

# From the Depths of Hell: Disaster, Crisis Management and Innovation in a Chilean Mine

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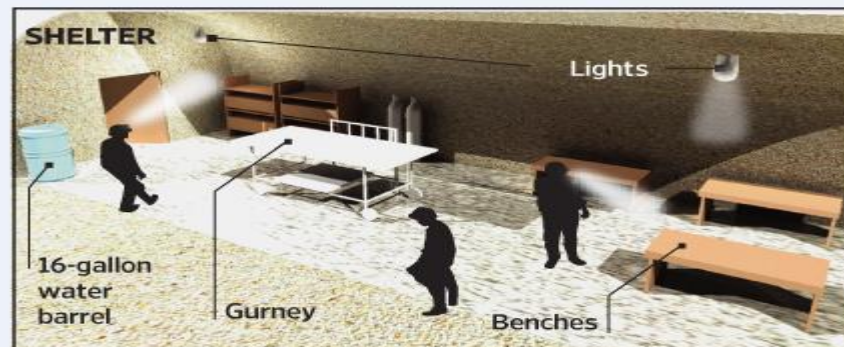
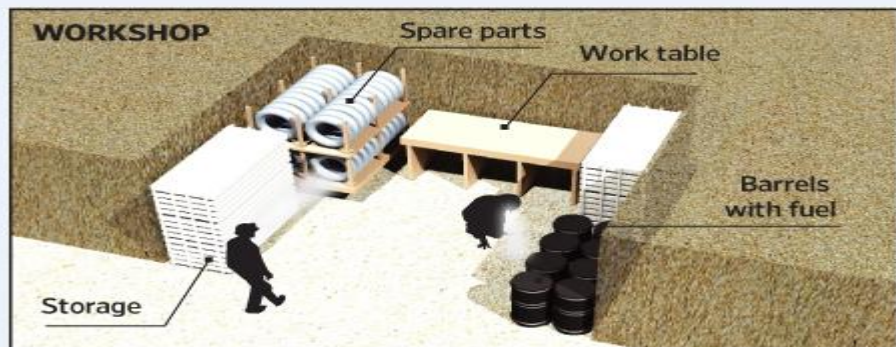
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GETTY IMAGES

# Overview

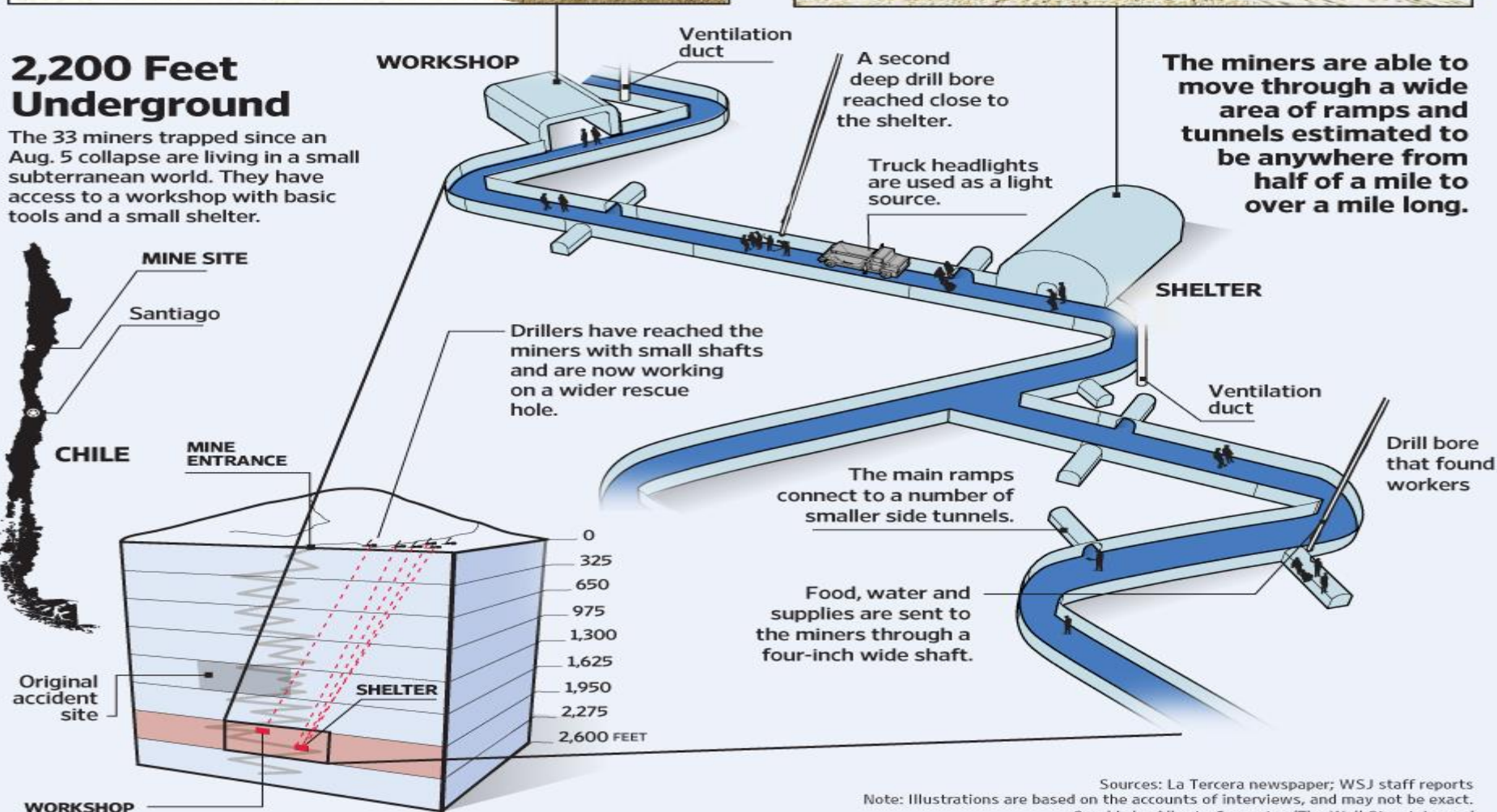
- You are the medical consultant....
- 33 men are trapped in a mine 2,400 feet below solid rock.
- Ages range from 19 to 62
- Known medical conditions in some of the miners are Type 2 diabetes, Silicosis, Hypertension, Coronary Disease, COPD.





## 2,200 Feet Underground

The 33 miners trapped since an Aug. 5 collapse are living in a small subterranean world. They have access to a workshop with basic tools and a small shelter.

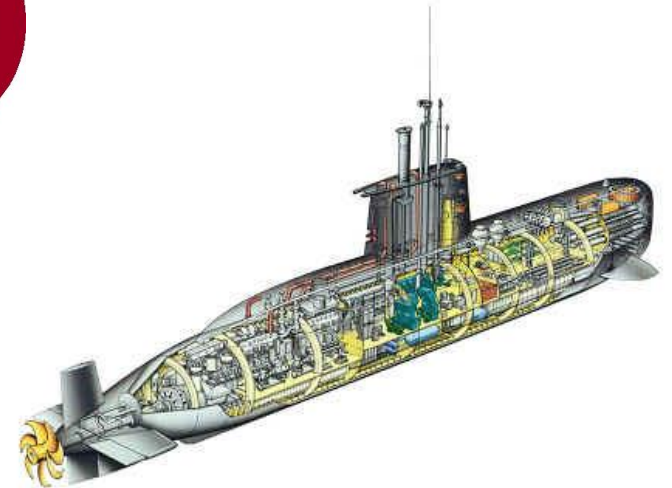


Sources: La Tercera newspaper; WSJ staff reports  
 Note: Illustrations are based on the accounts of interviews, and may not be exact.  
 Graphic by Alberto Cervantes/The Wall Street Journal

# *Benchmarking*



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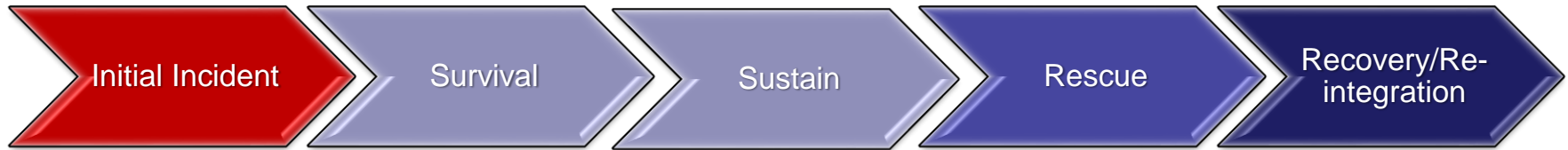
# *Leadership*



**FLAT, EMPOWERED Leadership chain**  
**Daily Briefings**  
**Crisis Management Team**

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# *Recommendations by Phase*

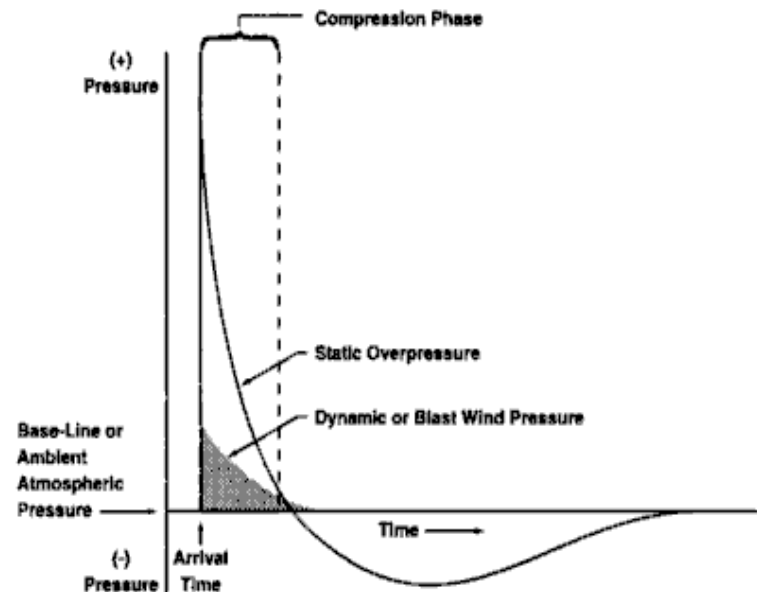


# *What are the initial concerns?*

- 600,000 tons of rock collapsed into the mine.
- What two things kill the majority of victims in mine accidents?
- Trauma
- Asphyxiation

# *Phase 1- Initial Incident*

- Trauma
- Blast pressure
  - Air Filled spaces
- Asphyxia
- Explosion/ignition
- Lethal gases
- Air Sampling performed
- Fresh air pumped in



*Figure 3-II. Variations of Overpressure and Dynamic Pressure with Time*

# *Masters of their Own Fate*

- 17 days before being found
- Dug wells
- Divided up the rations



# *Survival*

- The miners had one teaspoon, one quarter of a peach, and a teaspoon of milk every other day.
- You finally have a paloma that has reached them.
- You are about to send food down. What is your initial concern?
- Refeeding syndrome
- Liver glycogen has been used up.
- Down-regulation of insulin.
- Brain switches to ketones.

# *Refeeding Syndrome*

- What is the main electrolyte disturbance in refeeding syndrome?
- What other electrolytes are effected?
- What vitamin is of concern?
- Phosphorus (hypophosphatemia)
- Potassium and magnesium (hypokalemia and hyomagnesemia)
- Thiamine (B1)

# *Phase 2- Survival Re-feeding Syndrome*

- Impaired carbohydrate utilization
- Increased insulin release with decreased ability to use free fatty acids
- Increased CO<sub>2</sub> production
- Profound hypophosphatemia and hypokalemia
- Gradually increase calories
- Keep the RQ (respiratory quotient) as close to 0.85 as possible.
- Supplement **with phosphorus**, potassium, and magnesium.
- Water soluble vitamins

Harris- Benedict Equation on caloric need based on basal metabolic rate

$$\text{BMR} = 66.47 + 6.23 * \text{Wt (lb)} + 12.67 * \text{Ht (in)} - 6.76 * \text{age (yrs)}, \text{Men}$$

$$\text{BMR} = 655.1 + 4.34 * \text{Wt (lb)} + 4.69 * \text{Ht (in)} - 4.68 * \text{age (yrs)}, \text{Women}$$

Protein requirements in catabolic states

1.4gm/Kg/day

# *Phase 2- Survival*

## *Re-feeding Syndrome*

*Ensure plus and Supportan: thiamine, phosphate, potassium, and protein and “going low and slow” (10-20 kcal/kg initially) allowed the liver stores to regenerate without causing intracellular shifts. This prevented life-threatening complications from the re-feeding.*

- Hypophosphatemia
- Hypokalemia
- Hypomagnesium
- Cardiac dysrhythmias
- Cardiac failure
- Cardiac arrest

Product	Energy (kcal/8 oz)	Protein (g/8 oz)	Potassium (mg/8 oz)	Phosphorus (mg/8 oz)	Magnesium (mg/8 oz)	Thiamin (mg/8 oz)
Ensure	249	9	370	300	100	0.374
Ensure Plus	352	13	440	200	100	0.375
Ensure Plus High Nitrogen	358	14.8	430	250	100	0.750
Traumacal, Rtu	355	19.5	330	178	47.5	0.452
Supportan Drink	356	23.7	303	284	61.6	0.711
<b>1000 ml of product provides:</b>						
Ensure	1049	38	1559	1264	421	1.6
Ensure Plus	1483	55	1854	843	421	1.6
Ensure Plus High Nitrogen	1509	62	1812	1054	421	3.2
Traumacal, Rtu	1496	82	1391	750	200	1.9
Supportan Drink	1500	100	1277	1197	260	3.0

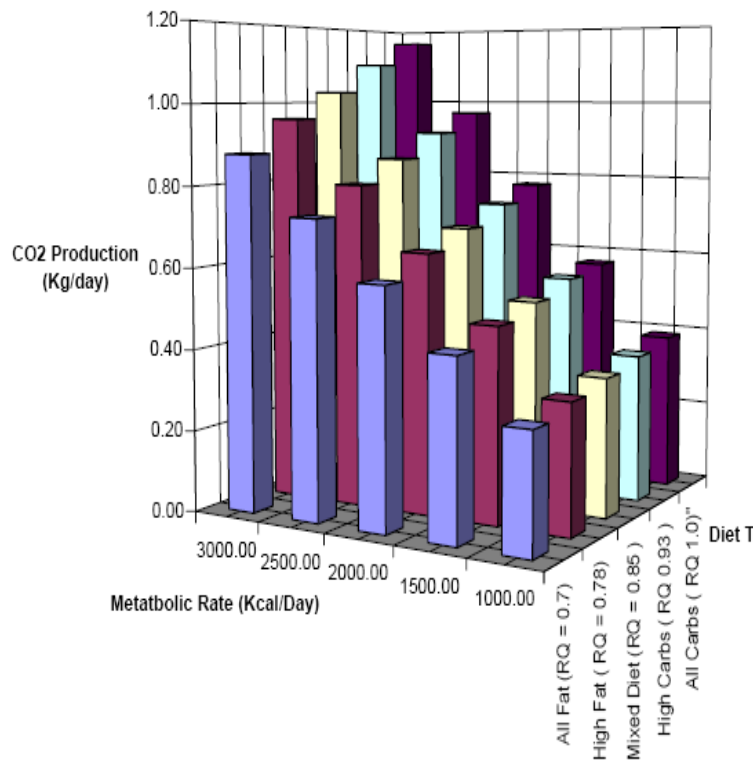
Courtesy Scott Smith, PhD and team

*Why would the space program be experts in this area?*

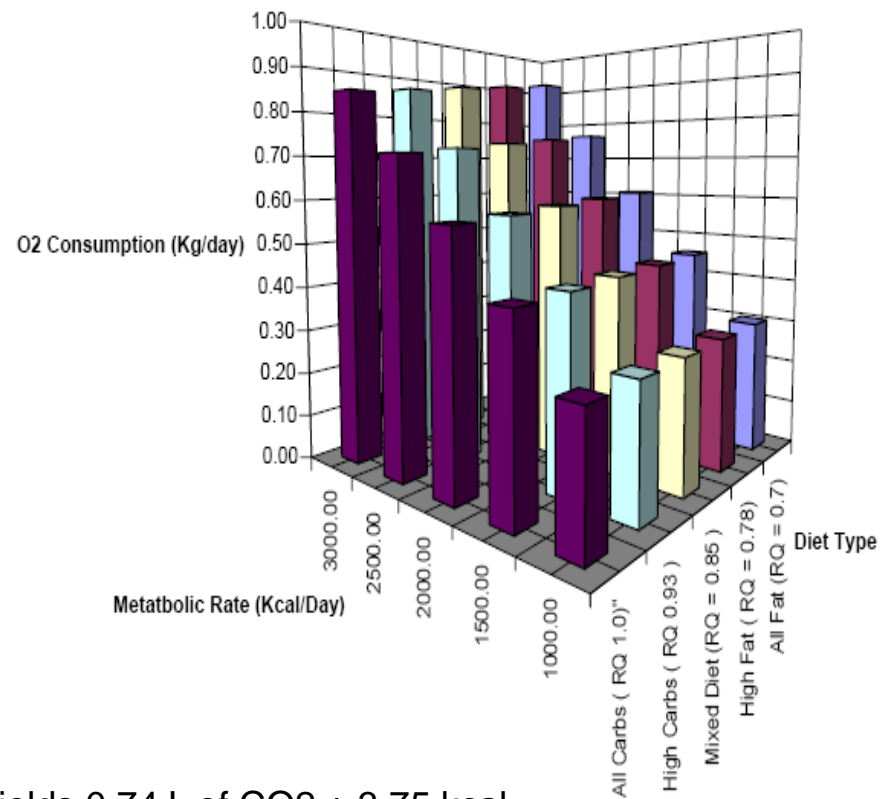


Courtesy of Dr. Doug Hamilton and Team

CO2 Production vs Met Rate and RQ  
(Calculated 75 Kg Crewmember)



Oxygen Consumption vs Met Rate and RQ  
(Calculated 75 Kg Crewmember)



1 gram of glucose + 0.74L of Oxygen yields 0.74 L of CO2 + 3.75 kcal

# *Who else gets refeeding syndrome?*

- Neurosurgical patients
- Greater than 5-7 days of malnourishment
- TPN without adequate phosphate.



# *Starvation and Dehydration*

- The mine is 90 degrees and 90 percent humidity
- The miners were sleeping on hot rocks, vehicles, and just about anywhere
- What could be the consequences?
- What test would you use?
- Urine dipstick test was one of first sent down.
- 50% of the miners were positive for myoglobin.
- Rhabdomyolysis and acute tubular necrosis
- Those miners targeted for consumption of 5 liters of water.

# *Innovation*



# *Competition*



4/13/2015

## A group of men are gathered in a meeting room. In the center, a man stands wearing a white hard hat with the number '320' on it. He is wearing a dark jacket and glasses. To his left, another man in a dark jacket and glasses is looking towards him. In the foreground, a man in a blue jacket is looking towards the group. On the right, a man in a black cap and blue jacket is seen from the back. A whiteboard is visible in the background with some diagrams and text. A poster with a green snake-like diagram is on the wall to the right.



# *Phase 3- Sustain*

## *Contingency Re-supply and Stocking*

- *Contingency Supply*
  - *Send medical, water, and food supplies sufficient for enough time to re-establish supply chains, in the event of a contingency cave-in or the miners are again cut off from the surface.*



# *Treatment of Chronic Conditions*

- The patient with Type 2 diabetes was on metformin prior to the accident.
- Should you begin sending that down?
- What is the physiologic concern with metformin under these circumstances?
- Consider him diet controlled until his calorie count is over 1800 calories and he is no longer spilling ketones.
- Lactic acidosis is the concern.

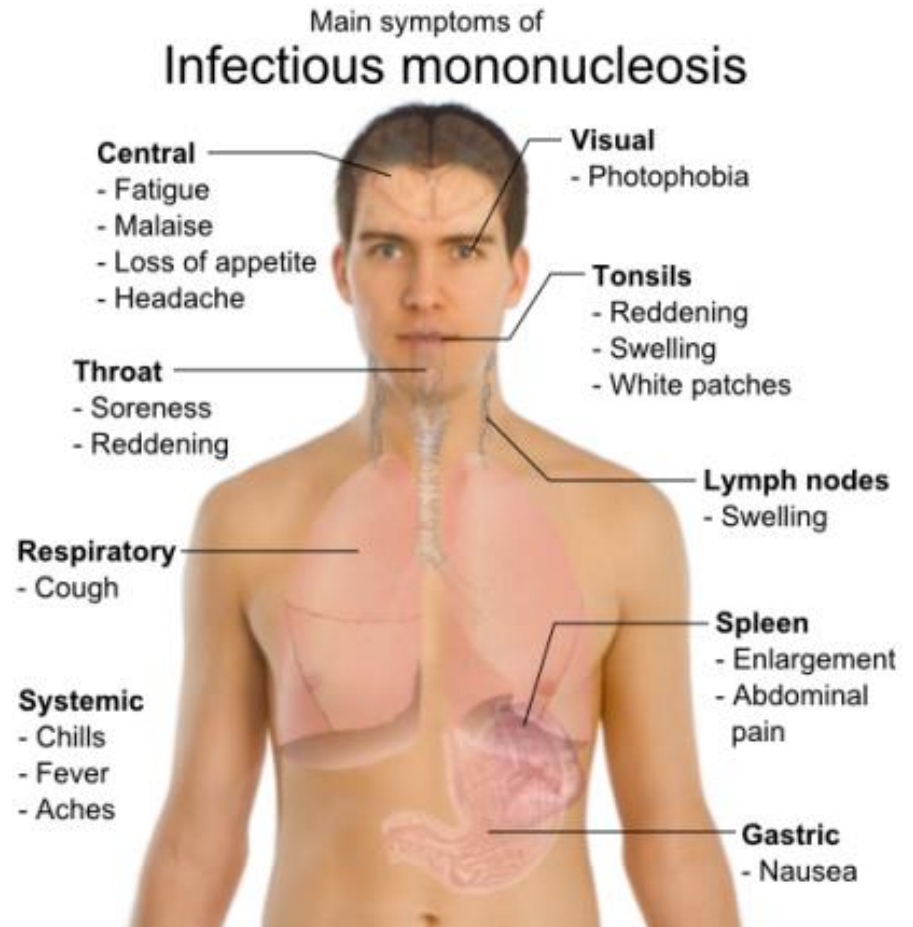
# *Skin*

- Linoleic Acid deficiency-
- Eczema-like rash with neutropenia and thrombocytopenia.
- Unresponsive to steroids or anti-fungals,
- This is easily treated with linoleic acid capsules and supplementation or safflower oil 15cc/day.



# *Latent Virus Activation*

- Herpes Virus family
  - EBV



# *Immunization*

- Vaccination for tetanus (in the form of diphtheria/tetanus toxoid), pneumococcal, and meningococcal strains
- Influenza
- Debate



# ***Phase 3- Sustain***

## ***Common Medical Maladies Seen in Long Duration***

- Vitamin D deficiency
- Epstein Barr/Herpes Latent Virus Reactivation
- Constipation
- Respiratory Infections
- Skin Infections/Irritations
- Dental caries and peridontal disease



# *Alcohol and Tobacco*

- Medical versus psych recommendations
- Concerns for nutritional status and unknown Thiamine status
- Assumption of intake upon rescue
- Lung disease versus second hand smoke
- Potential for revolt due to need for control
- Choosing the battles

# *Psychological Support*

- Circadian and sleep-wake cycles
  - Regular cycles of light/dark, exercise and eating in community area (eating, social, etc)
    - Regular time each day for each miner for these things.  
Preserve an individual's 24h cycle.
  - Since miners work in 3 shifts, organized 3 distinct lighting areas in mine:
    - Sleeping area
    - Community social area
    - Mining work areas

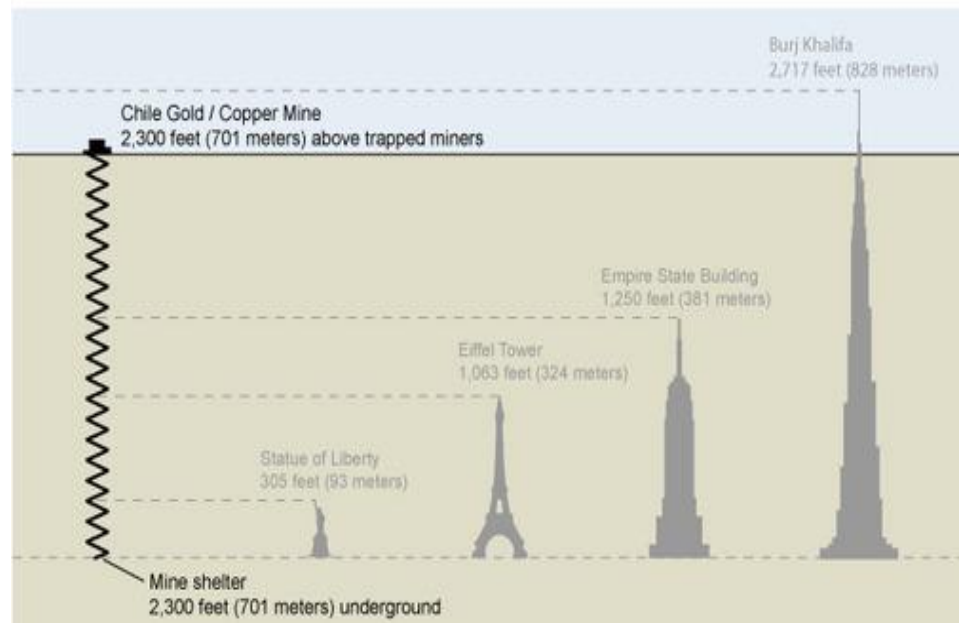
# *Phase 4- Rescue*

## *Decompression Risk*

- Since the miners are saturated at 3.3 FSW and the most conservative limit for safe direct ascent is 17 FSW, it is unlikely that DCS is a problem

### Chile mine deeper than height of Empire State building

August 26, 2010 -- Updated 2357 GMT (0757 HKT)



Tan et al. 2008, Courtesy of Johnny Conkin

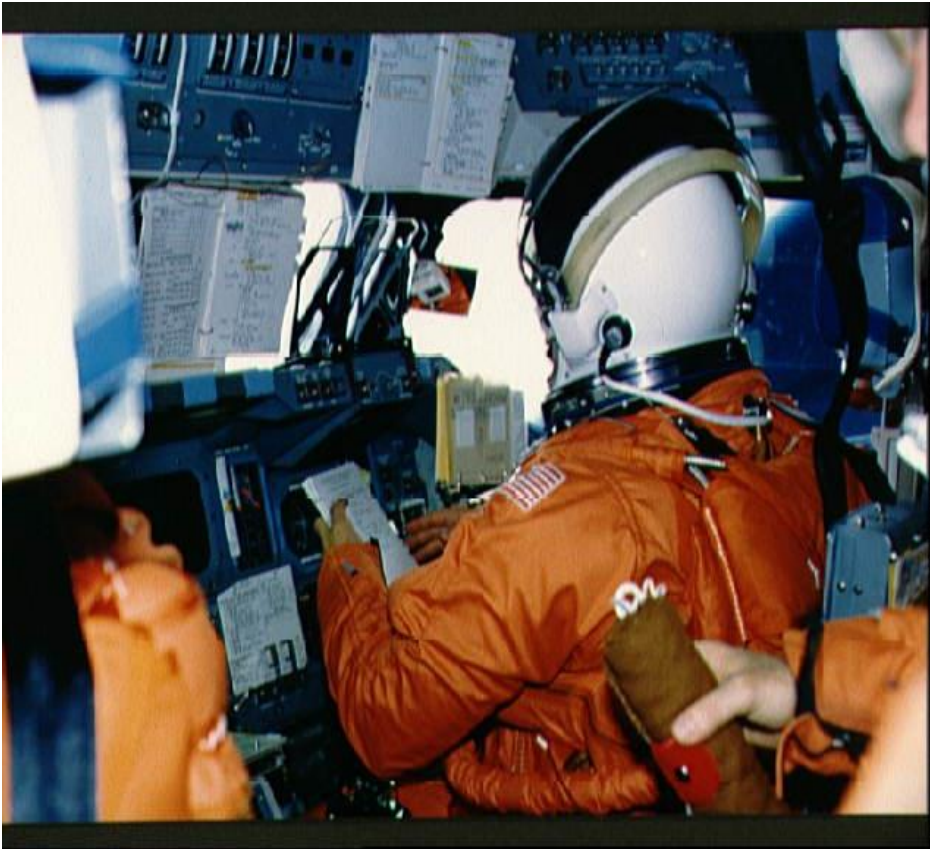


We know a thing or two about  
Boyle's Law

# *The Rescue*

- The miners are well nourished, and you have been successful in treating their chronic medical conditions.
- It is time to contemplate the rescue.
- They will have to be upright for the duration of the rescue. What physiologic complications could occur?
- Orthostatic hypotension
- Hypoxia
- Hypercarbia
- Anxiety reaction

# *How would you combat the physiologic consequences?*



- Compression garment
- Salt tablets
- Fluid load
- Sunglasses for UV protection

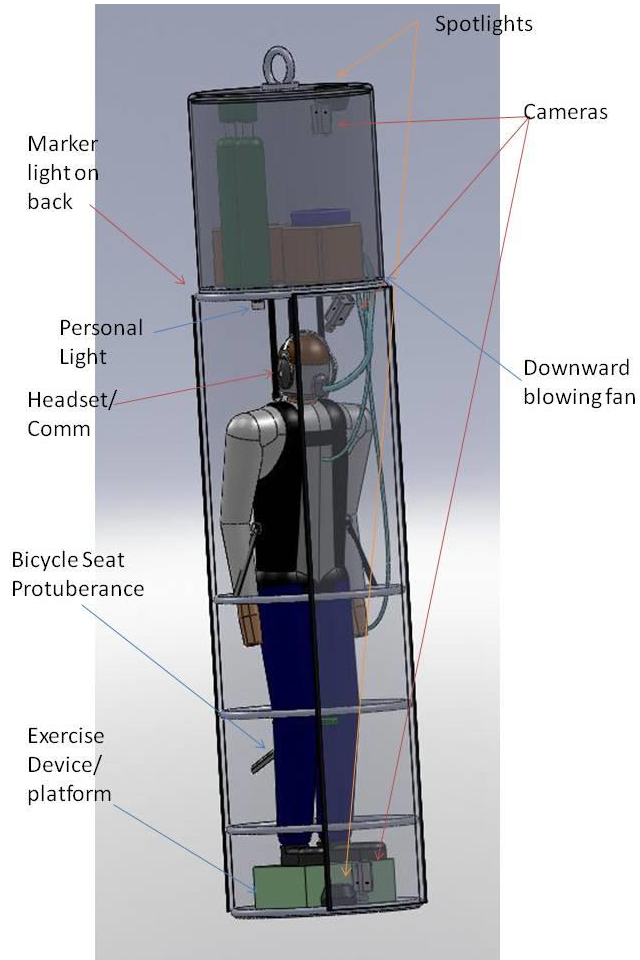
# *Fluid Loading Protocol*

Miners Mass	Number of 500mg salt tablets at 12 hours prior to ascent	Amount of electrolyte solution at 12 hours prior	Number of 500mg salt tablets at 4 hours prior to ascent	Amount of electrolyte solution at 4 hours prior to ascent
75 kilos	4	38 ounces (1121 ml)	4	38 ounces (1121 ml)
80 kilos	5	40 ounces (1180 ml)	5	40 ounces (1180 ml)
85 kilos	5	40 ounces (1180 ml)	5	40 ounces (1180 ml)
90 kilos	6	44 ounces (1298 ml)	6	44 ounces (1298 ml)
100 kilos	6	44 ounces (1298 ml)	6	44 ounces (1298 ml)

# ***The “NASA Diet”***

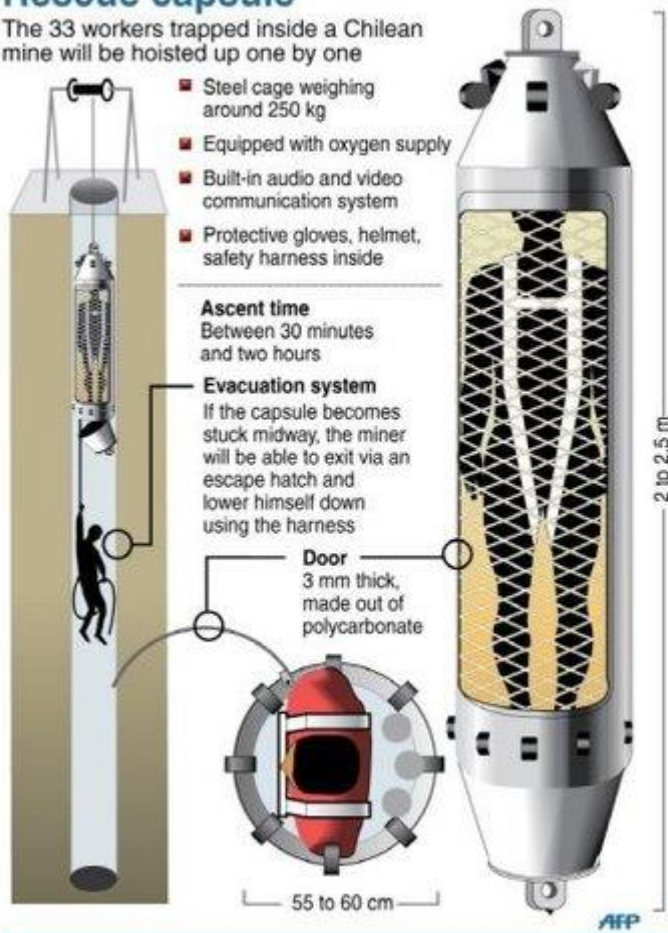
Product	Serving	Calories	Carbohydrates (g)	Sodium (mg)	Potassium (mg)
Gatorade G Series 01 Prime	118ml	100	25	110	35
Gatorade G Series 02 Perform	240ml	50	14	110	30
Gatorade G Series 03 Recover	240ml	60	7	120	45
Gatorade G Series 01 Pro Prime	355ml	330	82	220	60
Gatorade G Series 02 Perform	240ml	50	14	200	90
Gatorade G Series 03 Recover	240ml	200	33	190	270

# *What requirements would you write for the escape pod?*



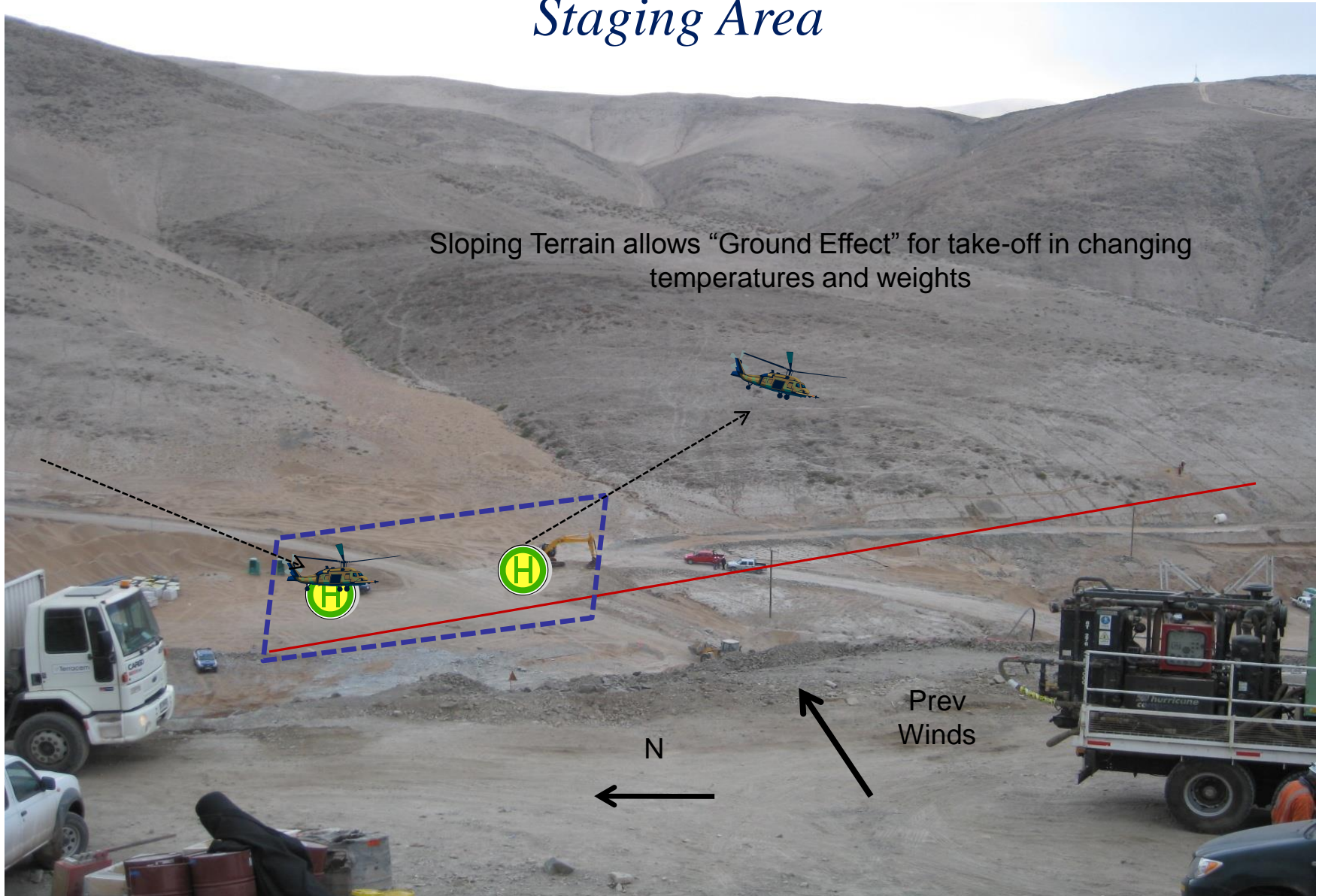
## Rescue capsule

The 33 workers trapped inside a Chilean mine will be hoisted up one by one



# *Suggested features and location of Helipad Staging Area*

Sloping Terrain allows “Ground Effect” for take-off in changing temperatures and weights



# *Six Sigma*

Why did each miner get placed on a cot and taken to the triage tent when they looked so good coming out?



# *Phase 5- Convalescence, Recovery, Reintegration*

- *The miners are being followed for a period of months for respiratory, skin, and viral syndromes.*
- *Post Traumatic Stress*
- *Depression*
- *Why?*



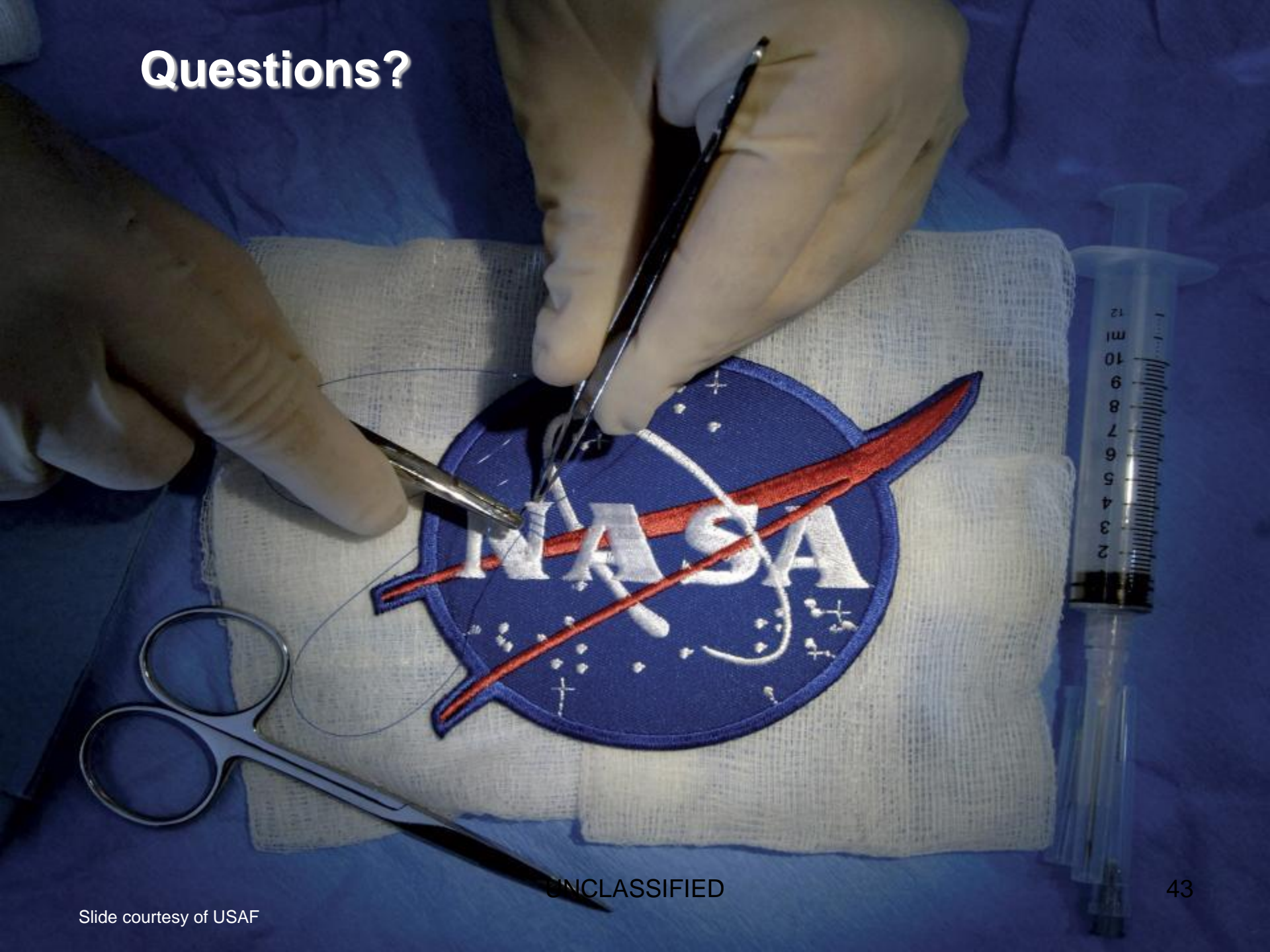
A wide-angle, fisheye photograph taken from inside an astronaut's helmet. The astronaut's gloved hands are visible, holding a camera. The Earth's horizon and clouds are visible through the helmet's visor. The helmet's interior and various equipment are also visible.

# *Conclusions*

- Innovation, leadership, and mindset of the Chilean government, medical and mining personnel were paramount to the success.
- Lessons from Spaceflight were directly applicable to the ground.
- Spaceflight has a tangible value that is difficult to quantify.



# Questions?



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Slide courtesy of USAF