CETDP Cross Enterprise Technology Development Program

The Changing Role of Robotics Research Within NASA Cross-Enterprise Program

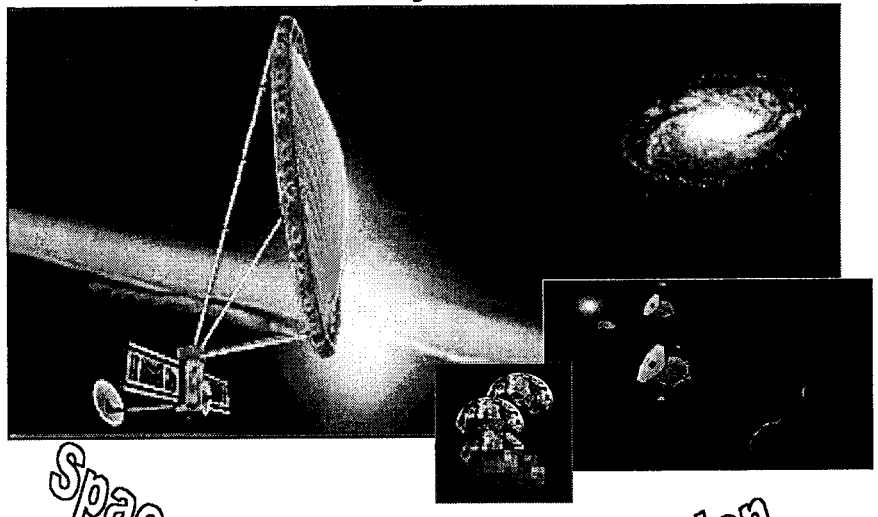
1999 Robotics Industry Forum
Orlando, FL
November 3-5, 1999

Dr. Charles R. Weisbin
Surface Systems Thrust Area Manager
Charles.R.Weisbin@jpl.nasa.gov (818) 354-2013
http://cetdp.jpl.nasa.gov/surface/ssys.html

Surface Systems

NASA Mission

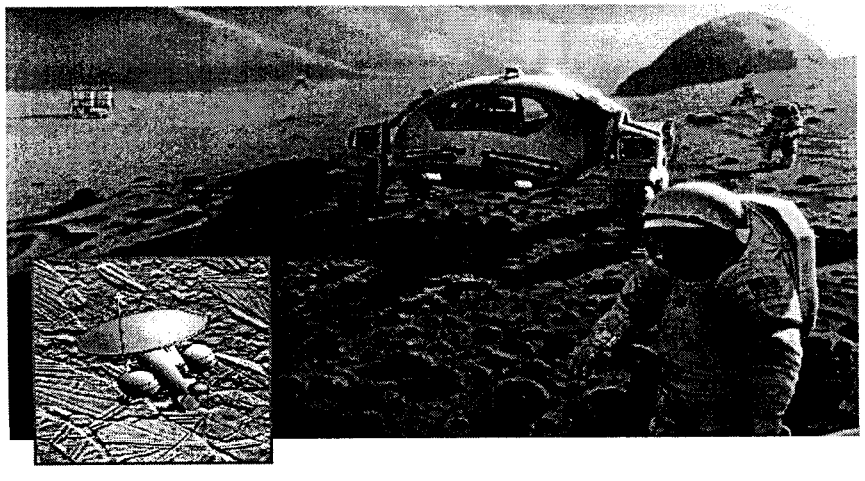
To advance and communicate scientific knowledge and understanding of Earth,he Solar System, and the Universe.

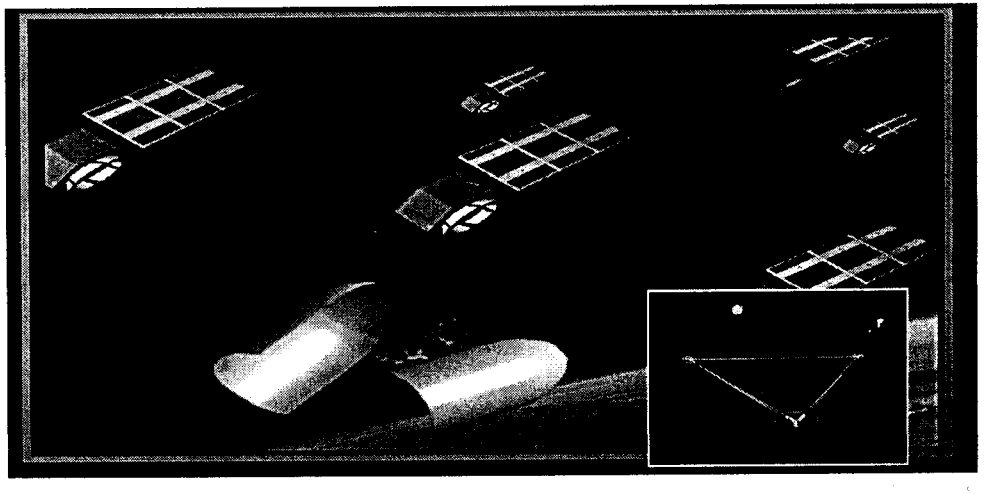


Permanent Human Presence in Space

Space Discovery & Exploration

Understanding Earth System Changes

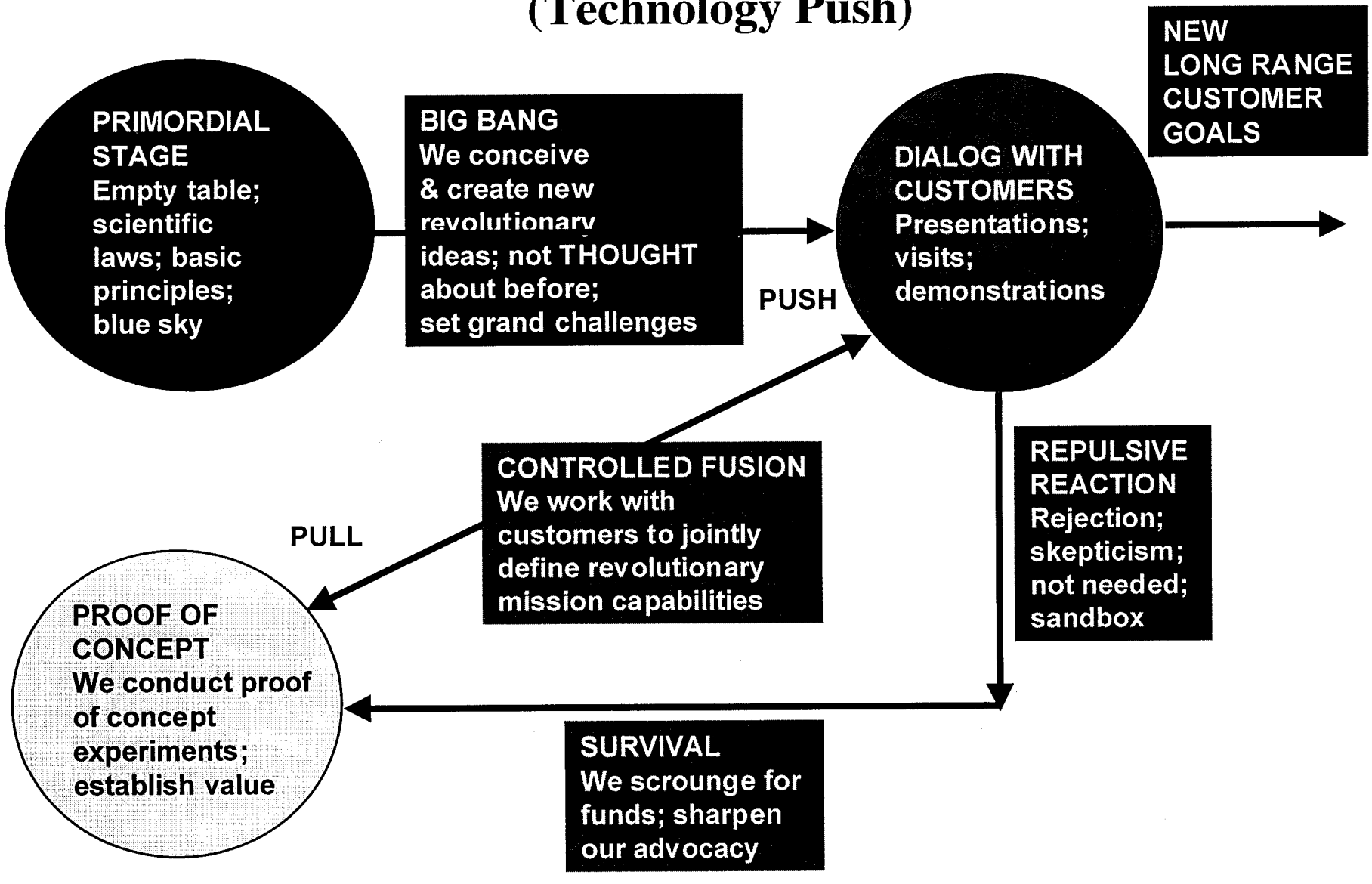




CETDP Charter is for Revolutionary Technology

- With a "Pull" component of vested Enterprise Strategic Tech Requirements.
- With a "Push" component guided by the Thrust Area Managers
- With a Core Competence responsibility to the NASA Centers
- With a duty to make use of academia, industry and agencies
- With the responsibility to have a strong positive effect on NASA

We Create Revolutionary Challenges and Work with Customers To Create New Long Range Goals (Technology Push)



Inputs to CETDP Come From A Variety Of Sources

- Enterprise Requirements and Roadmaps
- Direct Meetings with Code S Theme Directors And Codes Y and M Management
- Inter-Agency Committees Plans and Priorities
- Related Program (e.g. SBIR, Explorer) Coordination
- Direction from the Administration and Congress

Our Customer Long Range Challenges are Our Challenges

SPACE SCIENCE

ORIGINS: Precision, ultra-light optics; very large diffraction-limited telescopes

STRUCTURE & EVOLUTION OF THE UNIVERSE: Large ultra light/stable observatories; high-precision formations for VLBI; measure cosmic radiation from faint astronomical sources

SOLAR SYSTEM EXPLORATION: Robust economical colonies of intelligent robots for planetary exploration

SUN EARTH CONNECTION: Solar sails; constellations of autonomous miniature S/C enabled by innovative instruments

EARTH SCIENCE

ADVANCED SENSORS : Discover new events and interactions from unique vantage points of space, aircraft, and in situ platforms

SENSOR WEBS: Respond quickly, intelligently and cost effectively to events in the Earth system

ACCESS TO KNOWLEDGE: Information system architectures for easy access to global information for science, education, and applications

INFORMATION SYNTHESIS: Integrated architectures, to cut cost, and support productive, economical and timely missions

HEDS

OPERATIONS: Enable autonomous operations in support of humans in Space

SCIENCE RESEARCH: Extend scientific discovery and expand scientific knowledge

EXPLORATION: Enable affordable and robust human exploration beyond LEO

HUMAN LIFE SCIENCE: Enable humans to live and work permanently in space

Revolutionary Technology That Has Been Accepted that Does Not Exist

Revolutionary Technology That Has Not As Yet Been Accepted

Cross-Enterprise Technology Development Program Thrusts

- Ultra-Lightweight Structures & Observatories
- Surface Systems
- Breakthrough Sensors
- Thinking Space Systems
- Next Generation Infrastructure
- Power & Advanced Propulsion
- High Rate Data Delivery
- Micro/Nano Spacecraft
- In-Space & Atmospheric Systems
- Thinking Systems

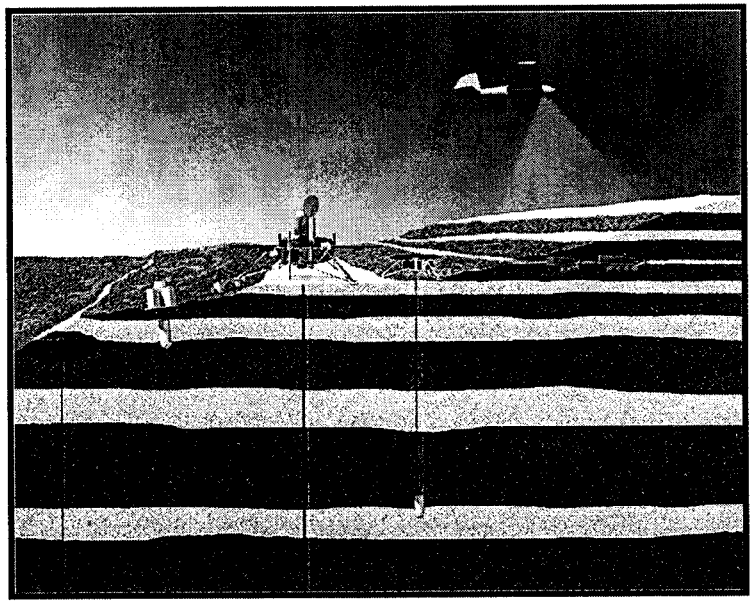
Outputs from CETDP Are Widely Used

- To: focussed programs in all enterprises for further development and space flight validation
- To: industry for commercialization
- To: other agencies as requested

GETDP Cross Enterprise Technology Development Program

Robotic Outposts: A New Paradigm of Exploration

Mars Polar Terrain Science Laboratory



Elements:

Surface, subsurface, orbiting and airborne investigations

Central labs for analysis/coordination

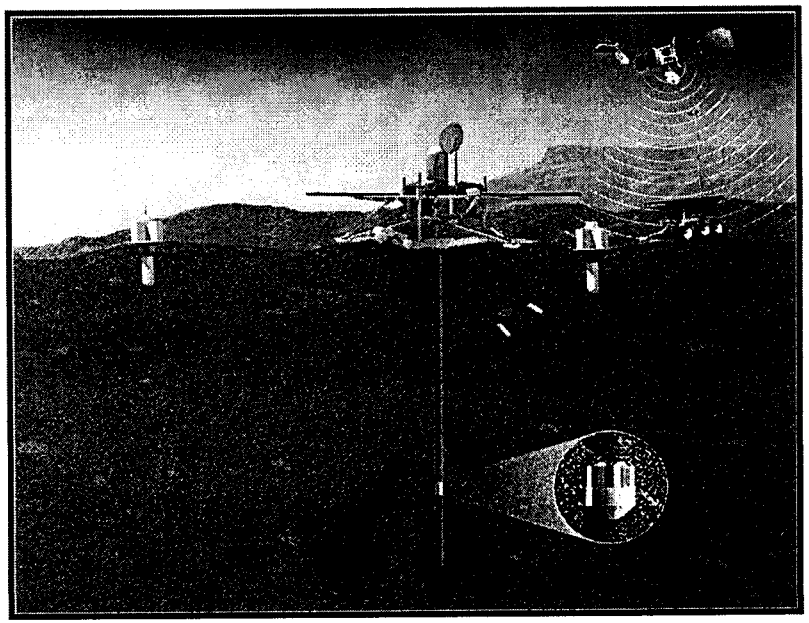
Miniature ascent vehicles

Characteristics:

Distributed robots for wide-area, 3-D exploration and sampling

Ultra-miniature, extended life, expendable/replaceable, adaptable, interactive

Hydrothermal Vent Science Stations



Mars Robotic Outposts and Future Sample Returns

- Surface Systems / Aerial Systems
  - Miniaturized long-life sampling rovers
  - Aerial vehicles - aerobots, airplanes
  - Subsurface sampling and mobility
- Aeroassist
  - Aerocapture and lightweight systems for Mars / Earth entry
- Advanced Power
  - Miniature radioisotope systems
  - Lightweight solar arrays for surface applications
- In situ Sensing Components, In situ Resource Extraction and Processing Components
  - Sample acquisition and handling systems
  - Miniature chemistry and geophysics labs
  - Smart sample identification and selection sensors
- Autonomous Execution and Control
  - Precision landing and hazard avoidance
  - Autonomous surface mobility
  - Interactive spacecraft and goal-directed behavior

Miniaturized Surface Robotics Systems

(Illustrative Examples)

State-of-the-Art	5 Years	15 Years
SMALL ROVERS • 10-100 gm mass • Wheels or legs • R & D labs; flat surfaces • Tens of discrete sensor, actuator & computing devices	NANOHOPPERS • Self-sustaining devices • Integrated sensors • Hop over fractal terrain • Move long distances • Deploy from small containers	NANOROVER NETWORKS • 10-1000 member arrays • Mobile large-area network • Cooperative science • Collection of multiple data types
SMALL MOLES • Tethered lab devices • Penetrate < 1 m regolith • Local subsurface operations	NANOMOLES • Tether-less • Penetrate ice & hard materials • Deep subsurface exploration	NANOMOLE COLONIES • Multiple subsurface sites • Cooperative science • Mobile multi-sensor fusion
SMALL WORK DEVICES • Grasp, grip, dig, trench & scoop • Discrete electromechanical components	NANOGRIPPERS • Muscle-like actuating devices • Nanorover mounted • Grip & move particles, pebbles and other scientific samples	ARRAYS OF MULTI-LIMB • NANOROBOTS • Centipede & ant like • Useful cooperative work • Multi-level coordination

Will Our Dreams Materialize?

- Majestic Challenges Facing Us
  - WE picked these challenges "not because they are easy but because they are hard"
  - As we take the long view, WE may never get there
  - Some of the challenges may take generations to overcome
  - Autonomy is easy to conceive but difficult to implement
  - For the foreseeable future, there will be fundamental limits in ways to interact with the environment
  - Human like dexterity, touch, and intelligence are yet to be matched
  - Much revolutionary technology is in its infancy (e.g. Sojourner)
  - Stakeholders (sponsors, public, everyone) may lose patience and cut budgets

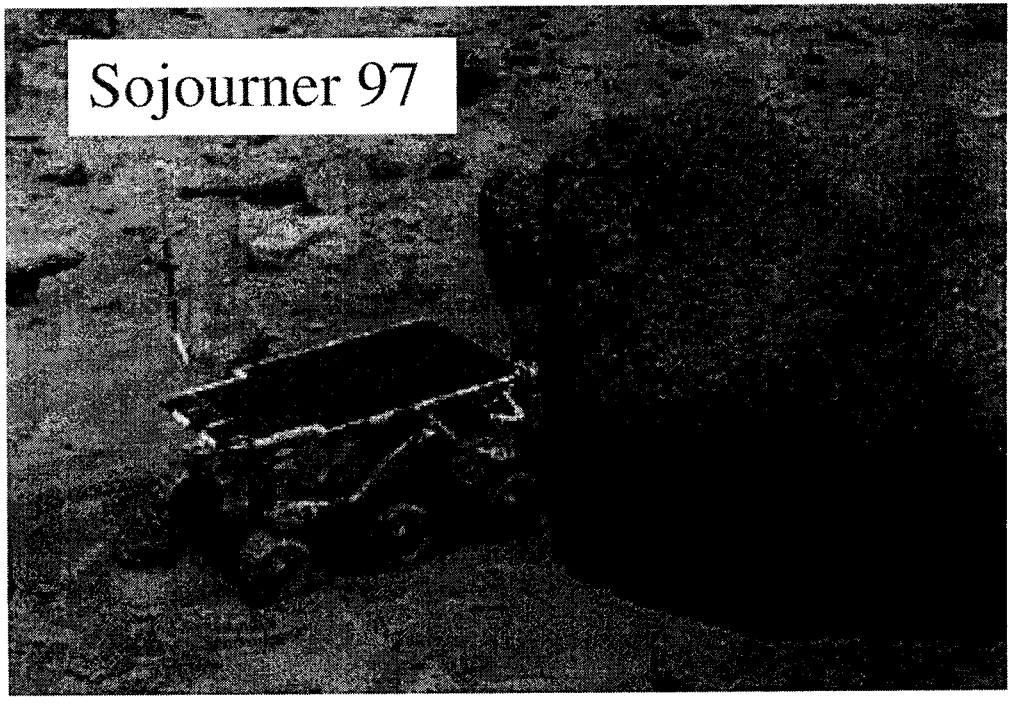
The Giant Rover that Could

Key Technologies

- Autonomous hazard avoidance & navigation
- 6-Wheel rocker-bogie mechanism
- APXS instrument deployment
- Miniaturized rover system

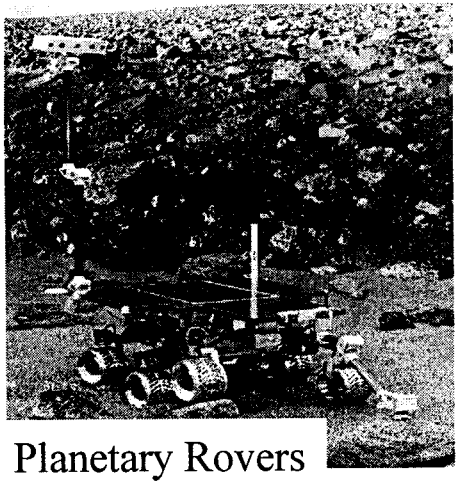
In-Space Robotics Performance

- ~100 m traverse
- ~15 APXS measurements
- ~20 Soil mechanics measurements
- Deployment Maneuver from Lander

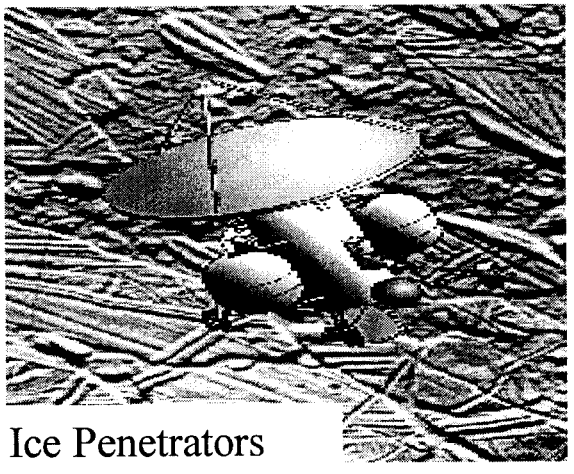


CETDP Cross Enterprise Technology Development Program

Relevance to Space and Earth Science Enterprise

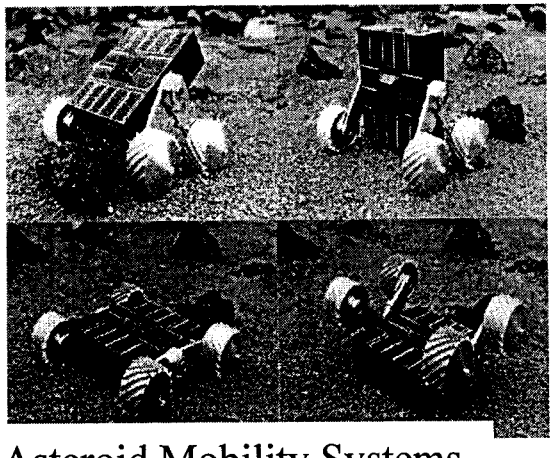


Planetary Rovers

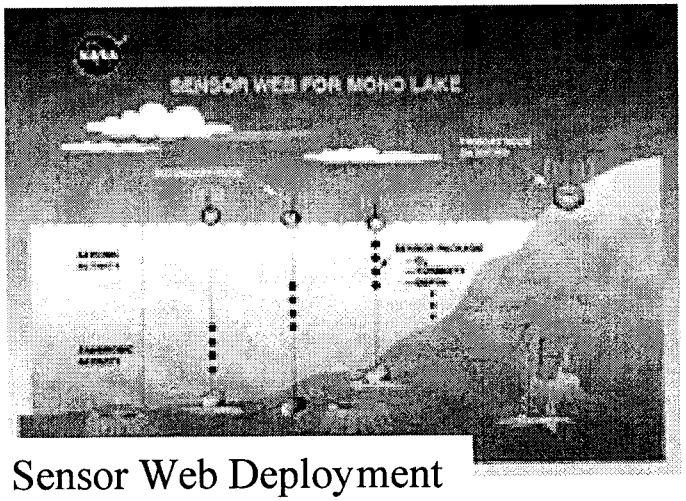


Ice Penetrators
Sub-Sea Robots

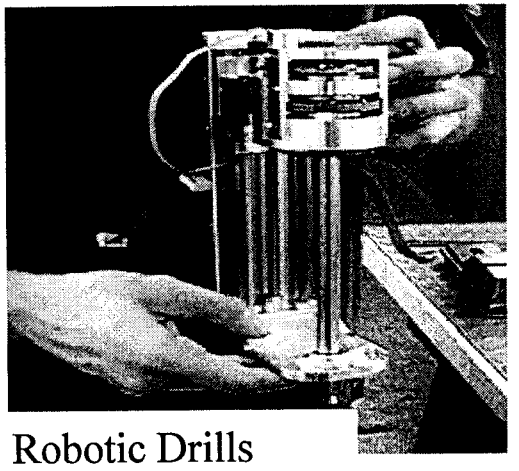
Asteroids & Comets
Anchor & Sample Systems



Asteroid Mobility Systems



Sensor Web Deployment



Robotic Drills
Mini-Core Devices

Surface Systems

CETDP Cross Enterprise Technology Development Program

Robots for Facility Assessment

PRODUCT DESCRIPTION: a remotely operated system for structural assessment of the Chernobyl nuclear facility structure.

PRODUCT FUNCTION: locomotes through rubble, makes 3-D photo-realistic maps, acquires samples & logs radiation data

UNDERLYING TECHNOLOGIES:

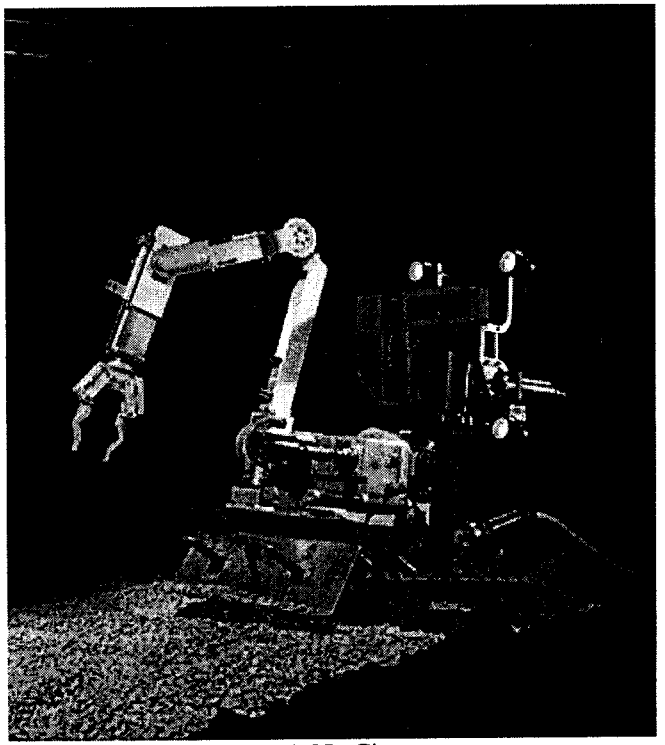
- trinocular stereo imaging
- 3-D surface mesh merging & colorizing
- automated drill sampling
- radiation hardened components

Current TRL

- TRL 6 (99)
- Delivered to Chernobyl Nuclear Power Plant 4/99
- First entry expected Summer 99

PRODUCT DEVELOPERS

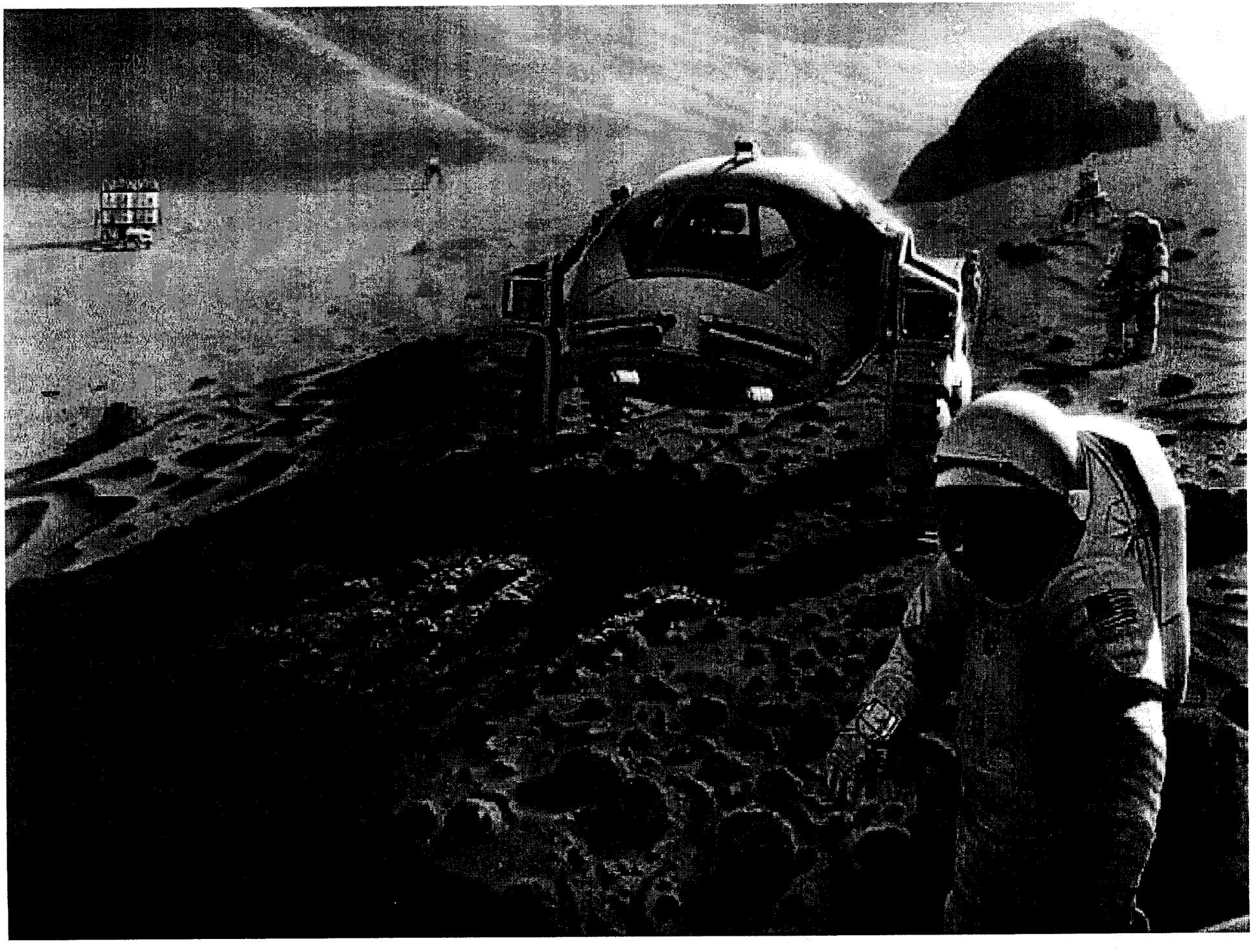
- CMU: Osborn; (412) 268-6553; oz@cmu.edu
- RedZone; Denmeade; tdenmeade@redzone.com

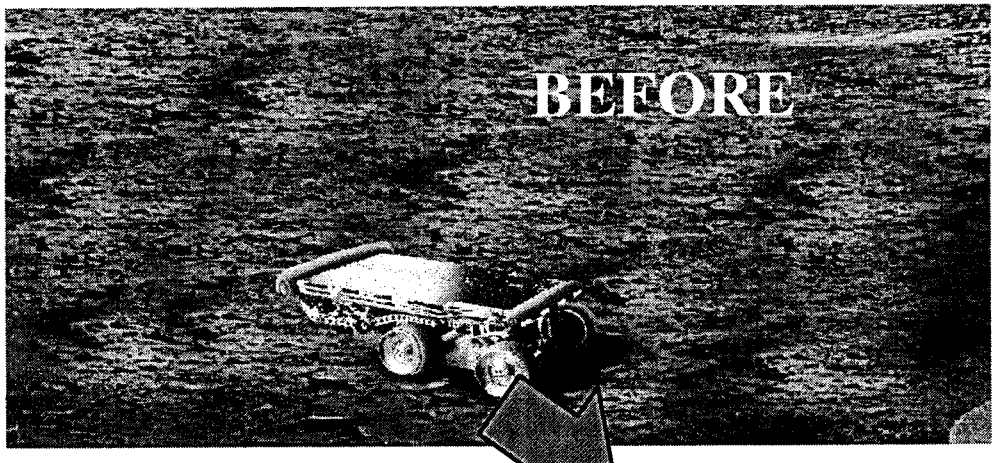


CUSTOMERS

- Construction and facility management companies
- 50% co-funded by US DOE International Nuclear Safety and Non-proliferation Programs

Surface Systems

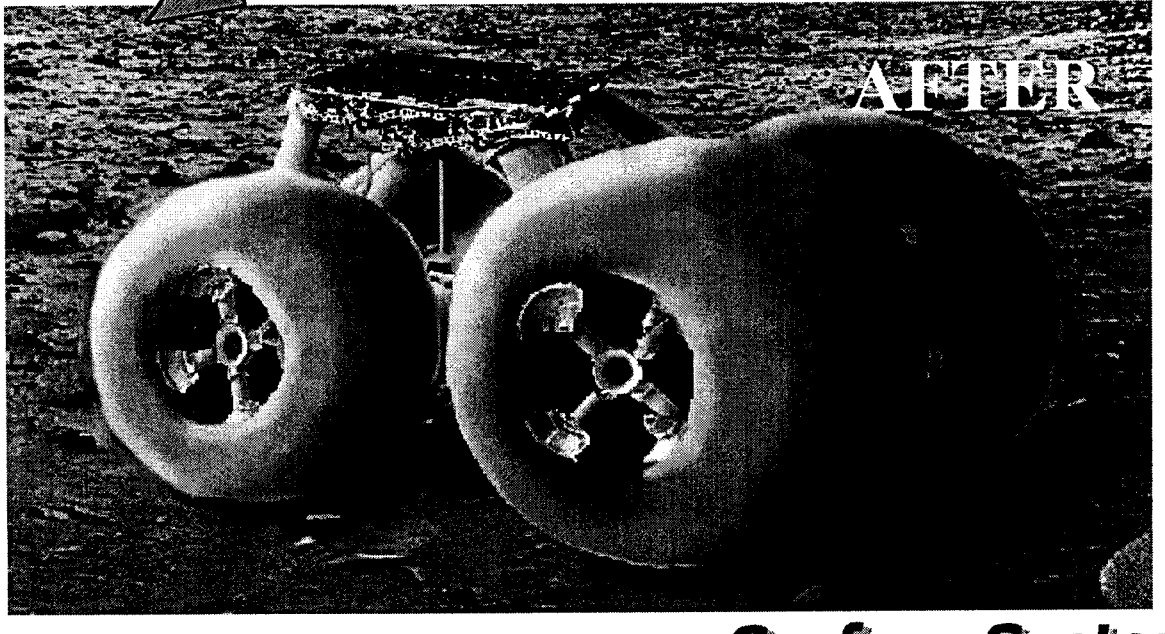




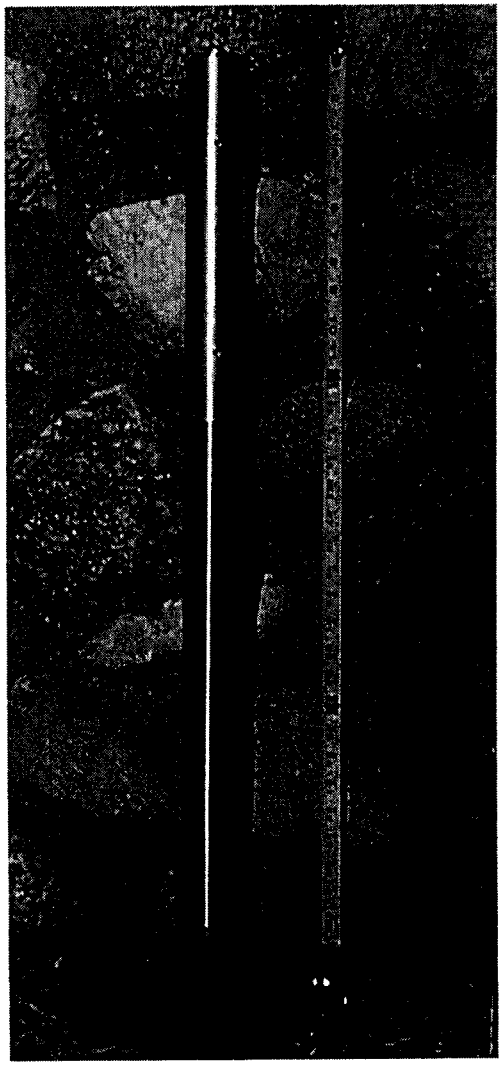
Monster Rover

A paradigm shift from nanorovers:

A small rover inflates its tires, spokes, chasis, growing to Monster Truck size which can scale most of the obstacles.



Subsurface Explorer



Surface Systems

- **DESCRIPTION:** Approximately 0.3-1 m long, 3 cm dia, 10Kg, ~100W electrical over ~2Km fine-wire tether with samples returned to surface over 0.1 mm capillary.
- **FUNCTION:** Capable of penetrating 10m to 3Km (depending on vehicle length/power).
- **UNDERLYING TECHNOLOGIES:**

Highly efficient patent-pending percussive mechanism converts >70% of tether power to hammer energy. High voltage power system efficiently delivers power over 3Km of fine wire. Sampling system uses liquid CO2 (Mars) or Argon (Comets) to return 100μ particles to surface lander.

- **Current TRL**
  - TRL 2 (99)
  - TRL 6 (03)
- **PRODUCT DEVELOPERS**
  - PI: Brian.H.Wilcox@jpl.nasa.gov
  - PH 818.354.4625/FAX 818.354.8172
- **CUSTOMERS**
  - Mars Exploration
  - Comet Nucleus Sample Return

CETDP Cross Enterprise Technology Development Program

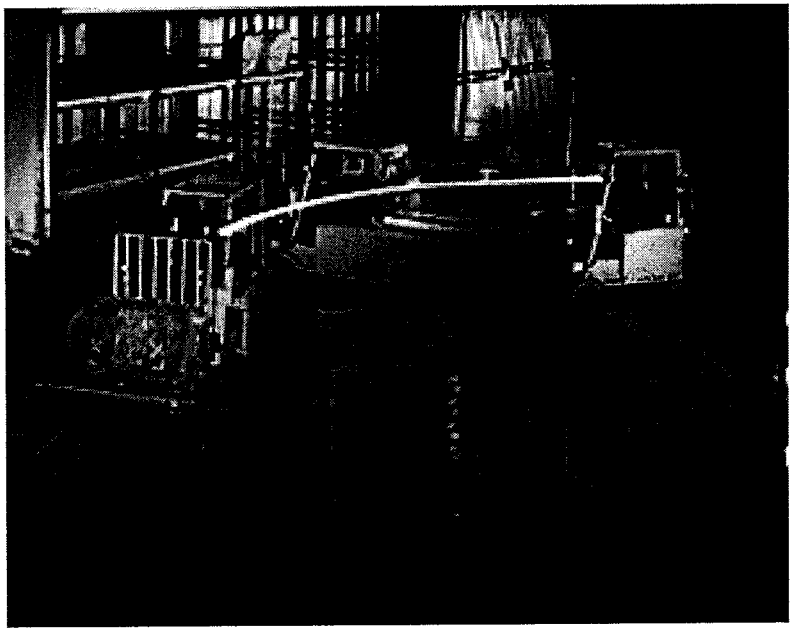
NASA

Automated Material Transport System

•**PRODUCT DESCRIPTION:** Free ranging, visually guided, infrastructure-free Automated Guided Vehicle (AGV).

•**PRODUCT FUNCTION:** Unprecedented functions of transport, automated trailer unloading, rack stacking without infrastructure.

•**UNDERLYING TECHNOLOGIES:** low-cost computer vision, image mosaicing, laser striping, multi-vehicle scheduling.



•**Current TRL**

- •TRL 7 (99)
- •First installation in FY00

•**PRODUCT DEVELOPERS**

- •CMU:Kelly;(412)576-9016,alonzo@ri.cmu.edu
- •Ford:Wagner;(313)592-2142;twagner@ford.com
- •FMC: Douglas; Hyster; Siriani

•**CUSTOMERS**

- •Material handling industries
- •Floor cleaning and building maintenance
- •Manned and unmanned vehicles
- •50% Industry funded

Surface Systems

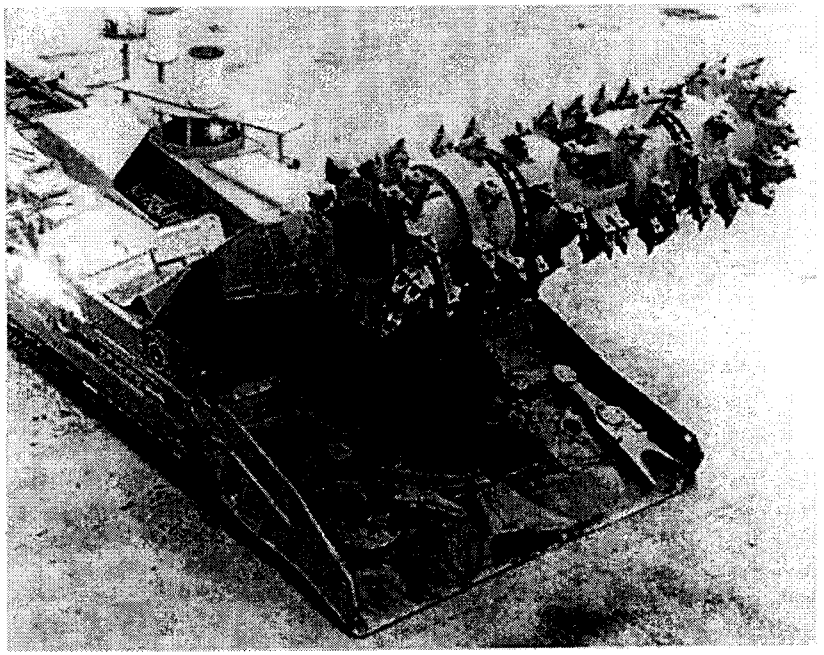
CETDP Cross Enterprise Technology Development Program

Underground Mining Automation

•**PRODUCT DESCRIPTION:** vision and sensor systems that improve coal mining productivity by measuring vehicle position.

•**PRODUCT FUNCTION:** provides steering and tramming advice for continuous miner operators. Future version will directly control machine.

•**UNDERLYING TECHNOLOGIES:** stereo vision, Kalman filtering, automated camera calibration, smart drilling.



•**Current TRL**

- •TRL 6 (99)
- •Prototype ready Fall 1999

•**PRODUCT DEVELOPERS**

- •CMU:Stentz;(412)576-9008; tony+@cmu.edu
- •Joy:Higgins;(814)432-1271; fhiggins@joy.com

•**CUSTOMERS**

- • Joy Mining Machinery (co-funds project)
- • US and International mining industry
- • Relevance to lunar and planetary mining operations

Surface Systems

CETDP Cross Enterprise Technology Development Program

Nursery Container Handling System

•**PRODUCT DESCRIPTION:** Robotic handling system for nursery containers.

•**PRODUCT FUNCTION:** Acquire, transport and arrange vast quantities of containers at large nurseries nationwide.

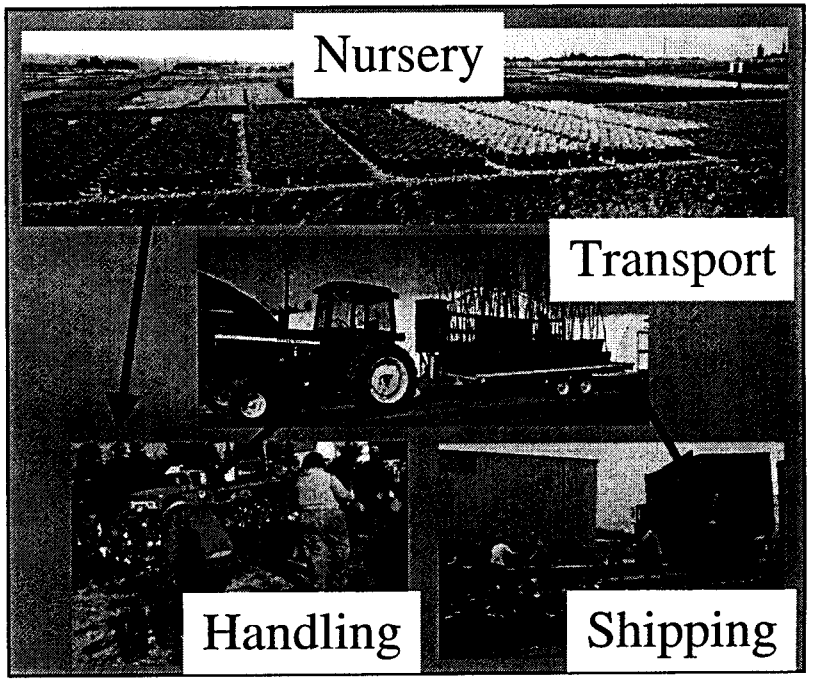
•**UNDERLYING TECHNOLOGIES:** Instrumented smart end-effector on semi-automated prime-mover base.

•**Current TRL**

- TRL 3 (99)
- Delivery in FY01; Field-Trials in FY01

•**PRODUCT DEVELOPERS**

- CMU;Schempf;(412)268-6884;hagen+@cmu.edu
- HRI;Ruden;(202)789-2900;aruden@anla.org
- ARS;St.John;(301)504-6252;jsj@ars.usda.gov



•**CUSTOMERS**

- •American Nursery & Landscape Assoc.
- •Commercial Nurseries Nationwide
- •Horticultural Research Institute (HRI)
- •USDA-Agricultural Research Service (ARS)
- •50% Co-funding from HRI and ARS

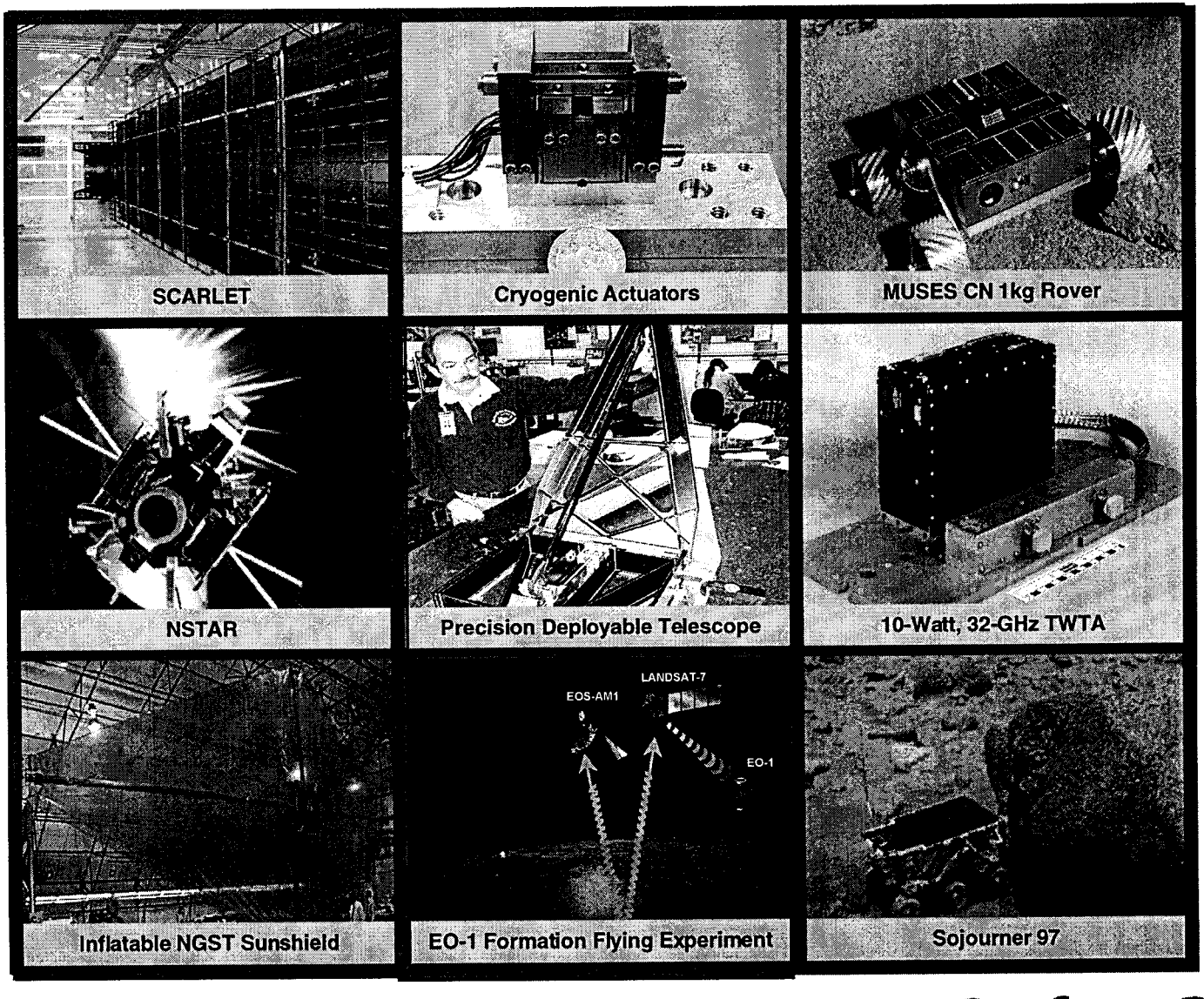
Surface Systems

The CETDP Technological Dream is Alive

Research responds to noble and inspirational goals

- Zero-uplink deep-space intelligent systems
- Ultra-deep sub-surface robotic steering and navigation
- All-access miniature power & propulsion systems
- High-data rate deep space webs
- Robot nomads, caravans and heavy duty work crews on planetary surfaces
- Sense & analyze every ion in the universe
- > 100 micro/nano spacecraft constellations
- Ultra-high-precision space telescopes
- Self-repair and self-reproducing systems

CETDP Cross Enterprise Technology Development Program



Surface Systems