Recommendations for Exploration Space Medicine from the Apollo Medical Operations Project

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Introduction: A study was requested in December, 2005 by the Space Medicine Division at the NASA-Johnson Space Center (JSC) to identify Apollo mission issues relevant to medical operations that had impact to crew health and/or performance. The objective was to use this new information to develop medical requirements for the future Crew Exploration Vehicle (CEV), Lunar Surface Access Module (LSAM), Lunar Habitat, and Advanced Extravehicular Activity (EVA) suits that are currently being developed within the exploration architecture. **Methods**: Available resources pertaining to medical operations on the Apollo 7 through 17 missions were reviewed. Ten categories of hardware, systems, or crew factors were identified in the background research, generating 655 data records in a database. A review of the records resulted in 280 questions that were then posed to surviving Apollo crewmembers by mail, face-to-face meetings, or online interaction. Response analysis to these questions formed the basis of recommendations to items in each of the categories. **Results**: Thirteen of 22 surviving Apollo astronauts (59%) participated in the project. Approximately 236 pages of responses to the questions were captured, resulting in 107 recommendations offered for medical consideration in the design of future vehicles and EVA suits based on the Apollo experience. **Discussion**: The goals of this project included: 1) Develop or modify medical requirements for new vehicles; 2) create a centralized database for future access; and 3) take this new knowledge and educate the various directorates at NASA-JSC who are participating in the exploration effort. To date, the Apollo Medical Operations recommendations are being incorporated into the exploration mission architecture at various levels and a centralized database has been developed. The Apollo crewmembers' input has proved to be an invaluable resource, prompting ongoing collaboration as the requirements for the future exploration missions continue to evolve and be refined.

Recommendations for Exploration Space Medicine from the Apollo Medical Operations Project

R.A. Scheuring, J.R. Davis, J.M. Duncan, J.D. Polk, J.A. Jones, D.B. Gillis

NASA-Johnson Space Center

Apollo Medical Operations Recommendations

Introduction

- This study followed a request made by the Medical Operations Branch, Space Medicine Division of NASA-JSC in December, 2005
- The objective was to identify problems that occurred during the Apollo missions relevant to medical operations that had an impact on crew health and/or performance
  - Validate and refresh our systems knowledge to make sure we get it right the second time around
  - Implications for the explorations effort
  - ***Not*** a review of information contained in the *Biomedical Results of Apollo*

Apollo Medical Operations Recommendations

- **Goals**
  - Develop or modify medical requirements for new vehicles
  - Create a centralized database
  - Take this new knowledge to the different directorates participating in the exploration effort

Apollo Medical Operations Recommendations

Methods

- Review of Apollo resources pertaining to Medical Operations*
  - Sources of data
    i. *Apollo Medical Mission Debriefs*
    ii. *Apollo Flight Surgeon Logs*
    iii. *Apollo Biomedical Engineer (BME) logs*
    iv. Apollo Mission Commentaries
    v. Apollo Mission Reports (11-17)
    vi. Apollo Lunar Surface Journals (11-17)
    vii. Preliminary Science Reports (11-17)
    viii. Apollo Lecture Series http://sf.jsc.nasa.gov/pastproged.aspx ⇨
    ix. Personal Communications

*Crew logs, crew questionnaires, and air-to-ground communications unavailable

Apollo Medical Operations Recommendations

- **Apollo 7-17 Categories**
  1. EMU/EVA suit
  2. Lunar surface operations
  3. In-flight illnesses
  4. Medical kit/medications
  5. Environmental (vehicle)
  6. Radiation
  7. Performance/Human factors
     - Crew schedule
  8. Exercise
  9. Food/nutrition
  10. Launch/re-entry/recovery
  11. Flight surgeon-crew interaction

Apollo 11 Launch

Apollo Medical Operations Recommendations

Results

- Development of MS Access® database with 655 records of categorical data pertaining to the Apollo 7-17 missions
- 236 pages of responses to 280 questions from the face-to-face meeting
- 64% (14/22) participation formed the basis of the Apollo Medical Operations recommendations

Apollo Medical Operations Summit, 7-9 June, 2006

Apollo Medical Operations Recommendations

Apollo Medical Operations Summit Statistics

13 of 22 astronauts astronaut provided input - (summit and post-summit) **59%**

Caution - this section is only post-summit responses! Does not count the 8 summit attendees responses since we could not individualize them as we did the post-summit group.	**# of Questions**	**Post-Summit # of Responses**	**Post-Summit Response Rate %**
Launch Recovery	34	113	55.39%
Crew Work-Rest Schedules	10	28	46.67%
Food Nutrition	28	73	43.45%
Performance	16	43	42.16%
Flight Surgeon Crew Interaction	2	5	41.67%
General Questions	14	31	36.90%
Environmental Impacts	35	71	33.81%
Bioinstrumentation	3	5	27.78%
Illnesses	16	24	25.00%
Exercise	20	30	25.00%
Medical Kit	3	4	22.00%
EVA	63	30	8.06%
Lunar Surface Ops	36	13	6.02%
Totals	**280**	**470**	

Apollo Medical Operations Recommendations

- **EMU/EVA Suit**
  - Comments
    - The most fatiguing part of EVA tasks was repetitive gripping
    - "Efficiency was no more than 10% of the use of the hand"
    - Fingernails being pulled back (onycholysis)
    - Skin being abraded from the top of the knuckles
    - The crew experienced no trauma in training, though muscle fatigue occurred.

Apollo Medical Operations Recommendations

- **EMU/EVA Suit**
  - Recommendations
    - **Improve glove flexibility, dexterity, fit**
      - Gloves should be custom designed for each crewmember that incorporate mechanical closure for gripping
      - Look into a wrist seal and depressurized glove
      - Robotic power-assisted glove for repetitive tasks
      - Glove liners should be worn

Apollo Medical Operations Recommendations

- **EMU/EVA Suit**
  - Recommendations
    - Reduce the mass of the suit by a factor of two
    - Increase general mobility by a factor of four
      - Primarily at the knee joint
        - "*Bending the knee was difficult in the suit. We need a better [more flexible] knee joint*."
    - Lower suit Center of Gravity
      - *"Don't make moving the CG your primary priority. Move the CG only if it becomes convenient to do so while taking care of other issues like reducing the mass of the suit, etc."*

Apollo Medical Operations Recommendations

EMU/EVA Suit

- Recommendations
  - Improve peripheral vision in the suit
    - Design the helmet to allow you to see your feet.
    - You would always have to turn your body to see
    - The Navy deep sea diving helmet with rotating neck ring is a good option and should be considered in the new suit design

Apollo Medical Operations Recommendations

Three astronauts on the Moon. Art by Pat Rawlings.

EMU/EVA Suit

- Recommendations *cont'd*
  - Develop a reliable Heads Up Display (HUD) displaying consumable information, limited BIOMED data, and navigation on demand
  - The HUD primarily should be presenting the operational information that you need in an instant. If you want to see oxygen, you say "oxygen" and it appears.
    - Be careful not to increase the complexity of the system thereby reducing its reliability

Apollo Medical Operations Recommendations

- **EMU/EVA Suit**
  - Recommendations
    - **The lunar boot functioned well and does not need to be improved**
      - The boot was very comfortable, however it was slippery on rocks or boulders.
        - There was not concern about ankle sprains or injuries with falls
    - Debriefs imply loping was the most biomechanically efficient form of movement
      - The metabolic cost was less with skipping than with walking. It took more time and was more difficult to walk. It was very comfortable in the 1/6 g environment.
      - Hills seemed steeper and tougher to climb on the lunar surface and loping could not be used

Apollo Medical Operations Recommendations

EMU/EVA Suit

- Recommendations *cont'd*
  - The drink bag should have capability to contain a high energy liquid along with plain water
  - Develop a better in suit Urine Collection Device (UCD) that will work in 1/6 g
  - The suit should be a low pressure (3.50 psia), single gas system
  - Develop a system that prevents helmet fogging during heavy exertion
  - Use a self-sealing pressure garment within the suit for puncture

Apollo Medical Operations Recommendations

EMU/EVA Suit

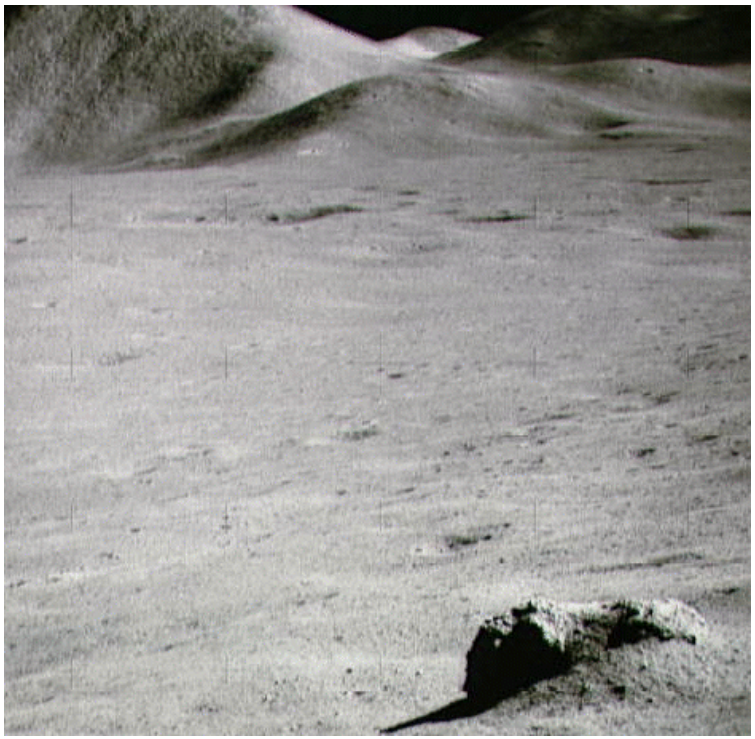
- Recommendations
  - **Protect the suit zipper function**
    - The A7LB was a single zipper system
    - Lunar dust was difficult to clear from the zipper and impaired normal function on each subsequent lunar EVA

Apollo Medical Operations Recommendations

Lunar Surface Operations

- Recommendations
  - Schedule crews for two Lunar EVA days on and one day for maintenance, alternating crews throughout the week
  - There is no special training needed for 1/6g EVA's other than a familiarization session
  - **Surface activities can begin once operationally feasible**
- Crews generally felt a little "wobbly" upon stepping on the moon
  - Coordination seemed to improve steadily during first couple of hours on the surface
- Crews denied problems with spatial disorientation on lunar landing

Apollo Medical Operations Recommendations



- **Lunar Surface Operations**
  - All sorts of ambiguities exist on the moon (i.e. slopes, terrains, sun shadows, bland environment).
    - "Reflective light in the shadows isn't as evident as on earth. Craters did appear steeper visually. We knew we had to go down into that crater, so it gave us concern."

Apollo Medical Operations Recommendations

- **Lunar Surface Operations**
  - Falls were not uncommon
    - Crews cited rocks, equipment, terrain features, suit CG, fatigue all contributed to falls
    - Returning to upright posture was met with varying degrees of difficulty
    - Crewmembers felt they were “well protected” in the suit

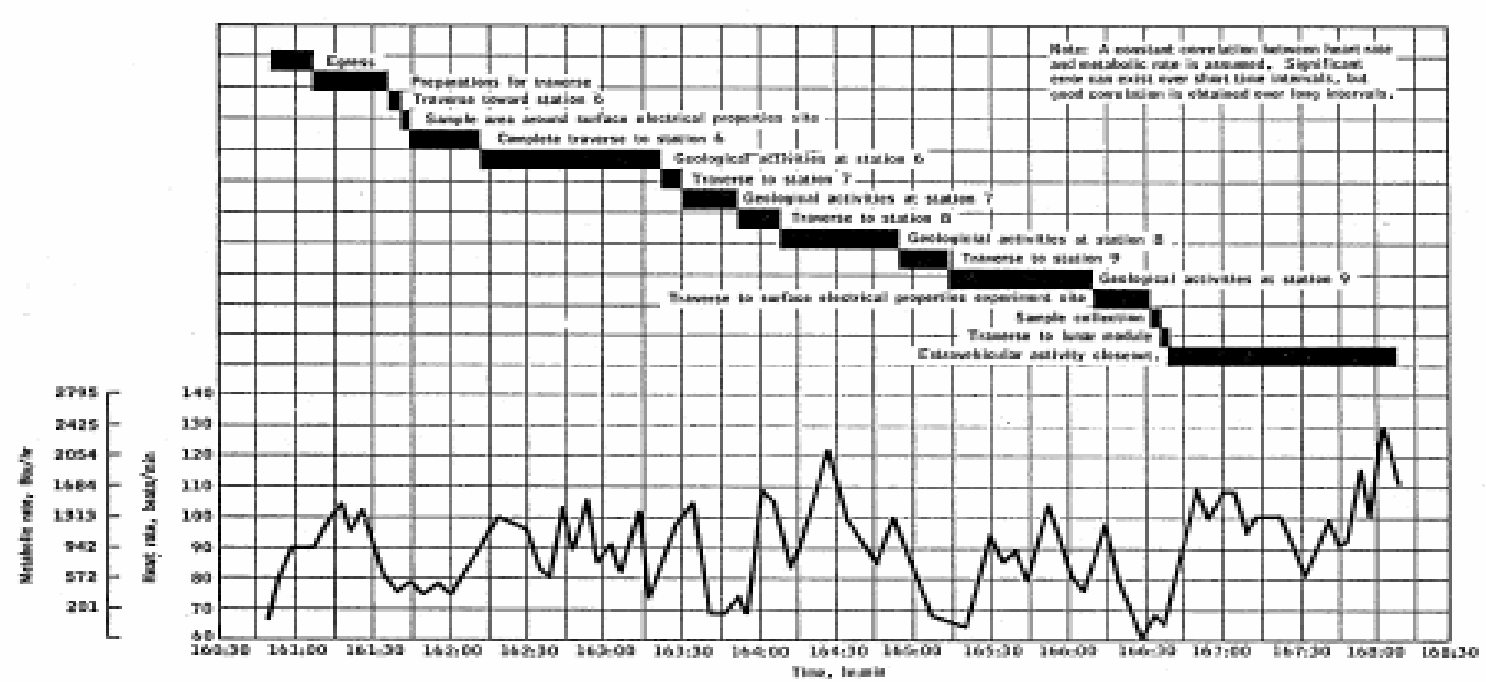
Apollo Medical Operations Recommendations

- **Lunar Surface Operations** *cont'd*
  - Risk factors for injuries identified
    - **Limit navigation into craters to < 20-26° slope**
    - Rover activities
      - CDR
      - LMP
    - Falling from a height
      - Ladder
      - Rim of a crater

Apollo 17 LMP H. Schmitt near North Massif at Taurus-Littrow

Apollo Medical Operations Recommendations

- **Lunar Surface Operations**
  - Metabolic expenditure: deconditioning or poor pre-flight preparation?



(b) Lunar Module Pilot.

Figure 11-4.- Concluded.

Apollo Medical Operations Recommendations

- **Lunar Surface Operations**
  - Recommendations *cont'd*
    - **The hatch and ingress corridor should be sized appropriately for an inflated 1/6 g pressure suit**

Apollo Medical Operations Recommendations

- **Lunar Surface Operations**
  - Recommendations *cont'd*
    - An airlock may make ingress/egress easier and will also be a good idea from a dust control standpoint
    - Dust is cleared rapidly in the cabin by lithium hydroxide.
      - Dust is very abrasive and there are jagged fragments. The dust on the surface was a problem because it covered all your gear, visors, etc.

Apollo Medical Operations Recommendations

Lunar Surface Operations

- Recommendations *cont'd*
  - Ladder rung height and width on the Lunar Module (LM) were good but the glove did not allow adequate grip for safety
  - **Ensure adequate water and food are available before and during lunar EVA**
  - Lunar EVA should be performed as one continuous event
  - Plan the operations on the surface so that you protect the crews from themselves
  - With extended ops on the moon, establish all the experiments in the first week

Apollo Medical Operations Recommendations

- **Lunar Surface Operations**
  - Recommendations *cont'd*
    - A robot should perform routine, systematic, repetitive, menial tasks (may help prevent repetitive use injuries)
    - The Rover should have the ability to recharge your suit
    - Crews requested that a automatic position determination device be available to aid navigation on the lunar surface

Apollo Medical Operations Recommendations

- **Lunar Surface Operations**
  - To ensure operational success and optimize performance of the crews
    - **Allow adequate time to practice mission activities in a variety of environments including good analogs that allows preparation for off-nominal events**

Apollo 16 Geological field training in New Mexico

Apollo 12 Lunar Lander Training Vehicle (LLTV) Ellington Field

Apollo 17 Lunar Surface Activity training at JSC

Apollo Medical Operations Recommendations

In-Flight Illnesses

- Recommendations
  - Low back pain should be treated with aggressive pre-mission and in-flight core strengthening program ⇨
  - **Therapy to relieve muscle soreness, primarily in the forearms, must be available (improved glove design may assist this)**
  - Constipation: improve the waste management collection system
  - Screen for CAD prior to selection for lunar missions
  - **A physician crewmember would increase the comfort level among the crewmembers and can be cross-trained to do other activities**
  - Adequate preventive measures and treatment for diarrhea must be available

Apollo Medical Operations Recommendations

Medication/Medical Kits

- Recommendations
  - A card in the med kit to inform the crew of the medication duration, indication, and interaction with other meds is needed
  - Add non-sedating antihistamines for allergy symptoms due to lunar dust exposure
  - Saline eye drops need to be available in large quantities (however an eyewash will be available as part of the environmental health kit)
  - **Provide items that are needed in daily life, e.g. nail clippers, lotions, band-aids, etc**. (Individual hygiene kit will be available)
  - Sufficient analgesia to treat headaches
  - Sleep medication must promote restful sleep but not be too sedating

Apollo Medical Operations Recommendations

- **Environmental Impacts**
  - Recommendations
    - **Consider adapting the Skylab waste management system into the new vehicles**
    - The sleep restraint system on Apollo worked well and should be incorporated into the new vehicle design
      - Sleeping bag needs to be large enough for crewmembers to get both knees to their chest

Apollo Medical Operations Recommendations

- **Environmental Impacts**
  - Recommendations *cont'd*
    - **Thermal protective clothing or equipment should be available on board**
    - Drinking water should be available during sleep periods
    - Lunar Surface Ascent Module (LSAM) windows should be designed to see only what is necessary for landing and/or rendezvous with IR protection

Apollo 13 CDR Jim Lovell in the Aquarius LM

Apollo Medical Operations Recommendations

Environmental Impacts

- Recommendations *cont'd*
  - Minimize noise but do not eliminate it (earplugs are an adequate countermeasure for noise)
  - **CO_2 monitoring device needs to be robust and reliable** ⇨
  - A food warmer is desirable
  - **Astronaut participation in the design and development phases of the new vehicles is essential**
  - Radio Frequency ID (RFID) tags should be considered for stowage items

Apollo Medical Operations Recommendations

- **Environmental Impacts**
  - Recommendations *cont'd*
    - **Hot water capability for hygiene, beverage and food preparation is essential**
    - Apollo bag aperture and capacity needs to be larger and easier to apply in microgravity ⇨
    - Create a device that would allow crewmembers to assume a squatting position in microgravity
    - Do not design the galley and waste management areas together

Apollo 17 CDR G. Cernan in the LM following EVA #2

Apollo Medical Operations Recommendations

- **Radiation**
  - Recommendations
    - Vehicle should have active radiation detectors with alarms that sound when the dose gets too high for safety
    - A Passive Radiation Dosimeter (PRD) is a requirement for all crewmembers
      - Design it into the suit garments
    - The rover should be equipped with a radiation shield
    - Radiation protectants should be made available to the crewmembers
    - Create a trench with shovels or explosives to protect the crew short term in the event of a Solar Particle Event (SPE)

Apollo Medical Operations Recommendations

- **Behavioral Health and Performance**
  - Recommendations
    - Preflight quarantine is very valuable that allows time for sim time, exercise, and rest
    - Recreational activities need to be made available for crews during Trans Lunar Coast (TLC) and Trans Earth Coast (TEC)
      - CMP during lunar surface operations
    - **Lunar crews should have one day/week for "rest" (freedom to select their activity)**
    - **Mental and physical rest plans should be introduced into extended moon stays to allow adequate rest between lunar EVA**

Apollo Medical Operations Recommendations

Behavioral Health and Performance

- Recommendations *cont'd*
  - Mission focus should be project-oriented and not timelined
  - Provide adequate capabilities for sleeping on the lunar surface
  - **If a crewmember dies during the mission you cut him loose**
  - **In planning crew size/makeup, the authority structure is much more significant than crew size**
  - The pre-flight training schedule should allow for crews to concentrate on issues that will be used for the nominal mission

Apollo Medical Operations Recommendations

- **Behavioral Health and Performance** *cont'd*
  - **An eight hour/day sleep period must be protected in the daily schedule and must not be compromised**
  - Crew sleep periods should be scheduled at the same time
  - Use of sleeping medication should be encouraged where appropriate

Apollo 17 CDR G. Cernan asleep in the CM during TLC

Apollo Medical Operations Recommendations

- **Behavioral Health and Performance**
  - Recommendations *cont'd*
    - The pre-flight training schedule should allow for crews to concentrate on issues that will be used for the nominal mission
    - Countermeasures to combat mental fatigue are necessary throughout the mission
    - **Education and psychological services should be available to the crewmember's families**

Apollo Medical Operations Recommendations

- **Exercise**
  - Recommendations
    - Loosen the pre-mission timeline to allow adequate time for pre-flight conditioning program
    - A more robust (and lightweight) piece of in-flight exercise equipment is needed than the Apollo Exer-Genie ⇨
    - The flight surgeon/mission planners should not plan specific exercise prescriptions for short duration (< 14 days) mission
    - **Exercise is not necessary on short trips (14 days or less) [from a fitness standpoint], however crews demanded that the capability be available and varied as much as possible for crew "rest and relaxation" in all phases of the mission**

Apollo Medical Operations Recommendations

- **Exercise**
  - Recommendations *cont'd*
    - **Develop a better pre-flight and in-flight forearm muscle conditioning program for lunar crewmembers**
      - **In addition to the core stabilization program as described earlier**
    - New vehicle design should allow a variety of different exercise capabilities (hardware vs. cabin structure)
    - **New exercise device should be reliable, simple and not develop excessive heat in use**

Apollo Medical Operations Recommendations

Food/ Nutrition

- Recommendations
  - **Mission activity (e.g. coast, rendezvous, lunar orbit, lunar OPS, etc.) will dictate what type and how much food will be consumed**
    - High activity- wet-packages, bite-sized snacks, canned foods
    - Low activity- spoon-bowls, dry juice or meals (rehydratable) requiring mixing etc.
  - **Plain water in large quantities needs to be available for lunar EVA**
  - Optimize diet and food intake for overall performance during long duration missions

Apollo Medical Operations Recommendations

Food/ Nutrition

- Recommendations *cont'd*
  - An in-suit non-caffeinated solid or liquid carbohydrate food source for lunar EVA would be helpful.
  - Design adequate space and useful area in the new vehicles to store food packs during meals
  - Spicy and salty foods are preferred items in the menu
  - **Allow adequate time in the daily schedule for meals**
  - Determine how different environmental factors (e.g. O_2 concentration, cabin pressure) effect food flavor

Apollo Medical Operations Recommendations

Launch, Landing and Recovery Ops

- Recommendations
  - **Provide adequate cooling capabilities for the crew on landing to mitigate the hot cabin contribution to crewmember sea sickness**
  - **Ground landings are discouraged**
  - Apollo seat configuration for water landings were adequate
    - The restraint system needs to include loose equipment items
  - Medication for motion sickness and fatigue will be available prior to re-entry
  - Hatch should open outward and seal with pressure ⇨
  - **Sea state should be limited to < 6-8 foot swells if recovery is to be delayed**

Apollo Medical Operations Recommendations

- **Launch, Landing and Recovery Ops**
  - Recommendations *cont'd*
    - Have food and plain water within reach of buckled crewmembers for delayed recovery
    - Apollo Command Module (CM) hatch location and size was adequate for egress
    - All control panels and switches were within reach of crewmembers during launch and landing
    - Training for pad abort was adequate and should be continued
    - Crew surgeon should be on the recovery vessel and not the helicopter

Apollo Medical Operations Recommendations

- **Flight Surgeon-Crew Interaction**
  - Recommendations
    - Crews encouraged FS to "act as more of an advocate of the crew" than an experiment
    - The collaboration established between the current flight surgeons and Apollo crewmembers should continue and be an example to future generations

Apollo flight surgeon Chuck Ross, DO during the Apollo Med Ops Summit, June 2006

Apollo Medical Operations Recommendations

Discussion

- Goals
  1. Develop or modify medical requirements for new vehicles
  2. √ Create a centralized database
  3. √ Take this new knowledge to the different directorates participating in the exploration effort
- Study focus – "operationally driven outcomes"
  - Info to be used by flight surgeons, engineers, scientists, mission directors and anyone else involved in exploration
  - So far we have just been the "middle men" for the 107 recommendations
  - But are the results applicable today?
    - YES
  - Limitations – non-response bias and the volunteer effect, procedure bias, recall bias
  - Relevance varies among the recommendations
    - i.e. waste management vs. Lunar Surface Ops

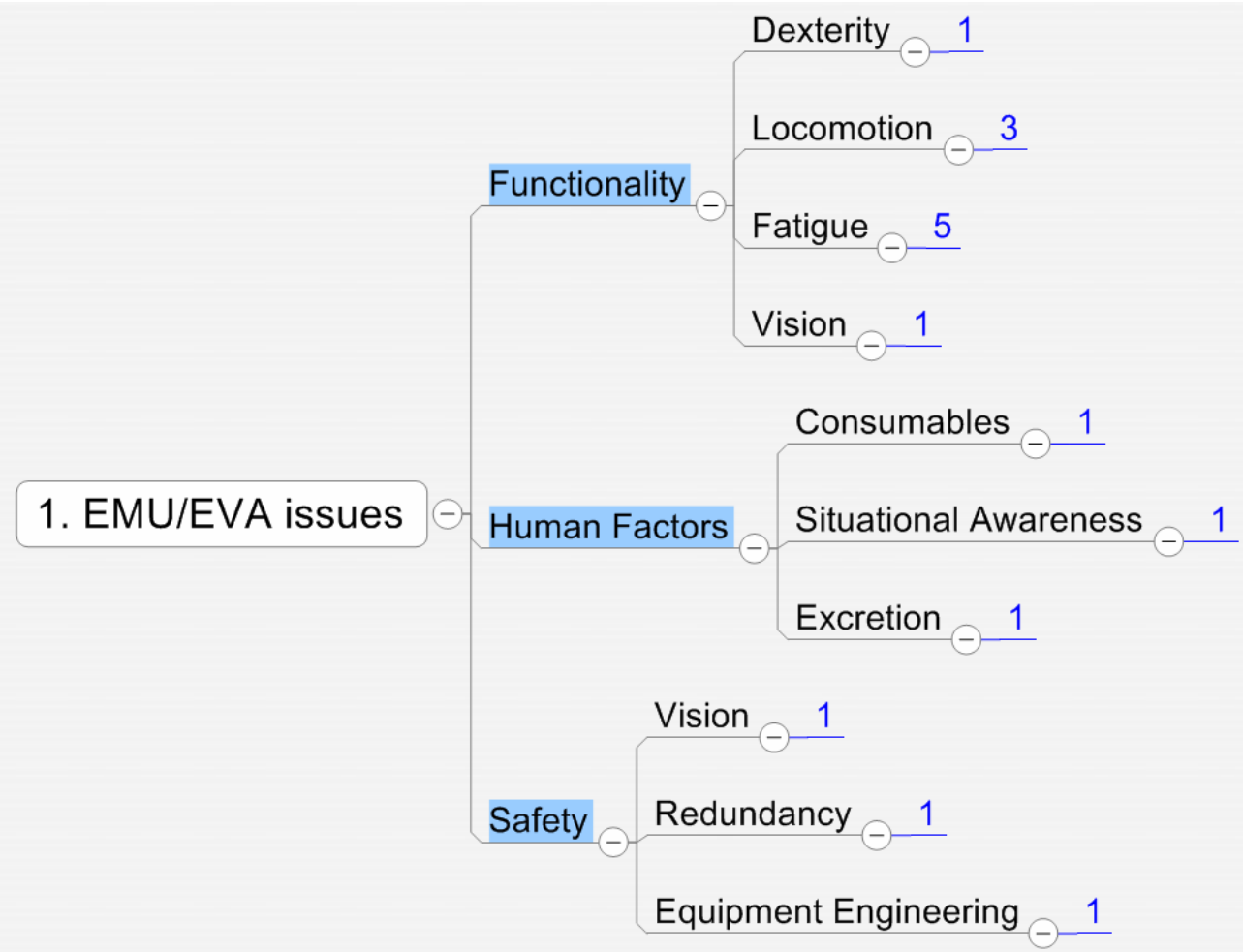
Discussion

- 3 Broad Themes
  - Mission Accomplishment and Safety – virtually inseparable and at the core of every recommendation
  - Human Factors – “astronauts are people too”
    - Undertone theme of crew limitations
    - Astronauts are not robots, test subjects, or infallible beings
    - Multiple recommendations made across the 11 categories
      - 23 scheduling-related recs in 4 categories
      - 10 sleep-related recs in 3 categories
      - 26 R&R recs in 6 categories

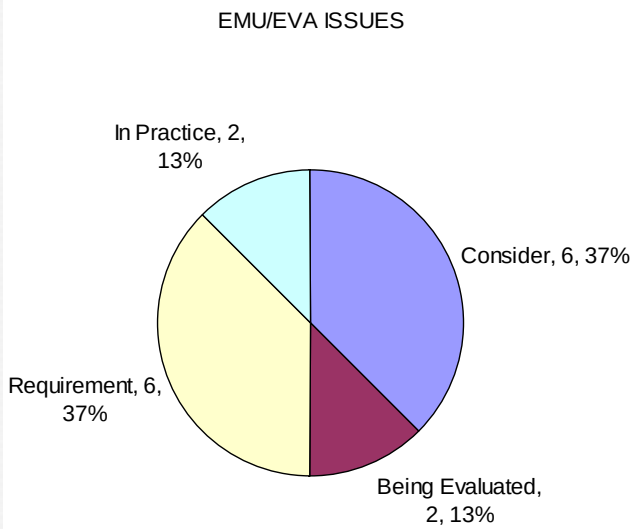
Apollo Medical Operations Recommendations

- **Discussion**

***Goal: Develop or modify medical requirements for new vehicles**



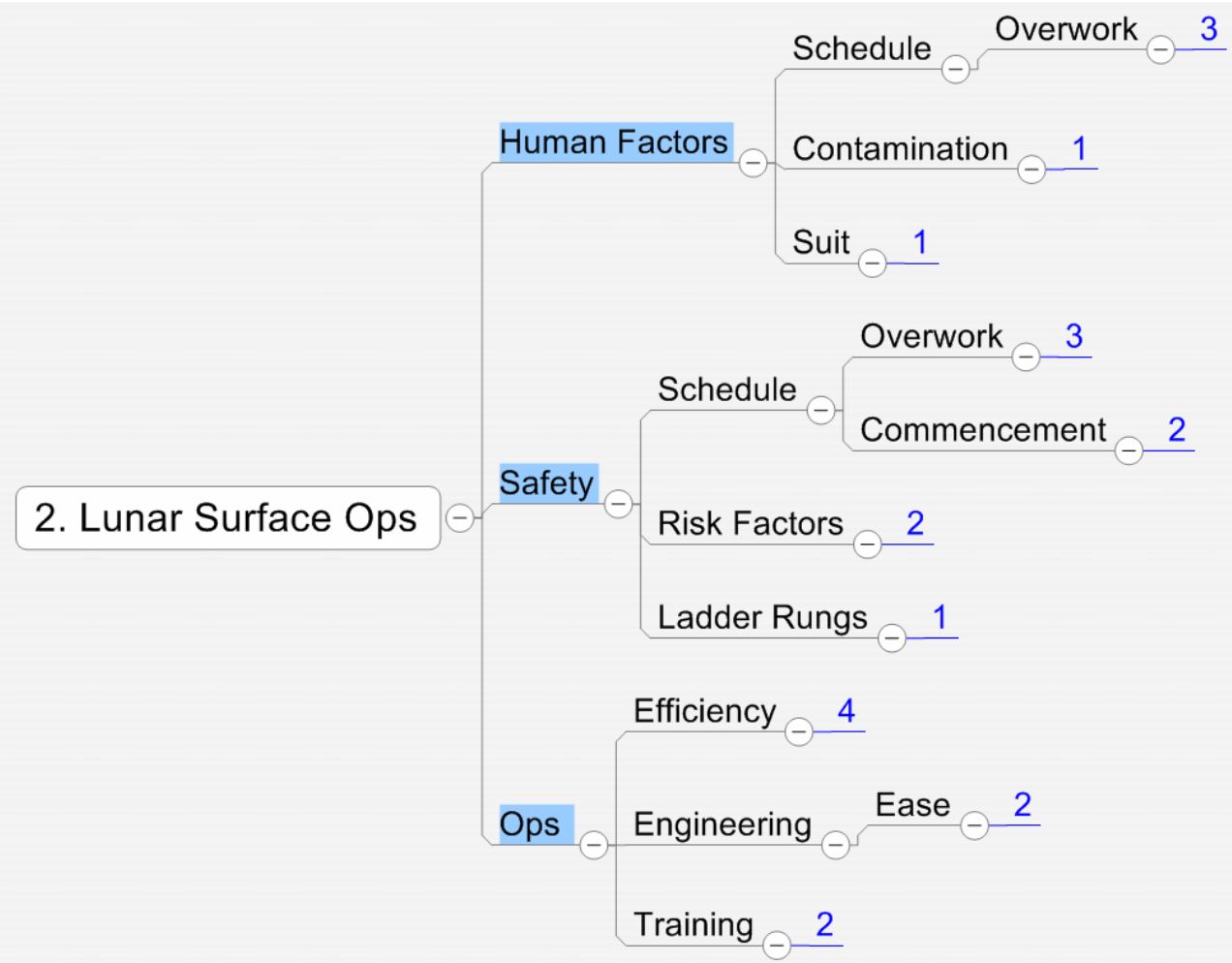
-Suit technology has improved over the years, however Apollo astronauts are the only ones to have worked in partial gravity



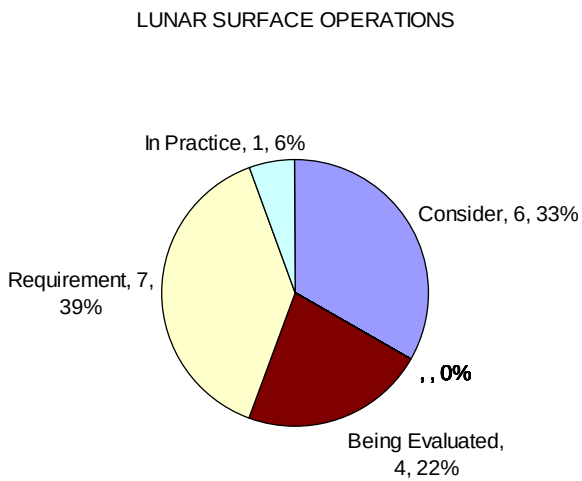
Apollo Medical Operations Recommendations

*Goal: Develop or modify medical requirements for new vehicles

Discussion



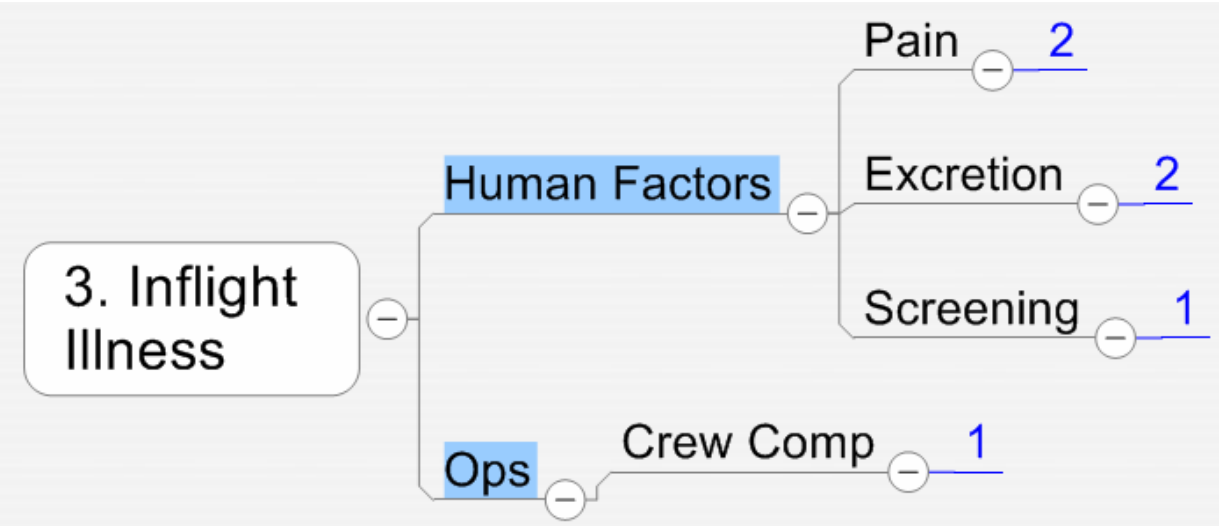
-Very relevant recommendations, the Apollo astronauts have the only experience operating on the moon



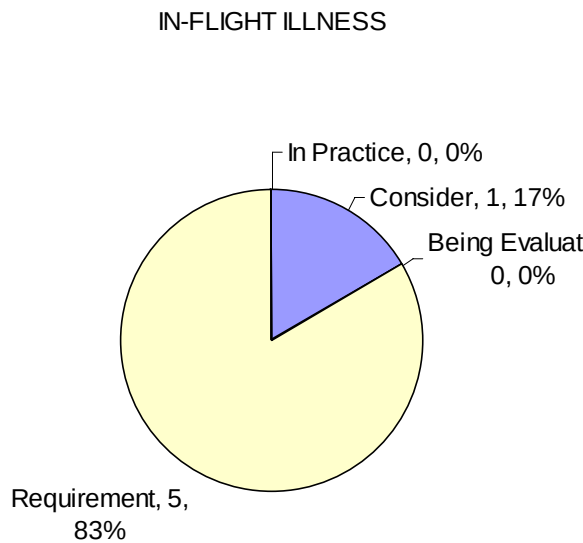
Apollo Medical Operations Recommendations

***Goal: Develop or modify medical requirements for new vehicles**

Discussion



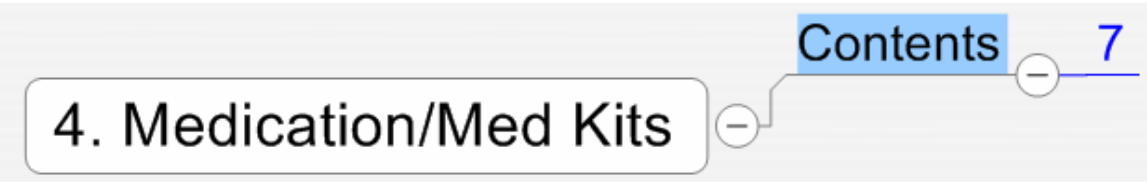
-Skylab, Shuttle, and ISS experience have improved our preventative measures and treatments in this area



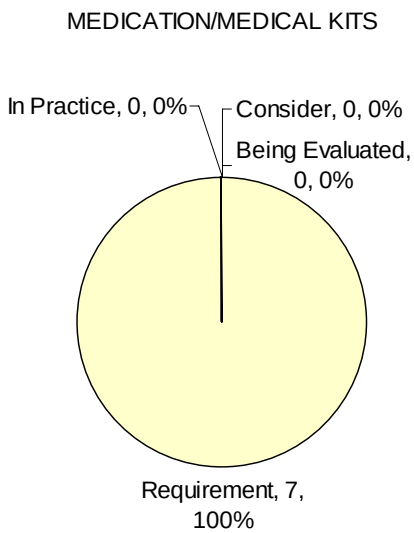
Apollo Medical Operations Recommendations

- **Discussion**

***Goal: Develop or modify medical requirements for new vehicles**



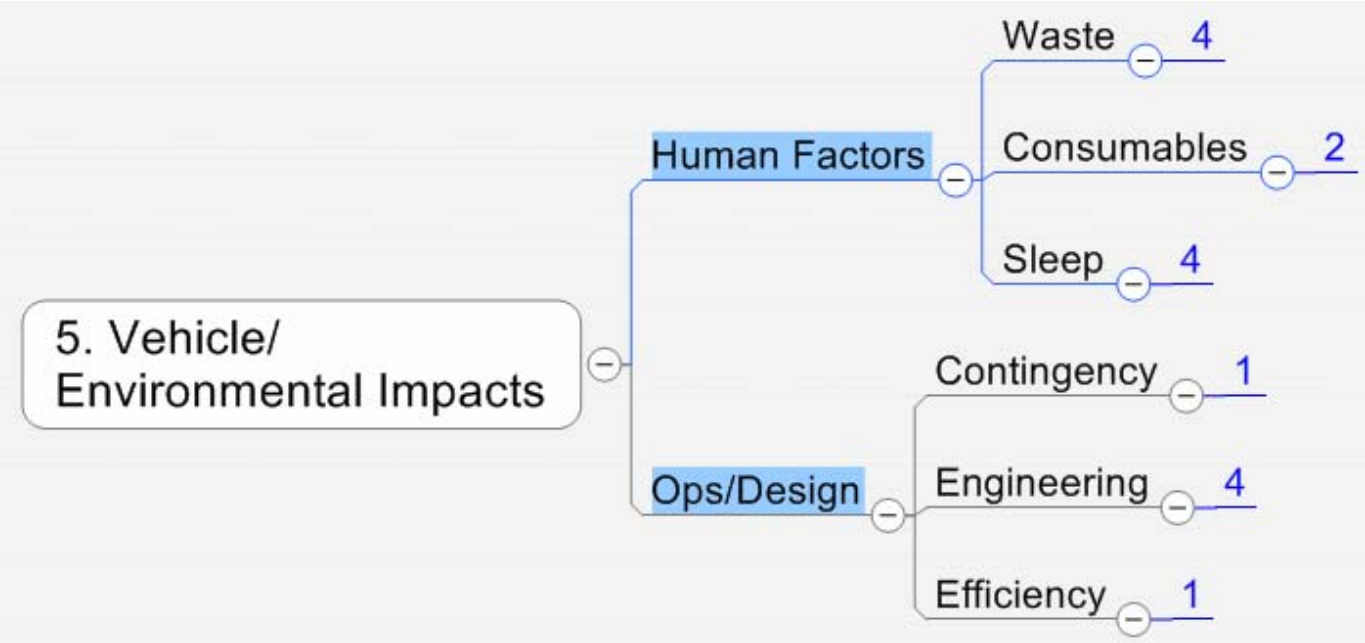
-Skylab, Shuttle, and ISS experience have improved the status of this category



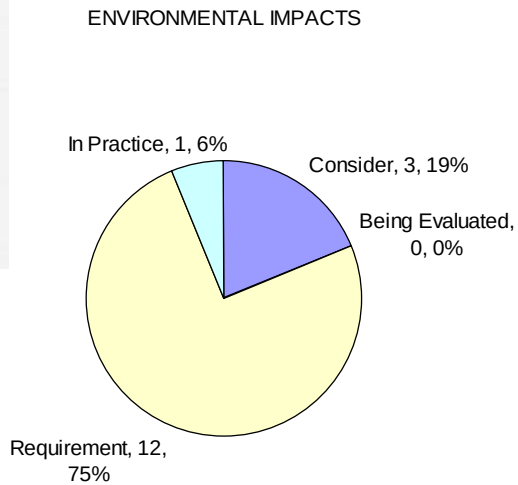
Apollo Medical Operations Recommendations

Discussion

***Goal: Develop or modify medical requirements for new vehicles**



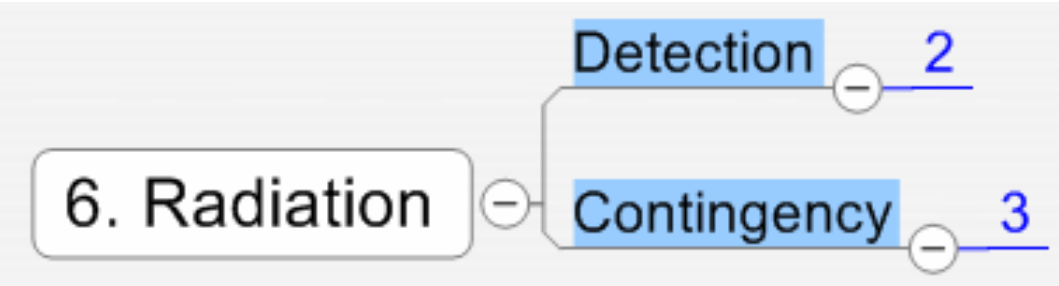
-This category yielded many recommendations that resulted in new requirements for the vehicle



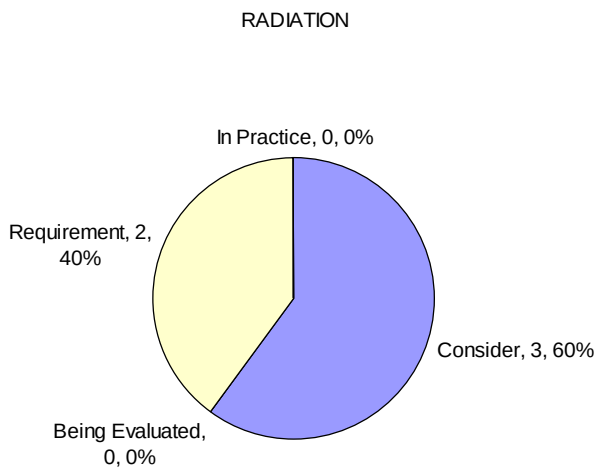
Apollo Medical Operations Recommendations

- **Discussion**

***Goal: Develop or modify medical requirements for new vehicles**



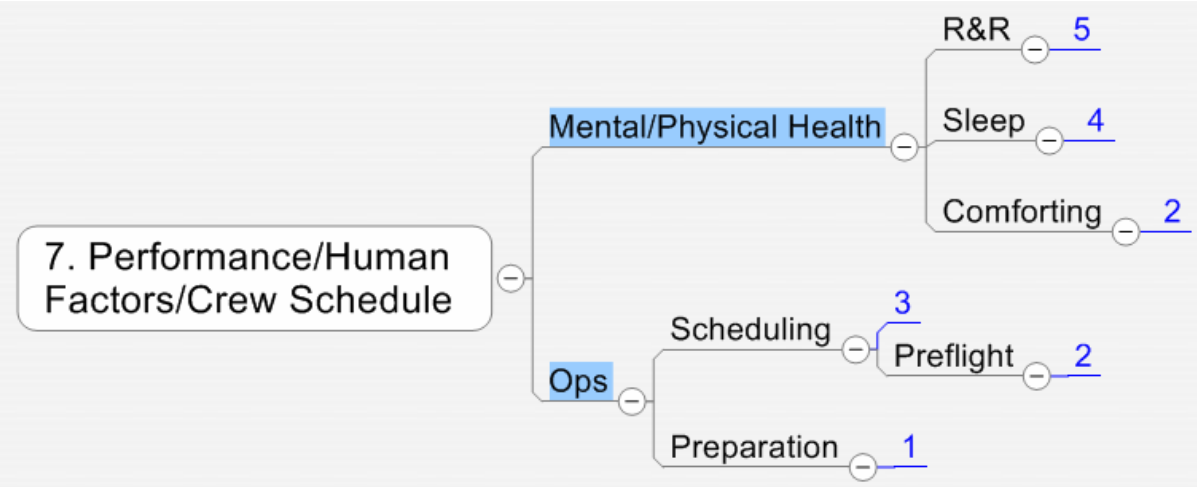
-Radiation on the surface of the moon has different characteristics than LEO radiation, hence this is a very relevant category



Apollo Medical Operations Recommendations

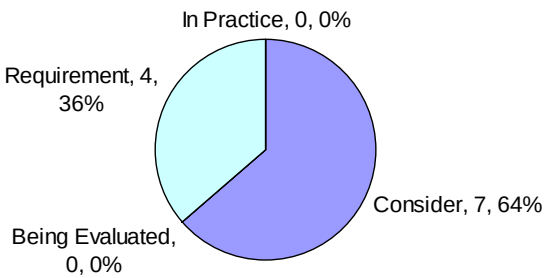
***Goal: Develop or modify medical requirements for new vehicles**

Discussion

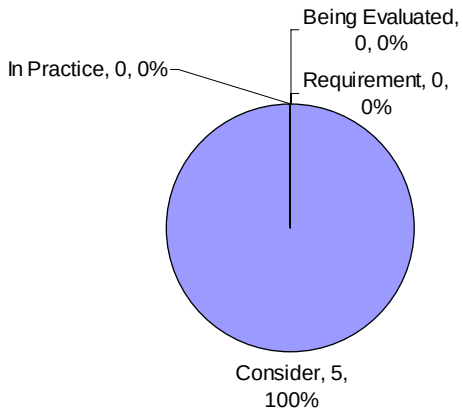


-Many issues have yet to be addressed in this category

PERFORMANCE/ HUMAN FACTORS



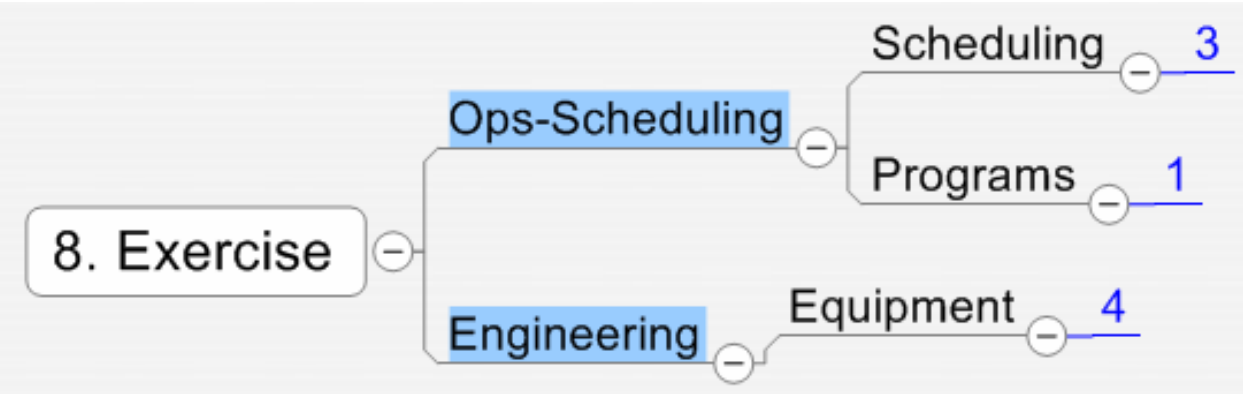
CREW SCHEDULE



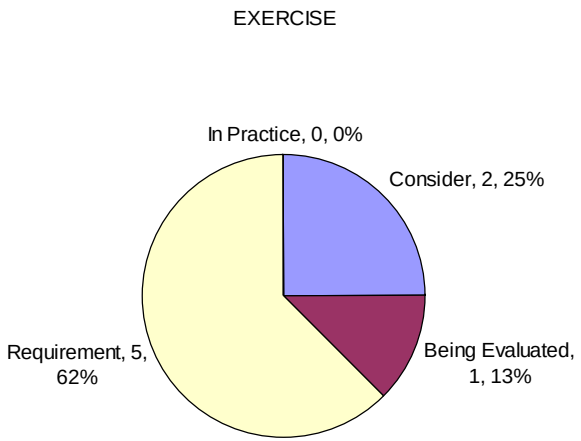
Apollo Medical Operations Recommendations

*Goal: Develop or modify medical requirements for new vehicles

Discussion



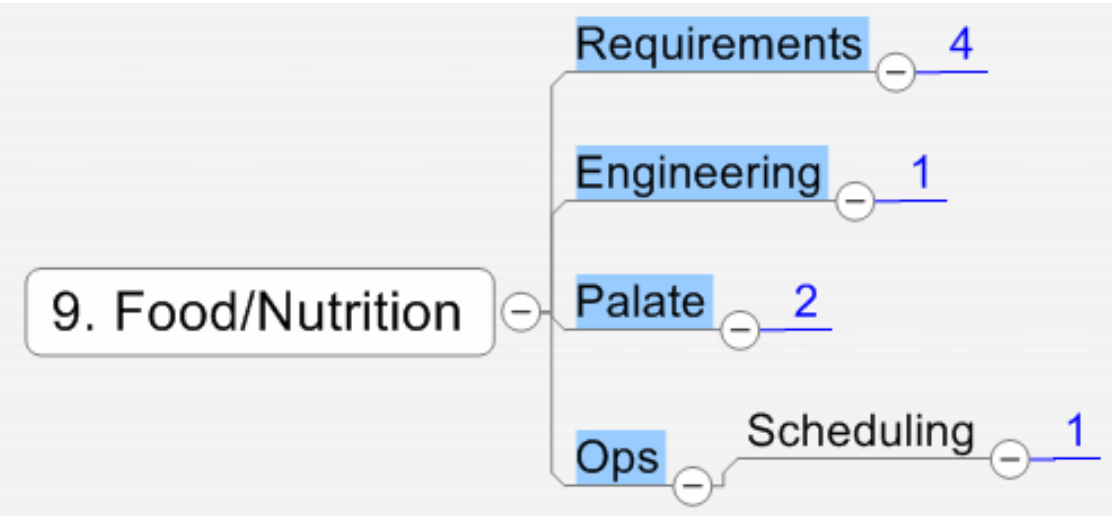
-Much progress has been made over the years since the Exer-Genie



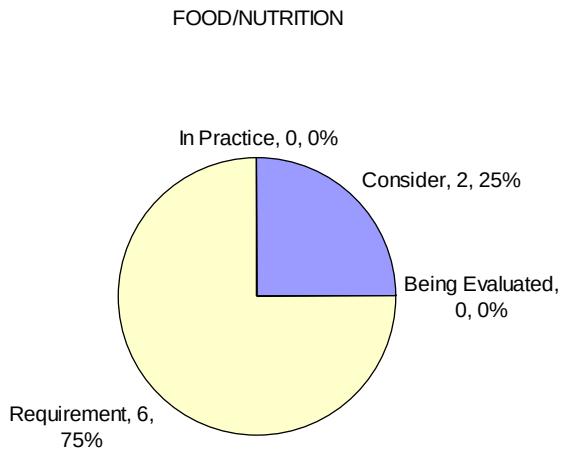
Apollo Medical Operations Recommendations

*Goal: Develop or modify medical requirements for new vehicles

Discussion



-Future work needs to be done regarding the environmental affects on the sense of taste

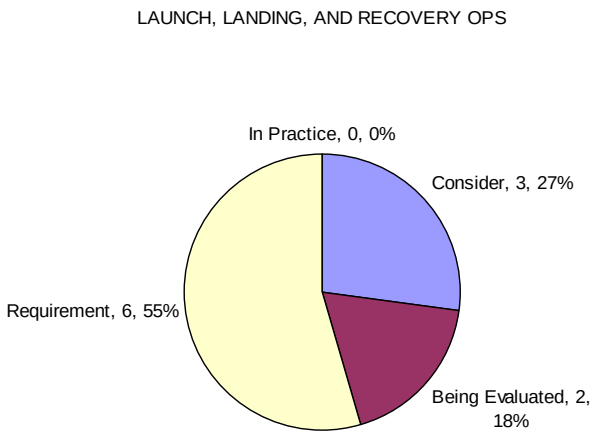


Apollo Medical Operations Recommendations

***Goal: Develop or modify medical requirements for new vehicles**

- **Discussion**

-Ground landings are part of the Constellation requirements, however, multiple relevant recommendations were still made

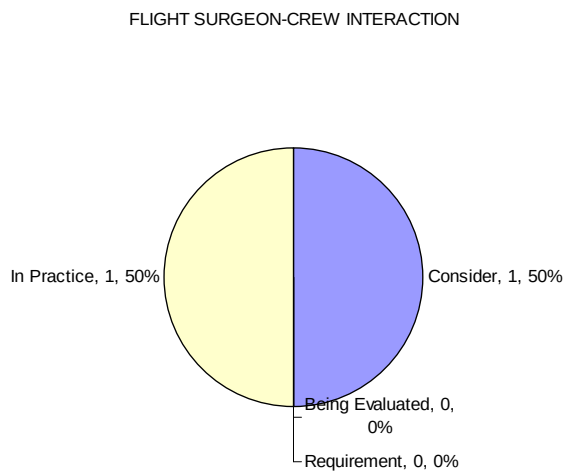


Apollo Medical Operations Recommendations

***Goal: Develop or modify medical requirements for new vehicles**

- **Discussion**

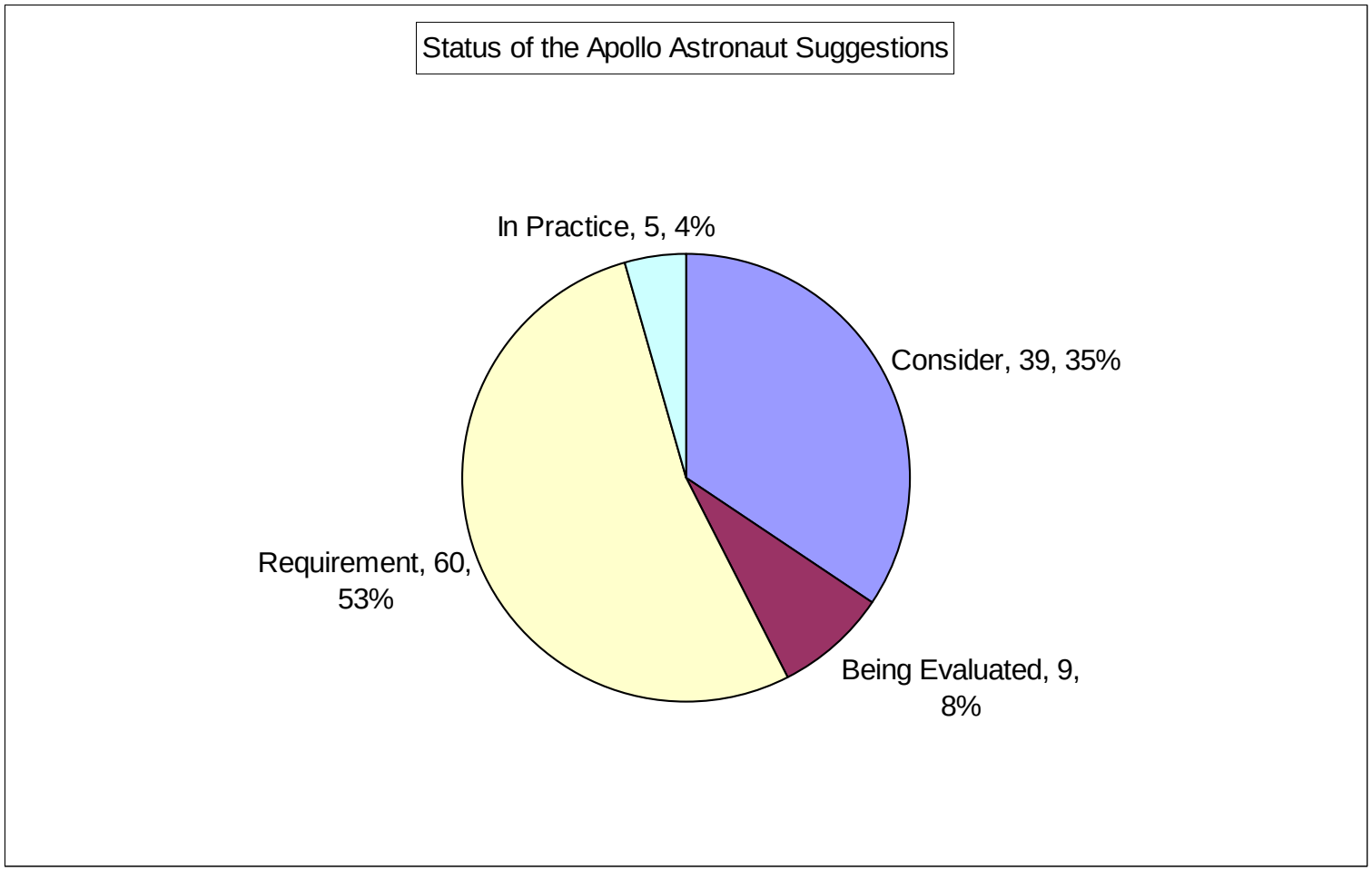
11. Flt Surgeon-crew interactions — 2



Apollo Medical Operations Recommendations

- **Discussion**

***Goal: Develop or modify medical requirements for new vehicles**



Apollo Medical Operations Recommendations

- **Conclusion**
  - The goals of the study have been achieved
  - 65 (57%) of the recommendations are in practice or have already been implemented
  - However, 48 recommendations (43%) are still “Being Evaluated or Considered”
    - These recommendations should be either formally rejected, modified, or incorporated
  - Future work
    - Meet with stakeholders to discuss recommendations vs. current designs and feasibility for implementation
      - CB, EVA, MOD, BHP, NSBRI, ARDIG, CxCB
    - Continue soliciting input from this group as we continue to evolve and refine requirements
  - The Apollo Medical Operations Project Recommendations have brought NASA one step closer to achieving the Vision for Space Exploration

Apollo Medical Operations Recommendations