NASA's Fifth Annual Robotic Mining Competition

Rules & Rubrics 2014

Kennedy Space Center, Florida

Introduction

NASA's Fifth Annual NASA Robotic Mining Competition is for university-level students to design and build a mining robot that can traverse the simulated Martian chaotic terrain, excavate Martian regolith and deposit the regolith into a Collector Bin within 10 minutes. There is particular relevance to NASA's recently announced mission to find an asteroid by 2016 and then bring it to Cis-Lunar space. The technology concepts developed by the university teams for this competition conceivably could be used to mine resources on Asteroids as well as Mars. NASA will directly benefit from the competition by encouraging the development of innovative excavation concepts from universities which may result in clever ideas and solutions which could be applied to an actual excavation device or payload. The unique physical properties of basaltic regolith and the reduced 3/8th gravity make excavation a difficult technical challenge. Advances in Martian mining have the potential to significantly contribute to our nation's space vision and NASA space exploration operations.

The complexities of the challenge include the abrasive characteristics of the basaltic regolith simulant, the weight and size of the limitations of the mining robot, and the ability to control it from a remote control center. The scoring for the mining category will require teams to consider a number of design and operation factors such as dust tolerance and projection, communications, vehicle mass, energy/power required, and autonomy.

The competition will be conducted by NASA at the Kennedy Space Center. The teams that can use telerobotic or autonomous operation to excavate the basaltic regolith simulant, called Black Point-1 or BP-1, and score the most points wins the Joe Kosmo Award for Excellence. The team will receive the Joe Kosmo Award for Excellence trophy, KSC launch invitations, team certificates for each member, and a $5,000 team scholarship. Awards for other categories include monetary team scholarships, a school trophy or plaque, team and individual certificates, and KSC launch invitations.

Undergraduate and graduate student teams enrolled in a U.S. college or university are eligible to enter the Robotic Mining Competition. Design teams must include: at least one faculty with a college or university and at least two undergraduate or graduate students. NASA has not set an upper limit on team members. A team should have a sufficient number of members to successfully operate their mining robot. Teams will compete in up to five major competition categories including: on-site mining, systems engineering paper, outreach project, slide presentation and demonstration (optional), and team spirit (optional).

The NASA Robotic Mining Competition is a student competition that will be conducted in a positive, professional way. This is a reminder to be courteous in all your correspondence and all interactions on-site at the competition. Unprofessional behavior or unsportsmanlike conduct will not be tolerated and will be grounds for disqualification. The frequently asked questions (FAQ) document is updated regularly and is considered part of this document. It is the responsibility of the teams to read, understand, and abide by all of NASA's Fifth Annual Robotic Mining Competition Rules and Rubrics, stay updated with new FAQs, communicate with NASA's representatives, and complete all surveys. These rules and rubrics are subject to future updates by NASA at its sole discretion.

For more information, visit the NASA Robotic Mining Competition on the Web at http://www.nasa.gov/offices/education/centers/kennedy/technology/nasarmc.html and follow the NASA Robotic Mining Competition on Twitter at https://twitter.com/NASARMC.

On-Site Mining Category Rules

The scoring for the Mining Category will require teams to consider a number of design and operation factors such as dust tolerance and projection, communications, vehicle mass, energy/power required, and autonomy. Each team must compete on-site at the Kennedy Space Center, Florida on May 19-23, 2014. A minimum

amount of 10 kg of BP-1 must be mined and deposited during either of two competition attempts according to the rules to qualify to win in this category. If the minimum amount of 10 kg of BP-1 is not met for an attempt, then the total score for that attempt will be 0. In the case of a tie, the teams will compete in a tie-breaking competition attempt. The judges' decisions are final in all disputes. The teams with the first, second, and third most Mining points averaged from both attempts will receive team plaques, individual team certificates, KSC launch invitations, $3,000, $2,000, and $1,000 scholarships and 25, 20, and 15 points toward the Joe Kosmo Award for Excellence, respectively. Teams not winning first, second, or third place in the mining category can earn one bonus point for each kilogram of BP-1 mined and deposited up to a maximum average of ten points toward the Joe Kosmo Award for Excellence. The most innovative design will receive the Judges' Innovation Award at the discretion of the mining judges.

1) Teams must arrive at the Robotic Mining Competition Check-In Tent in Parking Lot 4 of the Kennedy Space Center no later than 3:00 p.m. on Monday, May 19, 2014; but teams are encouraged to arrive earlier.
2) Teams will be required to perform two official competition attempts using BP-1 in the Caterpillar Mining Arena. NASA will fill the Caterpillar Mining Arena with compacted BP-1 that matches as closely as possible to basaltic Martian regolith. NASA will randomly place three obstacles and create two craters on each side of the Caterpillar Mining Arena. Each competition attempt will occur with two teams competing at the same time, one on each side of the Caterpillar Mining Arena. After each competition attempt, the obstacles will be removed, the BP-1 will be returned to a compacted state, if necessary, and the obstacles and craters will be returned to the Caterpillar Mining Arena. The order of teams for the competition attempts will be chosen at NASA's discretion. See Diagrams 1 and 2.
3) In each of the two official competition attempts, the teams will score cumulative Mining Points. See Table 1 for the Mining Category Scoring Example. The teams' ranking Mining Points will be the average of their two competition attempts.
    A) Each team will be awarded 1000 Mining points after passing the safety inspection and communications check.
    B) During each competition attempt, the team will earn 3 Mining points for each kilogram in excess of 10 kg of BP-1 deposited in the Collector Bin. (For example, 110 kg of BP-1 mined will earn 300 Mining points.)
    C) During each competition attempt, the team will lose 1 Mining Point for each 50 kilobits/second (kb/sec) of average data used throughout each competition attempt.
    D) During each competition attempt, the team will lose 8 Mining points for each kilogram of total mining robot mass. (For example, a mining robot that weighs 80 kg will lose 640 Mining points.)
    E) During each competition attempt, the team will earn 20 Mining points if the amount of energy consumed by the mining robot during the competition attempt is reported to the judges after each attempt. The amount of energy consumed will not be used for scoring; a team must only provide a legitimate method of measuring the energy consumed and be able to explain the method to the judges.
    F) During each competition attempt, the judges will award the team 0 to 100 Mining points for dust tolerant design features on the mining robot (up to 30 Mining points) and dust free operation (up to 70 Mining points). If the mining robot has exposed mechanisms where dust could accumulate during a Martian mission and degrade the performance or lifetime of the mechanisms, then fewer Mining points will be awarded in this category. If the mining robot raises a substantial amount of airborne dust or projects it due to its operations, then fewer Mining points will be awarded. Ideally, the mining robot will operate in a clean manner without dust projection, and all mechanisms and moving parts will be protected from dust intrusion. The mining robot will not be penalized for airborne dust while dumping into the Collector Bin. All decisions by the judges regarding dust tolerance and dust projection are final.

The 30 points for dust-tolerant design will be broken down in the following way:

1. Drive train components enclosed/protected and other component selection – 10 points
2. Custom dust sealing features (bellows, seals, etc.) –10 points
3. Active dust control (brushing, electrostatics, etc.) – 10 points

The 70 points for dust-free operation will be broken down in the following way:

1. Driving without dusting up crushed basalt – 20 points
2. Digging without dusting up crushed basalt – 30 points
3. Transferring crushed basalt without dumping the crushed basalt on your own Robot – 20 points

G) During each competition attempt, the team will earn up to 500 Mining points for autonomous operations. Mining points will be awarded for successfully completing the following activities autonomously:

1. Successfully crossing the obstacle field: 50 pts
2. Successfully crossing the obstacle field and excavating: 150 pts
3. Successfully crossing the obstacle field, excavating and depositing regolith, 1 time: 250 pts
4. Successful fully autonomous run for 10 minutes: 500 pts

For a team to earn mining points in the autonomous category, the team cannot touch the controls during the autonomous period. If the team touches the controls then the autonomy period for that run is over; however, the team may revert to manual control to complete that run. Start and stop commands are allowed at the beginning and end of the autonomous period. Orientation data cannot be transmitted to the mining robot in the autonomous period. Telemetry to monitor the health of the mining robot is allowed during the autonomous period. The mining robot must continue to operate for the entire 10 minutes to qualify for a fully autonomous run.

The teams with the first, second, and third most Autonomous points averaged from both attempts will receive the Caterpillar Autonomy Award and $1,500, $750, and $250 team scholarships respectively. Points will count toward the Caterpillar Autonomy Award even if no regolith is deposited. In the case of a tie, the team that deposits the most regolith will win. If no regolith deposited in the case of a tie, the judges will choose the winner. The judges' decision is final.

Mining Category Elements	Specific Points	Actual	Units	Mining points
Pass Inspections				1000
BP-1 over 10 kg	+3/kg	110	kg	+300
Average Bandwidth	-1/50kb/sec	5000	kb/sec	-100
Mining Robot Mass	-8/kg	80	kg	-640
Report Energy Consumed	+20	1	1= Achieved 0= Not Achieved	+20
Dust Tolerant Design (30%) & Dust Free Operation (70%)	0 to +100	70	Judges' Decision	+70
Autonomy	50, 150, 250 or 500	150		+150
Total				800

Table 1: Mining Category Scoring Example

4) All excavated mass deposited in the Collector Bin during each official competition attempt will be weighed after the completion of each competition attempt.

5) The mining robot will be placed in the randomly selected starting positions. See Diagrams 1 and 2.

6) A team's mining robot may only excavate BP-1 located in that team's respective mining area at the opposite end of the Caterpillar Mining Arena from the team's starting area. The team's starting direction will be randomly selected immediately before the competition attempt. Mining is allowed as soon as the mining line is crossed.

7) The mining robot is required to move across the obstacle area to the mining area and then move back to the Collector Bin to deposit the BP-1 into the Collector Bin. See Diagrams 1 and 2.

8) Each team is responsible for placement and removal of their mining robot onto the BP-1 surface. There must be one person per 23 kg of mass of the mining robot, requiring four people to carry the maximum allowed mass. Assistance will be provided if needed.

9) Each team is allotted a maximum of 10 minutes to place the mining robot in its designated starting position within the Caterpillar Mining Arena and 5 minutes to remove the mining robot from the Caterpillar Mining Arena after the 10-minute competition attempt has concluded.

10) The mining robot operates during the 10-minute time limit of each competition attempt. The competition attempts for both teams in the Caterpillar Mining Arena will begin and end at the same time.

11) The mining robot will end operation immediately when the power-off command is sent, as instructed by the competition judges.

12) The mining robot cannot be anchored to the BP-1 surface prior to the beginning of each competition attempt.

13) The mining robot will be inspected during the practice days and right before each competition attempt. Teams will be permitted to repair or otherwise modify their mining robots anytime the Pits are open.

14) At the start of each competition attempt, the mining robot may not occupy any location outside the defined starting position in the Caterpillar Mining Arena. See Caterpillar Mining Arena definition for description of the competition field.

15) The Collector Bin top edge will be placed so that it is adjacent to the side walls of the Caterpillar Mining Arena without a gap and the height will be approximately 0.5 meter from the top of the BP-1 surface directly below it. The Collector bin top opening will be 1.65 meters long and .48 meters wide. See Diagrams 1 – 3. A target(s) or beacon(s) may be attached to the Collector Bin for navigation purposes only. This navigational aid system must be attached during the setup time and removed afterwards during the removal time period. If attached to the Collector Bin, it must not exceed the width of the Collector Bin and it must not weigh over 9 kg. The mass of the navigational aid system is included in the maximum mining robot mass limit of 80.0 kg and must be self-powered. The target/beacon may send a signal or light beam but lasers are not allowed for safety reasons except for Visible Class I or II lasers or low power lasers and laser based detection systems. Supporting documentation from the laser instrumentation vendor must be given to the inspection judge for "eye-safe" lasers. The Judges will inspect and verify that all laser devices are a class I or II product and they have not been modified (optics or power). Any objects placed on the Collector Bin cannot be more than 0.75 m above the BP-1 surface, and cannot be permanently attached or cause alterations (ie. no drilling, nails, etc).

16) There will be three obstacles placed on top of the compressed BP-1 surface within the obstacle area before each competition attempt is made. The placement of the obstacles will be randomly selected before the start of the competition. Each obstacle will have a diameter of approximately 10 to 30 cm and an approximate mass of 3 to 10 kg. There will be two craters of varying depth and width, being no wider or deeper than 30 cm. No obstacles will be intentionally buried in the BP-1 by NASA, however, BP-1 includes naturally occurring rocks.

17) The mining robot must operate within the Caterpillar Mining Arena: it is not permitted to pass beyond the confines of the outside wall of the Caterpillar Mining Arena and the Collector bin during each competition attempt. The BP-1 must be mined in the mining area and deposited in the Collector bin. A team that excavates any BP-1 from the starting or obstacle areas will be disqualified. The BP-1 must be carried from the mining area to the Collector bin by any means and be deposited in the Collector bin in its raw state. A secondary container like a bag or box may not be deposited inside the Collector bin. Depositing a

container in the Collector bin will result in disqualification of the team. The mining robot can separate intentionally, if desired, but all parts of the mining robot must be under the team's control at all times. Any ramming of the wall may result in a safety disqualification at the discretion of the judges. The walls may be used for the purposes of mapping autonomous navigation and collision avoidance. Touching or having a switch sensor springwire that may brush on a wall as a collision avoidance sensor is allowed.

18) The mining robot must not use the wall as support or push/scoop BP-1 up against the wall to accumulate BP-1. If the mining robot exposes the Caterpillar Mining Arena bottom due to excavation, touching the bottom is permitted, but contact with the Caterpillar Mining Arena bottom or walls cannot be used at any time as a required support to the mining robot. Teams should be prepared for airborne dust raised by either team during each competition attempt.

19) During each competition attempt, the mining robot is limited to autonomous and telerobotic operations only. No physical access to the mining robot will be allowed during each competition attempt. In addition, telerobotic operators are only allowed to use data and video originating from the mining robot and the NASA video monitors. Visual and auditory isolation of the telerobotic operators from the mining robot in the Mission Control Center is required during each competition attempt. Telerobotic operators will be able to observe the Caterpillar Mining Arena through overhead cameras in the Caterpillar Mining Arena via monitors that will be provided by NASA in the Mission Control Center. These color monitors should be used for situational awareness only. No other outside communication via cell phones, radios, other team members, etc. is allowed in the Mission Control Center once each competition attempt begins. During the 10 minute setup period, a handheld radio link will be provided between the Mission Control Center team members and team members setting up the mining robot in the Caterpillar Mining Arena to facilitate voice communications during the setup phase only.

20) The mining robot mass is limited to a maximum of 80.0 kg. Subsystems on the mining robot used to transmit commands/data and video to the telerobotic operators are counted toward the 80.0 kg mass limit. Equipment not on the mining robot used to receive data from and send commands to the mining robot for telerobotic operations is excluded from the 80.0 kg mass limit.

21) The mining robot must provide its own onboard power. No facility power will be provided to the mining robot. There are no power limitations except that the mining robot must be self-powered and included in the maximum mining robot mass limit of 80.0 kg.

22) The mining robot must be equipped with an easily accessible red emergency stop button (kill switch) of minimum diameter of 40 mm on the surface of the mining robot requiring no steps to access. The emergency stop button must stop the mining robot's motion and disable all power to the mining robot with one push motion on the button. It must be highly reliable and instantaneous. For these reasons an unmodified "Commercial Off-The-Shelf" (COTS) red button is required. A closed control signal to a mechanical relay is allowed as long as it stays open to disable the mining robot. The reason for this rule is to completely safe the mining robot in the event of a fire or other mishap. The button should disconnect the batteries from all controllers (high current, forklift type button) and it should isolate the batteries from the rest of the active sub-systems as well. Only laptop computers may stay powered on if powered by its internal battery.

23) The communications rules for telerobotic operations follow.

A. MINING ROBOT WIRELESS LINK

1. Each team is required to command and monitor their mining robot over the NASA-provided network infrastructure. Figure 1 shows
   a. the configuration provided to teams to communicate with their mining robot,
   b. the "Mars Lander" camera staged in the Caterpillar Mining Arena, and Mars Lander Control Joystick provided to the team in the Mission Control Center,
   c. the official timing display, which includes a real-time display of BP-1 collected during the match, and
   d. the handheld radios that will be provided to each team to link their Mission Control Center team members with their corresponding team members in the Caterpillar Mining Arena during setup.

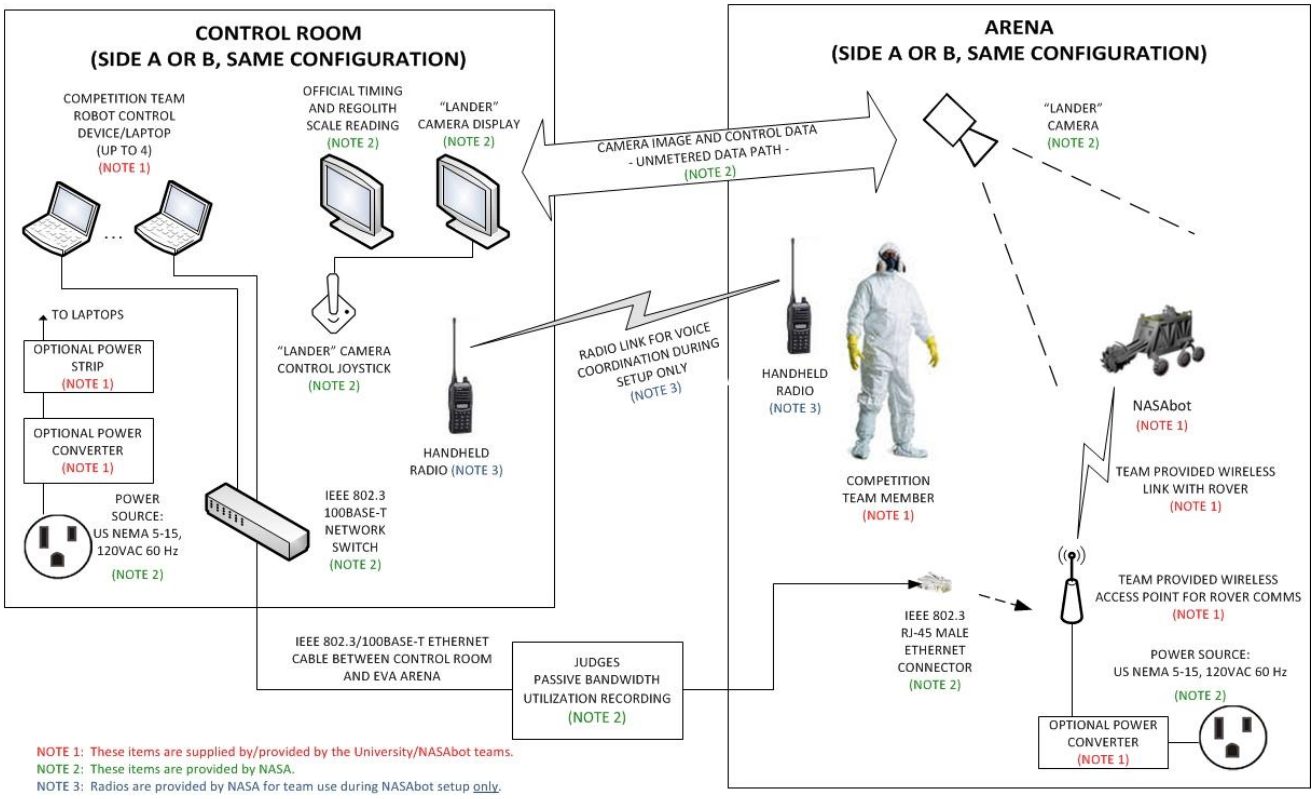


Figure 1

2. Each team will provide the wireless link (access point, bridge, or wireless device) to their mining robot, which means that each team will bring their own Wi-Fi equipment/router and any required power conversion devices. Teams must set their own network IP addresses to enable communication between their mining robot and their control computers, through their own wireless link hosted in the Caterpillar Mining Arena.
   a. In the Caterpillar Mining Arena, NASA will provide an elevated network drop (female RJ-45 Ethernet jack) that extends to the Mission Control Center, where NASA will provide a network switch for the teams to plug in their laptops.
      i. The network drop in the Caterpillar Mining Arena will be elevated high enough above the edge of the regolith bed wall to provide adequate radio frequency visibility of the Caterpillar Mining Arena.
      ii. A shelf will be set up next to the network drop, will be 4 to 6 feet off the ground, and will be no more than 50 feet from the mining robot. This shelf is where teams will place their Wireless Access Point (WAP) to communicate with their mining robot. The Caterpillar Mining Arena will be 150 to 200 feet from the Mission Control Center.
      iii. The WAP shelves for side A and side B of the Caterpillar Mining Arena will be at least 25 feet apart to prevent electromagnetic interference (EMI) between the units.
   b. Power interfaces:
      i) NASA will provide a standard US National Electrical Manufacturers Association (NEMA) 5-15 type, 110 VAC, 60 Hz electrical jack by the network drop. Both will be no more than 5 feet from the shelf.
      ii) NASA will provide a standard US NEMA 5-15 type, 110 VAC, 60 Hz electrical jack in the Mission Control Center for each team.
      iii) The team must provide any conversion devices needed to interface team access points or Mission Control Center computers or devices with the provided power sources.
   c. During the setup phase, the teams will set up their access point and verify communication with their mining robot from the Mission Control Center.

3. The teams must use the USA IEEE 802.11 b/g standard for their wireless connection (WAP and rover client). Teams cannot use multiple channels for data transmission. Encryption is not required, but it is highly encouraged to prevent unexpected problems with team links.
    a. During a match, one team will operate on channel 1 and the other team will operate on channel 11.
    b. Channels will be assigned when the teams check in with the Pit crew chief.
4. Each team will be assigned an SSID that they must use for their wireless equipment.
    a. SSID will be "Team_##."
    b. Teams will broadcast their SSID.
5. Bandwidth constraints:
    a. A team will be awarded the Efficient Use of Communications Power Award for using the lowest average bandwidth during the timed and NASA-monitored portion of the competition. Teams must collect the minimum 10 kg of BP-1 to qualify for this award.
    b. The communications link is required to have an <u>average</u> bandwidth of no more than 5 megabits per second. There will not be a <u>peak</u> bandwidth limit.

B. RF & COMMUNICATIONS APPROVAL

1. Each team must demonstrate to the communication judges that their mining robot and access point are operating only on their assigned channel. Each team will have approximately 15 minutes at the communication judges' station.
2. To successfully pass the communication judges' station, a team must drive their mining robot by commanding it from their mining robot driving/control laptop through their wireless access point. The judges will verify the course of travel and verify that the team is operating only on their assigned channel.
3. If a team cannot demonstrate the above tasks in the allotted time, the team will be disqualified from the competition.
4. On Monday, May 19, 2014, on a first-come, first-serve basis, the teams will be able to show the communication judges their compliance with the rules.
5. The NASA communications technical experts will be available to help teams make sure that they are ready for the communication judges' station on Monday, May 19, 2014, and Tuesday, May 20, 2014.
6. Once the team arrives at the communication judges' station, the team can no longer receive assistance from the NASA communications technical experts.
7. If a team is on the wrong channel during their competition attempts, the team will be disqualified and required to power down.

C. WIRELESS DEVICE OPERATION IN THE PITS

1. Teams will not be allowed to power up their transmitters on any frequency in the Pits during the practice matches or competition attempts. All teams must have a hard-wired connection for testing in the Pits.
2. Teams will have designated times to power up their transmitters when no matches are underway.

24) The mining robot must be contained within 1.5 m length x 0.75 m width x 0.75 m height. The mining robot may deploy or expand beyond the 1.5 m x 0.75 m footprint after the start of each competition attempt, but may not exceed a 1.5 meter height. The mining robot may not pass beyond the confines of the outside wall of the Caterpillar Mining Arena and the Collector Bin during each competition attempt to avoid potential interference with the surrounding tent. The team must declare the orientation of length and width to the inspection judge. Because of actual Martian hardware requirements, no ramps of any kind will be provided or allowed. An arrow on the reference point must mark the forward direction of the mining robot in the starting position configuration. The judges will use this reference point and arrow to orient the mining robot in the randomly selected direction and position. A multiple mining robot system is allowed but the total mass and starting dimensions of the whole system must comply with the volumetric dimensions given in this rule.

25) To ensure that the mining robot is usable for an actual Martian mission, the mining robot cannot employ any fundamental physical processes, gases, fluids or consumables that would not work in the Martian

environment. For example, any dust removal from a lens or sensor must employ a physical process that would be suitable for the Martian surface. Teams may use processes that require an Earth-like environment (e.g., oxygen, water) only if the system using the processes is designed to work in a Martian environment and if such resources used by the mining robot are included in the mass of the mining robot. Closed pneumatic mining systems are allowed only if the gas is supplied by the mining robot itself. Note: the mining robot will be exposed to outside air temperatures averaging 90 degrees Fahrenheit during inspection and while waiting to enter the Caterpillar Mining Arena.

26) Components (i.e. electronic and mechanical) are not required to be space qualified for Martian atmospheric, electromagnetic, and thermal environments. Since budgets are limited, the competition rules are intended to require mining robots to show Martian plausible system functionality but the components do not have to be traceable to a Martian qualified component version. Examples of allowable components are: Sealed Lead-Acid (SLA) or Nickel Metal Hydride (NiMH) batteries; composite materials; rubber or plastic parts; actively fan cooled electronics; motors with brushes; infrared sensors, inertial measurement units, and proximity detectors and/or Hall Effect sensors, but proceed at your own risk since the BP-1 is very dusty. Teams may use honeycomb structures as long as they are strong enough to be safe. Teams may not use GPS, rubber pneumatic tires; air/foam filled tires; open or closed cell foam, ultrasonic proximity sensors; or hydraulics because NASA does not anticipate the use of these on a Mars mission.

27) The mining robot may not use any process that causes the physical or chemical properties of the BP-1 to be changed or otherwise endangers the uniformity between competition attempts.

28) The mining robot may not penetrate the BP-1 surface with more force than the weight of the mining robot before the start of each competition attempt.

29) No ordnance, projectile, far-reaching mechanism (adhering to Rule 24), etc. may be used. The mining robot must move on the BP-1 surface.

30) No team can intentionally harm another team's mining robot. This includes radio jamming, denial of service to network, BP-1 manipulation, ramming, flipping, pinning, conveyance of current, or other forms of damage as decided upon by the judges. Immediate disqualification will result if judges deem any maneuvers by a team as being offensive in nature. Erratic behavior or loss of control of the mining robot as determined by the judges will be cause for immediate disqualification. A judge may disable the mining robot by pushing the red emergency stop button at any time.

31) Teams must electronically submit documentation containing a description of their mining robot, its operation, potential safety hazards, a diagram, and basic parts list by April 30, 2014 at 12:00 p.m. (noon) eastern time.

32) Teams must electronically submit a **link** to their YouTube video documenting no less than 30 seconds but no more than 5 minutes of their mining robot in operation for at least one full cycle of operation by April 30, 2014 at 12:00 p.m. (noon) eastern time via e-mail to Bethanne.Hull@nasa.gov. One full cycle of operations includes excavation and depositing material. This video documentation is solely for technical evaluation of the mining robot.

Shipping

33) **Plan ahead for shipping your mining robot and its battery(s) as some batteries may not be allowed on board airplanes or in shipping containers.** Teams may ship their mining robots to **arrive no earlier than May 12, 2014**. The mining robots will be held in a safe, non air-conditioned area and be placed in each team's Space Pit by Monday, May 19, 2014. The **ship to** address is:

Transportation Officer, NASA
Central Supply, Bldg M6-744
Kennedy Space Center, FL 32899
M/F: KSC Visitor Complex, NASA's Robotic Mining Competition, M/C: DNPS

Note: Do not have the shipping company deliver the mining robot directly to the Kennedy Space Center Visitor Complex. They do not have facilities to store them until the Pits are set up. The shipper will come to the Pass & ID facility right before the Kennedy Space Center gate on State Road 405. Central Receiving will send an escort.

34) Return shipping arrangements must be made prior to the competition. All mining robots must be picked up from the Kennedy Space Center Visitor Complex **no later than 5:00 p.m. on Wednesday, May 28, 2014**. Any abandoned mining robots will be discarded after this date. The **return** shipping address is:

Kennedy Space Center Visitor Complex
Robotic Mining Shipping Area
Mail Code: DNPS
State Road 405
Kennedy Space Center, FL 32899

Caterpillar Mining Arena Diagrams

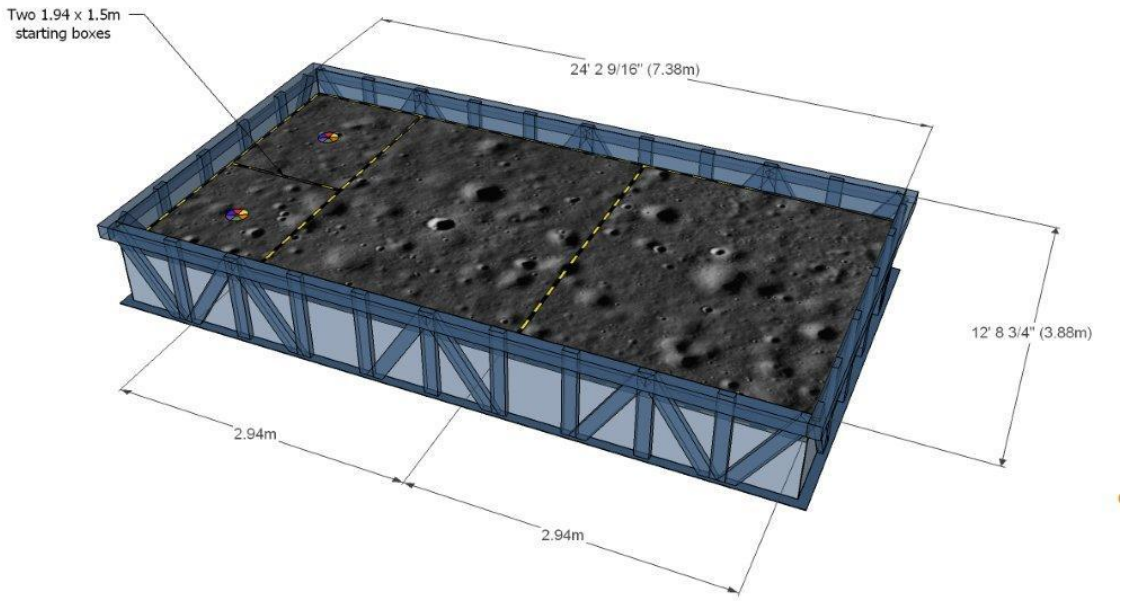


Diagram 1: Caterpillar Mining Arena (isometric view)

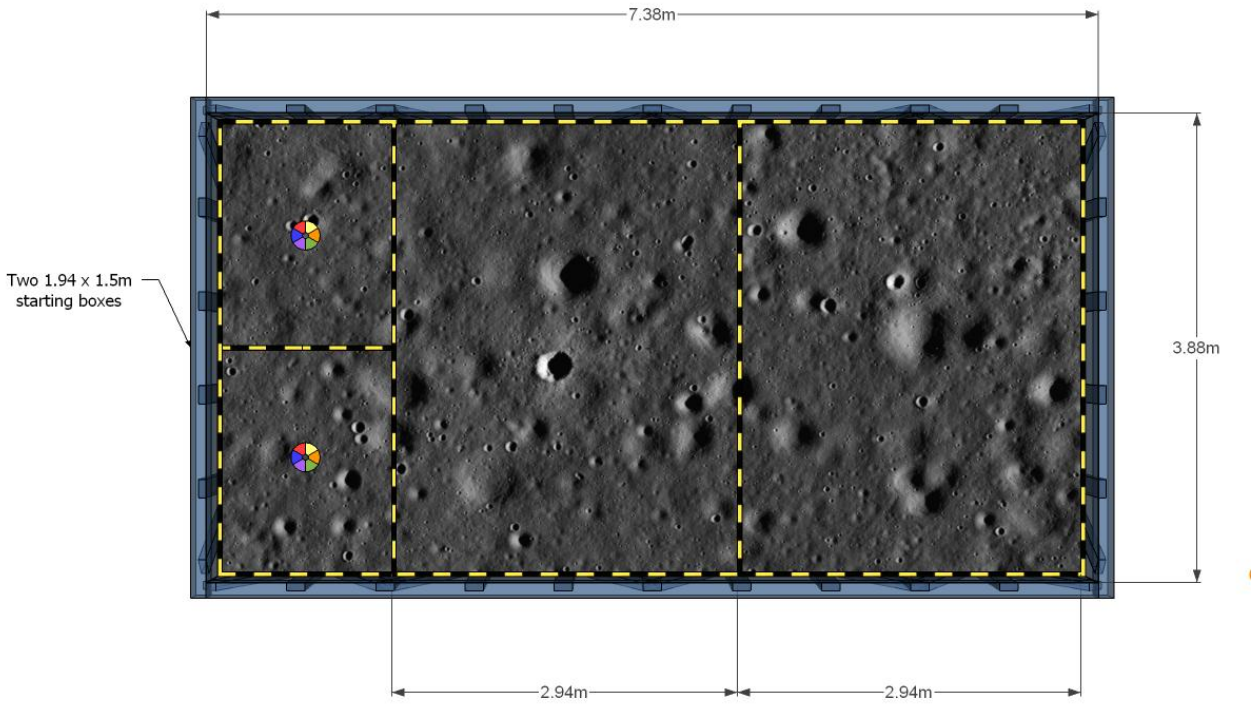


Diagram 2: Caterpillar Mining Arena (top view)

Collector bin Diagram

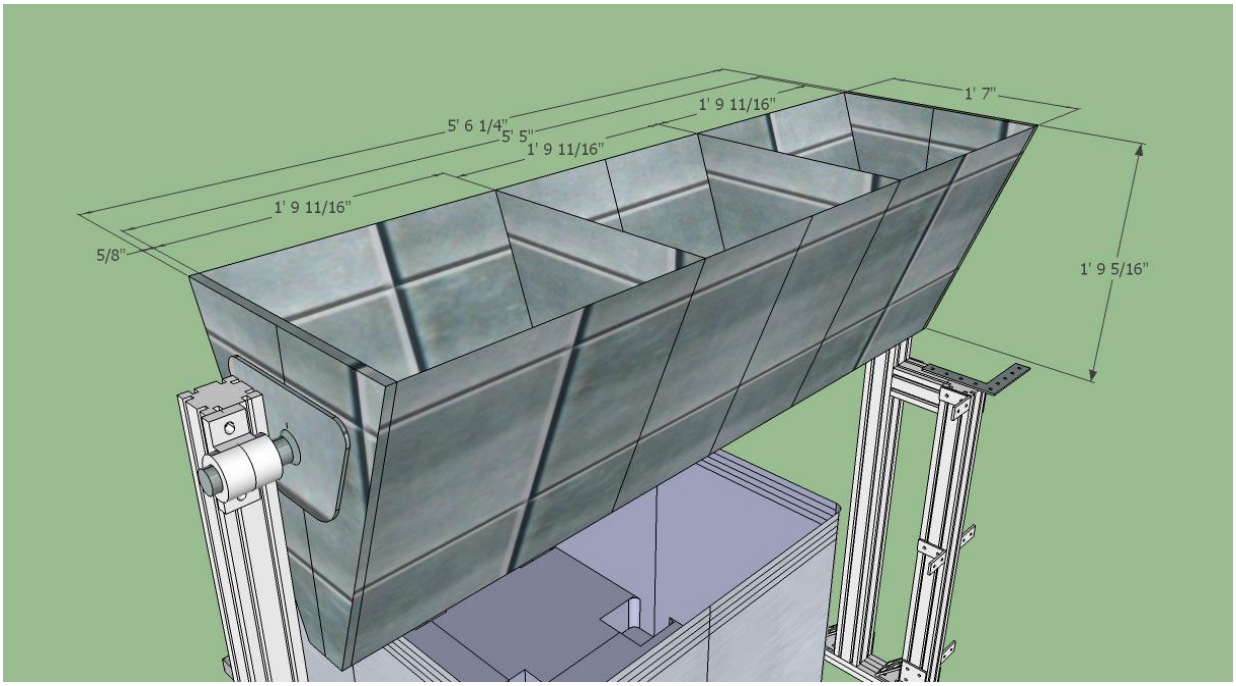


Diagram 3: Collector Bin

NASA's Robotic Mining Competition Systems Engineering Paper

Each team must submit a Systems Engineering Paper electronically in PDF by April 21, 2014 at 12:00 p.m. (noon) eastern time. Your paper should discuss the Systems Engineering methods used to design and build your mining robot. All pertinent information required in the rubric must be in the body of the paper. A minimum score of 16 out of 20 possible points must be achieved to qualify to win in this category. In the case of a tie, the judges will choose the winning Systems Engineering Paper. The judges' decision is final. The team with the winning Systems Engineering Paper will receive a team plaque, individual certificates, and a $500 team scholarship. Second and third place winners will receive certificates.

For reference, undergraduate course materials in NASA Systems Engineering, are available at www.spacese.spacegrant.org.

NASA's Robotic Mining Competition Systems Engineering Paper Scoring Rubric	
Elements	**Points**
Content: • Formatted professionally, clearly organized, correct grammar and spelling, size 12 font; single spaced, maximum of 20 pages not including the cover, table of contents, and source pages. Appendices are allowed and limited to 5 pages, and should referenced in main body. Cover page must include: team name, title of paper, full names of all team members, university name, and faculty advisor's full name. • Title page must include the signature of the sponsoring faculty advisor and a statement that he/she has read and reviewed the paper prior to submission to NASA. • Purpose Statement must be included and related to the application of systems engineering to NASA's Robotic Mining Competition.	There are 3 points for 3 elements.
Intrinsic Merit: • Cost budget (estimated costs vs. actual costs) • Design philosophy in the context of systems engineering; discuss what your team is optimizing in your design approach (light weight? automation? BP-1 capacity? etc.) • Schedule of work from inception to arrival at competition • Major reviews: system requirements, preliminary design and critical design	There are 4 points for 4 elements. Up to 2 additional points may be awarded for exceptional work related to systems engineering intrinsic merit, for a total of 6 points.
Technical Merit: • Concept of operations • System hierarchy • Interfaces • Requirements • Technical budgets (mass, power & data allocated to components vs. actual mass, power, & data usage) • Trade-off assessments • Reliability • Verification of system meeting requirements	There are 8 points for 8 elements. Up to 3 additional points may be awarded for exceptional work related to systems engineering technical merit, for a total of 11 points.

NASA's Robotic Mining Competition Outreach Project Report

Each team must participate in an educational outreach project in their local community. Outreach examples include actively participating in school career days, science fairs, technology fairs, extracurricular science or robotics clubs, or setting up exhibits in local science museums or a local library. Other ideas include organizing a program with a Boys and Girls Club, Girl Scouts, Boy Scouts, etc. Teams are encouraged to have fun with the outreach project and share knowledge of NASA's Robotic Mining Competition, engineering or Martian activities with the local community.

Each team must submit a report of the Outreach Project electronically in PDF by April 21, 2014 at 12:00 p.m. (noon) eastern time. A minimum score of 16 out of 20 possible points must be achieved to qualify to win in this category. In the case of a tie, the judges will choose the winning outreach project. The judges' decision is final. The team with the winning outreach project report will receive a team plaque, individual certificates, and a $500 team scholarship. Second and third place winners will receive certificates.

NASA's Robotic Mining Competition Outreach Project Report Scoring Rubric	
Elements	**Points**
Structure, Content and Intrinsic Merit: • Formatted professionally, clearly organized, correct grammar and spelling, size 12 font; single spaced, maximum of 5 pages not including the cover. Appendices are not allowed, however, a link in the body of the report to a multimedia site with additional photos or videos is allowed. Cover page must include: team name, title of paper, full names of all team members, university name and faculty advisor's full name. • Purpose for this outreach project, identify outreach recipient group(s). • Illustrations must appropriately demonstrate the outreach project.	There are 3 points for 3 elements. Up to 2 additional points may be awarded for exceptional work related to outreach intrinsic merit, for a total of 5 points.
Educational Outreach Merit: • The report must effectively describe what the outreach activity(s) was. • The report must describe exactly how the Robotic Mining Competition team participated. • The report must reflect how the outreach project inspired others to learn about robotics, engineering or Martian activities. • The report must demonstrate the quality of the outreach including how hands-on activities were used to engage the audience at their level of understanding. • The report must show statistics on the participants. Examples include an in-depth or long term outreach project or follow-up with the participants.	There are 10 points for 5 elements. Up to 5 additional points may be awarded for exceptional work related to educational outreach merit, for a total of 15 points.

NASA's Robotic Mining Competition Slide Presentation and Demonstration

The Robotic Mining Slide Presentation and Demonstration is an optional category in the overall competition. The presentation and demonstration must be no more than 20 minutes with an additional 5 minutes for questions and answers. It will be judged at the competition in front of an audience including NASA and private industry judges. The presentations must be submitted electronically in PDF by April 21, 2014 at 12:00 p.m. (noon) eastern time. Teams **MUST** present the slides turned in on April 21st. Visual aids, such as videos and handouts, may be used during the presentation but videos must be presented using the team's own laptop. You may NOT update/modify your slide presentation and present it from your laptop. A minimum score of 16 out of 20 possible points must be achieved to qualify to win in this category. The content, formatting and illustration portion of the score will be judged prior to the live presentation and scored based on the presentation turned in on April 21st. In the case of a tie, the judges will choose the winning presentation. The judges' decision is final. The team with the winning presentation will receive a team plaque, individual team certificates, and a $500 team scholarship. Second and third place winners will receive certificates.

NASA's Robotic Mining Competition Slide Presentation and Demonstration Scoring Rubric	
Elements	**Points**
Content, formatting, and illustrations: • Content includes a cover slide (with team name, presentation title, names of team members, university name, and faculty advisor's name). Also includes an introduction slide and referenced sources. • Formatting is readable and aesthetically pleasing with proper grammar and spelling. • Illustrations support the technical content • Illustrations show progression of the project and final design	There are 4 points for 4 elements. Up to 2 additional points may be awarded for exceptional slides, for a total of 6 points.
Technical Merit: • Design Process • Design Decisions • Final Design • Mining robot functionality • Special features - highlight what makes the mining robot unique or innovative	There are 5 points for 5 elements. Up to 2 additional points may be awarded for exceptional work related to technical merit, for a total of 7 points.
Presentation: • Handles slides and equipment professionally • Engages audience and infuses personality • Creative and inspirational • Demonstrates Robot • Answers questions	There are 5 points for 5 elements. Up to 2 additional points may be awarded for an exceptional presentation, for a total of 7 points.

NASA's Robotic Mining Competition Team Spirit

NASA's Robotic Mining Competition Team Spirit is an optional category in the overall competition. A minimum score of 12 out of 15 possible points must be achieved to qualify to win in this category. In the case of a tie, the judges will choose the winning team. The judges' decision is final. The team winning the Team Spirit Award at the competition will receive a team plaque, individual certificates, and a $500 team scholarship. Second and third place winners will receive certificates.

NASA's Robotic Mining Competition Team Spirit Competition Scoring Rubric				
Elements	**3**	**2**	**1**	**0**
Teamwork: • Exhibits teamwork in and out of the Caterpillar Mining Arena • Exhibits a strong sense of collaboration within the team • Supports other teams with a healthy sense of competition	All three elements are exceptionally demonstrated	Three elements are clearly demonstrated	Two or less elements are clearly demonstrated	Zero elements are clearly demonstrated
Attitude: • Exudes a positive attitude in all interactions, not limited to competition attempt • Demonstrates an infectious energy by engaging others in team activities • Motivates and encourages own team • Motivates and encourages other teams • Keeps pit clean and tidy at all times	All five elements are exceptionally demonstrated	Four elements are exceptionally demonstrated	Three or less elements are clearly demonstrated	Zero elements are clearly demonstrated
Creativity & Originality: • Demonstrates creativity and originality in team activities, name, and logo • Wears distinctive team identifiers • Decorates team's Pit to reflect school/team spirit	All three elements are exceptionally demonstrated	Three elements are clearly demonstrated	Two or less elements are clearly demonstrated	Zero elements are clearly demonstrated
Sportsmanship: • Demonstrates fairness • Shows respect for both authority and opponents • Promotes specific cultural and/or regional pride • Demonstrates fellowship with competitors	All four elements are exceptionally demonstrated	Three elements are clearly demonstrated	Two or less elements are clearly demonstrated	Zero elements are clearly demonstrated
Feedback at Competition	Up to three points for compliment cards collected at the Competition.			

Categories & Awards

In addition to the awards listed below, school plaques and/or individual team certificates will be awarded for exemplary performance in the following categories:

Category	Required/ Optional	Due Dates	Award	Maximum Points toward Joe Kosmo Award for Excellence
On-site Mining in the Caterpillar Mining Arena	Required	May 21-23, 2014	First place $3,000 team scholarship and Kennedy launch invitations Second place $2,000 team scholarship and Kennedy launch invitations Third place $1,000 team scholarship and Kennedy launch invitations Teams not placing 1st, 2nd, or 3rd will receive one point per kilogram mined and deposited up to 10 points	25 20 15 Up to 10
Systems Engineering Paper	Required	April 21, 2014	$500 team scholarship	Up to 20
Outreach Project Report	Required	April 21, 2014	$500 team scholarship	Up to 20
Slide Presentation and Demonstration	Optional	April 21, 2014 and On-Site on May 21-23, 2014	$500 team scholarship	Up to 20
Team Spirit Competition	Optional	All Year	$500 team scholarship	Up to 15
Joe Kosmo Award for Excellence	Grand Prize for Most Points	All Year	A school trophy, $5,000 team scholarship and KSC launch invitations	Total of above points, maximum of 100 points possible
Judges' Innovation Award	Optional	May 21-23, 2014	A school trophy	
Efficient Use of Communications Power Award	Optional	May 21-23, 2014	A school trophy	
Caterpillar's Autonomy Award	Optional	May 21-23, 2014	First place $1,500 team scholarship Second place $750 team scholarship Third place $250 team scholarship	

NASA's Robotic Mining Competition Checklist

All documents are due by 12:00 p.m. (noon) eastern time.

Required Competition Elements

If required elements are not received by the due dates, then the team is not eligible to compete in any part of the competition (NO EXCEPTIONS).

☐ Registration Application*	50 teams are registered
☐ Systems Engineering Paper	April 21, 2014
☐ Outreach Project Report	April 21, 2014
☐ On-site Mining	May 21-23, 2014
○ Team Check-in, Unload/Uncrate mining robot	May 19, 2014 by 3:00 p.m.
○ Practice Days	May 19-20, 2014
○ Competition Days	May 21-23, 2014
○ Awards Ceremony	May 23, 2014 (evening)

Optional Competition Elements

☐ Presentation File	April 21, 2014
☐ Team Spirit	All year

Required Documentation

☐ Letter of Support from lead university's Faculty Advisor	With Complete Application
☐ Letter of Support from lead university's Dean of Engineering	January 20, 2014
☐ Team Roster	January 20, 2014
☐ Student Participant Form	January 20, 2014
☐ Faculty Participation Form	January 20, 2014
☐ Transcripts (unofficial copy is acceptable)**	January 20, 2014
☐ Signed Media Release Form	January 20, 2014
☐ Corrections to NASA generated Team Roster	February 24, 2014
☐ Team Photo including faculty (high resolution .jpg format preferred)	March 24, 2014
☐ Team Biography (200 words maximum)	March 24, 2014
☐ Head Count Form	March 24, 2014
☐ Revised Team Roster (no changes accepted after this date)	March 24, 2014
☐ Rule 31 documentation	April 30, 2014
☐ Rule 32 video	April 30, 2014
☐ Shipping Bill of Lading/Commercial Invoice	April 30, 2014

Optional Documentation

☐ Student Resume (optional)	December 2, 2013

* Registration is limited to the first 50 approved U.S. teams. Registration is limited to one team per university campus. Registration will end when NASA approves 50 applications.

** Each student's Transcript must be from the university and show:

- name of university
- name of student
- current student status within the 2013-2014 academic year
- coursework taken and grades

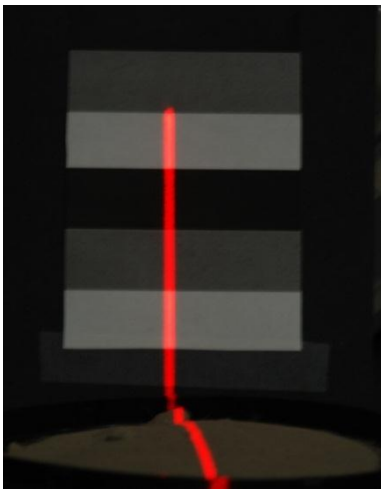
Definitions

Autonomous – The operation of a team's mining robot with no human interaction.

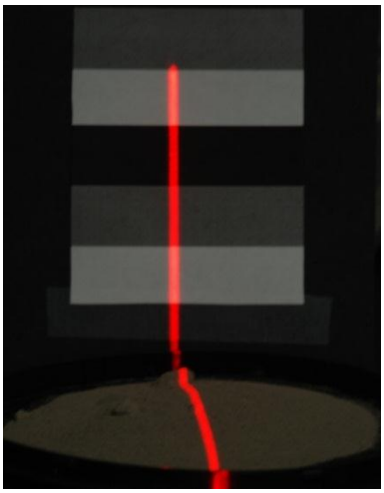
Black Point-1 (BP-1) – A crushed lava basalt aggregate which is similar to Mars Volcanic Ash. The BP-1 will be compacted with a fluffy top layer similar to the Martian surface. However, it does not behave like sand. The study on BP-1 is available on http://www.nasa.gov/offices/education/centers/kennedy/technology/nasarmc.html. Also, watch the Lunabotics Webcast where Dr. Philip Metzger, a NASA Physicist, describes BP-1 and its behavior. It is available at http://youtu.be/hMfrv7mlxbE. The density of the compacted BP-1 aggregate will be between 1.5 g/cm^3 and 1.8 g/cm^3. The top 2 cm will be raked to a fluffy condition of approximately .75 g/cm^3. There are naturally

occurring rocks in the BP-1 aggregate. The coefficient of friction has not been measured for BP-1. BP-1 behaves like a silty powder soil and most particles are under 100 microns diameter. The coefficient of friction and the cohesion of Martian soil have not been precisely measured due to a lack of scientific data from Mars. Instead, they have been estimated via a variety of techniques. Both parameters (coefficient of friction and cohesion) are highly dependent on the compaction (bulk density, porosity) of the Martian soil. Since the properties of Mars regolith vary and are not well known, this competition will assume that Martian basaltic regolith properties are similar to the Lunar regolith as stated in the Lunar Sourcebook: A User's Guide to the Moon, edited by G. H. Heiken, D. T. Vaniman, and B. M. French, copyright 1991, Cambridge University Press. Teams are encouraged to develop or procure simulants based on basaltic minerals and lunar surface regolith particle size, shape, and distribution. BP-1 is not commercially available and it is made from crushed basalt fines. However, JSC-1A is available from Orbital Technologies at: http://www.orbitec.com/store/simulant.html and NU-LHT is commercially available from Zybek Advanced Products (ZAP) at: http://www.zybekap.com/.

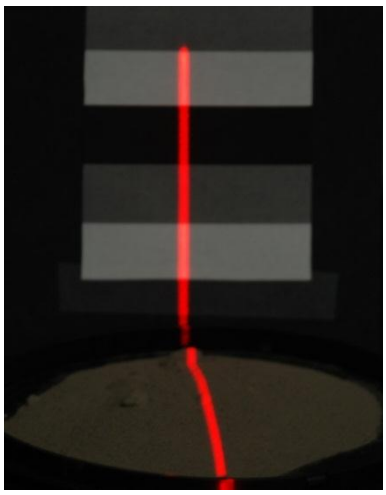
BP-1 reflectivity – NASA performed tests to answer questions about BP-1 reflectivity for LIDAR (or other LASER-based) navigation systems. The laser is not a beam – it is spread out as a sheet that is oriented in the vertical direction, so it is draped across the BP-1 and across a white/gray/black target that is standing up behind the BP-1 in the images. The BP-1 is the mound at the bottom of each image. Teams can get the reflectivity of the BP-1 by comparing the brightness of the laser sheet seen reflected from the BP-1 with the brightness of the same sheet reflected from the white and black portions of the target. The three images are for the three angles of the laser. Note the BP-1 is mounded so they need to account for the fact that it is not a flat surface if they choose to analyze the brightness in the images. The three pictures below were shot with the camera at 10, 16, and 21 degrees relative to the surface. The laser was at an angle of 15 degrees. The camera speed and aperture were set to (manual mode): 1/8 s, f/4.5.



10 degree



16 degree



21 degree

Caterpillar Mining Arena – An open-topped container (i.e., a box with a bottom and 4 side walls), containing BP-1, within which the mining robot will perform each competition attempt. The inside dimensions of the each side of the Caterpillar Mining Arena will be 7.38 meters long and 3.88 meters wide, and 1 meter in depth. The BP-1 aggregate will be approximately .5 meters in depth and approximately .5 meters from the top of the walls to the surface. The Caterpillar Mining Arena for the practice days and official competition will be provided by NASA. The Caterpillar Mining Arena will be outside in an enclosed tent. The Caterpillar Mining Arena lighting will consist of high intensity discharge (HID) lights such as metal halide lights inside a tent structure with clear sides, which is not quite as bright as outdoor daylight conditions. The atmosphere will be an air-conditioned

tent without significant air currents and cooled to approximately 77 degrees Fahrenheit. See Diagrams 1 – 3. The Caterpillar Mining Arena steel, primer and paint specifications are as follows:

1. Steel: A-36(walls) & A-992(I-beams) structural steel
2. Primer: Devran 201 epoxy primer, 2.0 to 3.0 mils, Dry Film Thickness (DFT)
3. Paint: Blue Devthane 379 polyurethane enamel, 2.0 to 3.0 mils, DFT (per coat)

Collector Bin – A Collector Bin in the Caterpillar Mining Arena for each competition attempt into which each team will deposit excavated BP-1. The Collector Bin will be large enough to accommodate each team's excavated BP-1. The Collector Bin will be stationary and located adjacent to the Caterpillar Mining Arena. See Diagram 3.

Competition attempt – The operation of a team's mining robot intended to meet all the requirements for winning the mining category by performing the functional task. The duration of each competition attempt is 10-minutes.

Excavated mass – Mass of the excavated BP-1 deposited to the Collector bin by the team's mining robot during each competition attempt, measured in kilograms (kg) with official result recorded to the nearest one tenth of a kilogram (0.1 kg).

Functional task – The excavation of BP-1 from the Caterpillar Mining Arena by the mining robot and deposit of BP-1 from the mining robot into the Collector Bin.

Martian like – Basis of merit associated with feasibility of:

1. Packaging into a small stowed volume for transportation to Mars (1.5 m x .75 m x .75 m)
2. Low mass - it costs $5,000 per kg to send mass to Low Earth Orbit and about 2.5 Million per kg to the Martian surface (based on NASA Mars Science Lab).
3. Simple and reliable – able to operate for 5 years without maintenance on the Martian surface
4. Martian dust tolerant
5. Easy to teleoperate
6. Able to survive a Martian winter

Mining robot – A teleoperated or autonomous robotic excavator in the Robotic Mining Competition including mechanical and electrical equipment, batteries, gases, fluids and consumables delivered by a team to compete in the competition.

Mining points – Points earned from the two competition attempts in the Robotic Mining Competition will be averaged to determine ranking in the on-site mining category.

Practice time – Teams will be allowed to practice with their mining robots in the Caterpillar Mining Arena. NASA technical experts will offer feedback on real-time networking performance during practice attempt. A maximum of two practice attempts will be allowed, but not guaranteed.

Reference point – A fixed location signified by an arrow showing the forward direction on the mining robot that will serve to verify the starting orientation of the mining robot within the Caterpillar Mining Arena.

Telerobotic – Communication with and control of the mining robot during each competition attempt must be performed solely through the provided communications link which is required to have a total average bandwidth of no more than 5.0 megabits/second on all data and video sent to and received from the mining robot.

Time Limit – 10 minutes to set up the mining robot in the Caterpillar Mining Arena, 10 minutes for the mining robot to perform the functional task, and 5 minutes to remove the mining robot.