Terrestrial telerobotic mining technology an enabler for extraterrestrial habitation, mining and construction?

Dr. Greg Baiden
Professor Mining Engineering – Robotics and

Canadian Mining Automation:

An Enabling Technology for Space

- The Mining Automation Program (MAP) lead by INCO developed and demonstrated underground mining automation and robotics capabilities (1992-1996) including the automation of over 20 mining systems from drills to LHDs
- Latencies (teleoperation delays) of 1.5 seconds were typical, and did not significantly reduce operator capabilities
- Greater than $300M was allocated to this IRAD investment
- Publication of this work was inhibited to protect corporate advantage

- Long distance teleoperation with embedded automation
- Technically "Autonomation"
  - One person runs multiple machines with "human touch"

Telemining

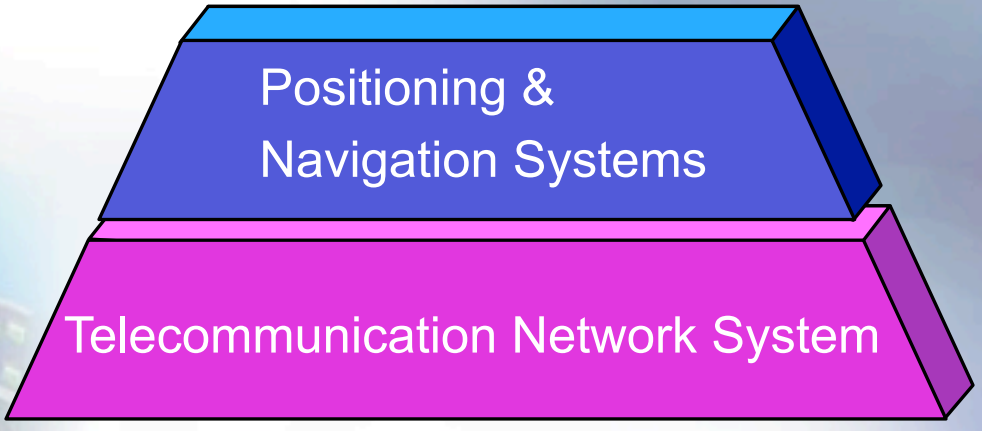
- Long distance teleoperation with embedded automation
- Technically "Autonomation"
  - One person runs multiple machines with "human touch"

Key Technologies for Telemining

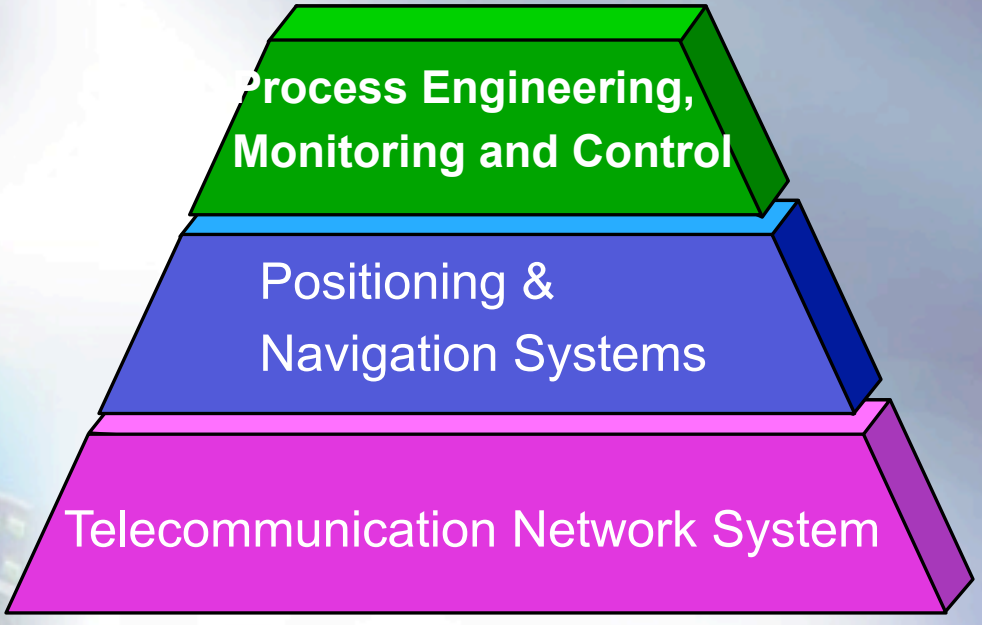
Key Technologies for Telemining

Telecommunication Network System

Key Technologies for Telemining



Key Technologies for Telemining



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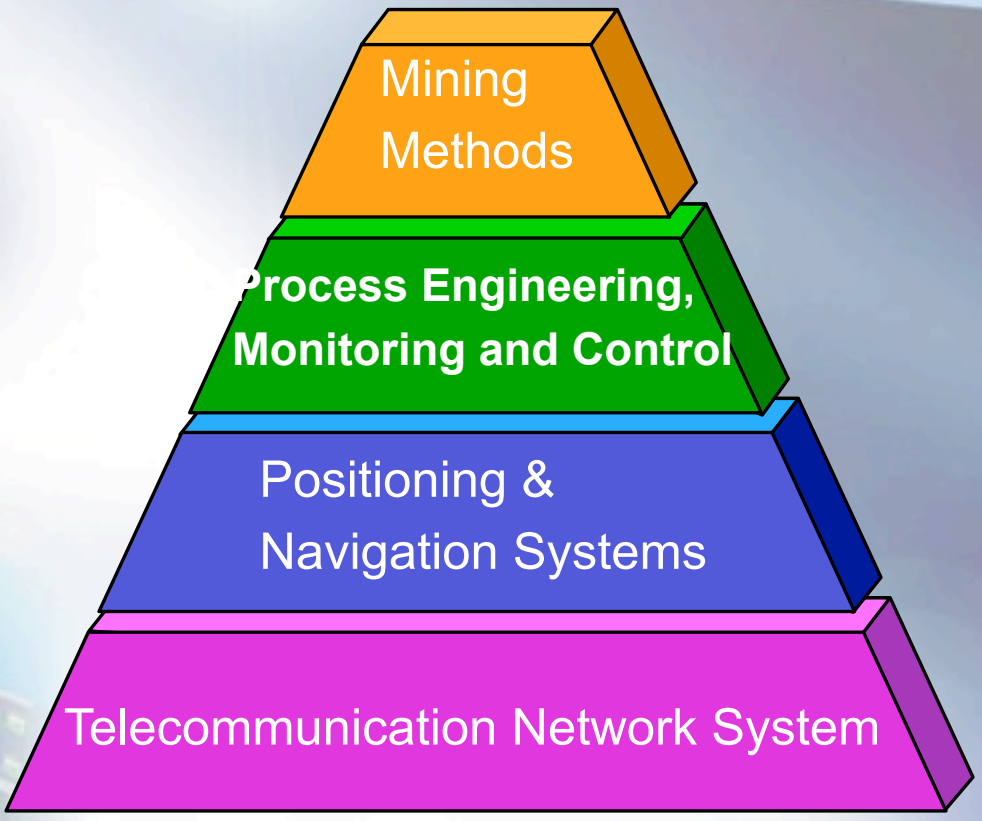

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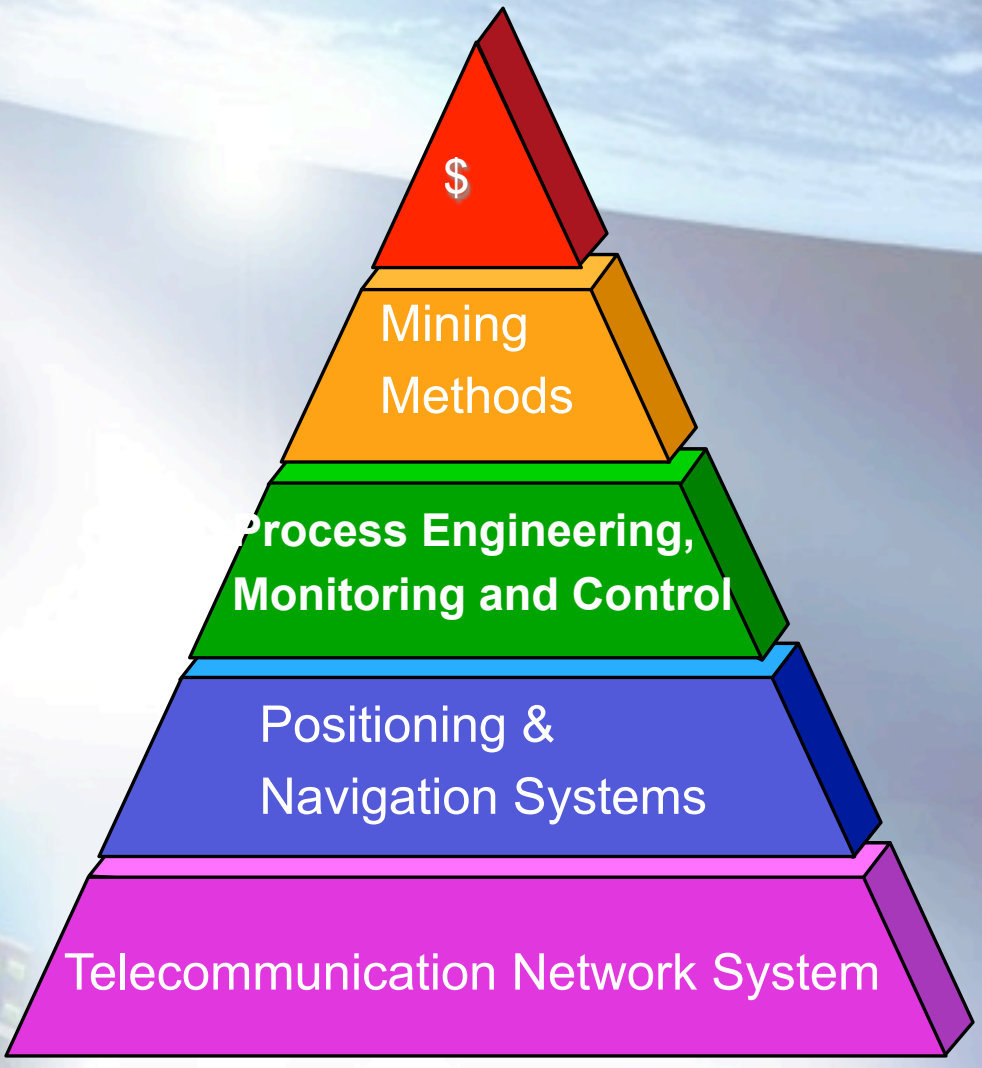

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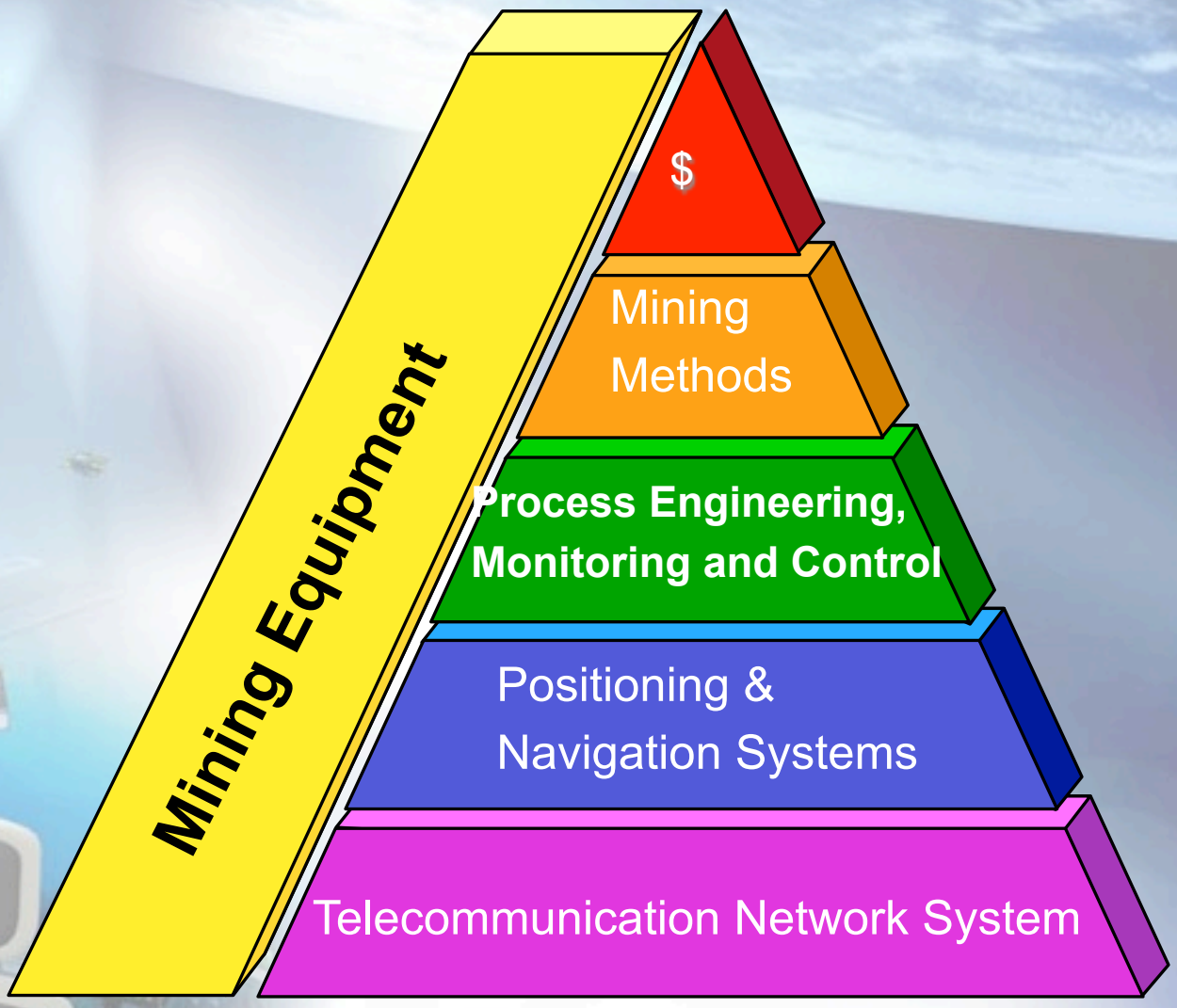

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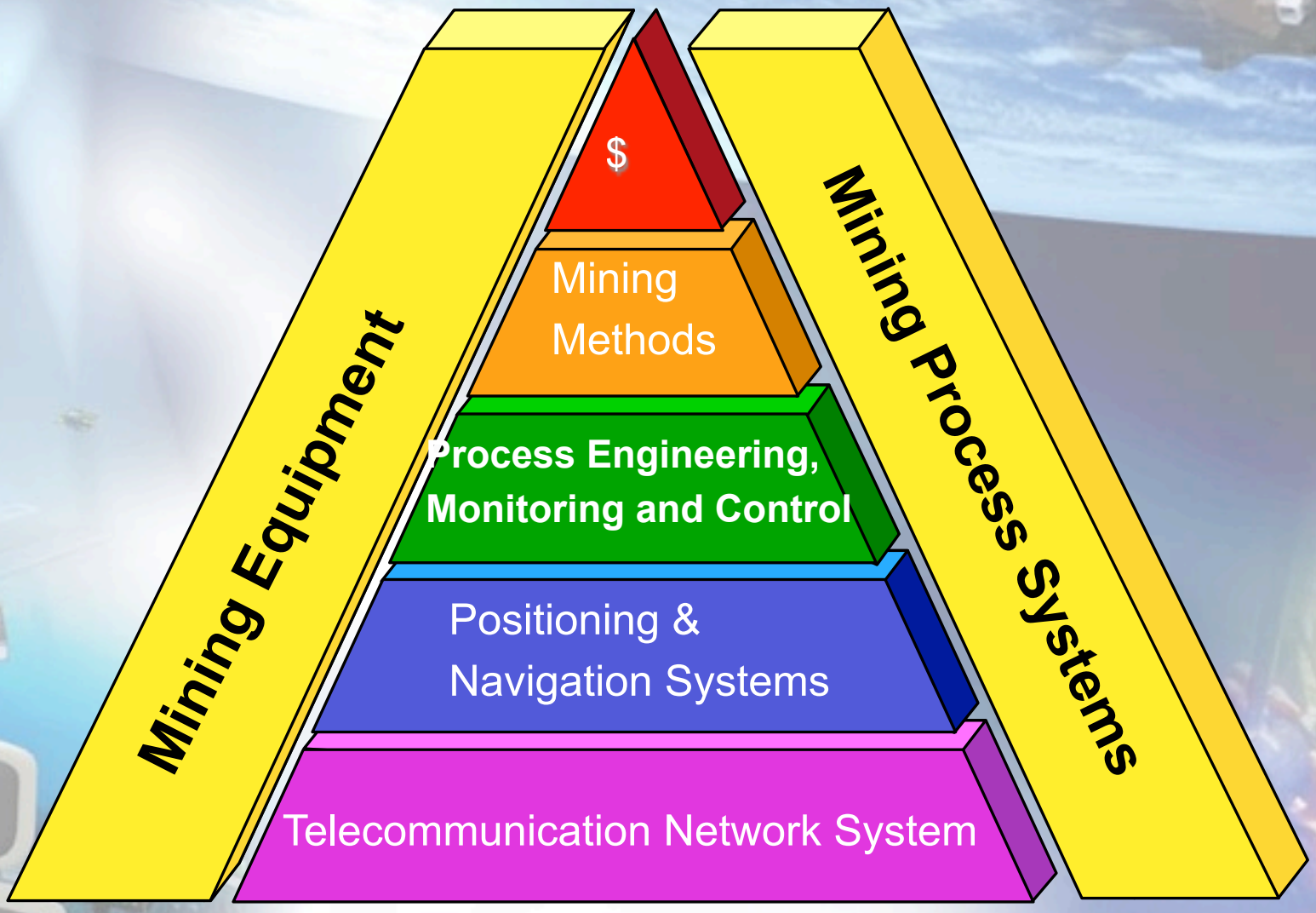

- High bandwidth radio network capable of
  - Hardwired communication
  - Wireless communication
- Advantage of Underground
  - Entire radio frequency spectrum is available for teleoperation

Underground Broadband Radio Network

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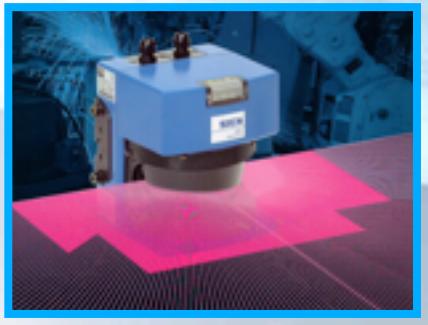
Non-GPS Mapping and Surveying

Non-GPS Mapping and Surveying

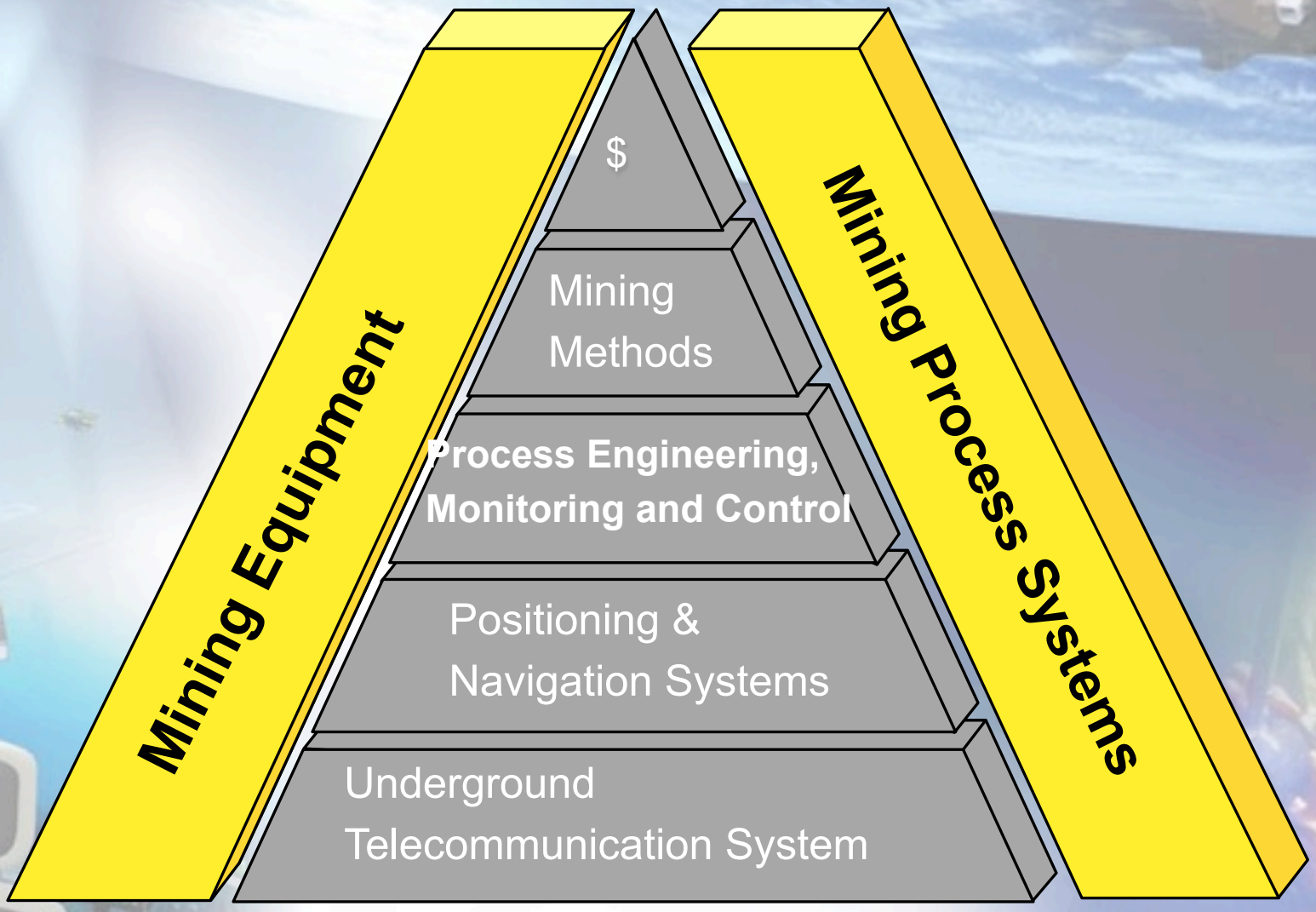
HORTA - IMU



PLS-Proximity
Laser Scanner

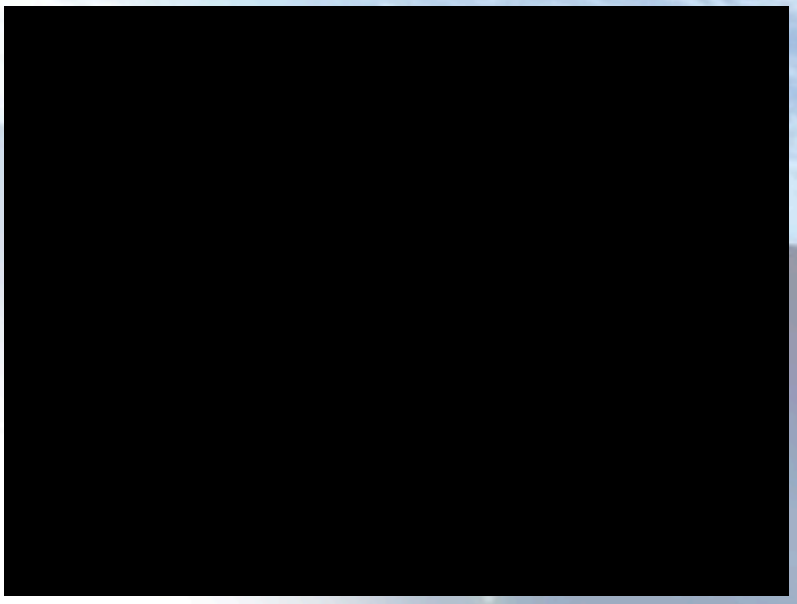
Key Technologies for Telemining

Key Technologies for Telemining

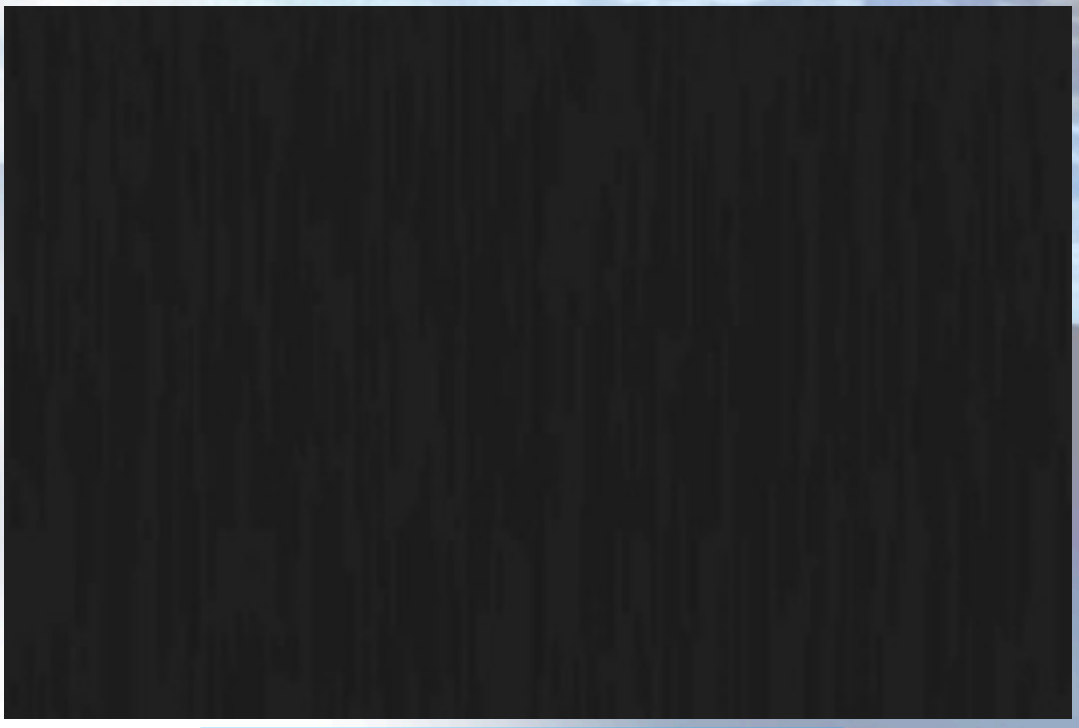


Tele- Tunneling

Tele-Production Drilling



Tele- Production Materials Handling



Mine Operations Center

Creighto

Test Mine

Mine Operation Centers

International Mining Business

Mine Operation Centers

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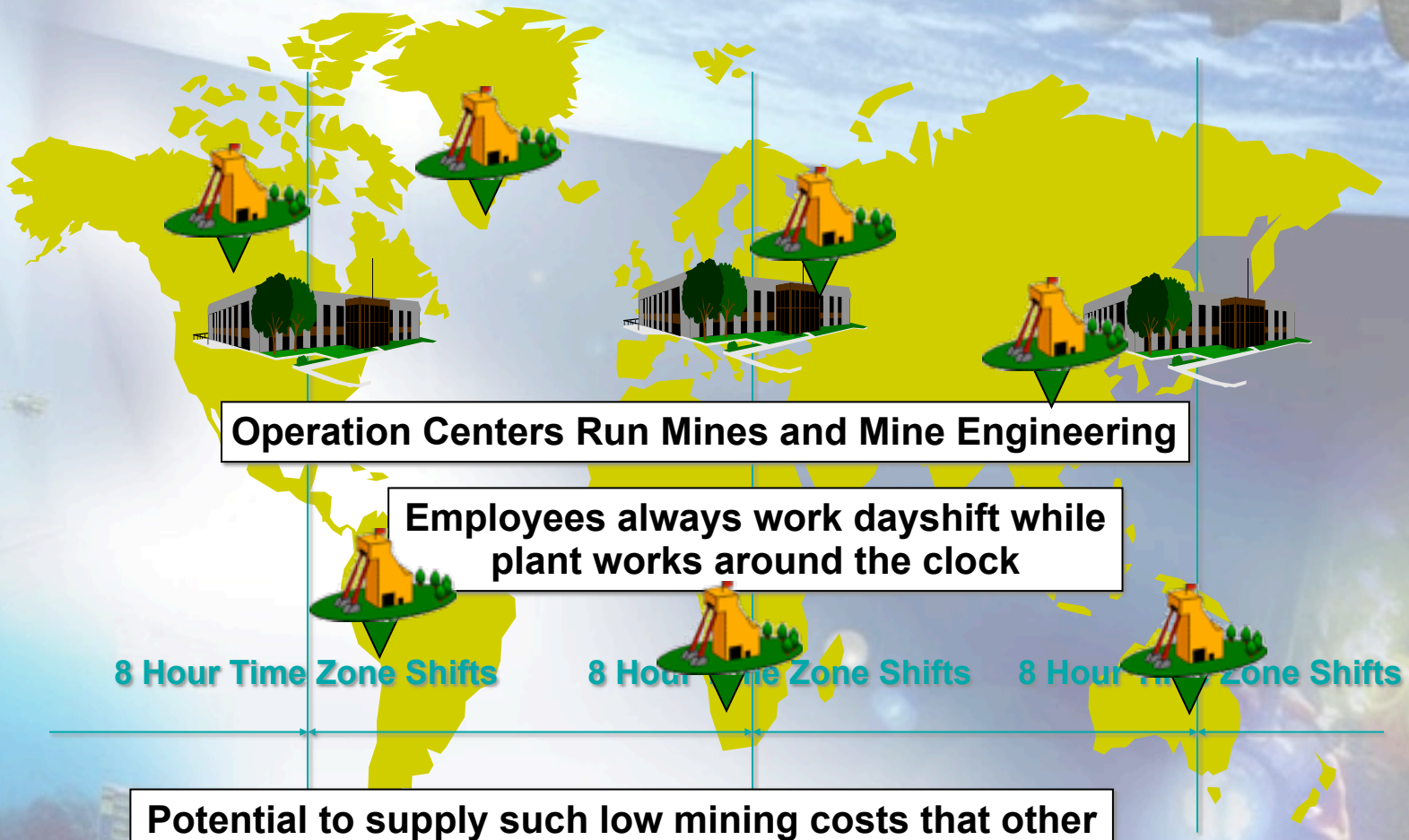

Operation Centers Run Mines and Mine Engineering

Employees always work dayshift while plant works around the clock

Potential to supply such low mining costs that other companies mines could be operated for them

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UNDERWATER MINING

NAUTILUS
Minerals Inc.

2010

SPACE MINING

Lunar Underground Mining and Construction: A Terrestrial Vision enabling Space Exploration and Commerce

SMART STEPS for Canada

Dr. Greg Baiden

Chief Technology Officer, Penguin Automated Systems Inc., Professor – Mining Automation and Robotics, Laurentian University, Sudbury, Ontario, Canada

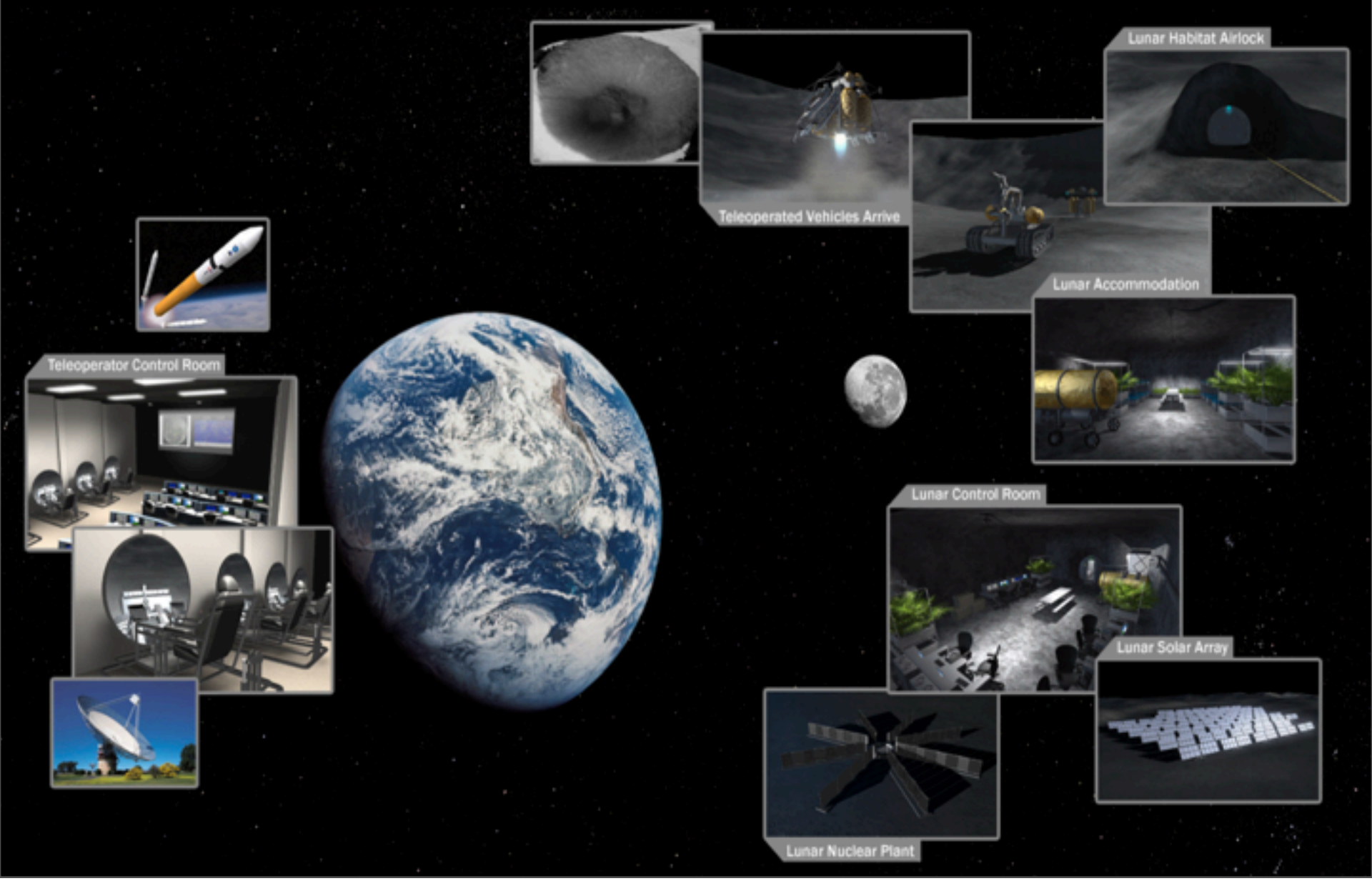
Louis Grenier

Senior Manager, Space Science and Exploration Planning and Performance, Canadian Space Agency, Montreal, Quebec, Canada

Brad Blair

Vice President of Space Technology, Penguin Systems U.S., Inc., Idaho Springs, Colorado, USA

SMARTSTEPS Lunar Architecture



MAP Technologies

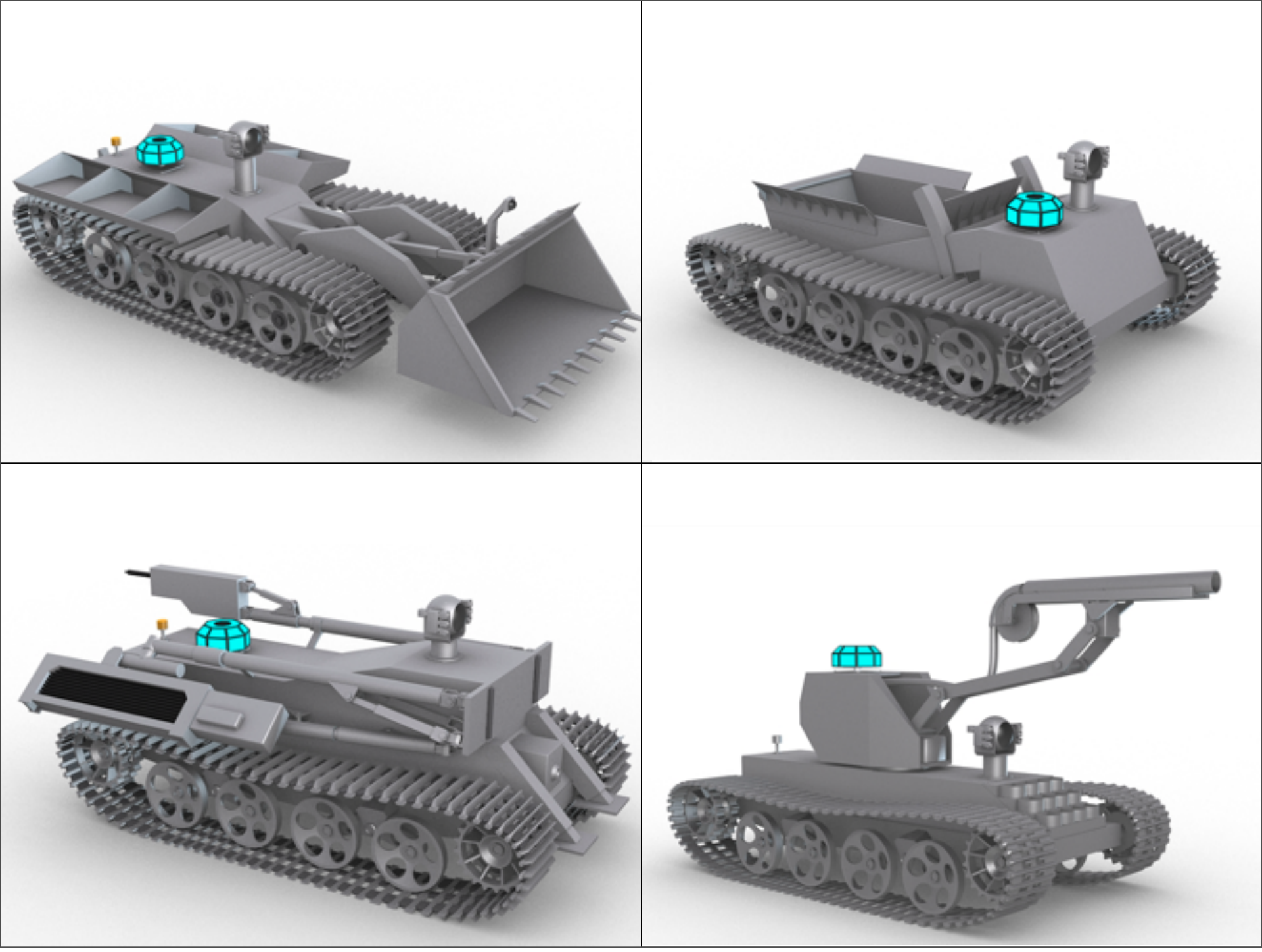
- The basic fleet to automate mining has been tested and is technically feasible
- These concepts are now being applied at mines around the world
- The techniques form the basis for considering teleoperated lunar outpost construction and lunar mining of water prior to full time astronaut habitation

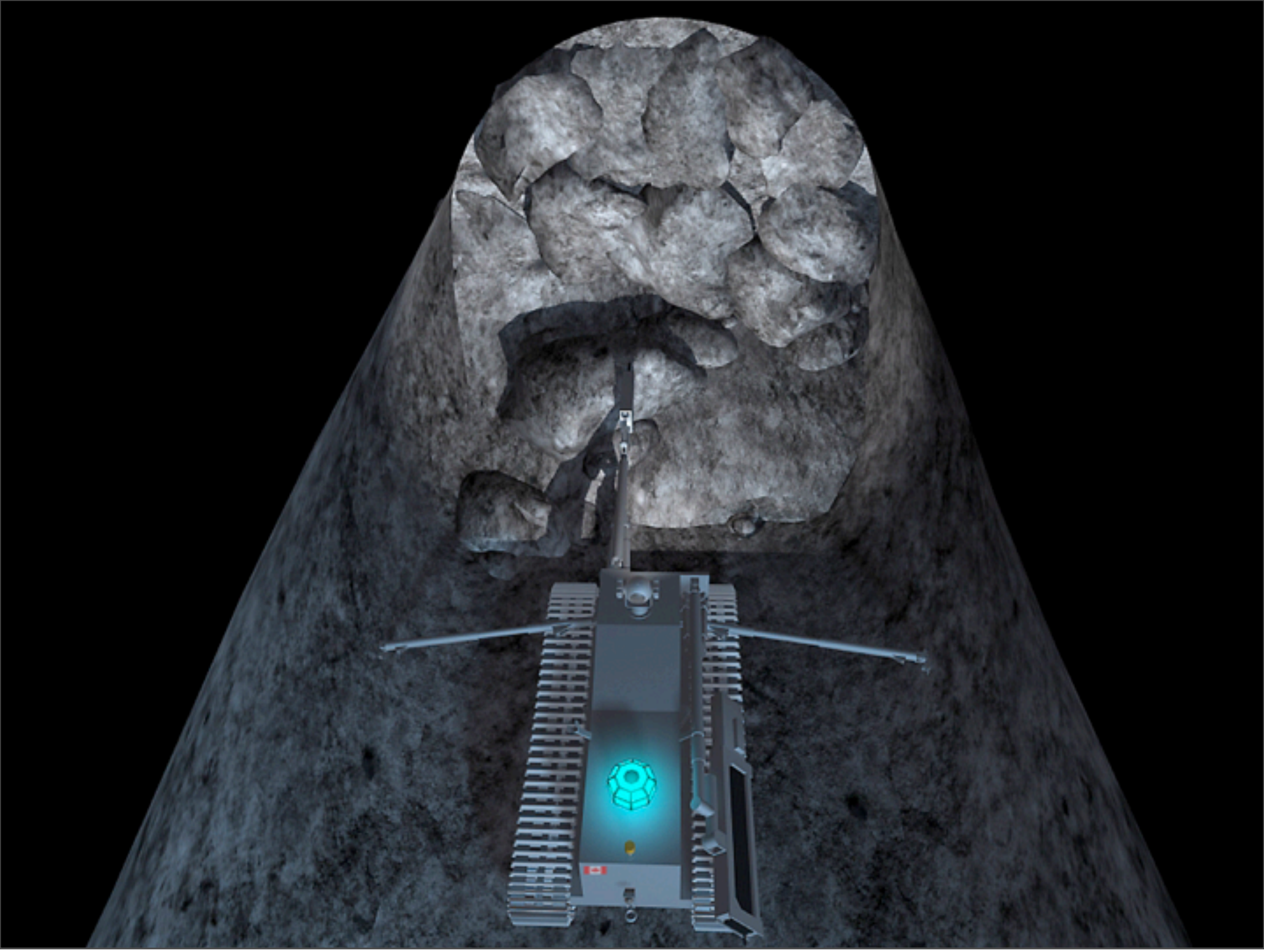
Assumptions

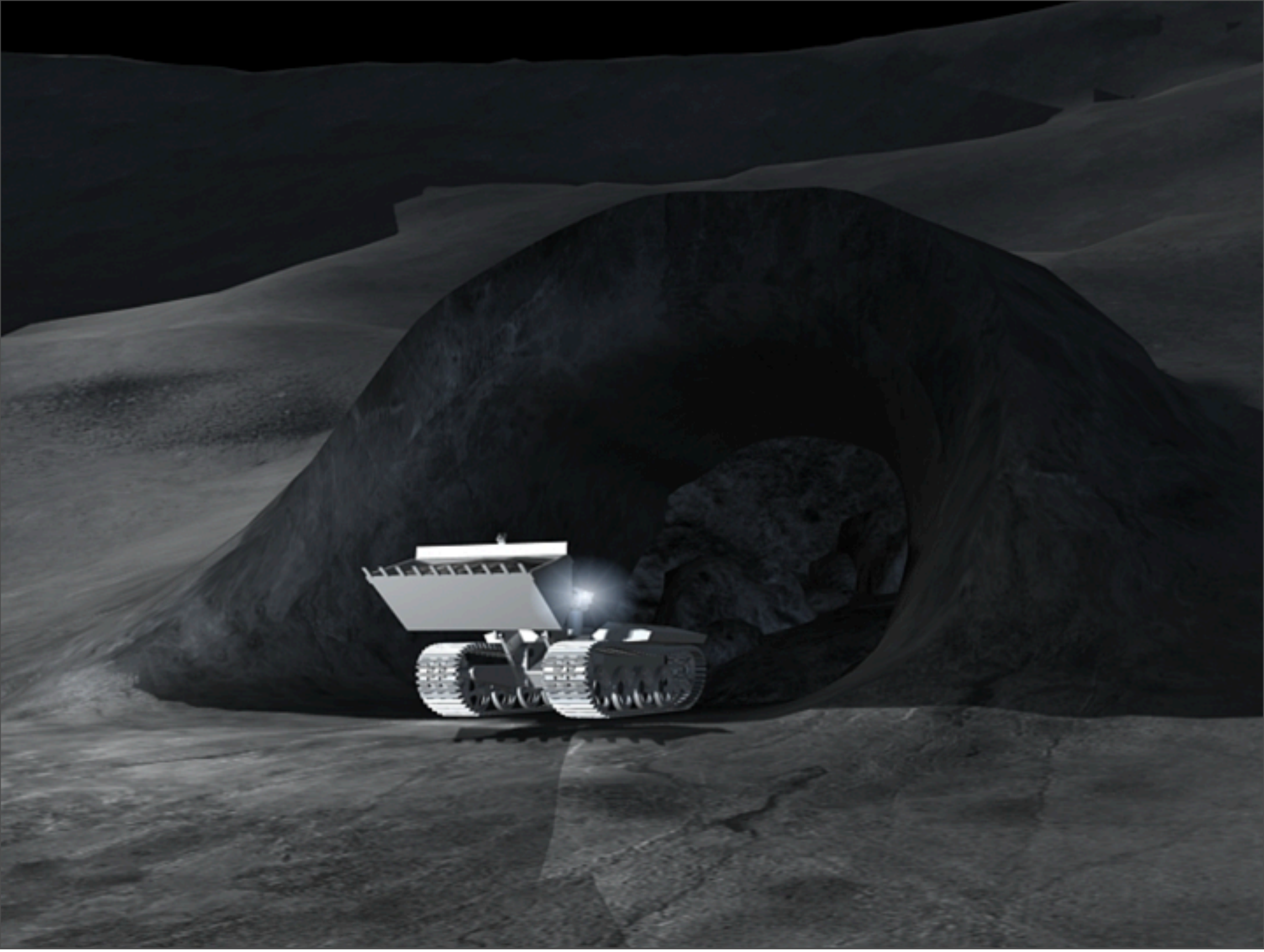
- Large concentration of H_2O found trapped in crater likely at a lunar pole
- Rock types similar to Earth
- 1/6 Gravity
- No water available during initial operations
- No atmosphere available during initial construct of Lunar Base and mine
- Small Scale Nuclear Power Plant installed at site
- Value of Water in LEO substantial and market exists
- Transportation of Equipment and Commodities available at reasonable cost
- Operating personnel initiated construct operation from earth at a Lunar Mining Teleoperation Centre

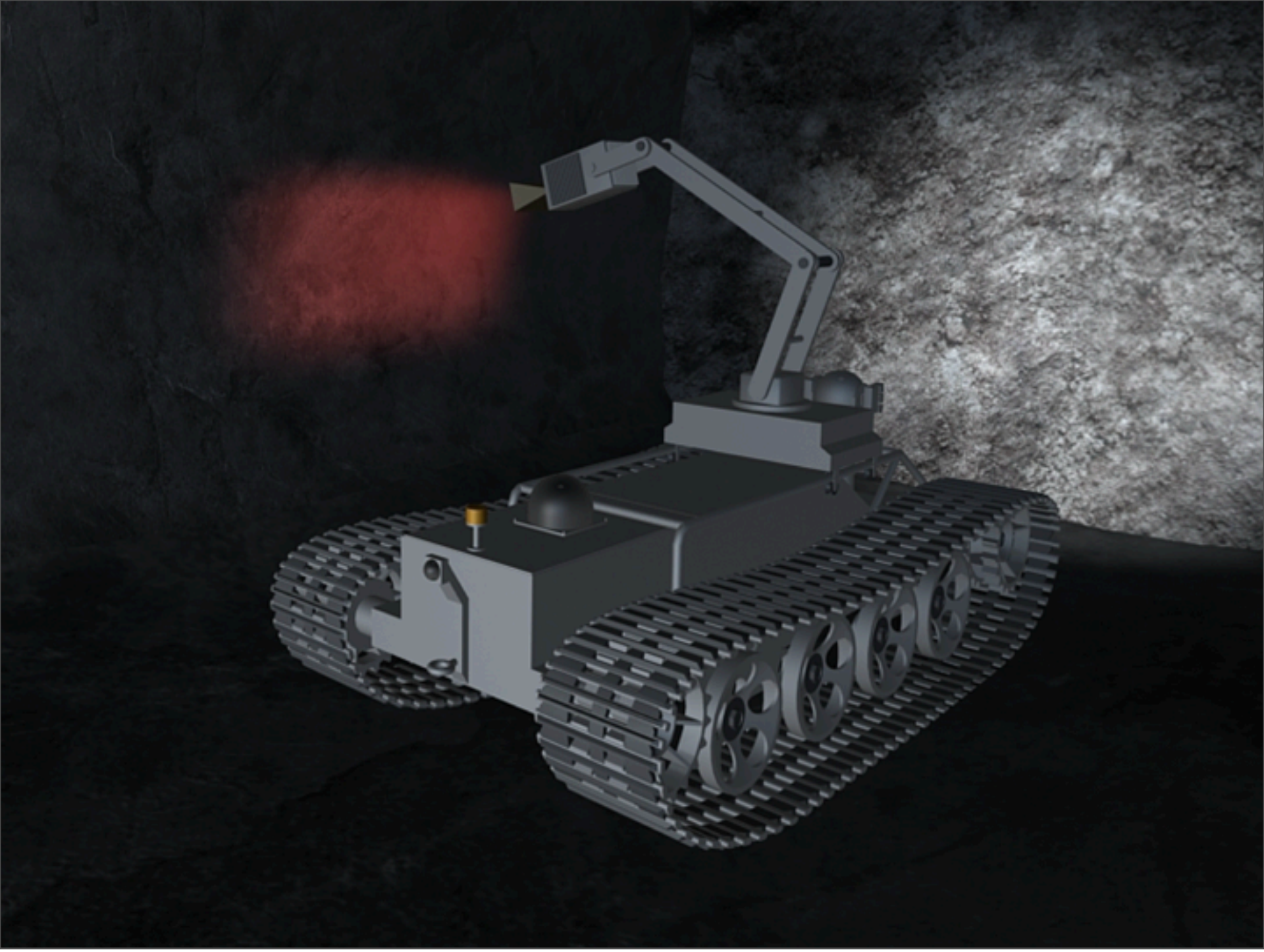
Requirements

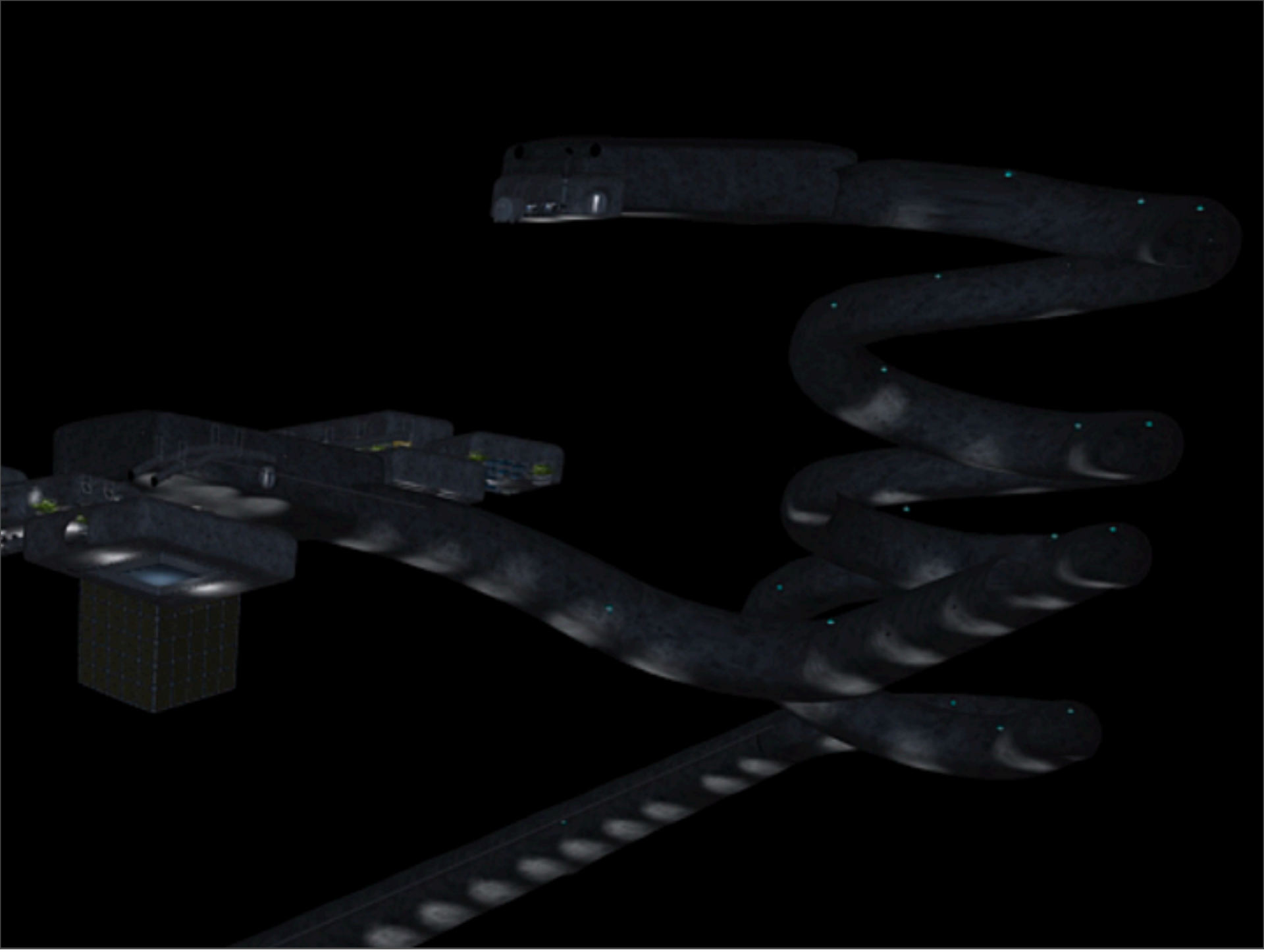
- Earth Based Lunar Mining Teleoperation Centre
- Lunar Power
  - Nuclear Reactor
- Equipment and Supply Transportation
- Air Lock in side of crater
- High Bandwidth Telecommunication Satellite established in Lunar Orbit
- Four basic pieces of Equipment
  - Delineation Drill
  - Development Drill
  - Digging Machine
  - Explosive Loading Unit
  - Sintering Machine for Ground Stabilitization

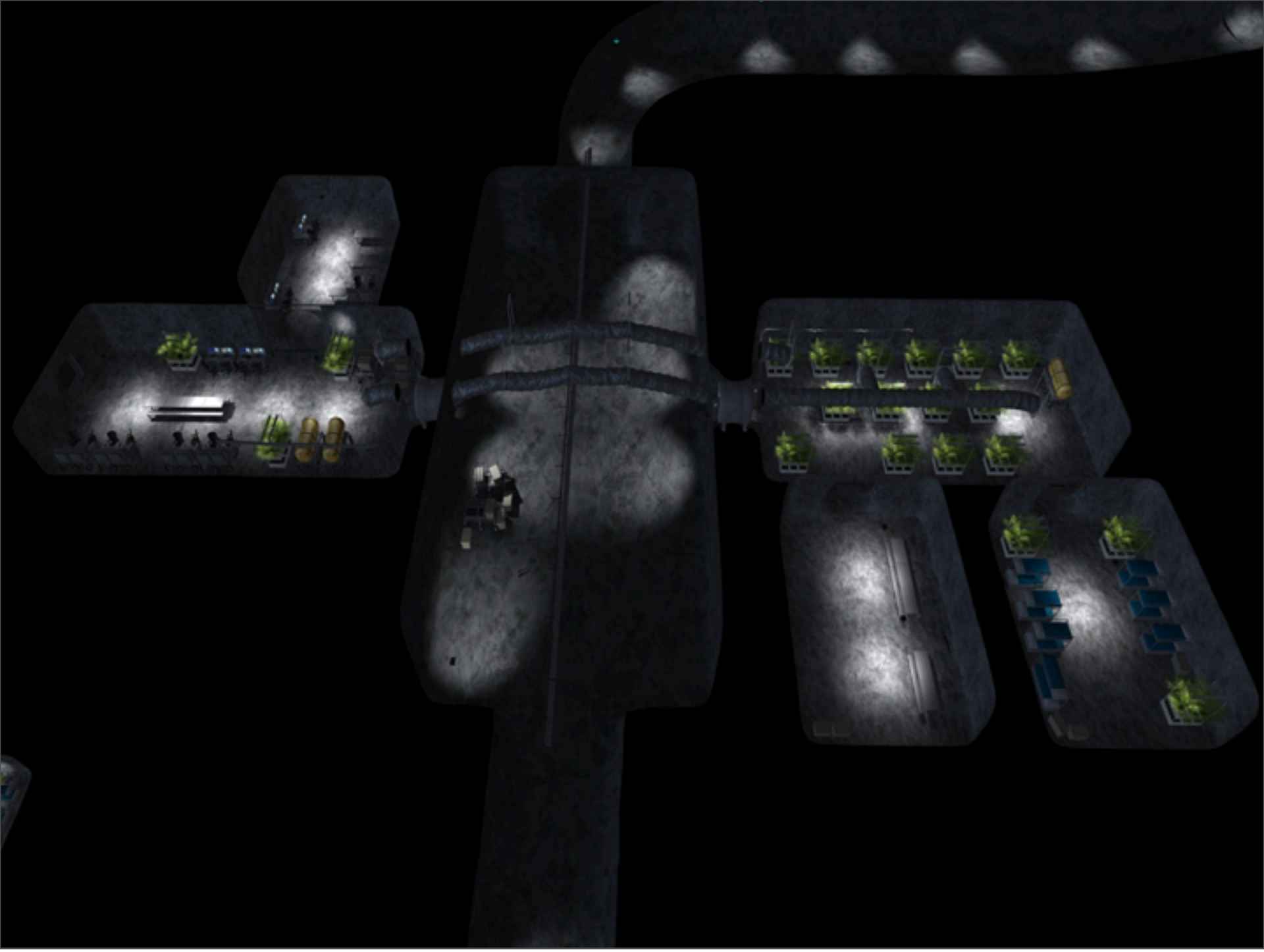


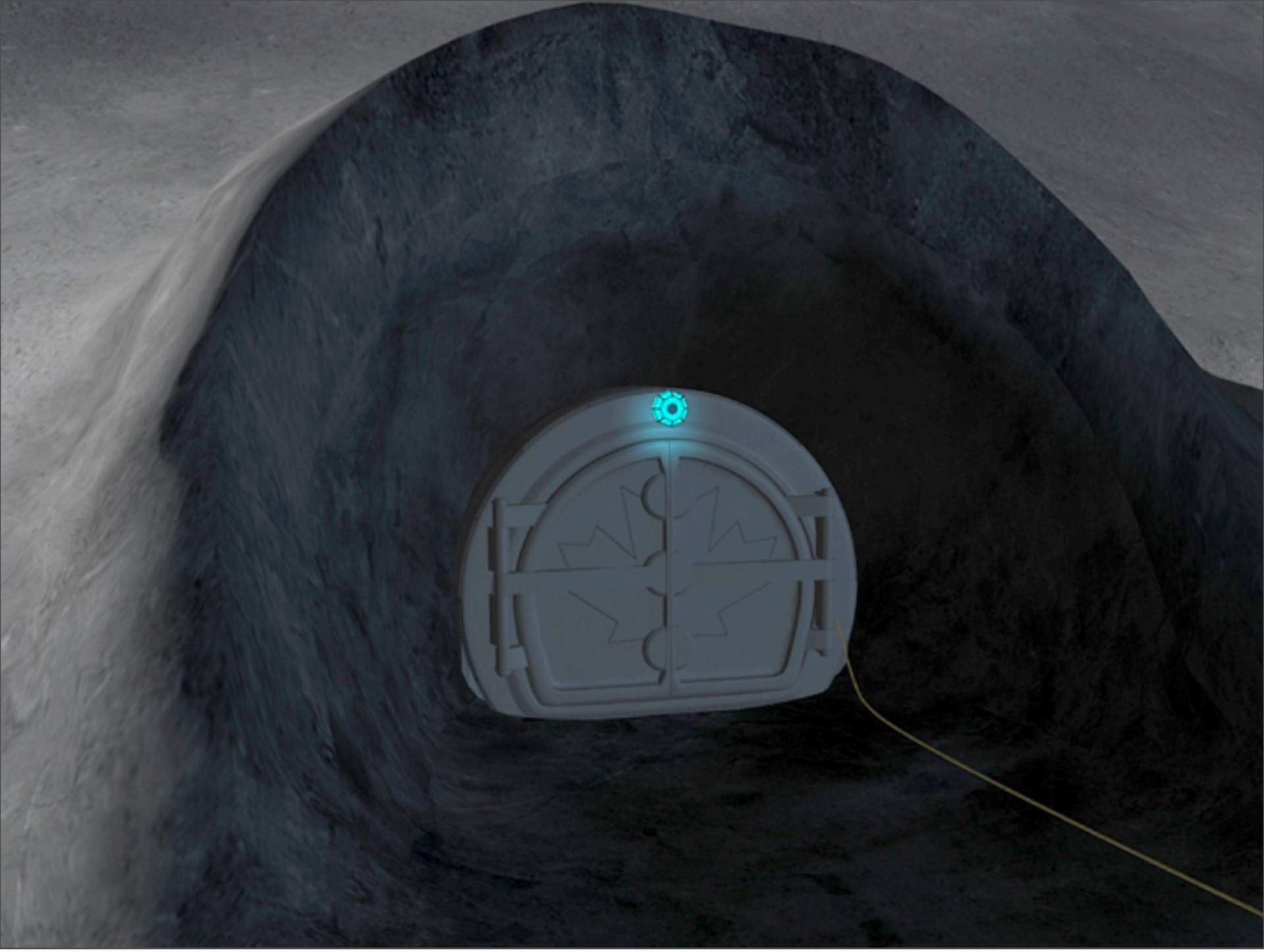


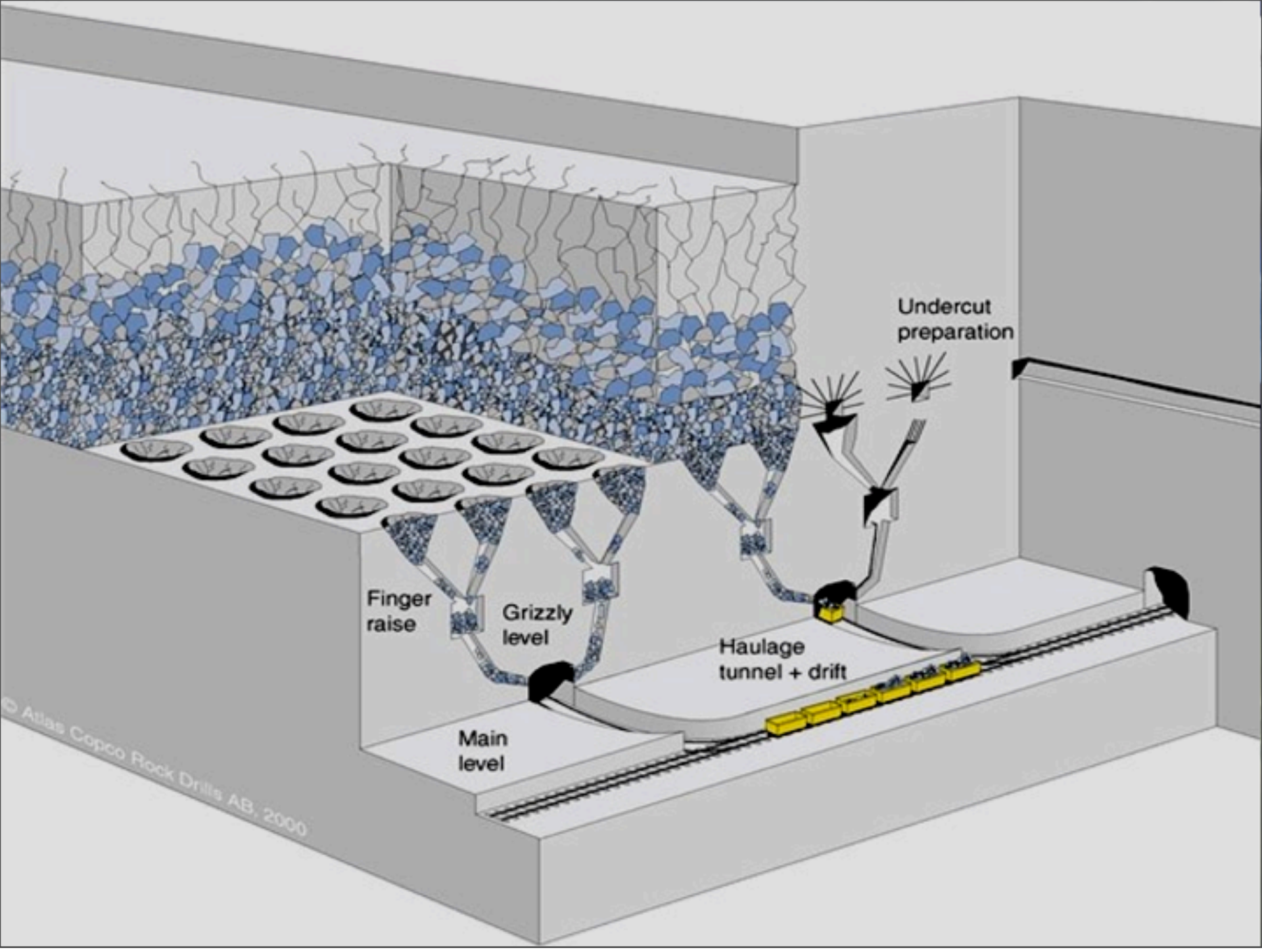











Undercut
preparation
Finger
raise
Grizzly
level
Haulage
tunnel + drift
Main
level
© Atlas Copco Rock Drills AB, 2000

Economic outlook: A lunar commercial mining forecast

- The space exploration cost equation **must be balanced** by revenues
- Future customers for **lunar-derived commodities** will extend from lunar surface outposts to orbital transportation to emerging manufacturing centers
- The Moon represents the discovery of a new continent of unexplored land and has **significant mineral potential** as indicated by its unique geologic features

Conclusions & Recommendations

- Teleoperated terrestrial mining will gradually become widely applied
- The Space industry can build on the capabilities being developed in teleoperated mining techniques
- SmartSteps proposes the construction of an underground outpost to provide humans with a safe haven on the moon free of environmental hazards with the bulk of construction occurring telerobotically from Earth
- SmartSteps is proposing an analogue site to test the concepts of teleconstruction for a Lunar Outpost

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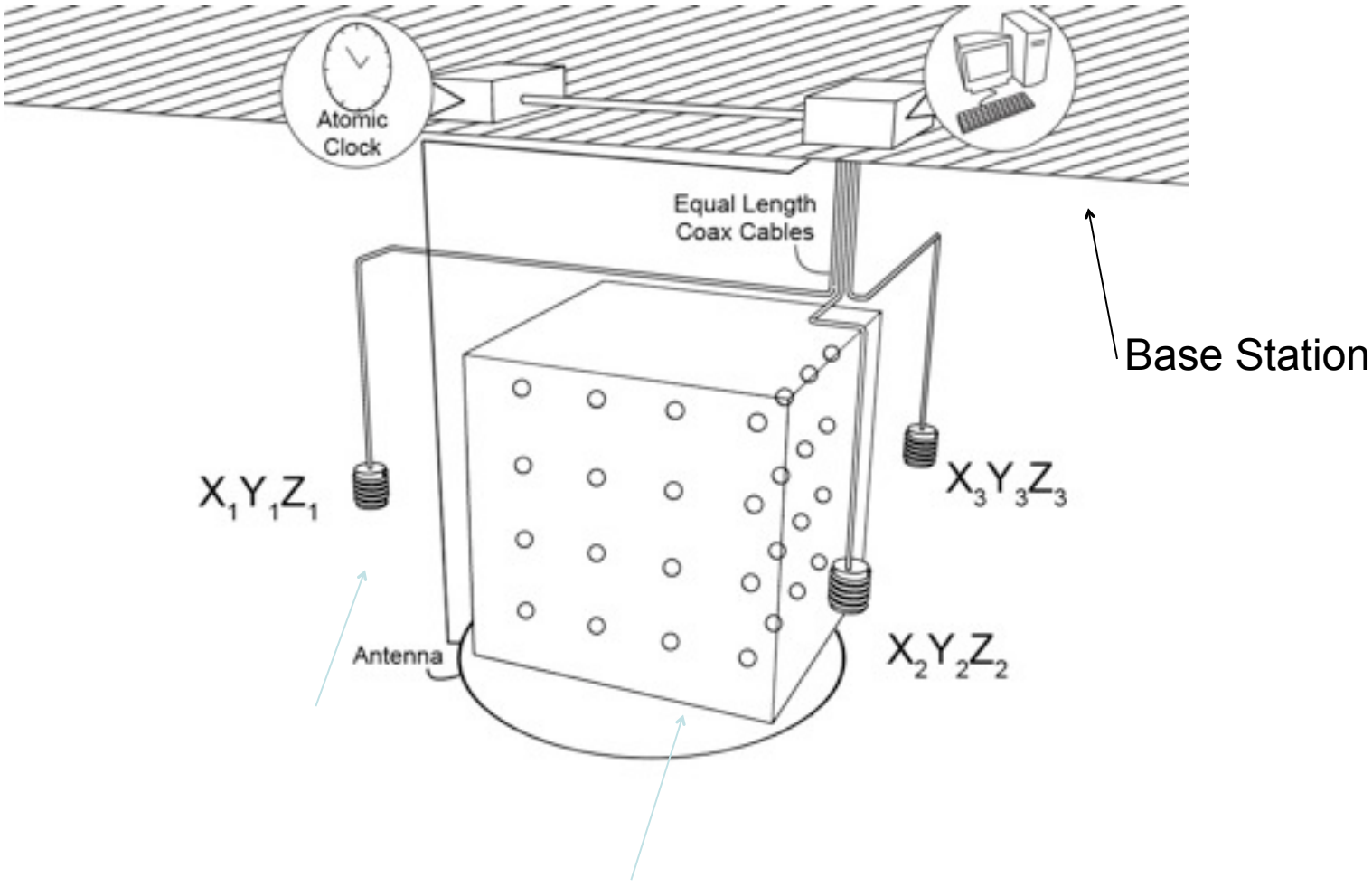
BREAKTHROUGHS

RESEARCH AND IMPLEMENTATION UNDERWAY

Sub-surface Avionics Systems

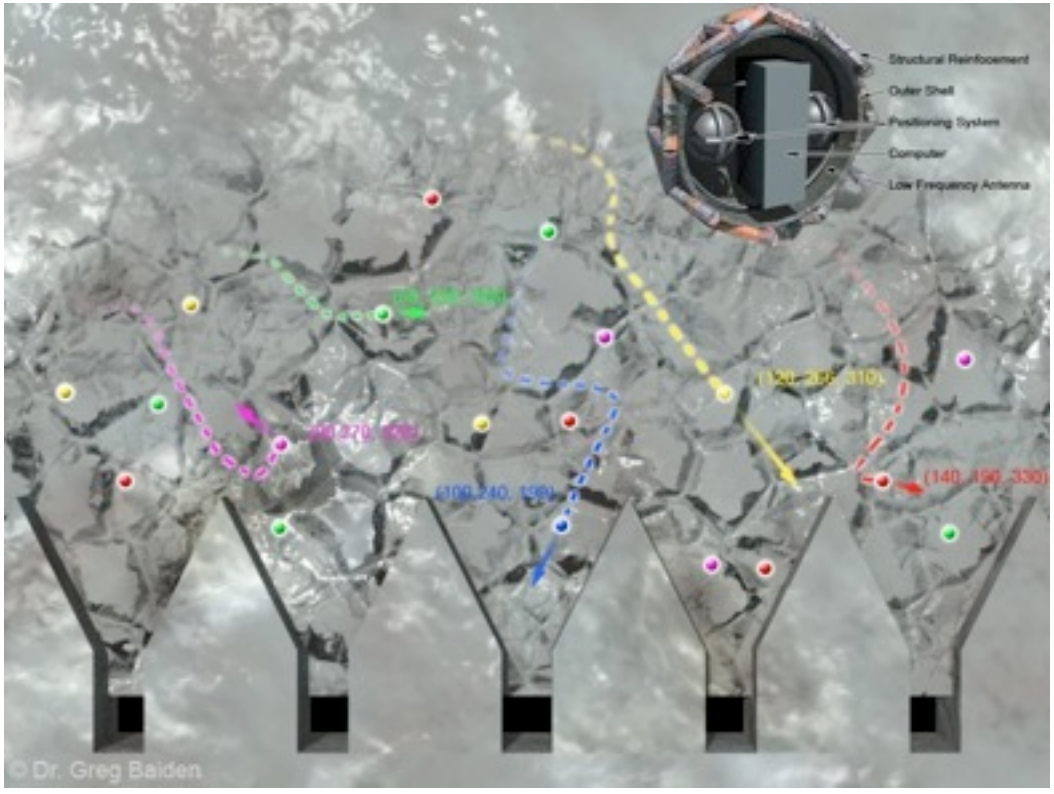
- Location of underground equipment
  - Position Location and Navigation System (PLANS)
  - GPS equivalent
    - Currently non existent until now
    - Very Low Frequency Underground Positioning System (VLF UPS)

VLF UPS System



Initial VLF UPS Application Conceptual Idea

- Create a dynamic sensing system using synthetic rocks to determine location and path of flow within the rock mass of a block cave operation in real time
- Outcomes
  - Material Flow Monitoring System
  - Underground equivalent of GPS
- Concept Mine testing early 2011

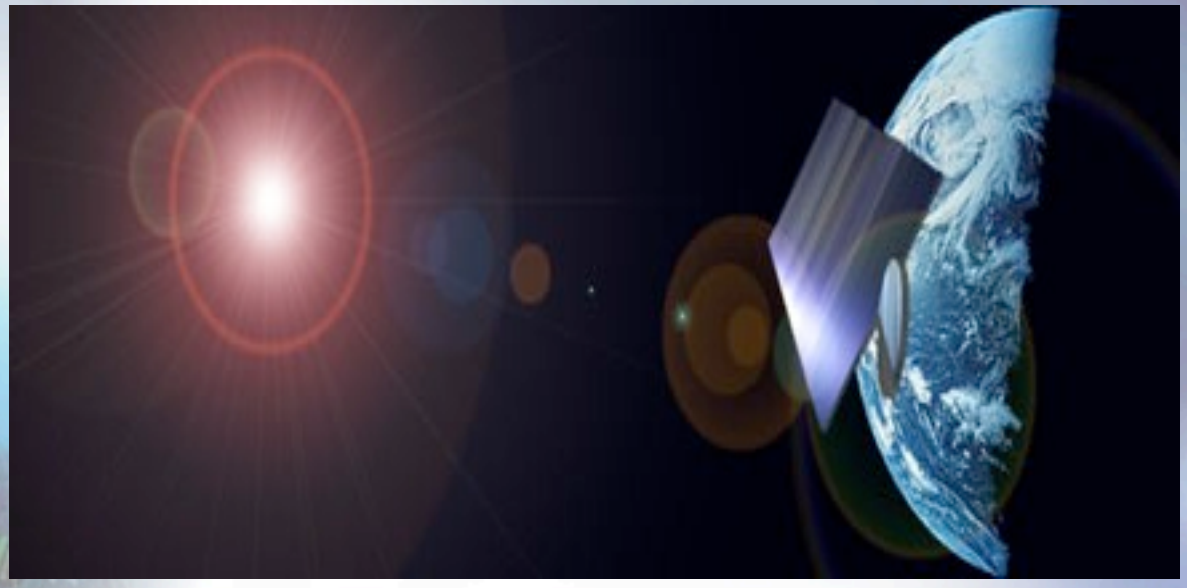


Alternative Wireless Communication Systems

Free Space Optical Communication

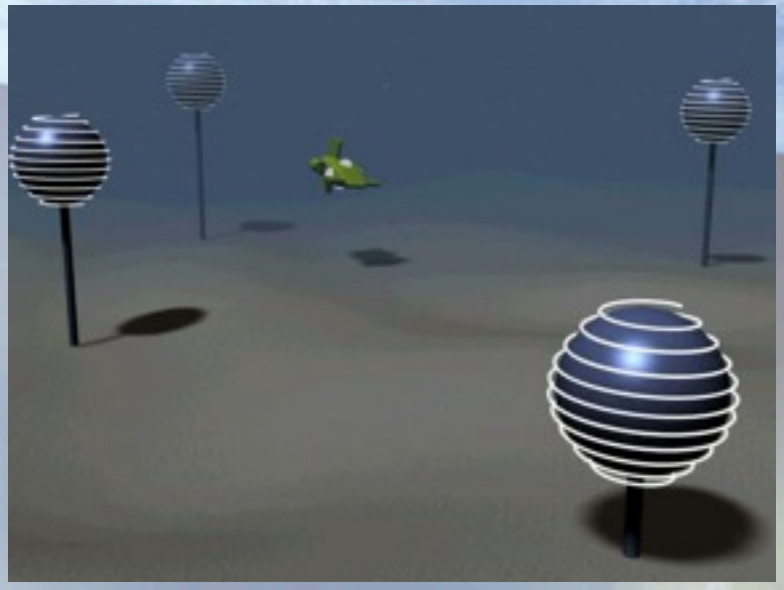
Teleautonomous Applications

- Several independent groups came asking for assistance based on what had been done underground
  - Mining Companies with the problem of Telemining in high altitudes due operator environmental conditions
  - A Mining company regarding underwater mining possibilities, and
  - NASA and the National Science Foundation regarding large scale space construction techniques



Wireless Optical Cellular Communication Concept

- Current wireless radio systems suffer from a lack of bandwidth due to regulations
- Teleoperation systems require significant bandwidth
  - High Altitude Mining
  - Surface teleoperation systems
  - Space systems (Orbiting Space Solar Power)
  - Subsea systems
- Develop a concept that:
  - Is a wireless optical network capable of transmitting/receiving multiple video, monitoring and control channels with high capacity and unnoticeable latency



Patent Pending

Optical Communication Technology

Long Distance Telerobotics for Hazardous Environments

Telerobotic Multi-purpose Robot System

- System consists of
  - Telecommand Trailer with two workstations
  - Robotic Network Construction
    - Communications is done using Long Distance Antennas meshed with short range broad coverage antennas
  - Multiple radio frequencies are employed to deal with the conditions
  - Two Robots
    - Work Robot - Beaverbot
    - Communications Robot - Combot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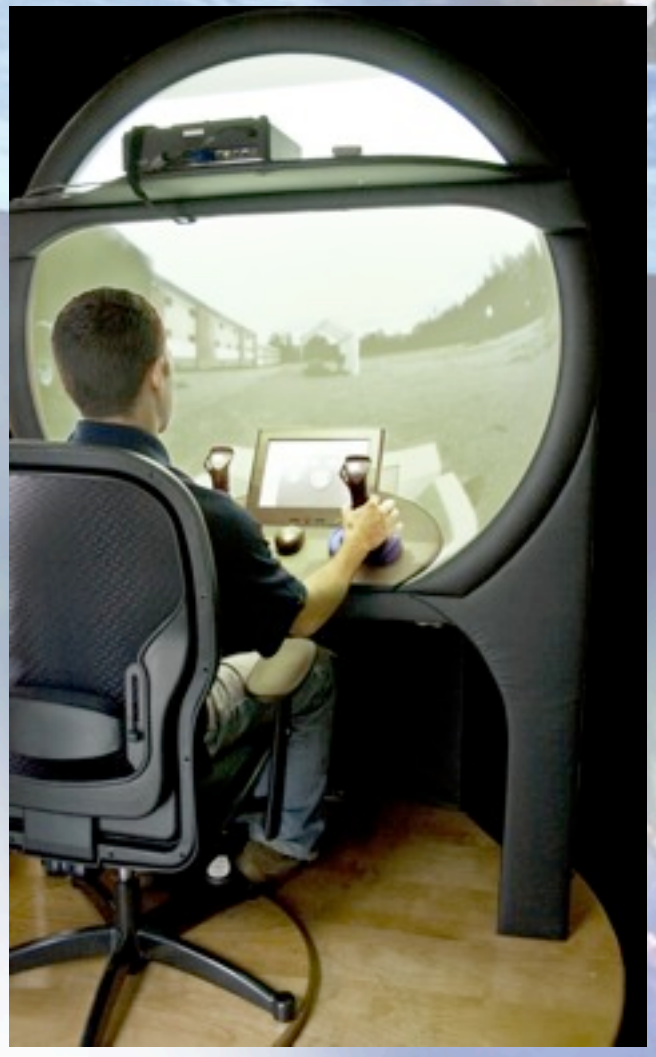
Mines	12	20	Golder Associates NI43-101, 2008. Inferred + indicated (4% Cu cutoff) is 2,170,000 t drilled.
Ave Mt	12	10	
Wt %			
Copper	1.6	2.1	**7.2**
Zinc	3.0	1.4	0.6
Lead	0.8	~0	-
g/t			
Silver	93	21	31
Gold	0.6	4.1	**6.2**

Teleoperation Control Centre

- Ethernet linked control centre
- Hemispherical Projected Screen to provide a large field of view
- Embedded Dashboard display
- Configurable Joystick Control
- Common Control Centre for all our Teleoperation systems (submarine, terrestrial, aerial, space)



TeleRobotic Sub TestBed

- Specifications
  - Computational System is a Stealth fan-less computer
  - Penguin developed Robotic CANOpen electronics for all sensor and actuator monitoring and control
  - Battery operated unit
  - Dual Motor Control designed specifically for teleoperation with joysticks
  - IPIX wide field of view cameras
  - Sufficient on-board computer resources to fit side scan sonar or any other devices required

Designed, Constructed and Launched at fully equipped Laboratory on Long Lake in Sudbury

Tri hull Pontoon boat
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Electric Winch to Lift and Lower Subs into water
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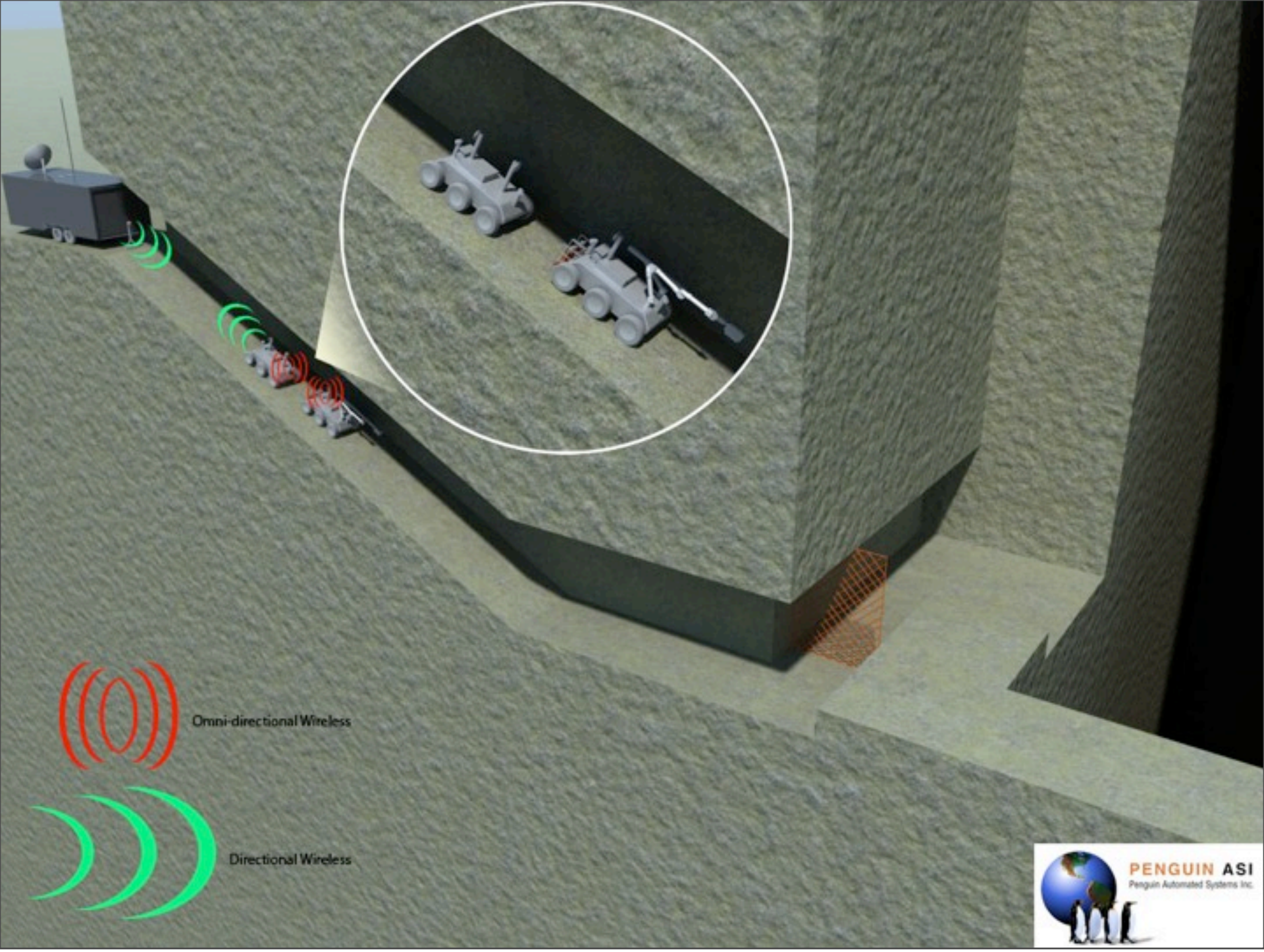
Omni-directional Wireless
Directional Wireless
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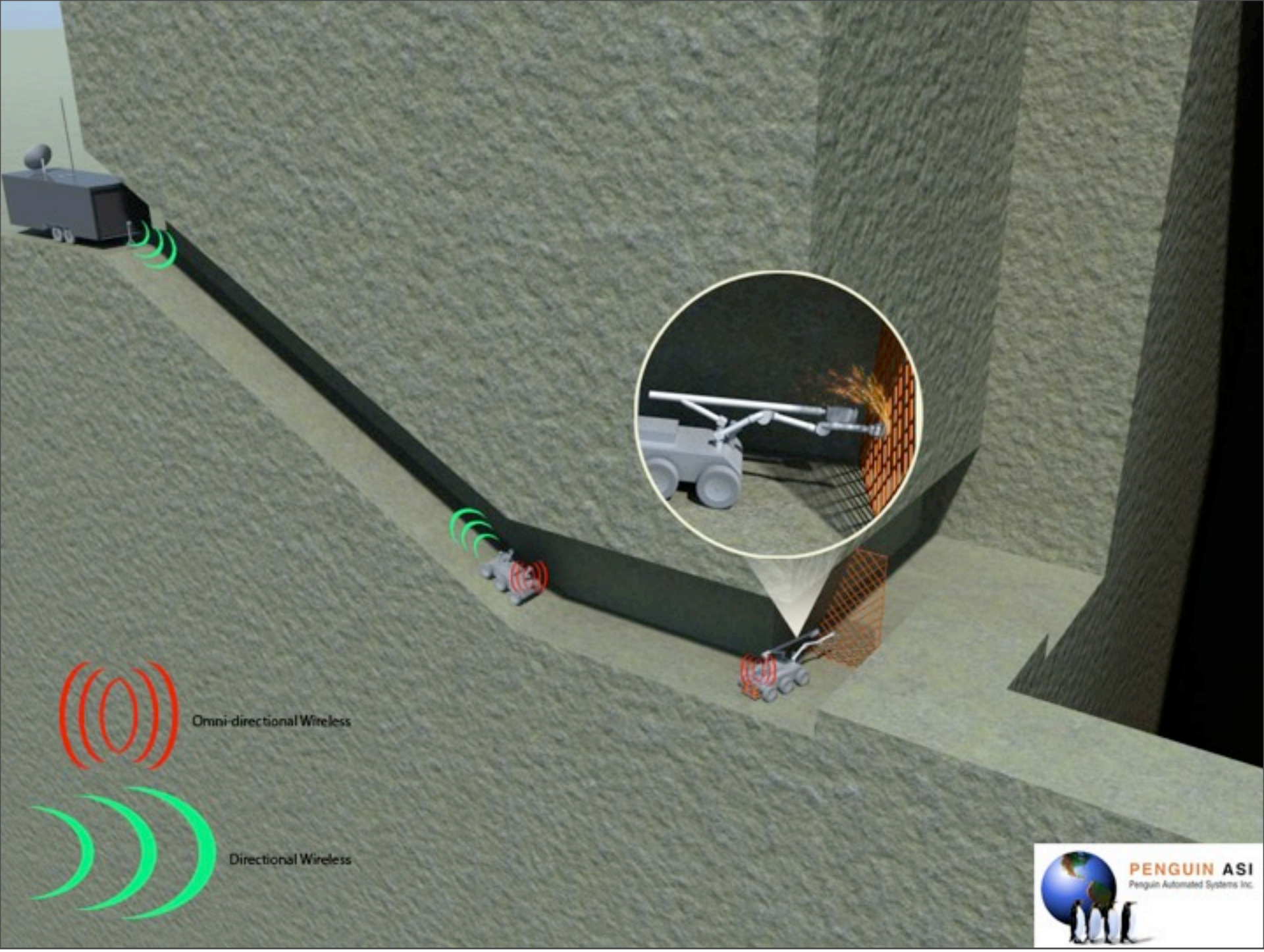
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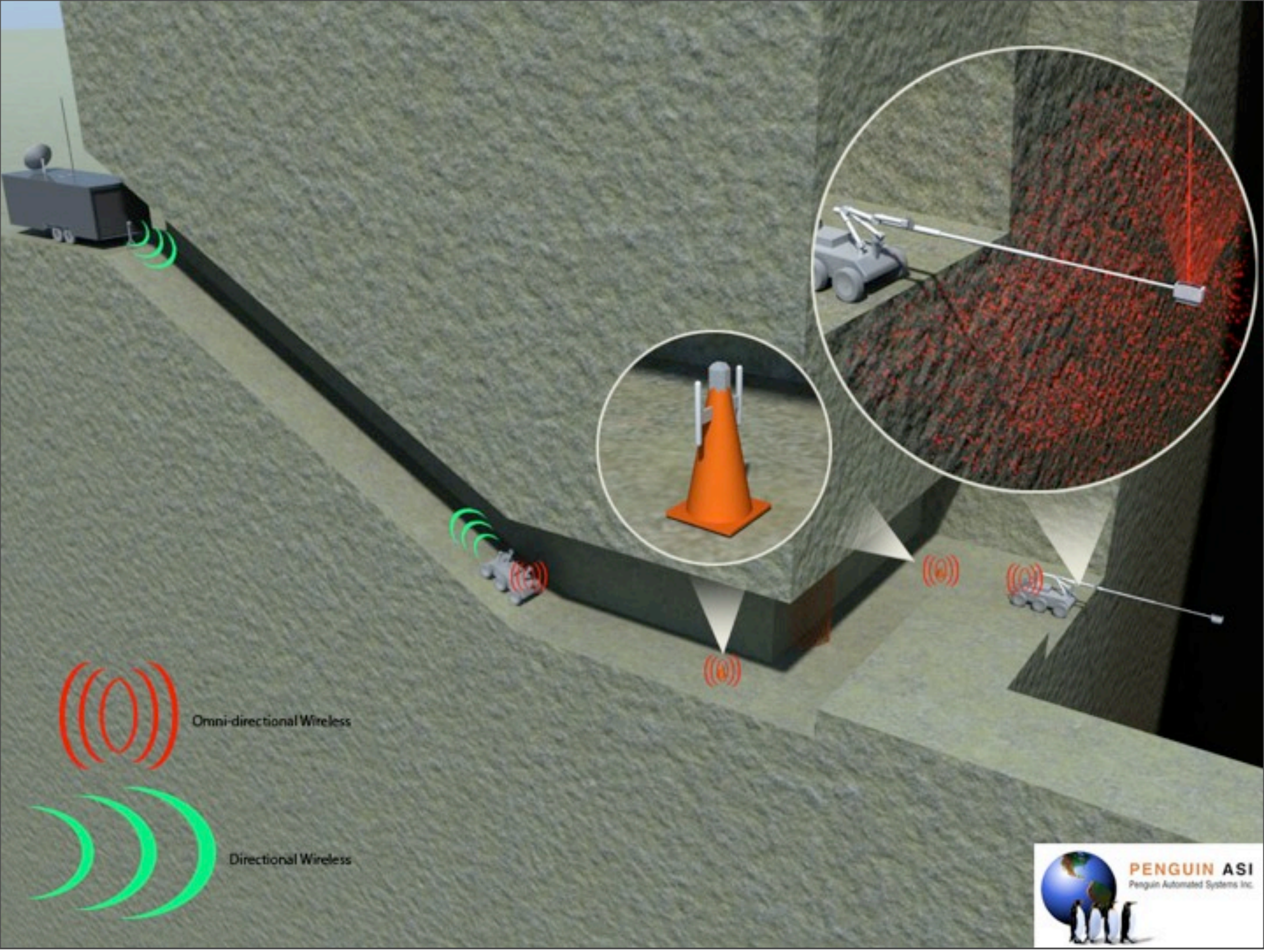
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Control Systems

NASA Rokbot

NASA Rokbot

Long Distance Robot System

- Purpose
  - Travel to unsafe conditions to inspect and determine conditions
- Current work
  - Travel into a mine 1.5 km where ground collapse is possible, no ventilation and no road maintenance to assess conditions
- Perform surveying and cavity scanning to assist the client in determining possibility of collapse

Multi-purpose Robot - Beaverbot

- Six wheeled Skid Steer
- Battery Electric – Diesel Power System
- Penguin Low Latency Electronics
- WiFi Communications for audio, data and video
- Several Arm attachments

Multi-purpose Robot – Beaverbot Attachments

- Several Arm attachments ranging from grinders to booms
- Grinder attachment to remove safety screen in the drift to allow robot access
- Laser Scanner and arm attachment

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Multi- purpose Communications Robot - Combot

- Six wheeled Skid Steer
- Battery Electric – Diesel Power System
- Penguin Low Latency Electronics
- WiFi Communications for audio, data and video at several different frequencies
- Long Distance WiFi – up to 25km line-of-sight
- Short Haul WiFi – 300 m
- Backup Cable System Ethernet – 1.2 km

Long Distance Laser Scanning Robot System

- Purpose
  - Travel to unsafe conditions to inspect
- Current work
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  - Two Robots
    - Work Robot - Beaverbot
    - Communications Robot - Combot

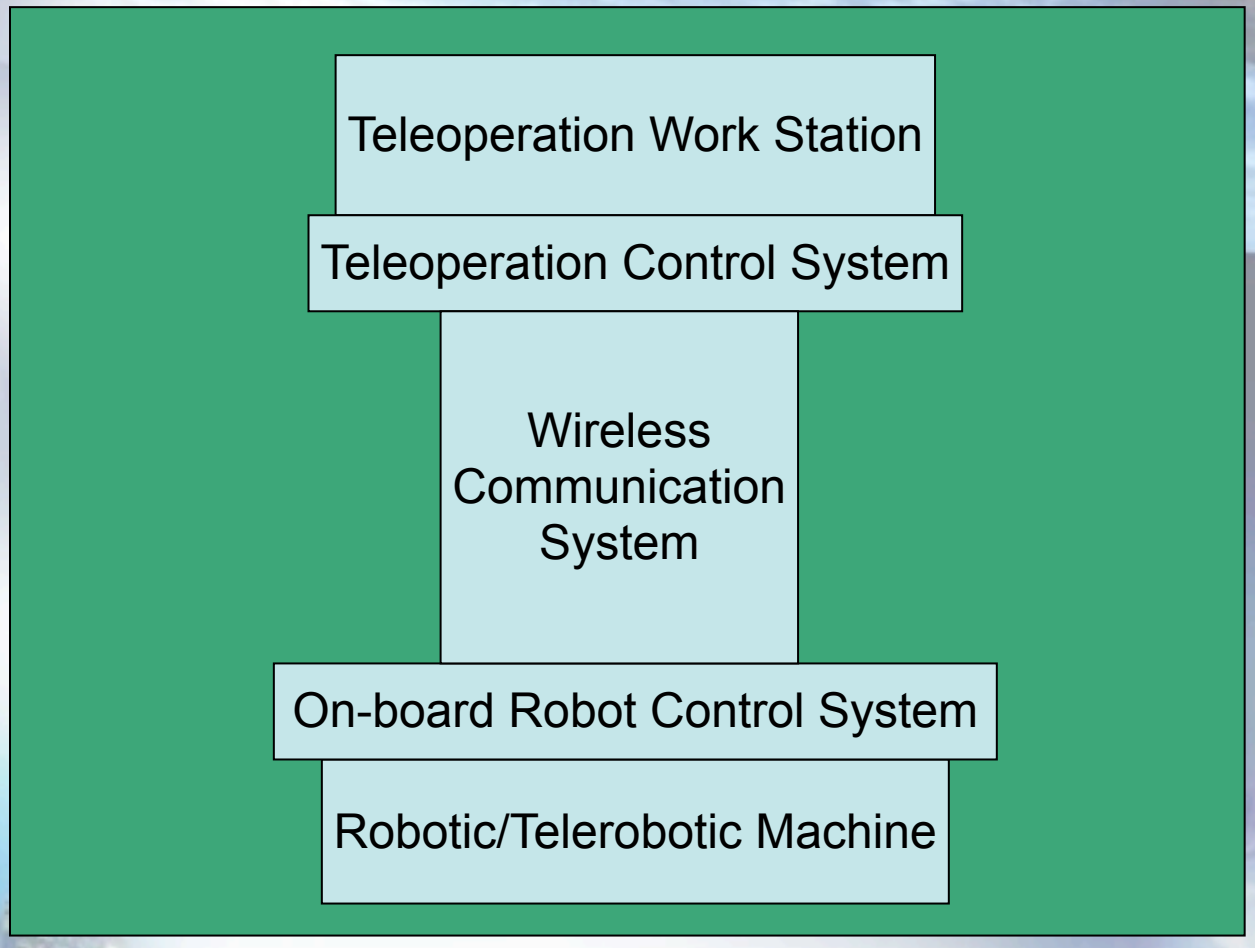
Advantages

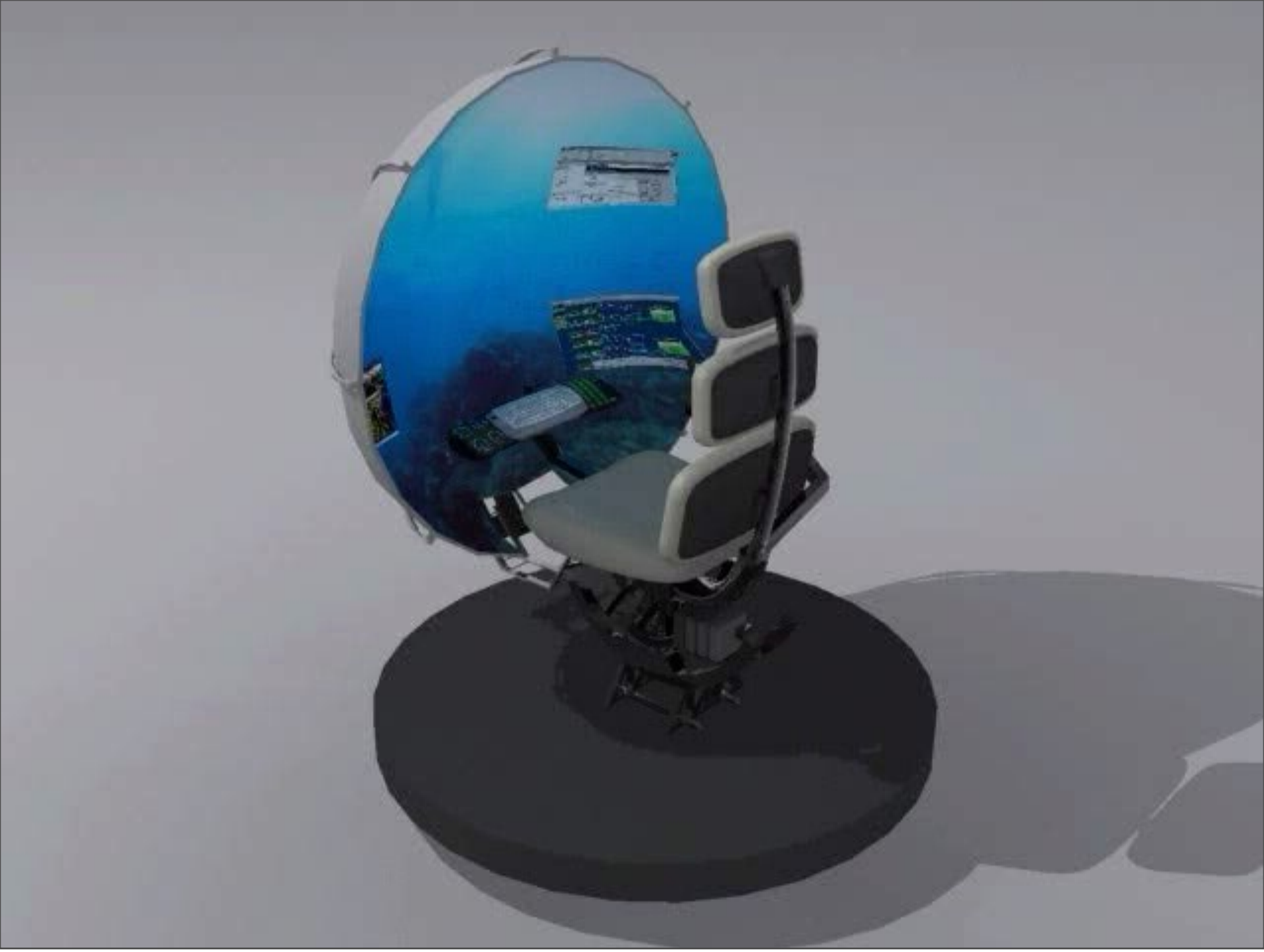
- Extremely accurate mapping for underground environments
- Very fast – the system can do what it would take traditional surveying days to do in hours
- Entire system is battery operated and will fit on any mining cage.
- Information can be directly deposited into any current mine planning system

Uses

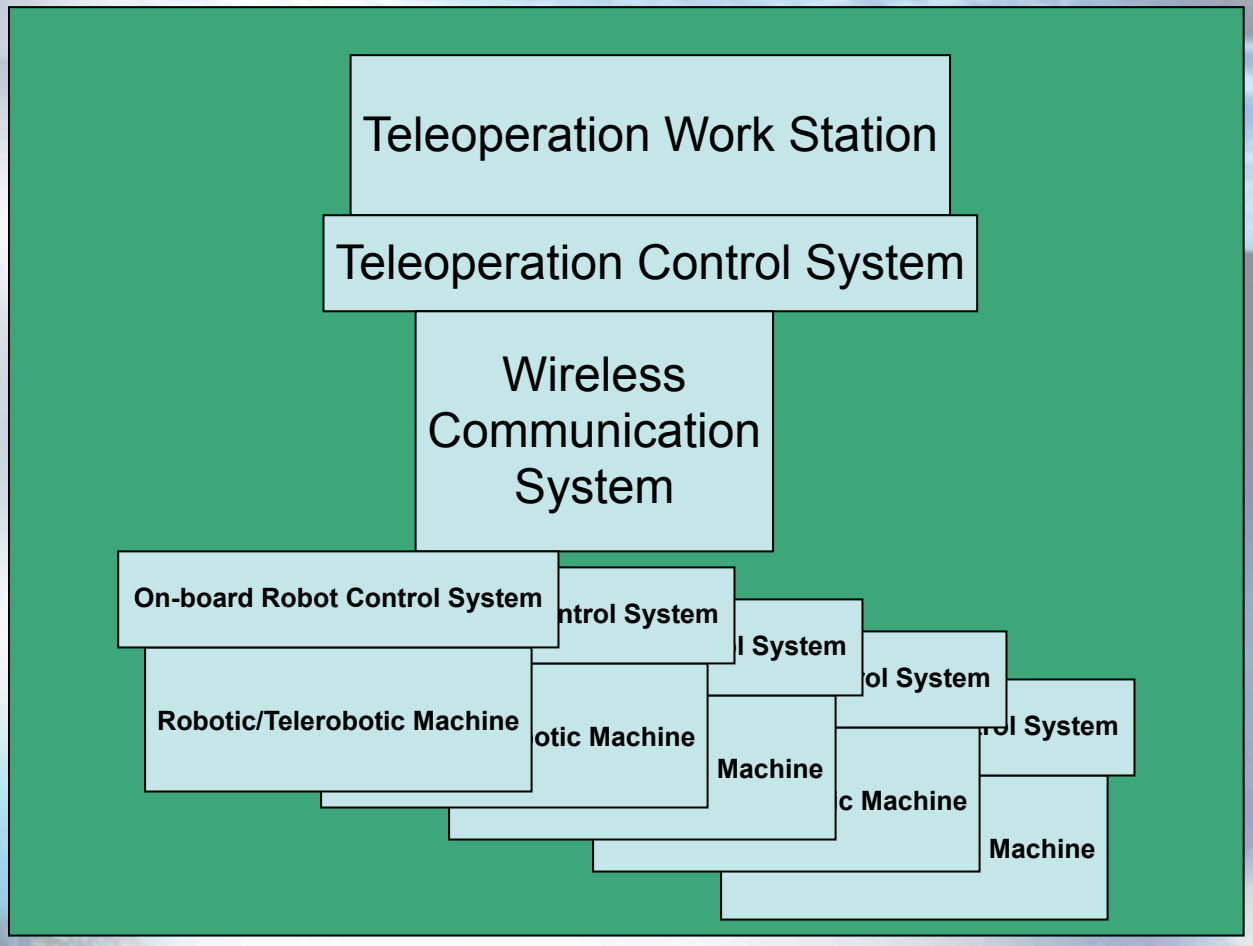
- Check surveys
- 3D mapping of drift walls to estimate shocrete thickness
- Calculate the “K” factor for ventilation
- Roadbed surveys
- Finding lost drill holes

Basic Teleoperation System

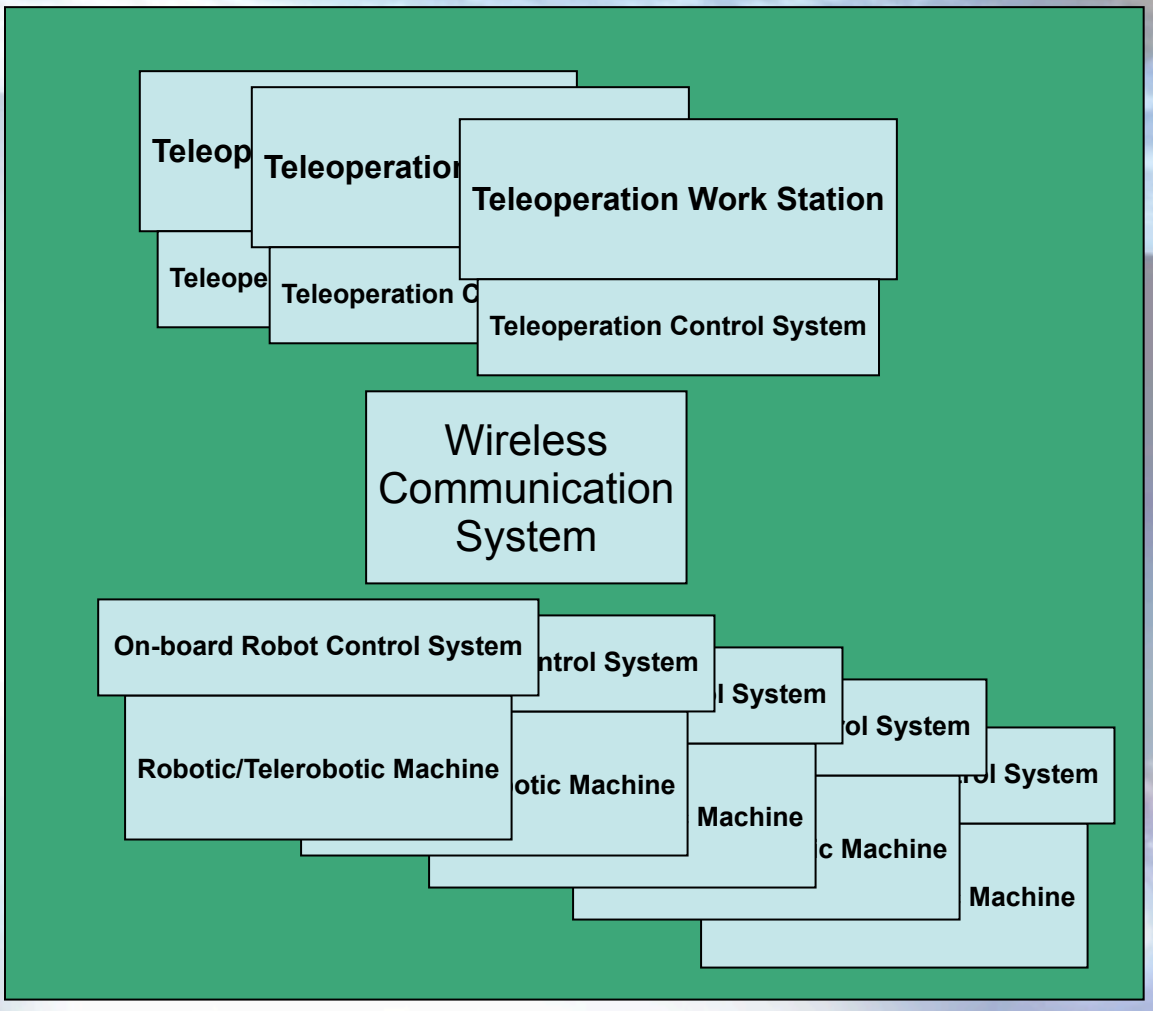




Multi-machine Teleoperation System



Nested Multi-machine/Multi-Control Teleoperation System



Diesel/Electric Robot with CMS Scanning Boom

Diesel/Electric Robots
CMS Scanning Boom and Directional and Local Communications Robot

Control Systems

A Bit of History

Path from Human to Robotic Control

Autonomy Tele-autonomy	Robot Initiative
Safeguarded Teleoperation Monitored Teleoperation	Human Initiative
Direct Teleoperation Manual Operation	Human Controlled

Automatic Haulage Truck 1992

Started by trying autonomous operation that worked but was not embraced

Path from Human to Robotic Control

Autonomy Tele-autonomy	Robot Initiative
Safeguarded Teleoperation Monitored Teleoperation	Human Initiative
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Teleoperation Chairs putting the person virtually in the

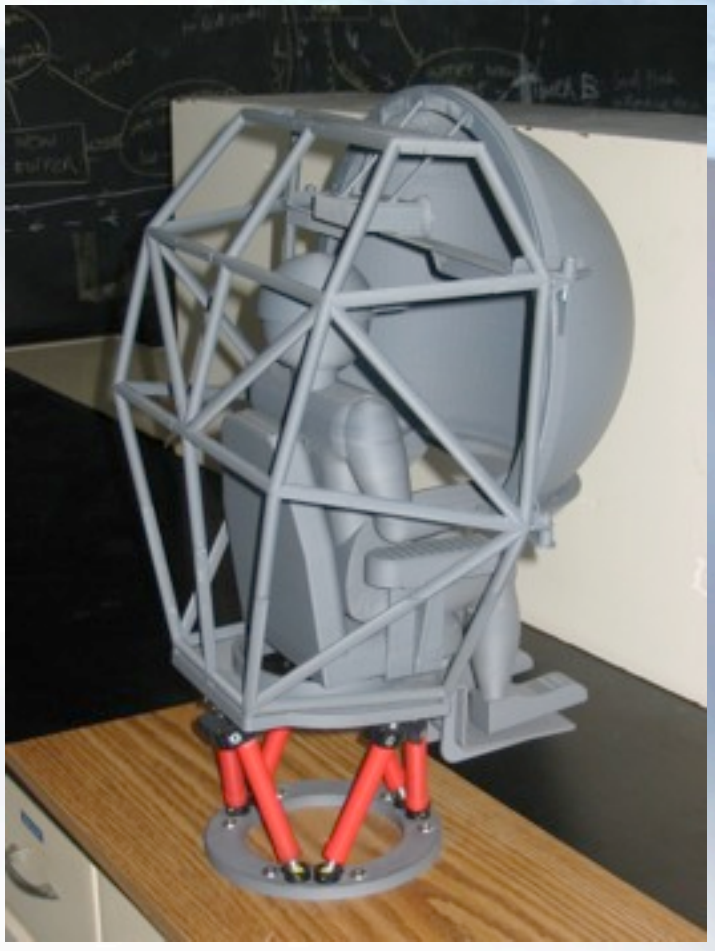
Main Research Project Thrusts

- **Teleoperation Control System**
  - Visual
  - Haptic
  - Vestibular
  - Audio
- **Communication**
  - High Bandwidth
  - Low Latency
  - RF, Optics, Hybrid and more
  - Standards (802 IEEE)
- **Telerobot**
  - Sensing
  - Actuation
  - Intelligence
  - Hardware and Software

Designed, Constructed and Launched at fully equipped Laboratory on Long Lake in Sudbury

Tri hull Pontoon boat
Large Deck for a pair of Tele-submarines
Electric Winch to Lift and Lower Subs into water
Full Diving Gear for three personnel
On Deck Computer Laboratory for Testing

Virtual Replicator Control System



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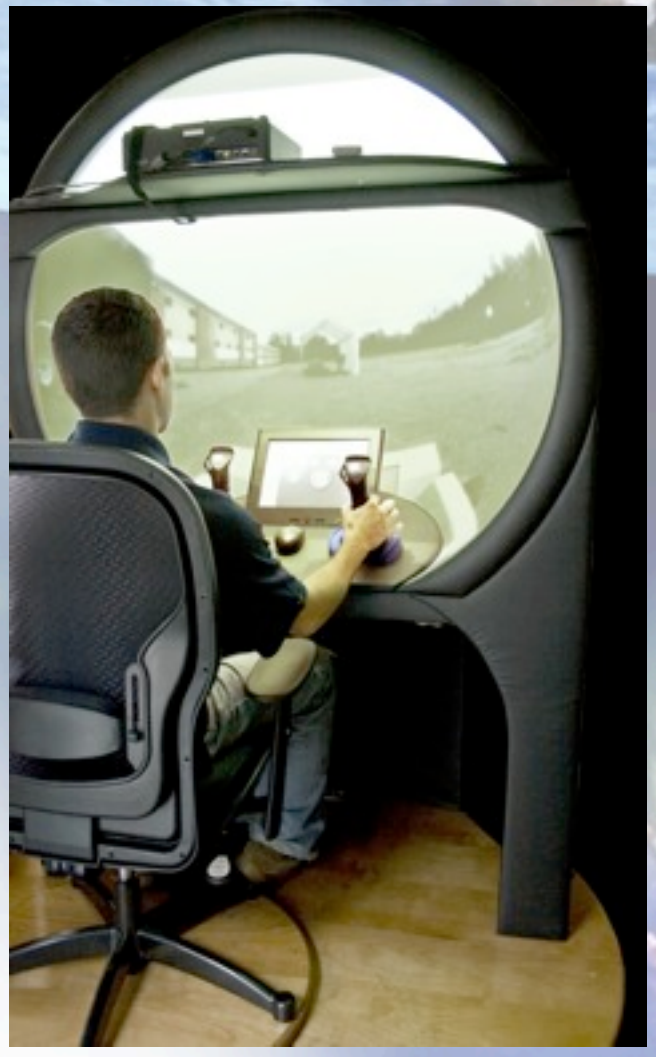

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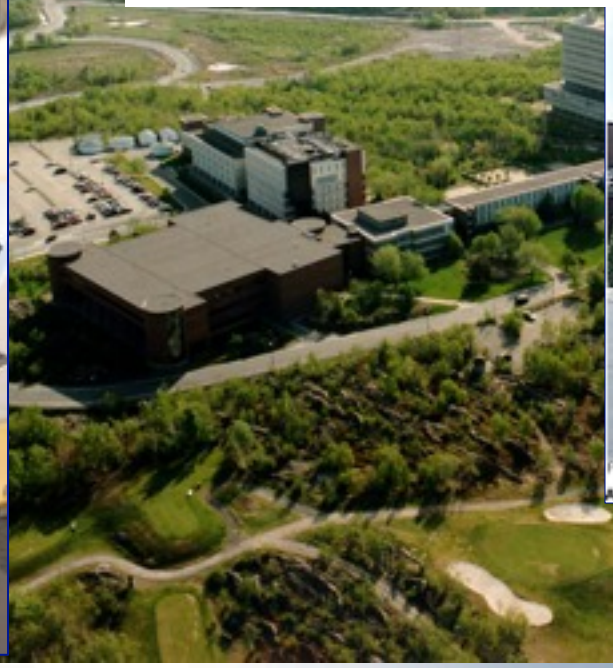
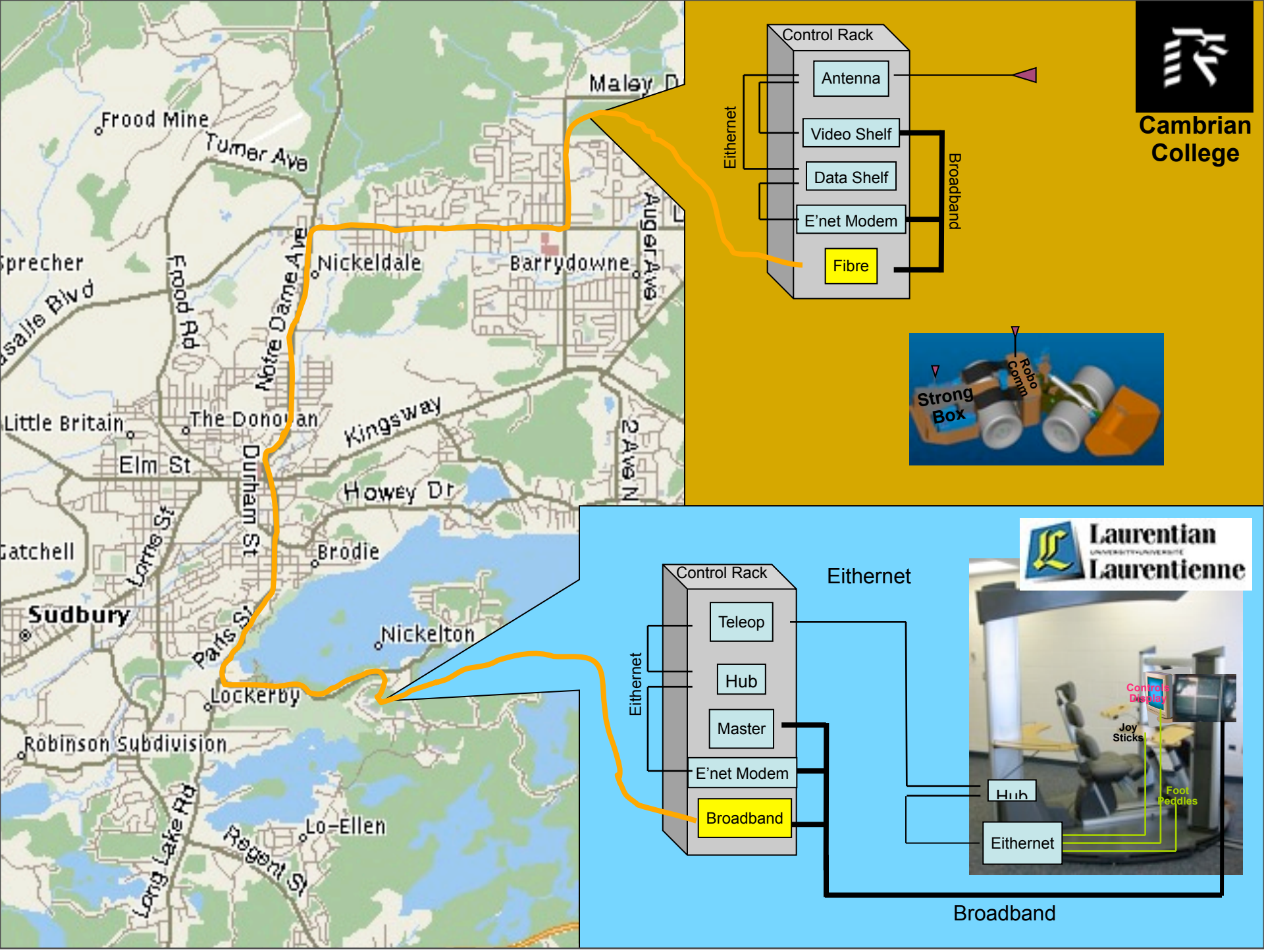


Telerobotics Laboratory

- Established in 2002 at Laurentian University
- to experiment with teleoperation issues (latency) and techniques
- a high speed network was established between Laurentian and Cambrian College for experimental purposes

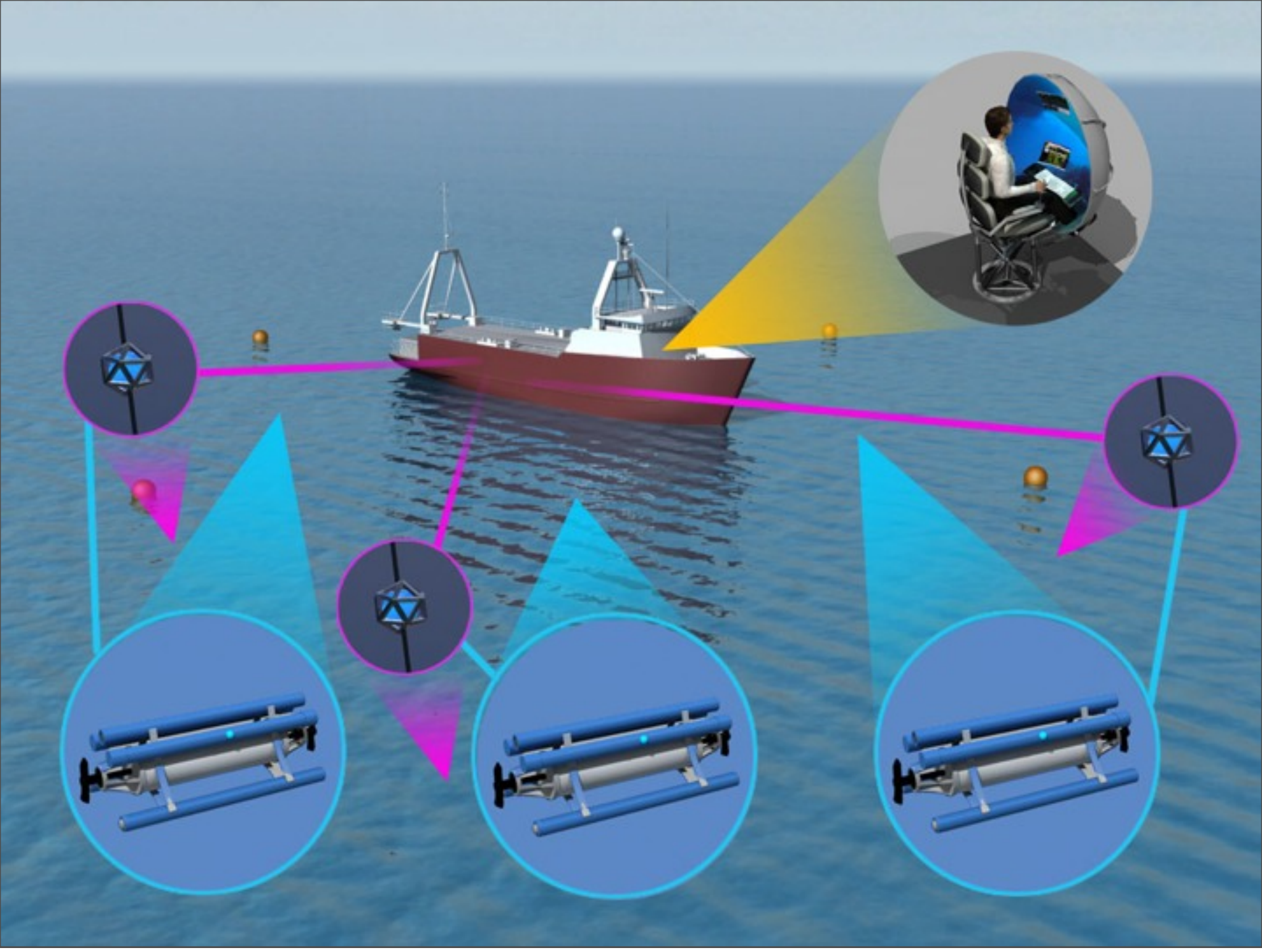


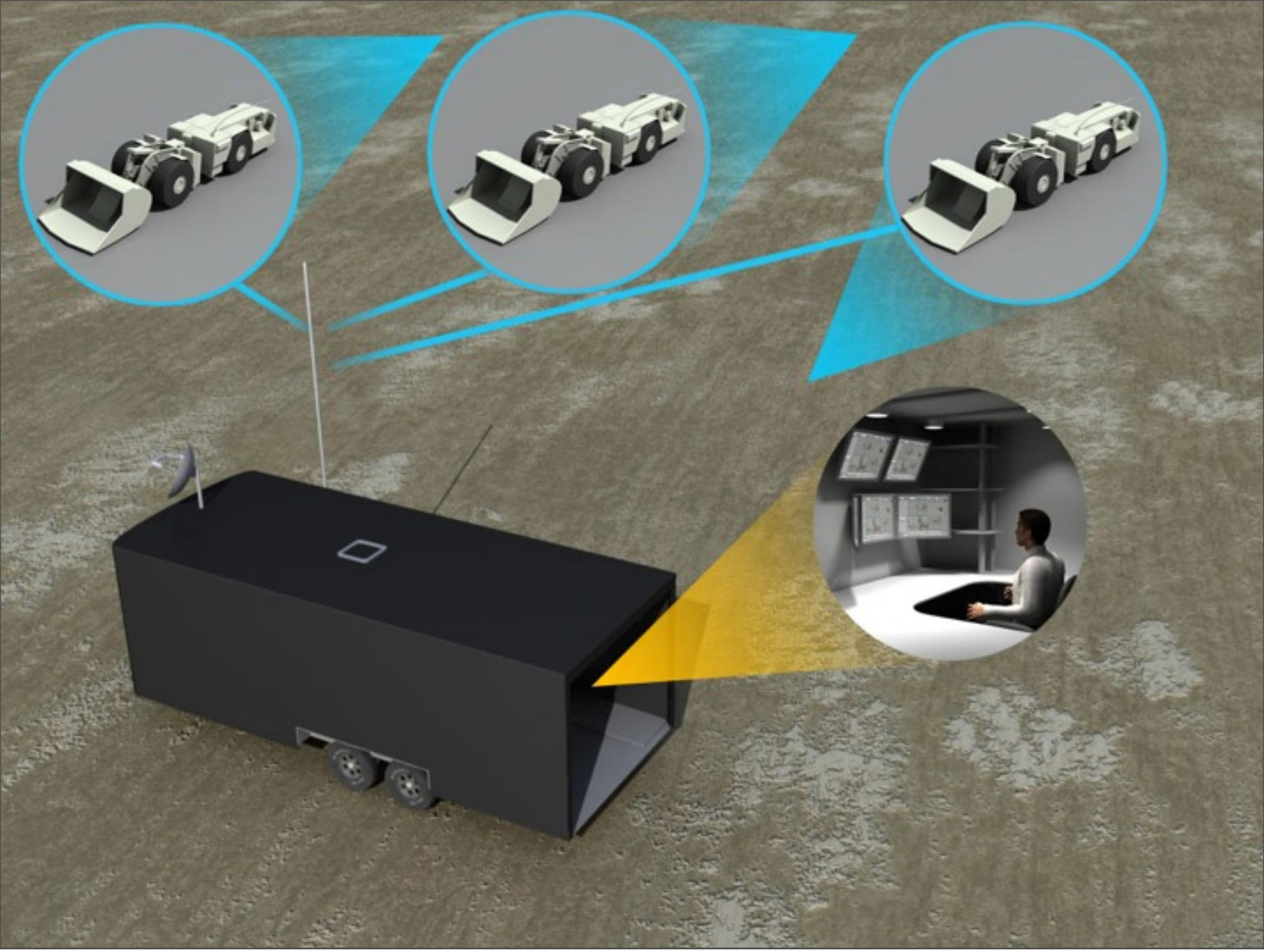
Saturday, November 20, 2010

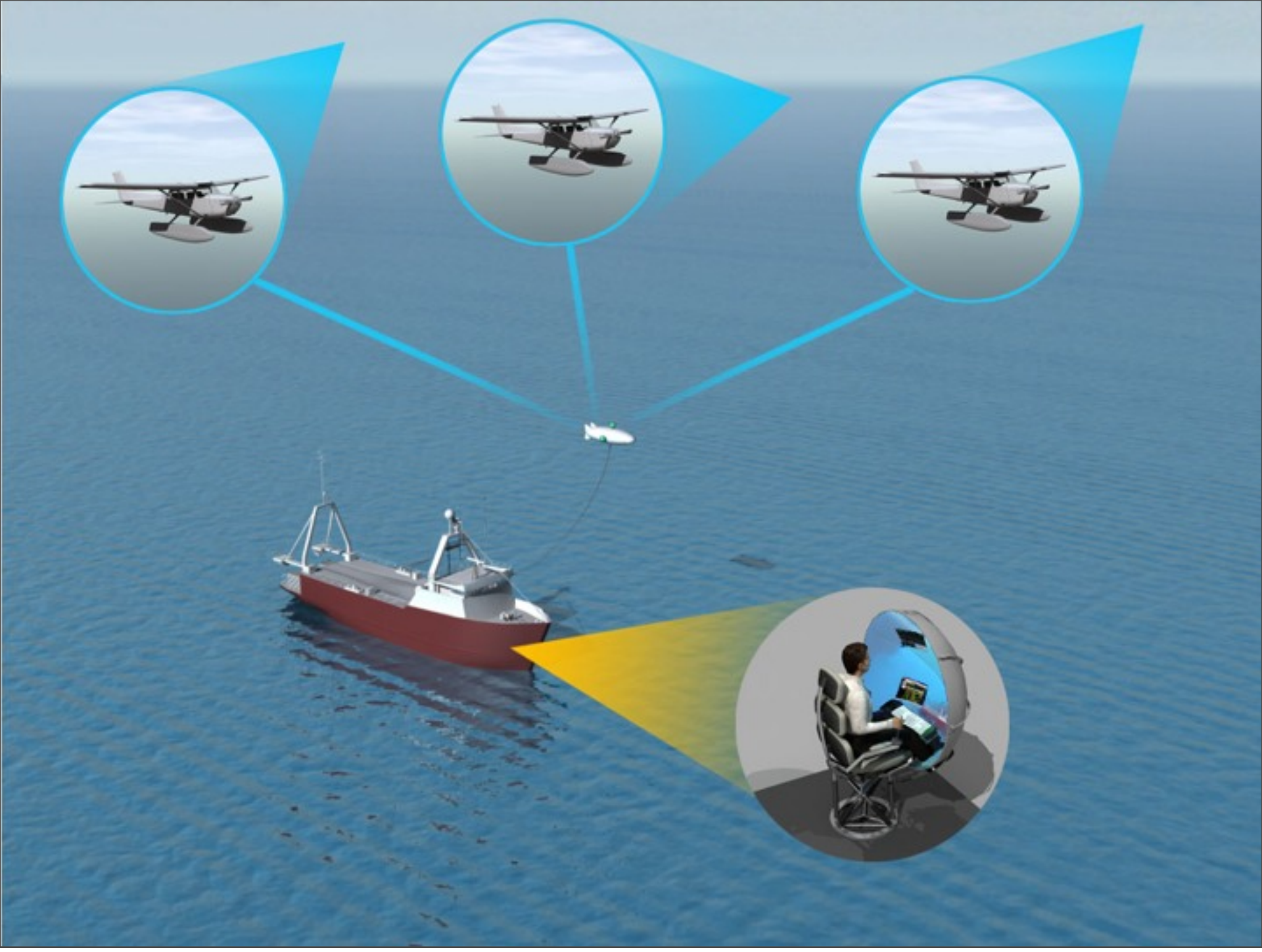
Project Focus Expanded

Underground, Underwater,
Terrestrial, Aerial and Space

Teleoperation Chair







Canadian Research Chair Research Team Main Project Thrusts

- *Teleoperation Control System*
  - *Visual*
  - *Haptic*
  - *Vestibular*
  - *Audio*
- **Communication**
  - High Bandwidth
  - Low Latency
  - RF, Optics, Hybrid and more
  - Standards (802 IEEE)
- **Telerobot**
  - Sensing
  - Actuation
  - Intelligence
  - Hardware and Software

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Tele-submarine
with Free Space Optical Communication System

Hemispherical Optical Transceiver

- Transceiver
  - 70 plus LEDs per plate
  - Optical receiver with 120 degree field of view
  - System capability 20 Mb/s/freq
  - Networking Software Protocol Ethernet
  - Current operational capability 1.5 Mb/s due to needing to redefine communication protocols

Patent Pending

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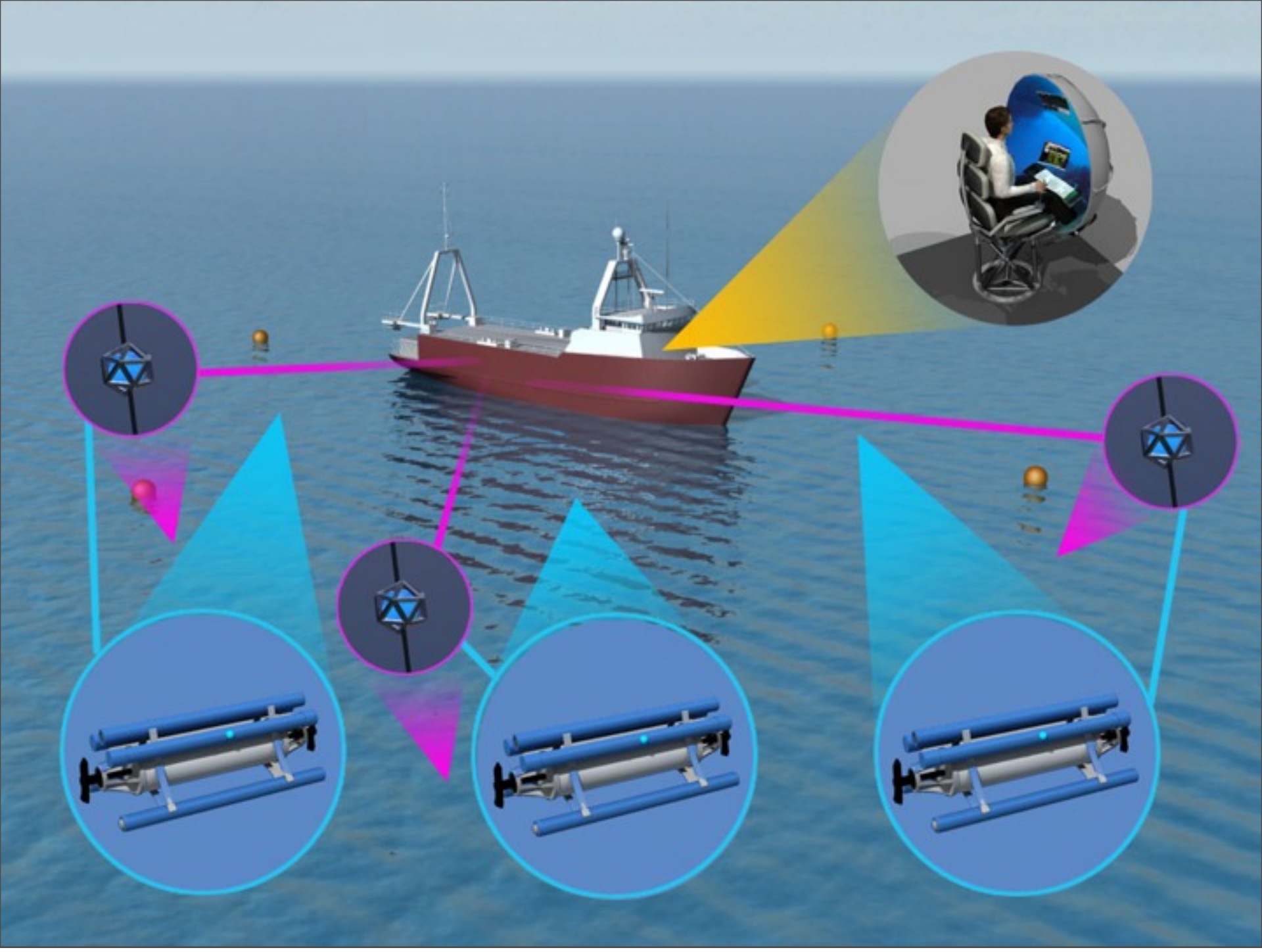
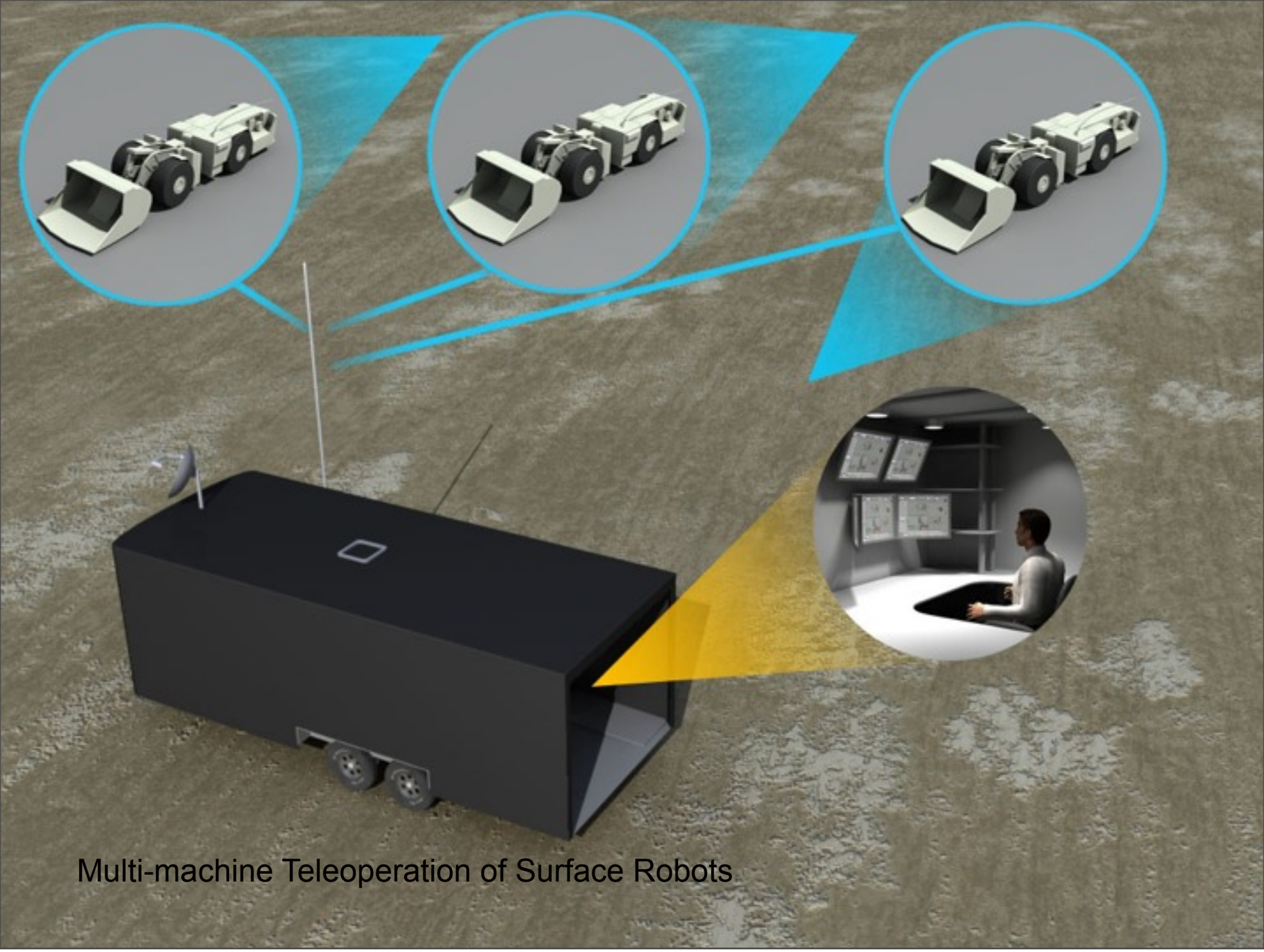
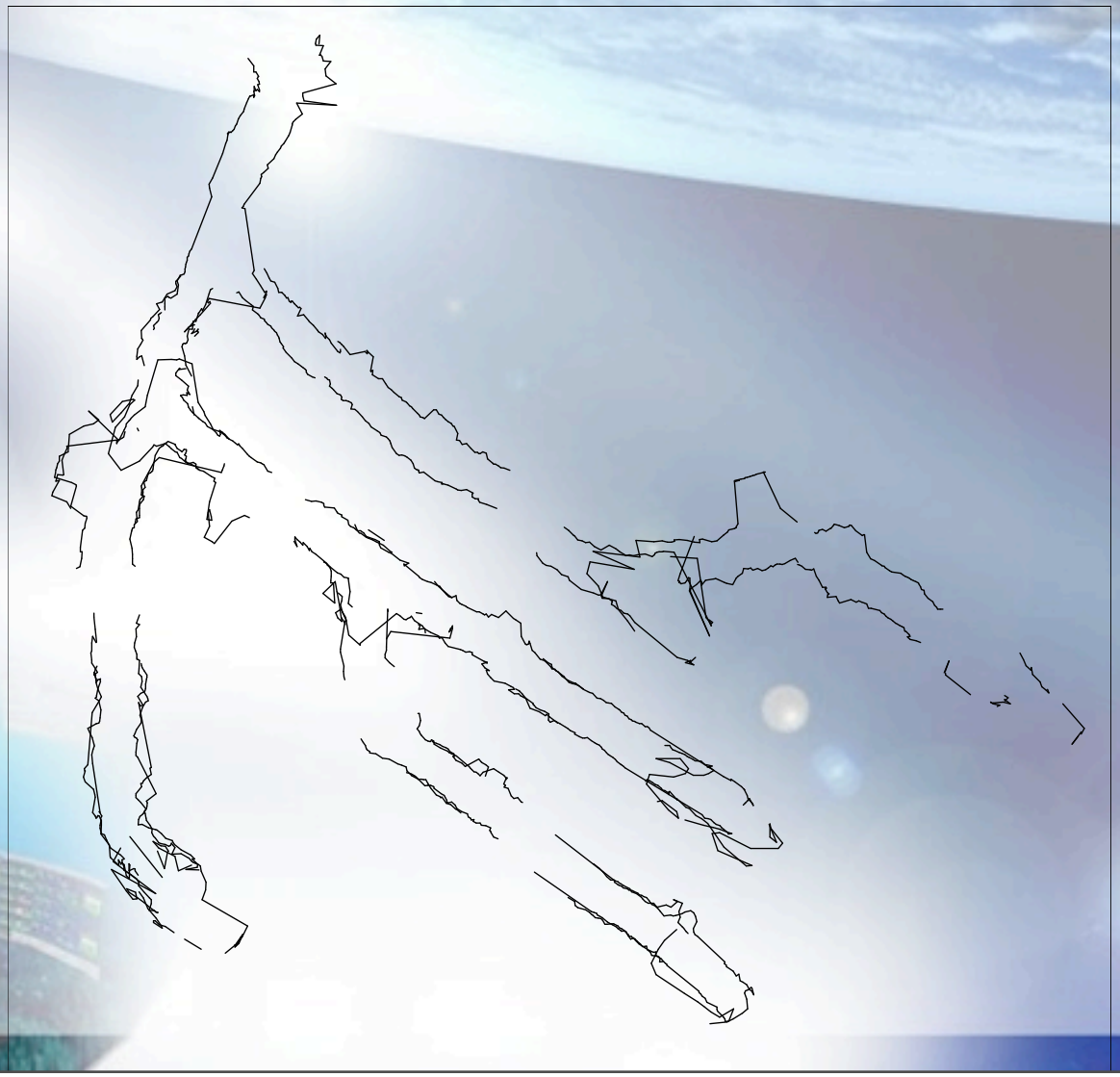



Multi-machine Teleoperation of Surface Robots

2nd Generation Model Telerobots

Day 1 - Survey

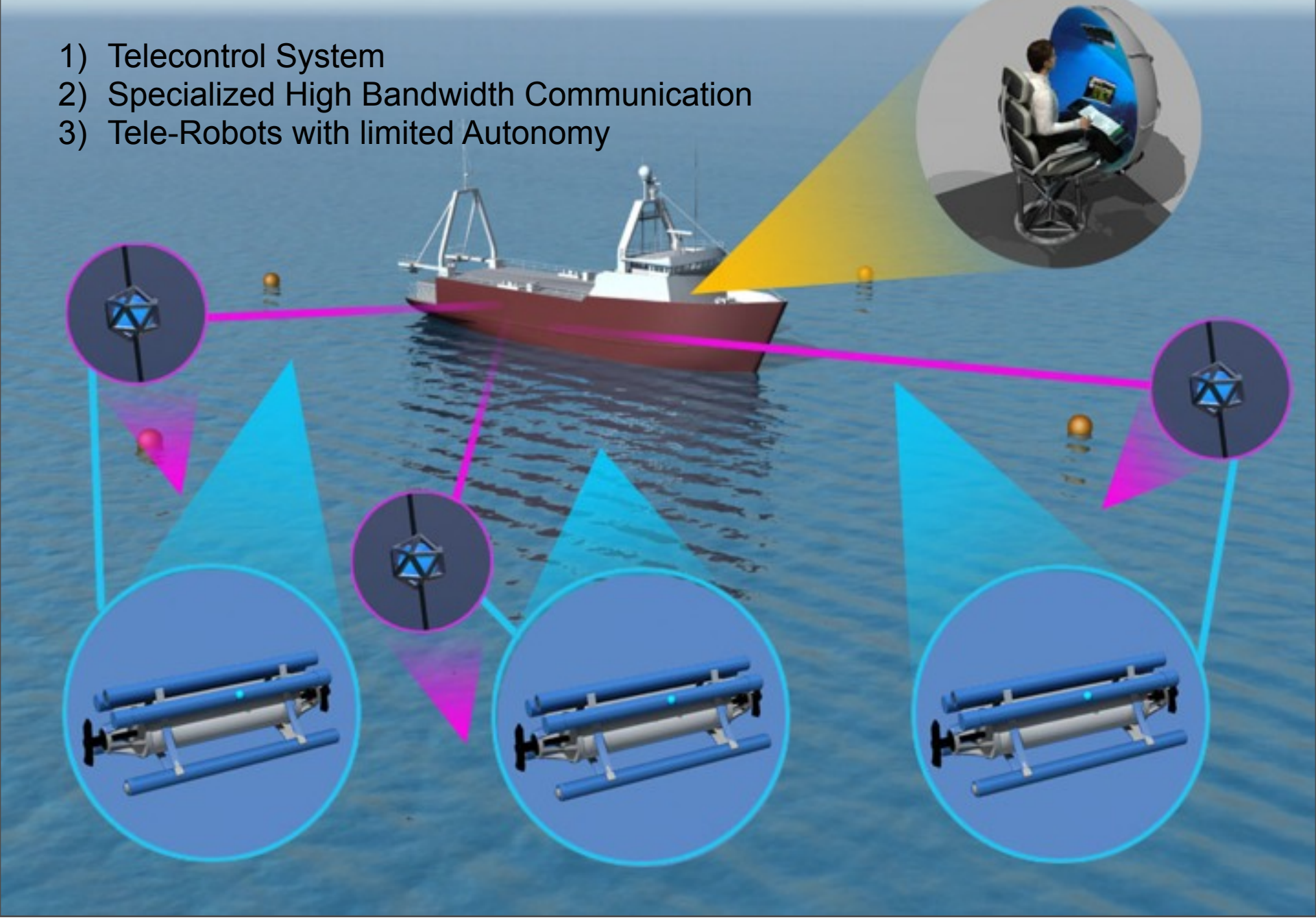


Day 2 - Survey

Day 1 and 2 Surveys Combined

Underwater Mining and Construction

1) Telecontrol System
2) Specialized High Bandwidth Communication
3) Tele-Robots with limited Autonomy



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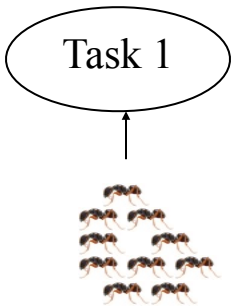
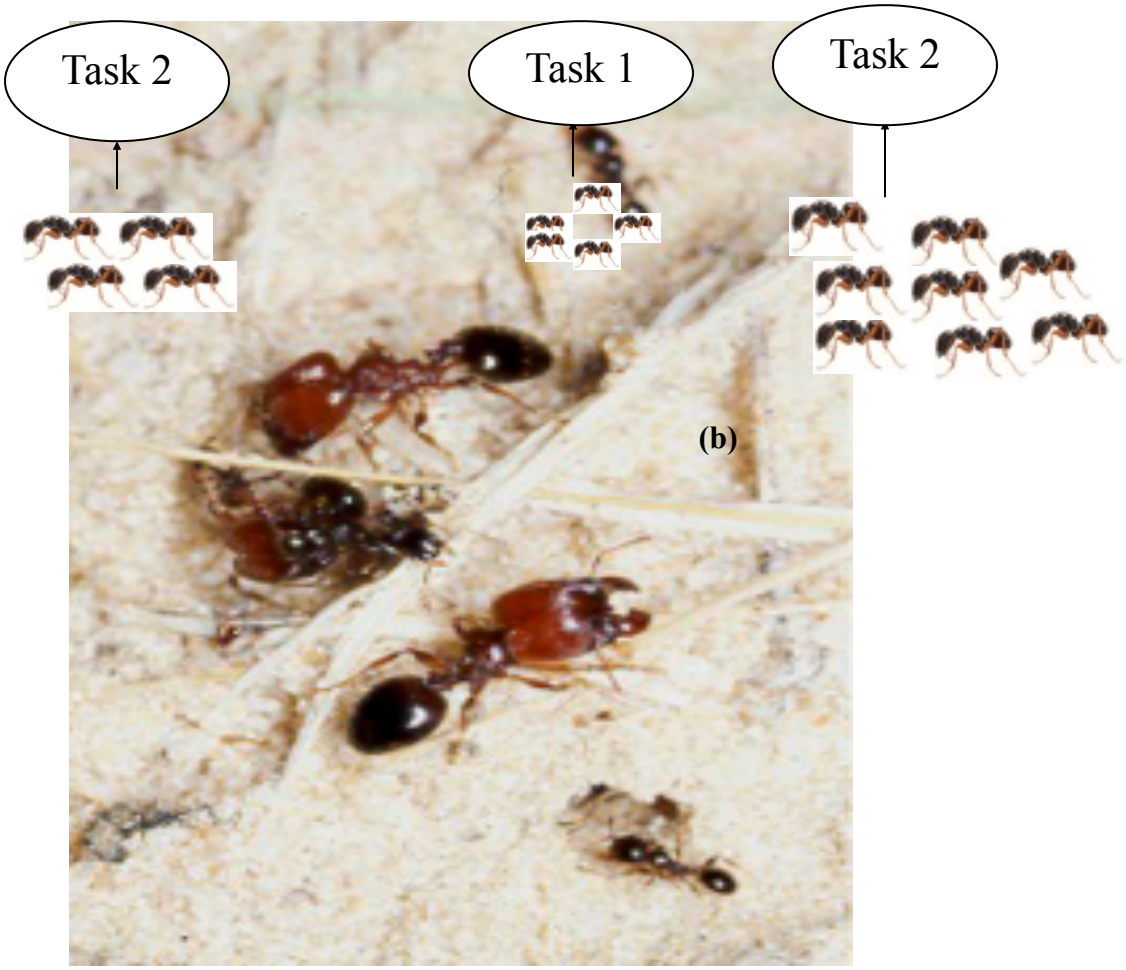
The Wilson Experiment

The Wilson Experiment

The Wilson Experiment



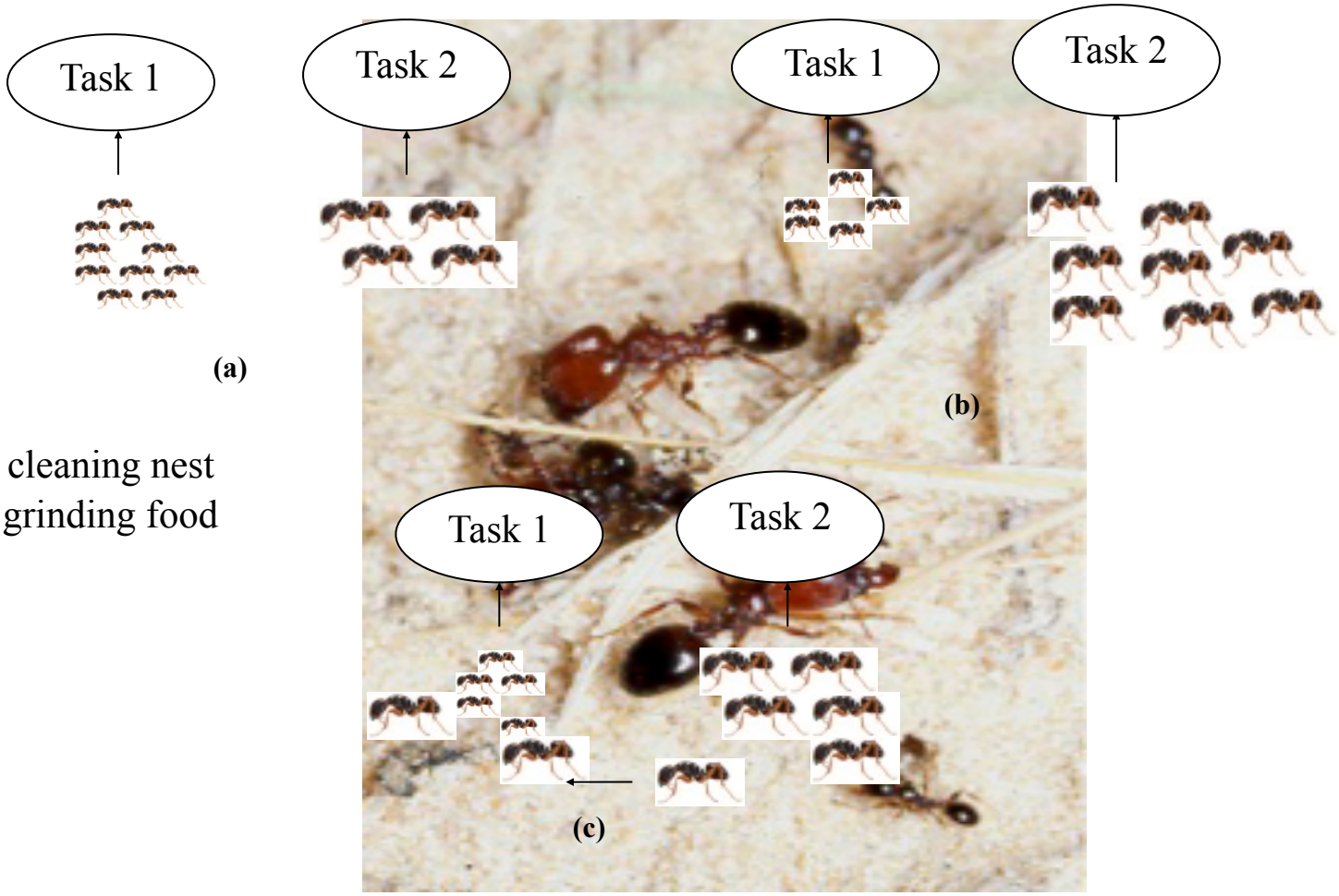
(a)



(b)

Task1 = cleaning nest
Task2 = grinding food

The Wilson Experiment



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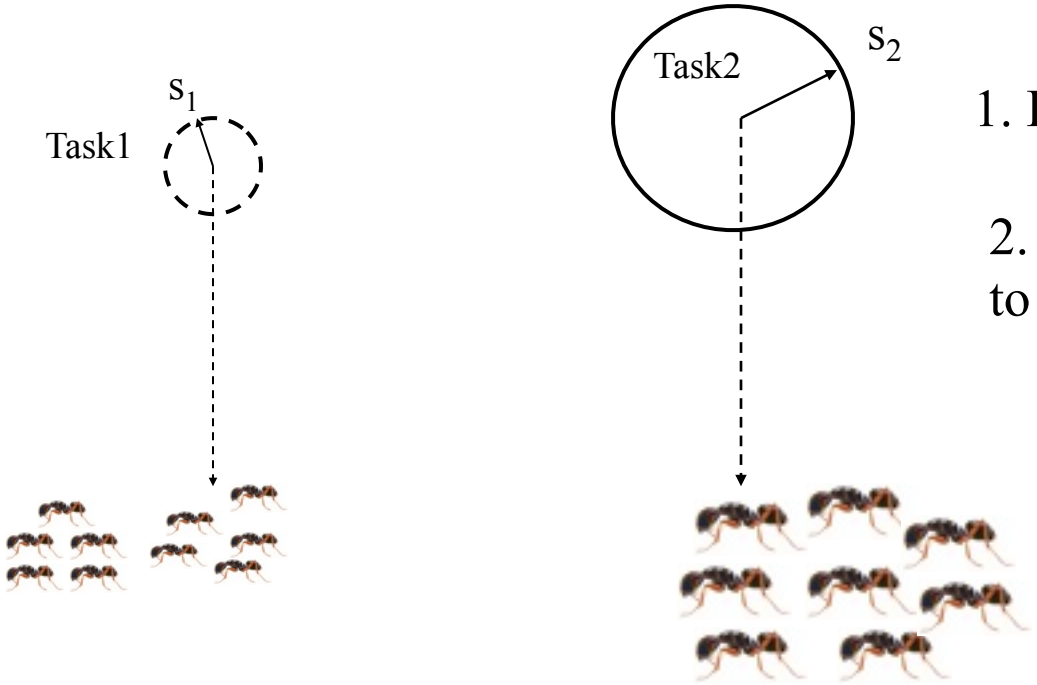
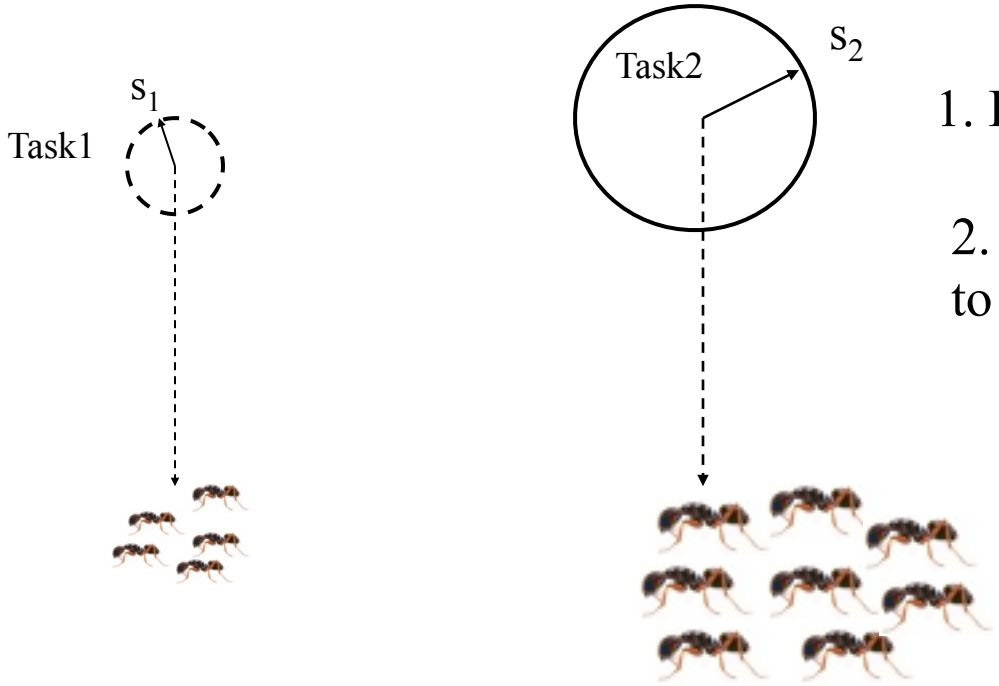


1. Demand or stimulus of a task = s

2. Threshold or ability to respond to a demand



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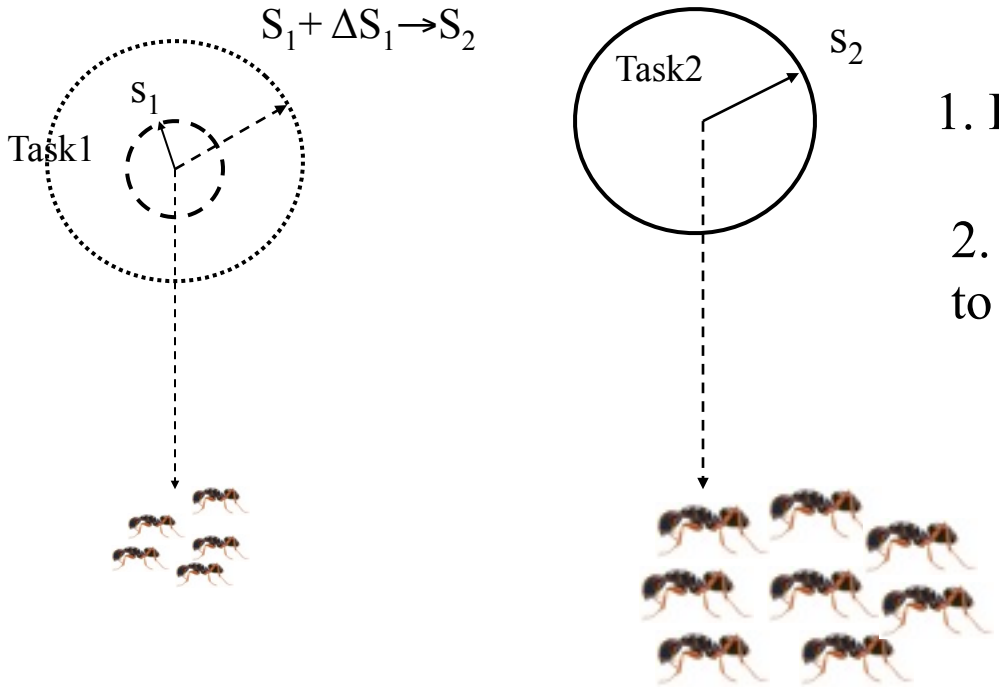

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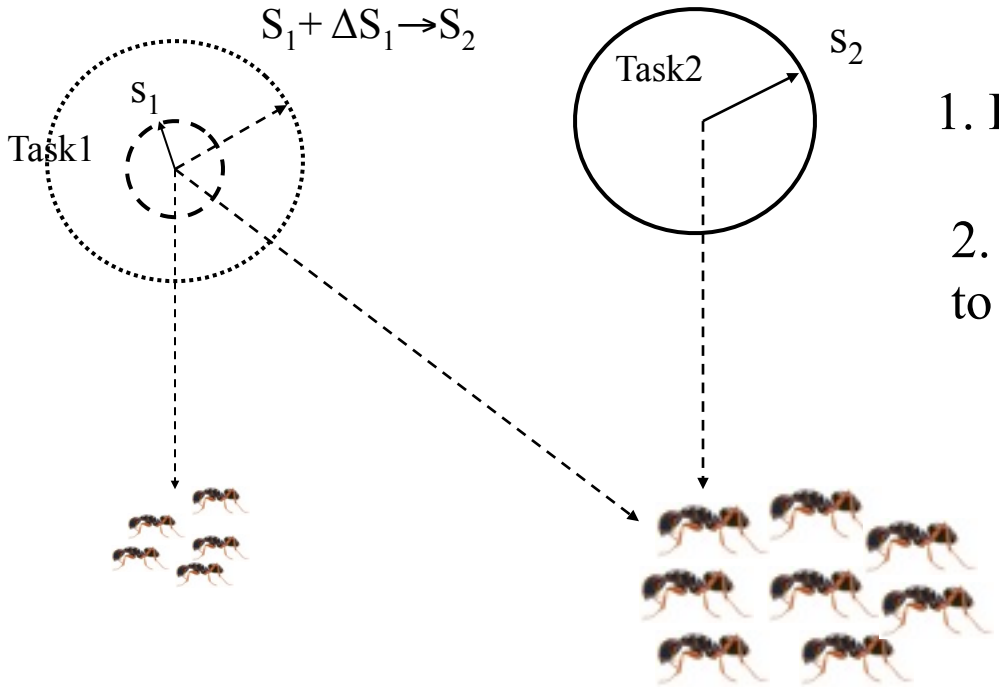

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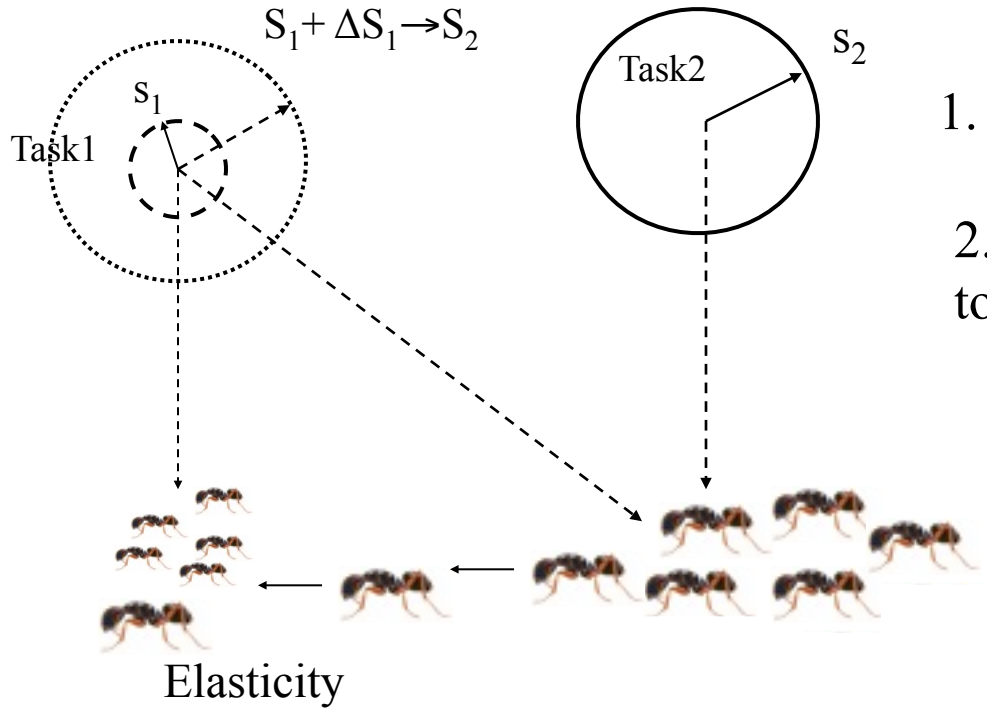

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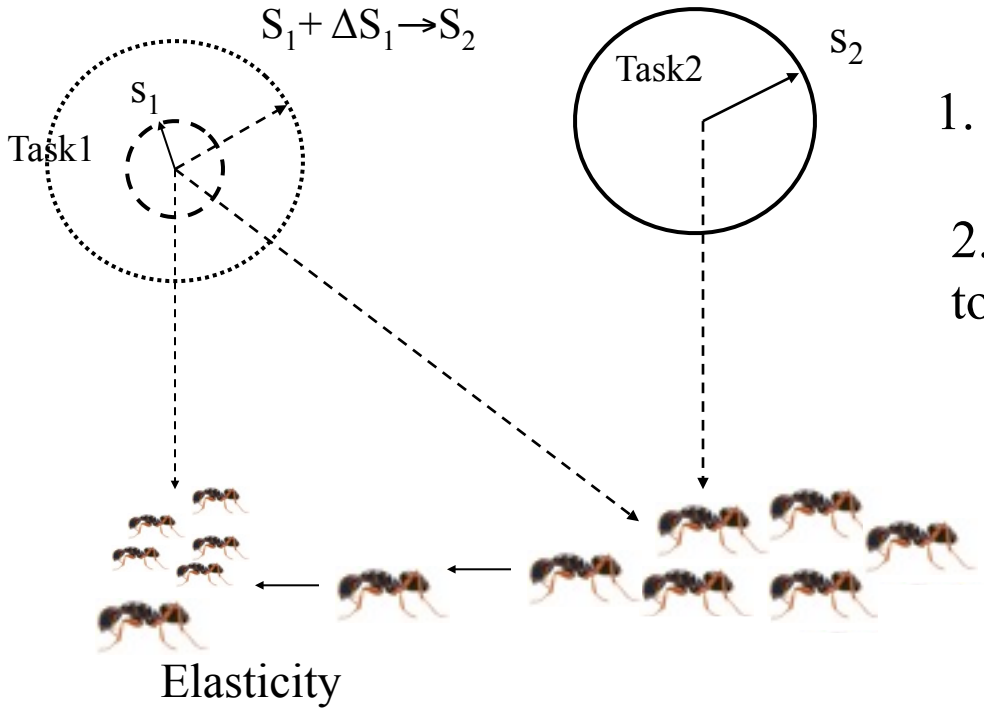

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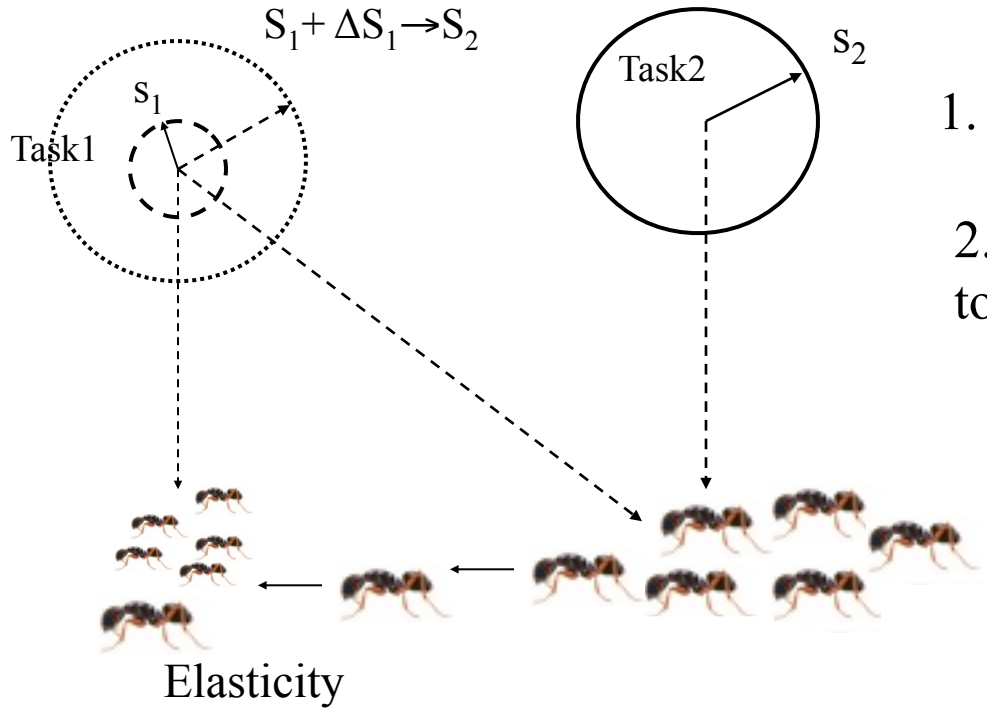
Threshold Model



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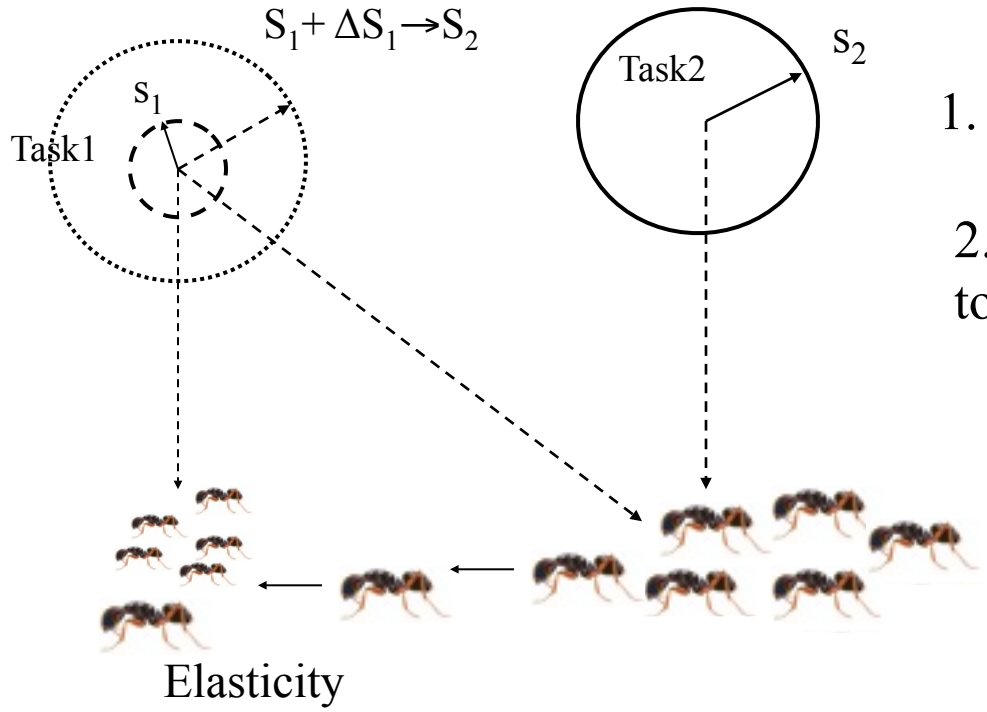
Threshold Model

<u>Tasks</u> = bidding agents

<u>Ants</u> = resources



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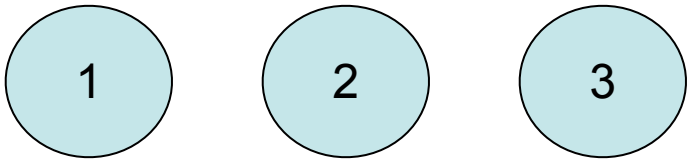
Inspiration → Dispatch system that is capable of adapting to continuous changing operational environment.

Dispatch Decision



A computer (central command) will calculate the response value relative to each agent

The resource (LHD) is allocated to the agent (drawpoint) with the highest response value at the time of decision making

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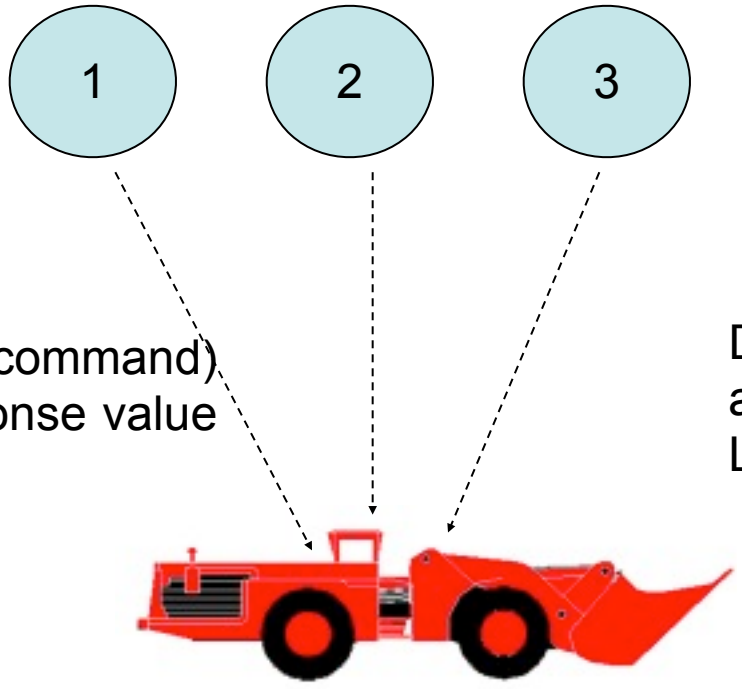


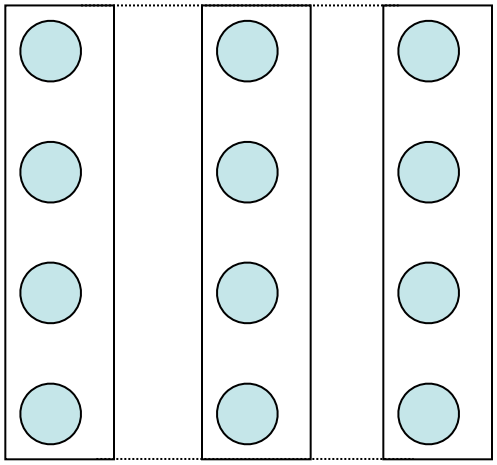
A computer (central command) will calculate the response value relative to each agent

Drawpoints 1, 2 and 3 are competing for this LHD

The resource (LHD) is allocated to the agent (drawpoint) with the highest response value at the time of decision making

The Nested Agent-Based Algorithm

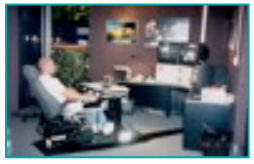
Drawpoints



Maintenance Module

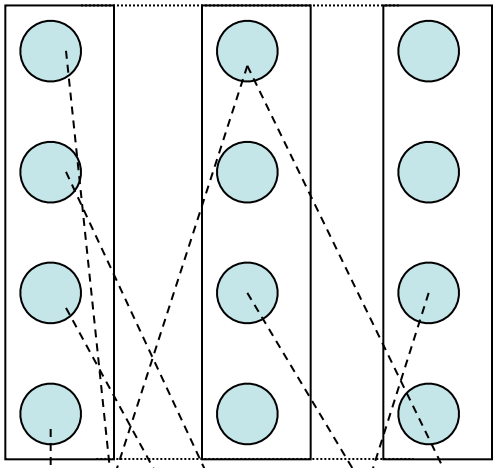
Fleet of LHD's

Teleoperators Fleet



The Nested Agent-Based Algorithm

Drawpoints



Drawpoints competing for LHD's

Maintenance Module

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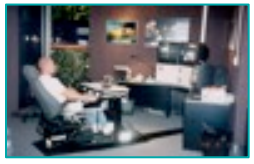

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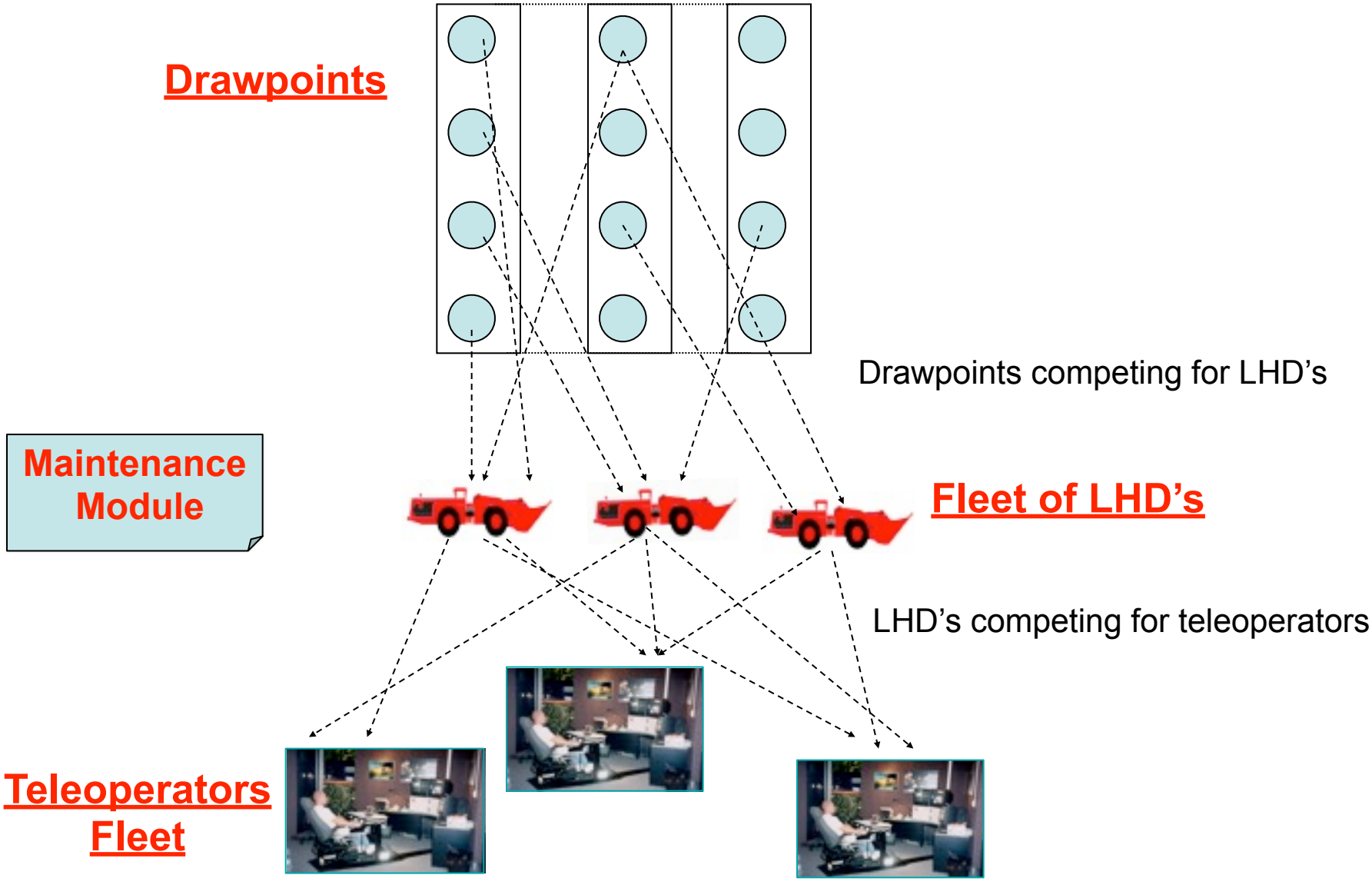

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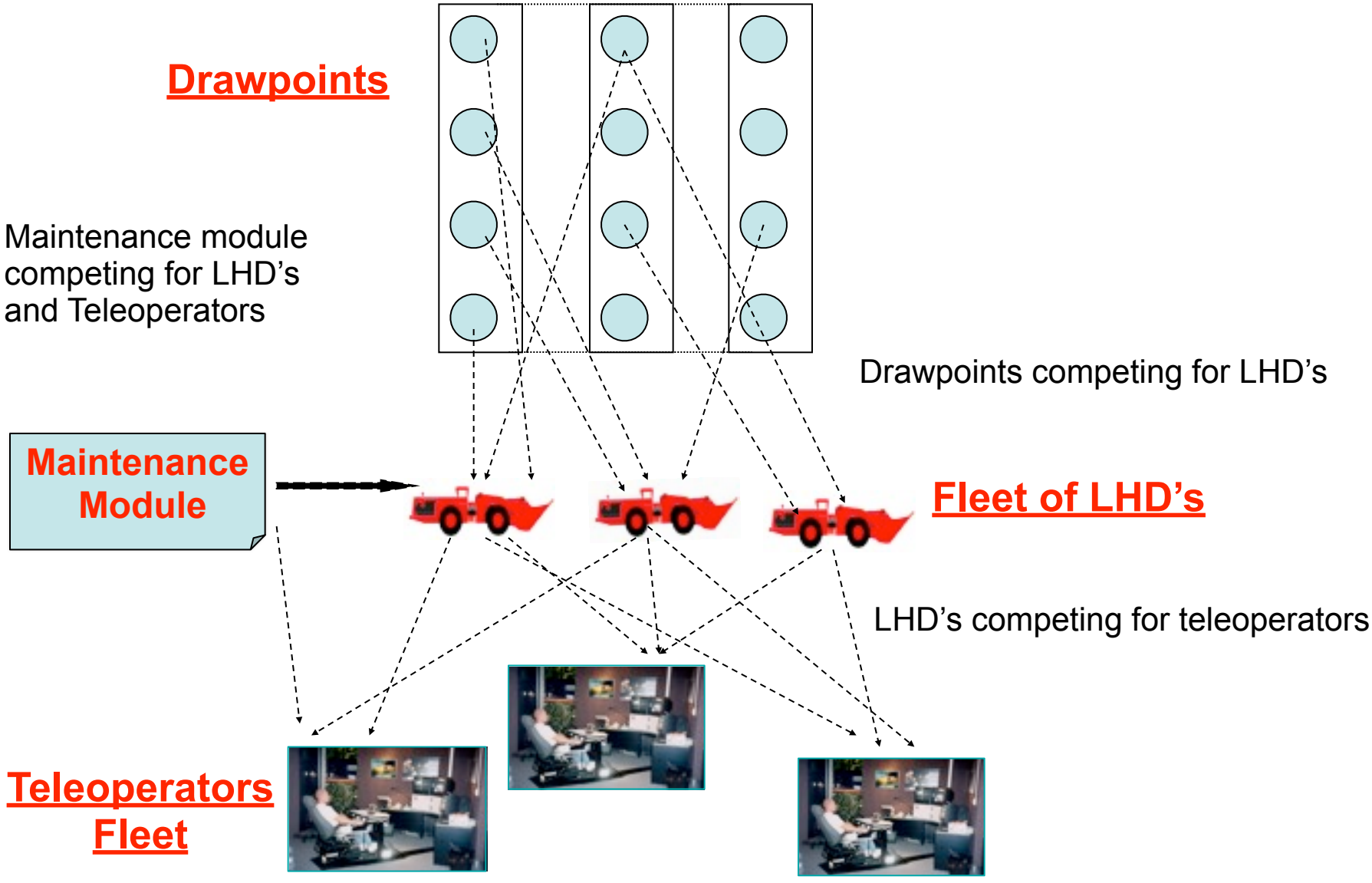
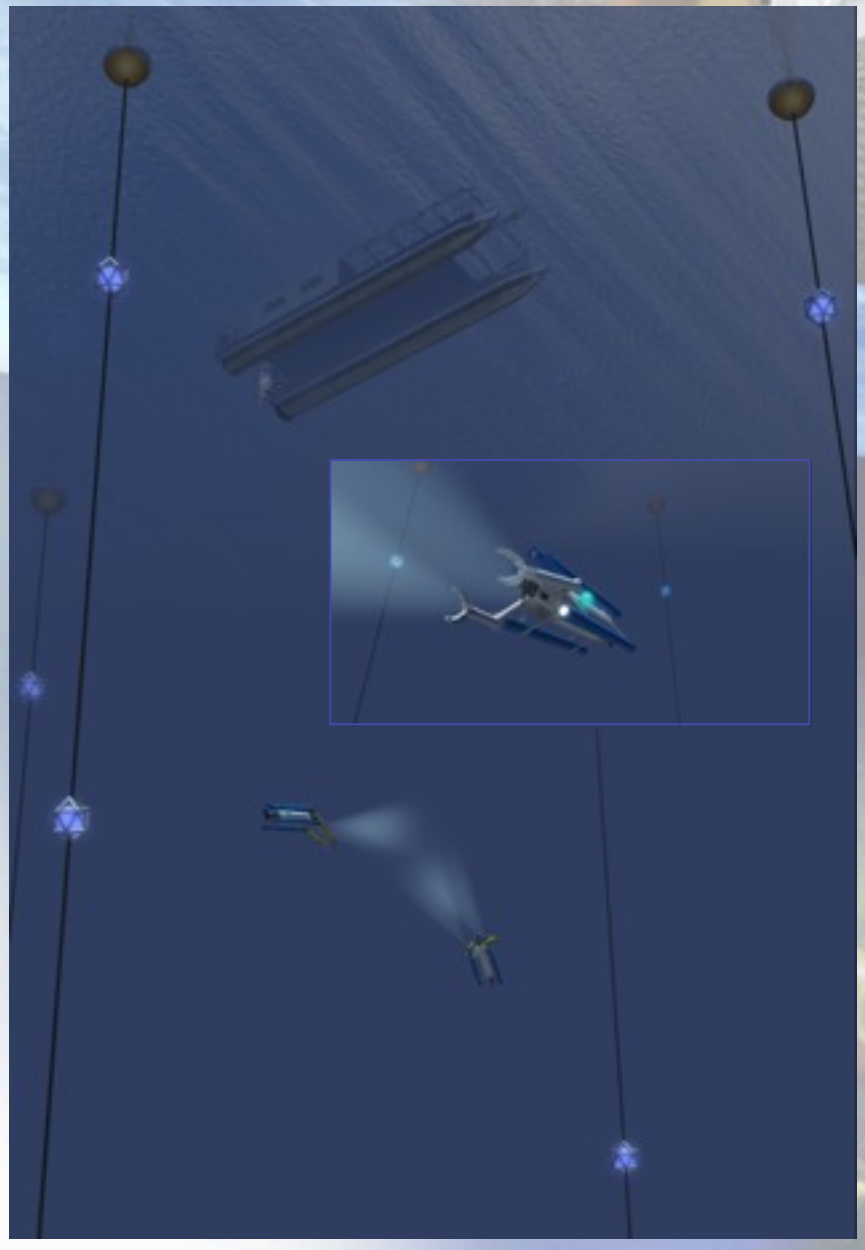
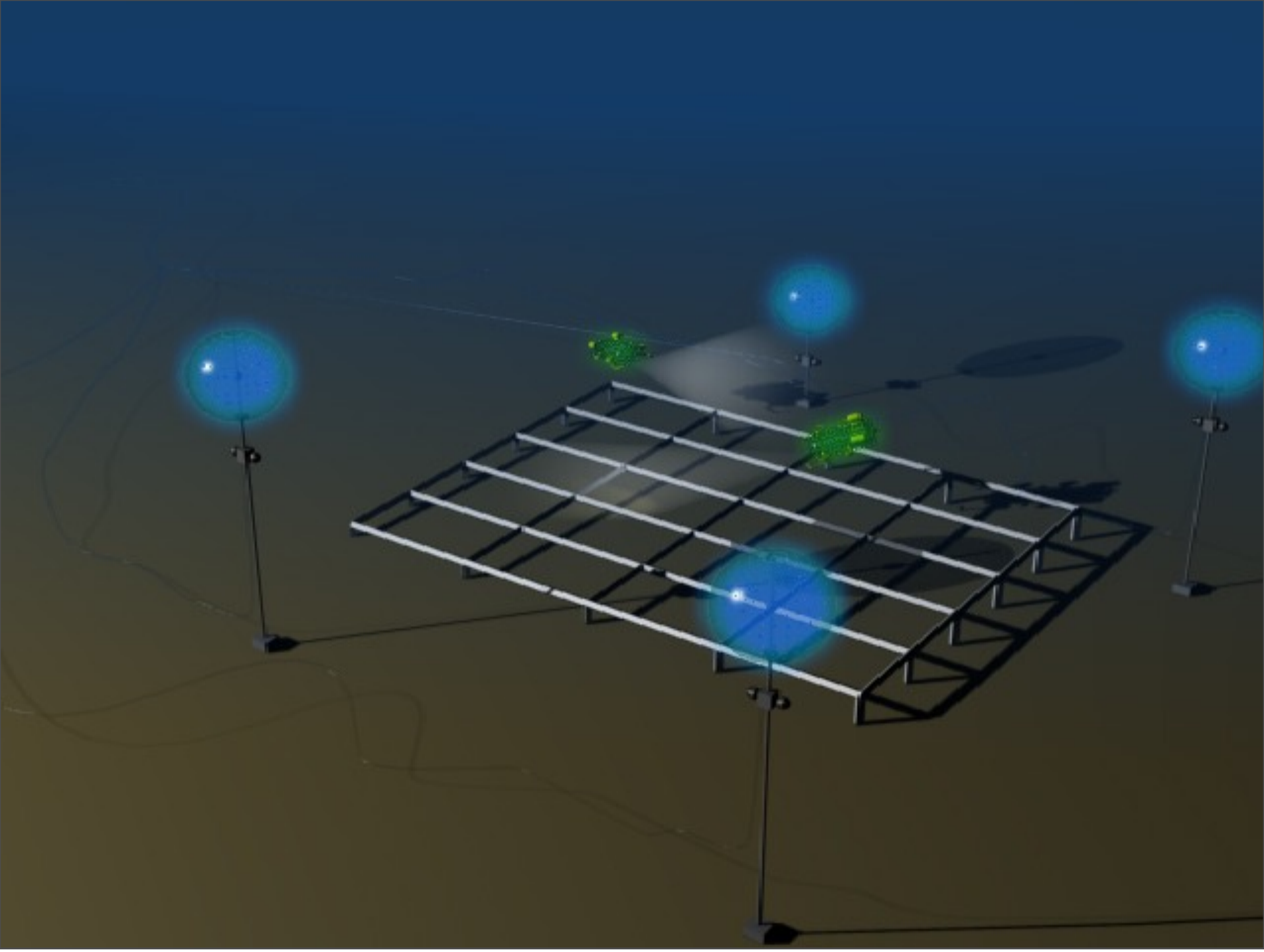


Technology

- The technology was originally built to allow the wireless support of a fleet of Untethered Telerobotic Submarines
- Accomplishments
  - Transmitter/Receiver has been built and tested underwater
  - 1.5 Mb/s tested in fresh water
  - 20 Mb/s tested in the lab





Spherical Optical Communications Technology

Penguin Automated Systems Inc.

PENGUIN ASI
Penguin Automated Systems Inc.

The World's Best Technology Conference 2007

Autonomous vs Teleautomous
After 20 years of doing this in mining
the cultural barriers are huge