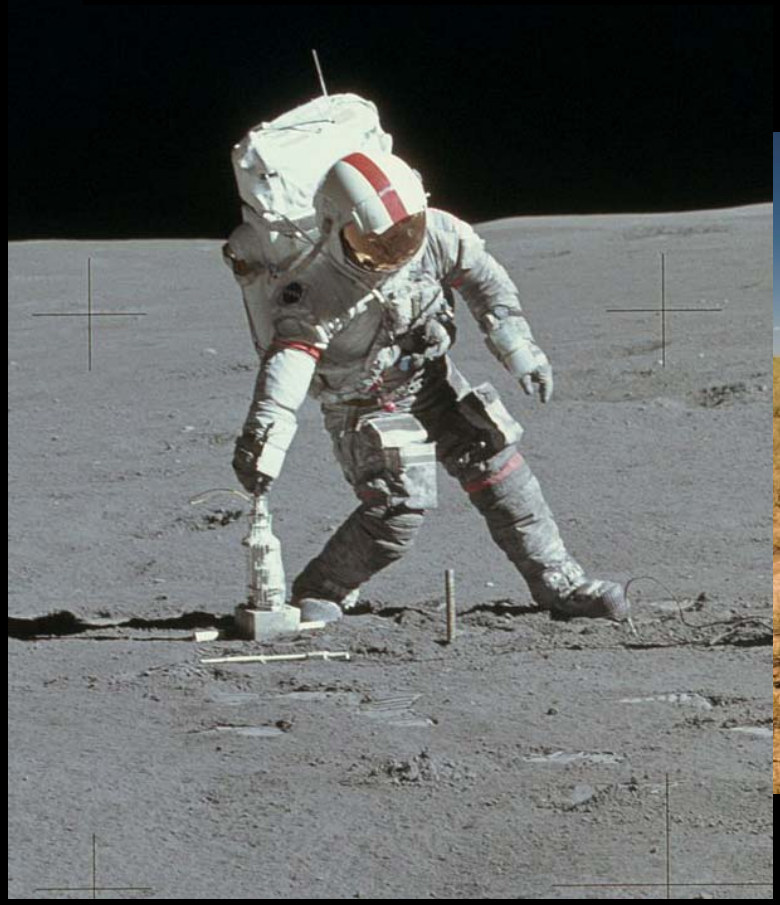
DRESSED FOR SUCCESS:
EVA System Competency and Containment for Science Capabilities and Contamination Control



Dean Eppler
SAIC

Workshop on Science Associated with the Lunar Exploration Architecture
27 February - 2 March 2007

What I'm Going To Talk About…

- Where we came from - specifically, the capability of the Apollo A7L/A7LB suit system
- The present capabilities of experimental planetary EVA suits
- What are the issues for meeting planetary protection protocols with crewmembers in pressure garments
- What's next - plans for the next generation lunar surface suit system

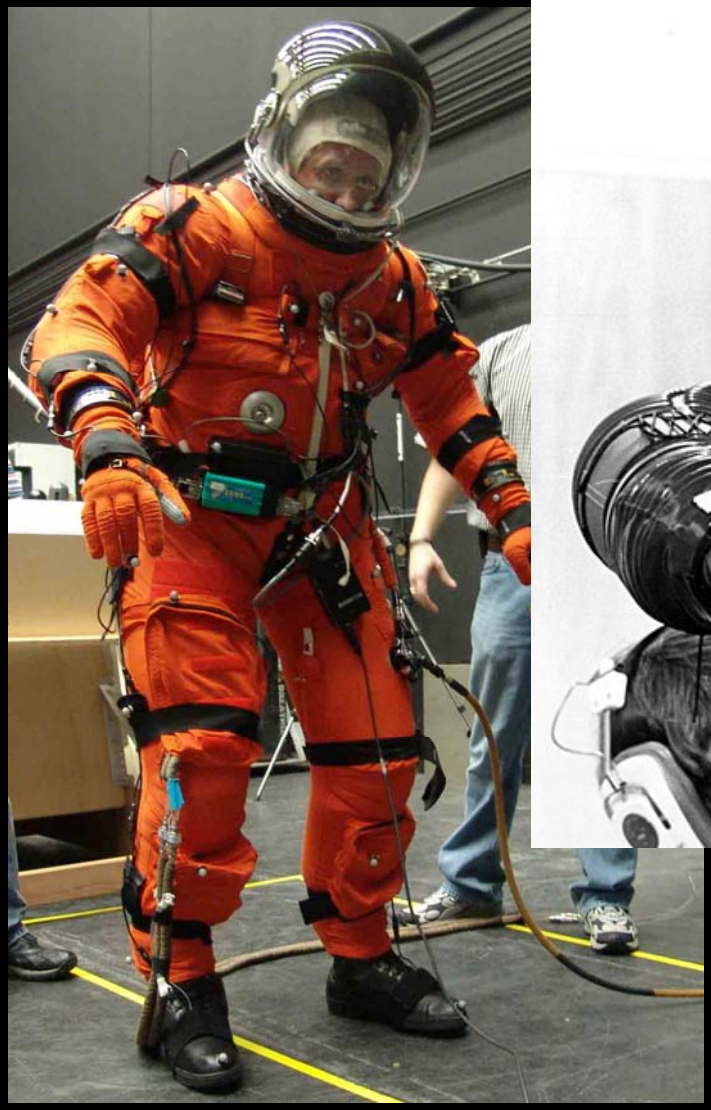
Apollo EVA Suit System - A7L/A7LB

- Apollo went to the Moon with the most advanced space suit system at the time, the A7L/A7LB pressure garment and a separate backpack style portable life support system (PLSS)
- This system had a number of tasks besides walking on the lunar surface, including
  - Provide a pre-breathe “container” pre-launch
  - Be comfortable when lying supine during a peak launch acceleration of ≈4.7g
  - Provide basic water survival capability in the event of a launch failure or an off-target entry
  - Be capable of supporting crewmembers’ vital functions for a period of up to 104 hours in the event of a multiple LM and CM pressurization failure
- Allowing the crewmembers to conduct useful work on the lunar surface, including using tools, deploy science packages, ingress/egress rovers, and walk-back to the LM from a disabled rover, was perhaps the biggest challenge to pressure garment design, due to the behavior of pressurized garments
  - Soft goods generally want to attain a particular shape when pressurized, and do not like to be displaced from that shape without the input of an external force

Pressure Garment Behavior

- This is an example of what happens to a suit subject when a pressure garment that does not have accommodations for movement is inflated
- In this case, I'm pretty much immobile; moving my arms away from this neutral position takes forces probably measured in 10s of pounds
- For this particular pressure suit (the Shuttle ACES emergency pressure suit), this is an acceptable condition as the suit is designed for unpressurized comfort, not pressurized mobility

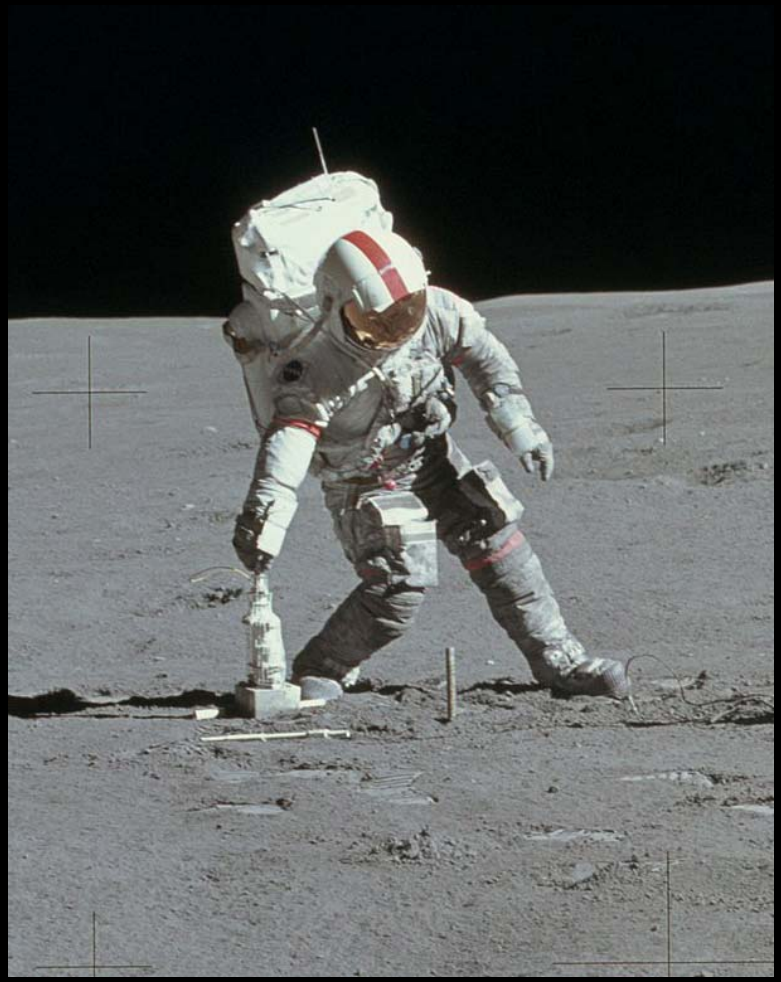
Pressure Garment Behavior



- This is Gene Cernan's flight A7LB; notice the improved arm mobility, enabled by the combination of bellows, cables and pulleys
- While aggressive, normal movement in each suit requires force, the A7LB provides significantly greater mobility than the ACES pressure garment

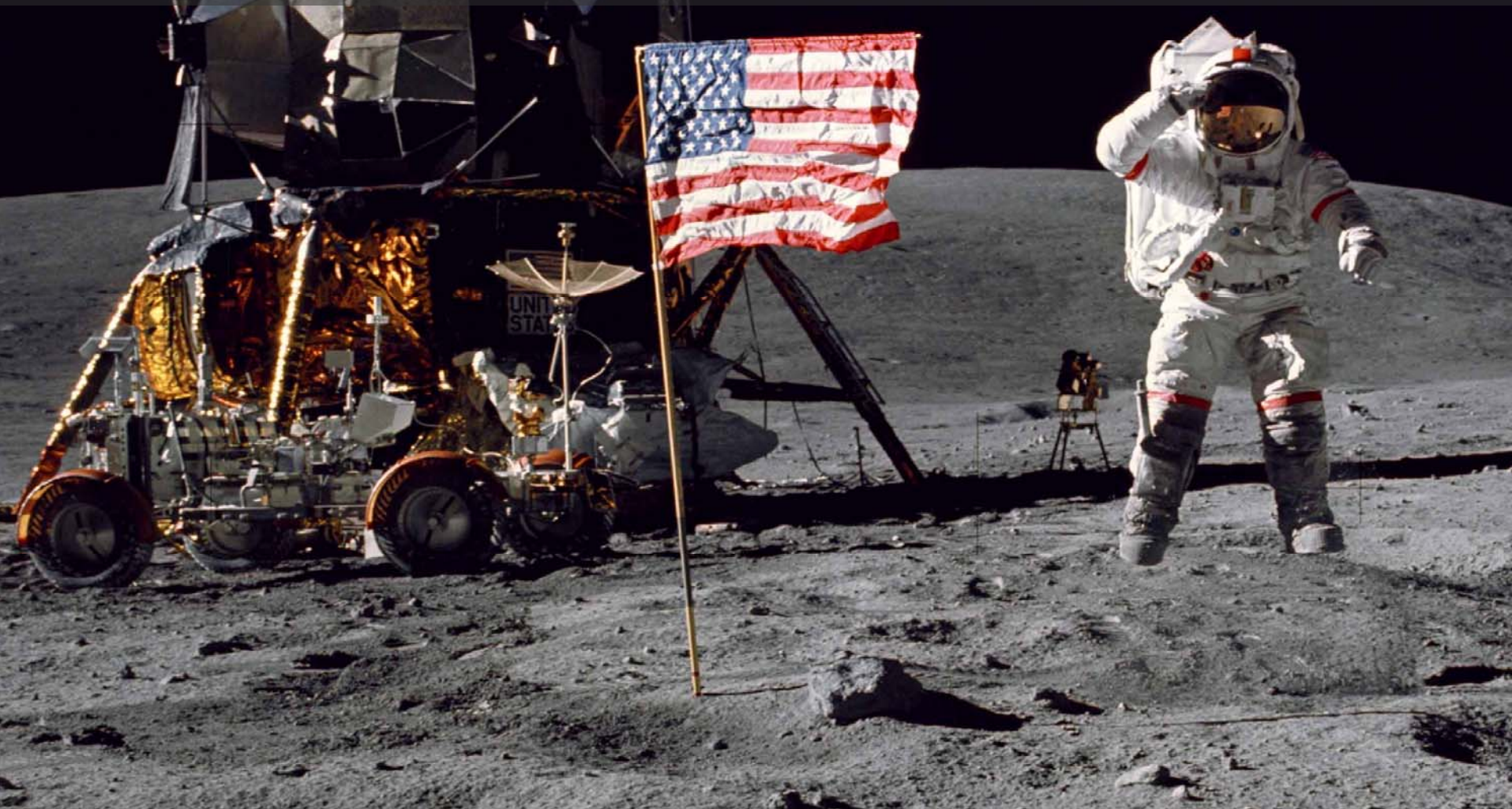
Apollo EVA Suit System - A7L/A7LB

- Although the A7LB had the best capability of any suit system at the time, there were limitations that put significant stress on the crew
- Chief among these was glove performance
  - The A7LB gloves were relatively simple, made with latex from molds of crewmembers hands and covered with a thermal garment to protect the hands, protect the glove and improve finger tip contact friction
  - In a pressurized state, these gloves were extremely cumbersome and had limited finger mobility, dexterity and tactility
  - In an effort to improve glove performance, most crewmembers had an extremely tight fit which, in turn, tended to damage finger tips and finger nails
- An additional significant issue was bending down
  - The force necessary to bend down was significant; in particular, touching the ground in forward bend was very difficult
  - In order to pick up rocks and other “ground-bound” objects, it was necessary to bend at the knees, lean back and sideways in order to get one hand close to the ground, as shown here by Dave Scott on Apollo 15, or kneel down



Apollo EVA Suit System - A7L/A7LB

- Despite the limitations of the A7LB system, the Apollo crews were able to coax every last bit of performance out the system with a combination good physical conditioning, figuring out how to get around the limitations of the pressure garment, and the ability to work through the pain the suit often induced on them by the pressure garment



Desert RATS

- Since 1998, the Crew and Thermal Systems Division at JSC, led by Joe Kosmo, Amy Ross and Barbara Janoiko, have been conducting annual forays to Flagstaff, AZ, to test suits, robots, information systems and field tools in preparation for conducting lunar and Martian exploration
- The purpose of these exercises has been extremely varied, but in general considered human-centered, external operations for exploration
  - Mobility and dexterity testing of experimental suit systems
  - Carry ergonomics of suit/backpack systems
  - Suited interfaces with surface mobility systems and EVA tools
  - In-suit, “extra-habitat” recharge of life support systems
  - Use and design of field tools, including basic geologic exploration and mobility tools as well as analytical equipment

Desert RATS - Suits

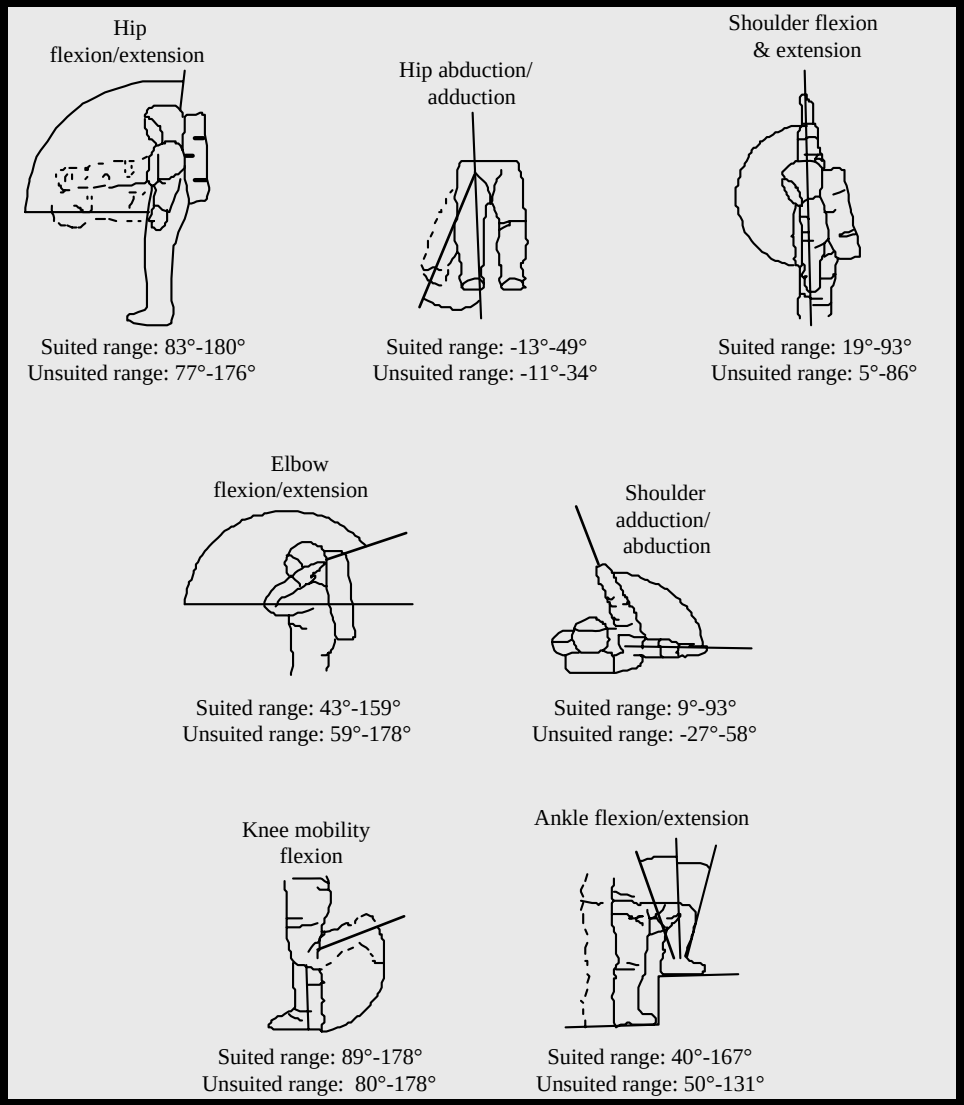
- We have been using two experimental pressure garments that represent departures from both the A7LB and the Shuttle/ISS EMU in ways that will improve their suitability for use on planetary surfaces

- On the left is the ILC-Dover Rear Entry I-Suit (REI Suit), a suit constructed mostly out of soft goods, with bearings at the shoulder, wrist, ankle and a two bearing hip,patterned convolute construction at the waist and shoulders, and mountaineering boots adapted to the pressure garment

- On the right is the ZPS Mark III, a hybrid hard and soft suit, with with a hard upper torso and briefs, bearings at the ankle, hip, waist, shoulder and wrist, with rolling convolutes at the waist and shoulder and military flight boots adapted to the pressure garment

Desert RATS - Suit Mobility Evaluation

- The diagram to the right shows the joint ranges of motion between the Mark III suit and shirt sleeve activity
- This data was acquired by doing short geologic traverses at Meteor Crater first un-suited and then in the Mark III



Desert RATS - PLSS Recharge Testing

- One of the approaches to reducing backpack weight is to carry a reduced supply of consumables and enabling top-off during EVA, either on the rover or at a previously cached recharge station
- This has worked very well, and we're now doing it routinely to extend our in-suit time on test EVAs

- The biggest concern is breaking hose connections in vacuum while ensuring you can't get a stuck connector and a pressure garment open to vacuum

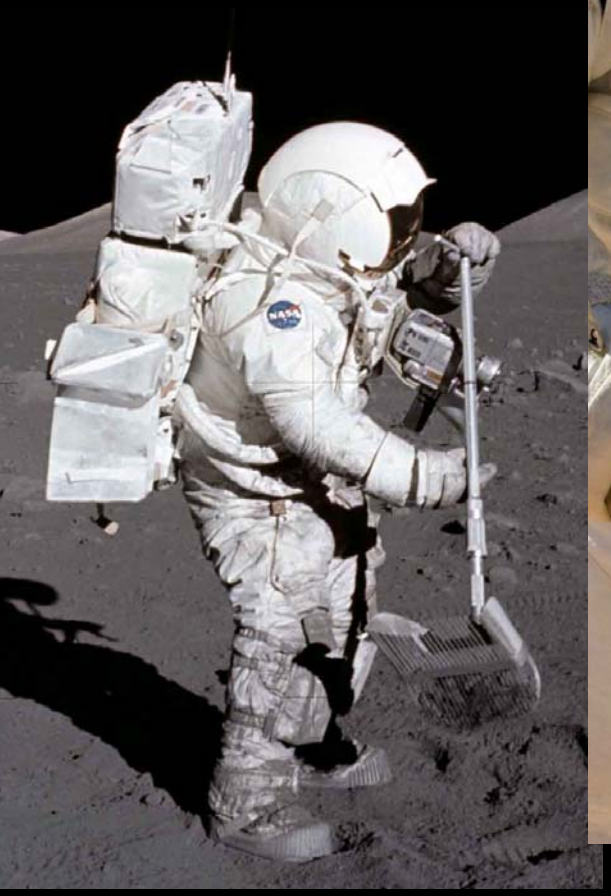
Desert RATS - Gloves

- For RATS, we have using a variety of operational and experimental gloves that capitalize on advances in patterning techniques to improve fit and mobility

- On the left is an Apollo era glove; note that it is in a “neutral grip” position, even when unpressurized; pressurization made it very difficult to move the hand out of that position
- On the right is an experimental glove with flat pattern sewing and a “universal joint” wrist mechanism that allows the subject’s hands to move freely through many normal hand motions, even when pressurized
- My experience with these gloves is that, although hand fatigue is an inevitable part of working in pressure gloves, the fatigue level is not debilitating
- The Shuttle and ISS EVA crews have done many hours of exacting, tedious work in the Phase IV and Phase VI gloves without the problems the Apollo crews experienced with finger damage and extreme fatigue

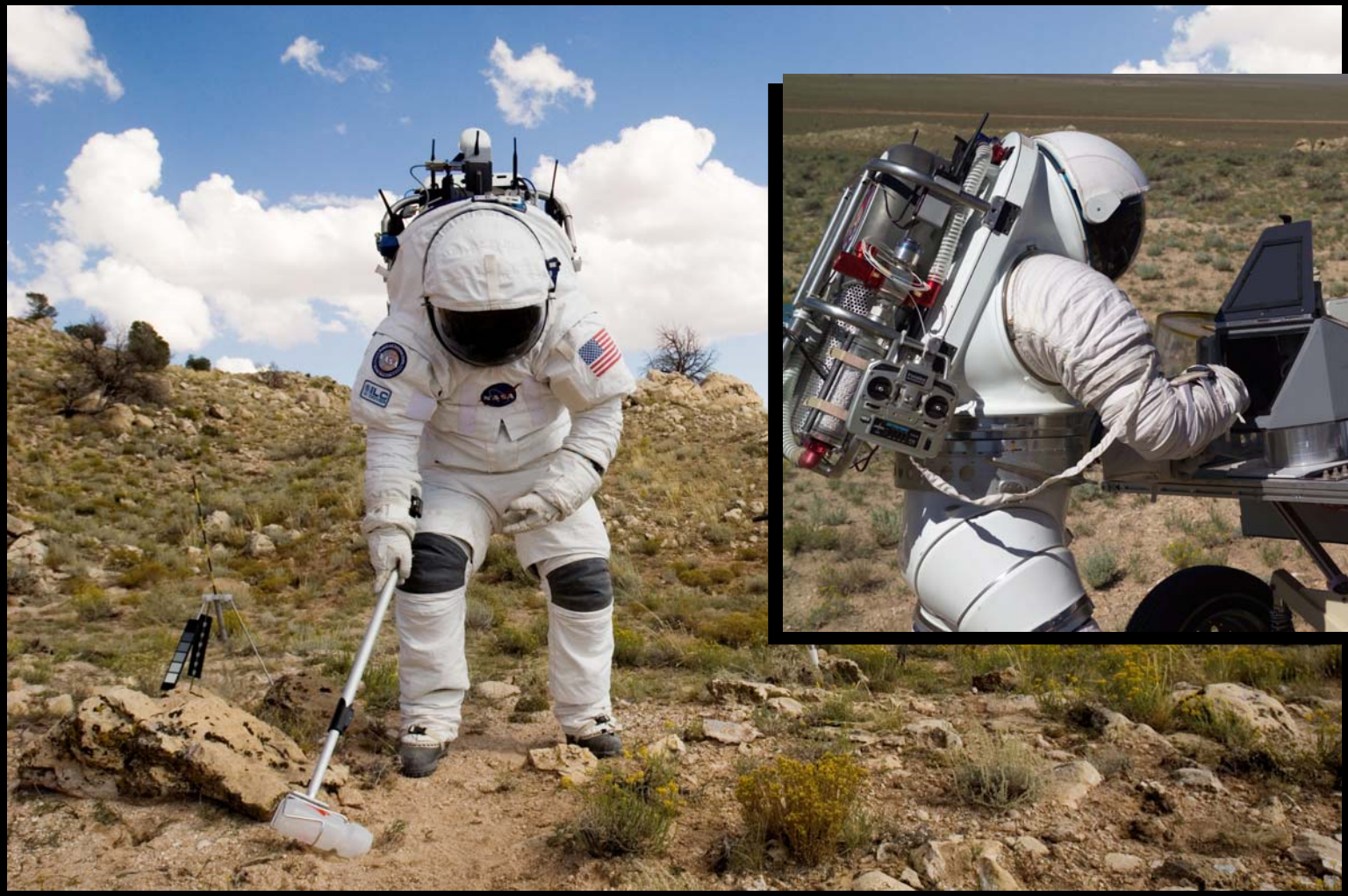
Desert RATS - Gloves

- Perhaps more important than fatigue is the dexterity we've achieved with the new gloves, including manipulating objects as small as a ball-point pen, and as complex as a multi-function hand-held RC airplane radio controller without substantial hand fatigue



Desert RATS - Field Hand Tools

- We have been using a variety of geologic hand tools similar to those used on Apollo, with the added task of looking at planetary protection approaches to tool usage and evaluating if chemical analysis is a reasonable task to do on EVA



Planetary Protection Issues with EVA Suits

- The biggest issue associated with planetary protection and pressure garments is that they leak…the "leak-proof" space suit is on the same par with a perpetual motion machine…
- When suits leak, they leak gas, but they also leak particulates present within the suit environment, including particles that undoubtedly harbor bugs
- What you can manage, through the use of seals and suit closure approaches, is the amount of leakage
- Nominal leak rates on Shuttle/ISS EMU are as follows:

	Ground-Level	In-Space Level
• Arms (each)	31.5 sccm/air	9.0 sccm/O2
• Lower torso	24.5 sccm/air	7.0 sccm/O2
• Gloves (each)	10.5 sccm/air	3.0 sccm/O2
• Upper torso	21.0 sccm/air	6.0 sccm/O2
• Helmet	7.0 sccm/air	2.0 sccm/O2
• TOTAL	136.5 sccm/air	39.0 sccm/O2

- The leak rates on the Mark III pressure garment are considerably higher
  - However, that pressure garment has been in use for almost 20 years, and has around 1,000 hours of pressurization time, which is far more time on the garment than any flight unit would be expected to have
  - We should expect to have leak rates similar to the Shuttle/ISS EMU for lunar surface operations

Planetary Protection Issues with EVA Suits

- Additional leakage constituents from portable life support system (PLSS)
  - Vent system loop (connector fittings)
  - Oxygen supply source (gaseous or cryogenic)
  - Heat removal system (water boiler - ≈1 lb/hr which will contain contaminants from the ALS water processor system)
  - Venting systems for regenerable CO_2 and humidity control are currently among leading contenders to limit expendables and on-back weight
    - These release ullage volume of space suit atmosphere as well as separated CO_2, H_2O, trace contaminants of ≈2 lbs CO_2 / EVA, ≈1.5 lbs H_2O/EVA, ≈0.02 lbs O_2 / EVA, with contaminants and higher O_2 losses possible with ejectors and other candidate technologies
    - Potential venting during assisted operations, emergency operations, EVA recharge or equipment change-out activities
- Additional potential contamination constituents
  - Trace chemical contaminants associated with suit leakage, such as lubricants associated with suit bearings and other components
  - Suit surface contaminants from habitat and human contact
  - Elastomeric and other fabric materials from outer space suit coverings lost due to mechanical abrasion and off-gassing of volatiles
- The lunar suits presently have no requirement to meet the planetary protection requirements established for Mars, however, all of these data suggest that minimizing contamination from space suit systems will be a difficult development activity for a Mars space suit system
  - There may be concerns in the lunar environment about off-gassing effects from suits on optical surfaces
  - This will need to be considered when items such as optical telescopes begin to be constructed on the lunar surface

Planetary Protection Issues with EVA Suits

- In an effort to understand the suit leakage of biological materials, we've run several ad-hoc experiments on the REI Suit on two RATS excursions
- These experiments, which Andrew Steele will report on, testing the biological load of suit components prior to and after a suit run to see how many bugs leaked out
- We hope to expand on this in the future by doing a rigorous biological challenge in a vacuum chamber to quantify the biological output of the future lunar spacesuit system

Desert RATS - Q & D Lessons Learned

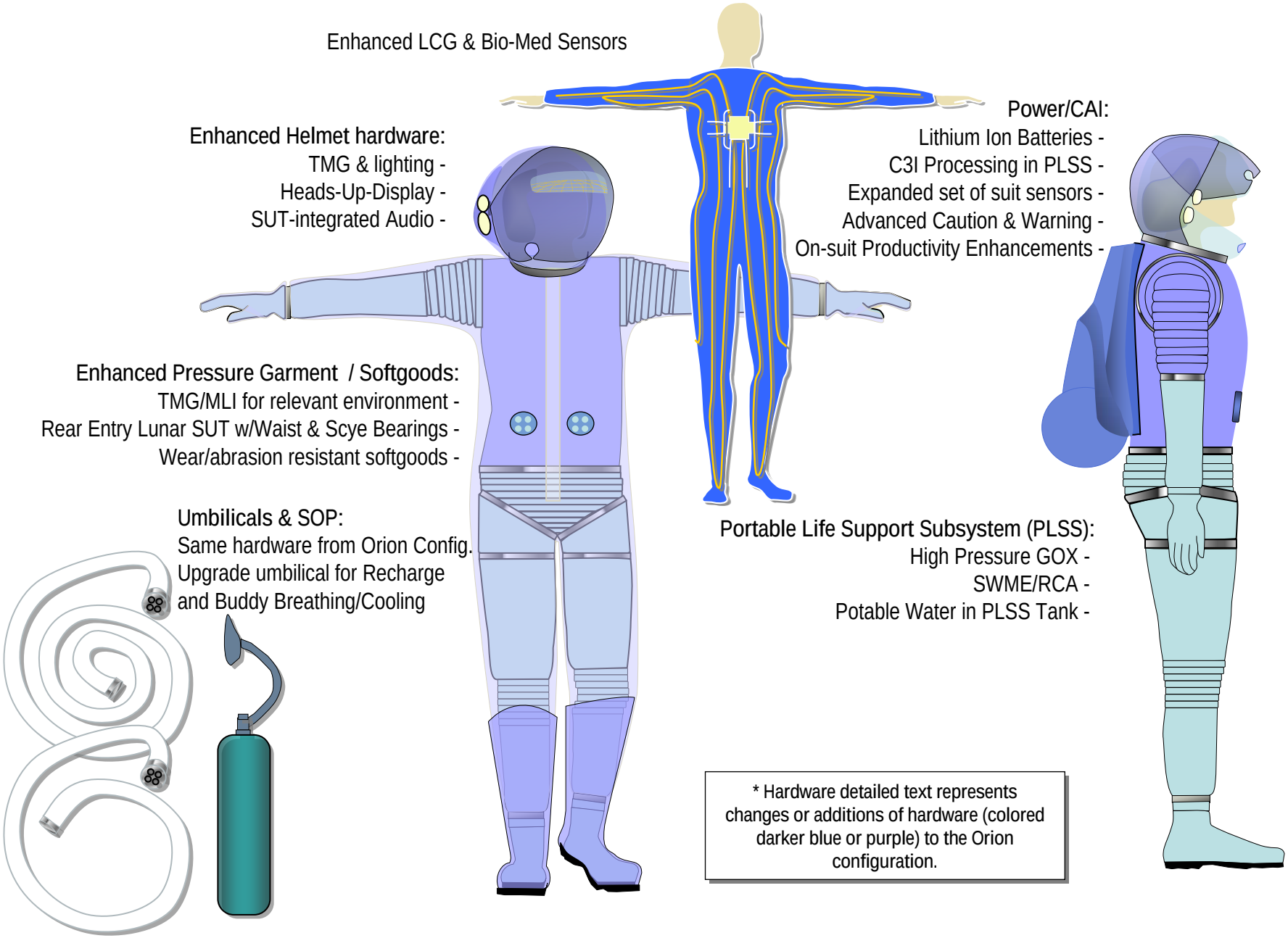
(From The Suit Subject's Perspective)

- Suit mobility and glove dexterity have made tremendous advances since Apollo, and can support the goal of frequent, routine EVAs without seriously beating up the crewmembers in the process
- In-suit and on-rover recharge are relatively easy activities, provided the appropriate valve interlocks are built to prevent malfunctions
- We can do analytical work in a suit, but it is difficult and time consuming
  - As good as the suits and gloves have become, we need to understand where the break point is between "exploration efficiency" and real-time analytical data collection
- Rovers are great devices, both robotic, manned and hybrid versions
  - Manned rovers greatly reduce crew fatigue and consumable usage and extend EVA time
  - Unmanned rovers are essential tools for a variety of operational duties
    - Scientific and operational reconnaissance
    - Equipment transport
    - Instrument deployment
- Planetary protection will be an important design challenge for the Mars suit system, but it's unclear to what degree we will be able to reduce contamination
- To a large extent, we know what works in spacesuit systems, but the ancillary systems that will interact with the crewmembers remains wide open territory
  - The cardinal rule that has to followed, however, is that crewmember is <u>not</u> a carbon-based robot
  - If we overwhelm the crewmember with systems management tasks that detract from their ability to observe and use their brains, we're wasting the investment made to send them to the lunar surface in the first place

Exploration Techniques - Open Questions

- Apollo barely pried open the door to planetary surface exploration
- Sustained scientific lunar and Mars exploration will require us to answer a host questions that are precipitated by having sustained exploration capability that was not available during Apollo
- These questions can be grouped into the following larger topics:
  - Scientific analysis capability
  - Exploration/science information management
  - Geographic information acquisition and delivery
  - Operations information delivery systems
  - Work allocation between human and robotic systems
  - Degree of autonomy of robotic systems
  - Operations philosophy and implementation
- I see the answers to these questions as part of re-inventing the sciences of field geology and biology so they can be practiced in places where we will never have the luxury working in a shirt-sleeve environment
  - In short, how do we do what geoscientists and field biologists have always done - apply geological and biological data to a geographic base so the geologic history, geochemistry, geophysics and biodiversity of an area can be deciphered and understood?

Conceptual Lunar Surface EVA Suit System



Concept Drawings of the Suit System Reference Configuration
Constellation Suit System Team - 26 Oct. 2006

Artwork by Jeannie Corte (ESCG)

Desert RATS is a strongly collaborative effort, involving enormous efforts by many people. My thanks goes out to all the engineers, suit techs, photographers, medics, comm guys, roboticists and general schleppers that have enabled us to learn all that we have in the last 10 years of work!