little bit of experience with question 2 will answer it for you. You're going to want a separate chamber where weight is not such a problem if you can use local materials.

MCKINLEY: So, separate the EVA airlock from the hyperbaric chamber?

HAMILTON: It will probably turn out to be a better way to do it. You can use the space; that can be your medical bunk or treatment facility. It's known, down in the hyperbaric and diving communities, that that space is not just sealed off and only used when it's absolutely needed for treatment; it can be used for other things, too.

BOVE: It would still be nice to have an outside lock on that. Because again, if you had a rover out there that got in trouble and was pressurized, you could mate that thing and bring the people in without having to try to decompress them.

MCKINLEY: Well, now we're offering to get into some details. It doesn't take very long to think about some of these things and work with an architect to try and get some ideas that have some credibility illustrated. And so, one of the questions is capacity – design this for one crew member plus an attendant? We have a crew of 12. These are difficult problems. There's no real formula for these.

BOVE: You're not going to have a steel mill down there, are you? There are still going to be weight problems getting this stuff there.

MCKINLEY: That's a big issue. Most of the habitat designs that I showed you are collapsible or inflatable.

HAMILTON: There's really nothing wrong with that. Make something that's light, made of a polymer, and inflated, and it will hold the pressure. It doesn't have to be made of aluminum. This one does because it has to be structural. But, build the thing out of basalt bricks and then line it with an airtight device that's wired on the inside. You don't have to take all the weight with you.

MCKINLEY: But still, the volume then that's necessary here is enough for at least two people within this facility, within this chamber. Now, are there dimensions that will go along with this?

HAMILTON: Well, you would provide one of them.

REIMERS: I think, based on previous discussions, there's really not a purpose for having a hyperbaric chamber except for treating ebullism. Within the time associated with that, you're probably going to find that it's sensible to have the chamber big enough to where all you've got to do is get the patient in, shut the door, and, once you've done that, you could take the suit off without having them spend the time to do that before you can get to your therapy.

PILMANIS: That's the ideal, yes. So, that's really intensive care you're talking about.

HAMILTON: You'd need a workstation and an ability for a lot of people to get around it.

BOVE: I think the best thing to say is, it should be bigger than the one we've got now.

WORKMAN: What about double locks?

SPEAKER: It would be nice to have a double lock.

MCKINLEY: Bill Norfleet and I spent a little time on this a year ago. The idea of a personnel lock, both inside and outside, that would be a total of a three-lock chamber plus a pass-through lock.

REIMERS: A personnel lock, in this sense, could be rather tiny. It doesn't have to be big.

WORKMAN: Yes, it doesn't have to be that size.

MCKINLEY: All the things that seem to be problems carry through here, including the gas efficiency and power and the launch weight and volume. All those are already concerns.

HAMILTON: Well, for example, unless you have the ability to make oxygen on site using solar energy and the local rocks, you're not going to throw oxygen away in this situation. You're going to reuse every bit of it. So, we do some things now because it's the easiest way to do it; but in that situation, everything is going to have to be recycled. Gas is not going to be such an issue; that's whether somebody is breathing oxygen or not. Because you're not wasting anything by doing that. He's got to have his metabolism.

PILMANIS: Mars is CO_2?

McKinley: It's a very thin CO_2 atmosphere.

Bove: That's a lot of CO_2 to do something with, even if it's rarefied. There are billions of cubic feet of CO_2.

Hamilton: And, what is that white stuff? Is that CO_2?

Speaker: That's frozen CO_2.

Pilmanis: You've got your fire extinguishers.

Hamilton: Chemists could deal with that real easily. That's a lot easier to get oxygen out of than a rock. There is presently also some water ice on Mars.

POWELL: It would be nice if you made your rover so that it could pressurize with the lock. It makes it easier back on the outside. Instead of having to put somebody back in the suit or decompress them during transfer back inside. That's like these personnel transfer capsules.

MCKINLEY: That's been discussed and, to my knowledge, it's what people use in diving for transferring injured divers; a small one-man hyperbaric oxygen chamber.

BOVE: The problem you have here is, if the rover was out and something happened and they had to bring a guy in and compress themselves to some pressure to keep him

BOVE: (Cont'd) stable, in order to get out of the rover and get back into the Station you'd have to go back into lower pressures. If you're just locking on as a docking device, you circumvent that. In fact, you'd almost need a docking source because, in order to get in the rover, everybody would have to put on their suits and go outside, get in the rover, and take their suits off. Whereas if this thing docks, you could just walk into it, close the hatch, and drive away. So, it almost has to dock.

HAMILTON: Yes. As a matter of fact, EVA from the rover will be something like EVA from the Station. It won't be a normal thing. They'll drive around a lot before they get out and look around.

MCKINLEY: The last question there addresses related uses for a hyperbaric treatment facility, basically having in mind an enclosed chamber. One thing I've mentioned would be a contingency operational mode for a habitat in which the life support system was not able to supply adequate oxygen and pressure. It would allow them to step into a small chamber periodically with high oxygen concentration. Or, if the habitat was only able to supply a high oxygen concentration at a degraded pressure, one could step into a small chamber periodically. I don't know whether that would solve the toxicity problem or not, or whether it would prolong the ability to stay.

BOVE: One way is to use the chamber as a lock to your rover, and then use the rover as a lifeboat and have it dock there anytime it's not in use. If something should occur, they could jump in and use the hyperbaric chamber as an airlock and get to the rover. The other idea, I'm not sure it would work, is: Intermittent therapy would involve having all 12 people down there in your tiny hyperbaric chamber.

MCKINLEY: Well, maybe not all at once.

BOVE: As time went on with this thing, you'll get to the point where you'll need the treatment more and more, and they'll all end up in there at some point.

MCKINLEY: The idea of a storm shelter is something else that's been discussed; a radiation storm shelter. People start thinking about a thick-walled chamber, and the idea of a radiation shield occurs. Now, that is one where you start getting to the point where everybody climbs into this chamber for a period of time.

BOVE: You are going to need some kind of an airraid shelter or a cosmic ray shelter.

MCKINLEY: That's right.

HAMILTON: Wouldn't some of this best be done by digging and placing it underneath the surface of the Moon?

MCKINLEY: That's an option that's being discussed. The cost of doing that will be considerable.

HAMILTON: Yes, tunneling under that rock would solve some problems; but those machines are very heavy.

BOVE: What kind of shelter do you need for something like this? A couple of inches of steel?

MCKINLEY: I don't know the details on that, but it dominates the Mars requirement.

HYPERBARIC TREATMENT CAPABILITY FOR SPACE EXPLORATION MISSIONS

SPACE STATION FREEDOM HYPERBARIC MEDICINE
AD HOC COMMITTEE MEETING

9/27/9

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Assumptions:

1. Exploration of moon and Mars by human crews.

2. Planet surface exploration from permanently emplaced habitats using rovers and EVA (surface) suits).

3. EVA during Mars transfer for contingency only.

4. Respirable atmosphere composition(s) and pressure(s) TBD; habitat and EVA technology able to accommodate required combinations.

Reference lunar exploration mission:

Crew: 6

Surface stay time: 45 - 180 days

Outpost description: 2 habitat modules
2 nodes
1 laboratory module
lunar liquid oxygen production plant and transfer vehicle fueling pallet
1 pressurized rover

EVA (from habitat or rover): 3 missions per week
≥2 crew members per mission
≤1 mission alternate days

- purpose: maintenance, expansion of indigenous space materials utilization pilot plants, outpost infrastructure, habitat; exploration, science.

Hyperbaric Treatment Capability for
Space Exploration Missions (cont'd)

Questions:

1. Assuming no need for pressure transition from habitat to EVA, is hyperbaric treatment capability needed for exploration missions?

2. Could EVA airlock and hyperbaric treatment facilities be combined, or would hyperbaric treatment facilities require dedicated work volume?

3. Should hyperbaric treatment facilities be located next to other medical care facilities of a habitat?

4. What would be basic design and performance requirements for hyperbaric treatment facilities for a lunar outpost/rover, Mars outpost/rover?

   capacity (number of patients, attendants)
   work volume, dimensions, shape
   communication (direct voice, vision; electronic data)
   working pressure
   gas supply system
   medical electronic equipment (hyperbaric/O_2 rated)
   personnel lock(s): EVA access
   IVA access
   equipment/supplies "pass through" lock, dimensions

5. Are there other related uses of a hyperbaric treatment facility that should receive attention?

Meeting Overview

BARRATT: Thanks, Bruce. Well, I wanted to recap very quickly, although I may totally abbreviate that. I made a list of what I considered to be very useful and valuable outcomes. I'm not going to belabor the point by reading all of this; but I think, overall, it's been a very productive couple of days. I'm sorry that it wasn't a 3-day period. I think a lot of these discussion could have gone on and, in particular, the treatment scenarios will need to go on in the future. We'll hopefully be addressing those sooner than later. Thank you all for coming. I've been reading your literature over the years, and it's a pleasure to finally meet you all.

Colonel Workman had spoken with me about the future of the committee and about the past before we reconvened this time. Apparently, there had been some problems with the information generated by the committee, or influenced by the committee, actually getting back to you all. We're trying to set a mechanism in place that will outlive the hyperbaric subsystem managers so that, whenever we generate formal information, it will be appropriately distributed. It should go without saying that this should be a permanent fixture.

The other point of the committee becoming a standing committee: I've been discussing that with Dr. Billica, who's our medical branch chief. Several times during these last couple of days, it's been brought up that decisions will be made in real time based on the CMO's impressions, the crew surgeon's impressions on the ground, and whatever bank of consultants is available – that is you. I think that should go without saying as well. You will be established as a roving hyperbaric consulting committee and, as such, some change in the status of the

BARRATT: (Cont'd) committee will I think be effected. What that means in NASA jargon, I'm not really sure. But, we'll try to keep you posted on how we do that. I think a formal status is in order in that regard.

WORKMAN: On that same thought; I don't think that any of us are hung up on how it happens. The issue is communications and our ability to maintain some reasonable awareness level of what's going on.

HAMILTON: And, we have to be a pronounceable acronym.

BARRATT: If I can swing it, you can come up with your own acronym, but we'll design the patch. And the final thing is, Bruce presented the Lunar Base; the SEI outlook overall will include a hyperbaric approach. And the committee, of course, will not stop with Space Station. We're in a very preliminary design process, but I think your continued input will be desired there. With that in mind and with the idea of the consulting group, we need to change the status and get this as a more permanent organization. Regarding the minutes and transcriptions of this, I'm not sure how soon it will be ready. It depends on whether we do the transcribing or we send it to NASA to have it done. Whatever comes out of that, I will try to make them available to you as soon as we can. I'll have an abbreviated form of the minutes, based on my personal notes, out to everybody within the next couple of weeks or so.

HAMILTON: Do you want anything back from us?

BARRATT: Well, I mentioned flippantly that the treatment scenarios might be done by mail. We may consider coming up with a list of the actual treatment scenarios that Bill mentioned, and possibly a couple of others, mailing those out to you, and getting a consensus return. I'd be very interested to see what people's treatment approach would be.

WORKMAN: Before Bill and I head out, I just want to reiterate our pleasure in having a chance to come to Houston. Thanks for all the leg work that all of you have put in to put us back together again. And, I've enjoyed everything. I think I can speak for everyone here: This has been a very productive experience for us. It's generated a "Gee, this is neat!" feeling. And, that's a good feeling to leave us with. Hopefully, what we've been able to do in the last couple of days has been helpful to you.

HAMILTON: We certainly agree with that.

BARRATT: Okay. Thanks everyone.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 1996	NASA Conference Publication

4. TITLE AND SUBTITLE

Space Station Hyperbaric Medicine Ad Hoc Committee Meeting

5. FUNDING NUMBERS

6. AUTHOR(S)

Michael R. Barratt, M.D.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Lyndon B. Johnson Space Center
Medical Sciences Division
Houston, TX 77058

8. PERFORMING ORGANIZATION REPORT NUMBERS

S-773

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

CP-10140

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified/Unlimited
Available from the NASA Center for AeroSpace Information (CASI)
800 Elkridge Landing Road
Linthicum Heights, MD 21090-2934
(301) 621-0390 Subject Category: 99

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

In September 1991, a previously established working group convened to discuss aspects of hyperbaric medical care for Space Station Freedom (SSF). A vigorous extravehicular activity schedule planned for SSF construction and maintenance led to the inclusion of an on-orbit hyperbaric treatment facility known as the Hyperbaric Airlock (HAL). This presented several technical and procedural challenges requiring expert consultation. The Ad Hoc Committee for Space Hyperbaric Medicine, which had been involved since the early planning stages of SSF, had been formed to address these issues. Seven highly experienced and world-renowned specialists in hyperbaric medicine and decompression related disorders, representing a wide experience base in the aviation and undersea environments, have participated. This latest meeting at the Johnson Space Center, which involved five of these specialists, was the third convening of this group. The meeting enjoyed heavy support and participation from local hyperbaric and space medicine specialists from the NASA community. Specific topics addressed included the risk of on-orbit decompression sickness (DCS), treatment options for DCS on orbit, overviews of the HAL layout and operation, crew duty constraints following DCS, and specific hazards of hyperbaric treatment on orbit. Over the course of several formal presentations and panel discussions, decompression disorders and the role of hyperbaric medicine in manned space flight were covered thoroughly. These proceedings reflect this enormously productive meeting, and will serve as a benchmark for further work in this highly specialized and critical aspect of manned space flight.

14. SUBJECT TERMS

Hyperbaric Medicine; Space Station Freedom; Decompression Sickness; Space Medicine; Treatment of Decompression Sickness

15. NUMBER OF PAGES

466

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited