

## ON-SITE MINING

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.

The teams with the first, second and third most mining points averaged from both attempts will receive 25, 20 and 15 points, respectively. Teams not winning first, second or third place in the mining category can earn one bonus point for each kilogram of BP-1 and/or icy regolith simulant (gravel) mined and deposited up to a maximum average of ten points.

Mining Points Attempt				
Mining Category Elements	Specific Points	Actual	Units	Mining Points
Pass Inspections:	0 or 1000	1	1=Achieved 0=Not Achieved	1000
BP-1 over 10 kg:	+3/kg	0	kg	0
Gravel (Icy Regolith Simulant) kg:	+15/kg	0	kg	0
Average Bandwidth:	-1/50kb/sec	1066	Kbps/sec	-21
Camera Bandwidth Usage	200kb/camera	400	Kbps/camera	-8
Mining Robot Mass:	-8/kg	62.55	kg	-500.4
Report Energy Consumed:	-1/Watt-hour	9	Watt-hour	-9
Dust Tolerant Design (30%) & Dust Fee Operation (70%)	0 to +100	30/19	Judges' Decision	49
Autonomy:	50, 150, 250 or 500	0		0
Total:				0

Table 1: Mining Category Scoring Sheet

1) Competition Teams will be required to perform two official competition attempts (10 minutes allowed for each run) using BP-1 in the Caterpillar Mining Arena. The Arenas are filled with compacted BP-1 that approximates basaltic Martian regolith. The mining area will contain BP-1 up to a depth of approximately 30 cm. Below the BP-1 there will be approximately 30 cm depth of gravel with a mean particle size diameter of ~ 2 cm which simulates icy regolith buried in the Martian regolith. Larger rocks may also be mixed in with the gravel and BP-1 in a random manner. Note that gravel may be mixed in with the BP-1, but the bulk of it will be in the bottom 30 cm of the mining area only. Three obstacles will be randomly placed and create two craters on each side of the Arenas. The mining robot will be placed in the arena in a randomly selected starting position. Each competition attempt will occur with two teams competing at the same time, one on each side of the Arena. After each competition attempt, the gravel will be returned to the lower 30 cm of the mining area and the BP-1 will be returned to the top 30 cm in a compacted state, and the obstacles and craters will be re-set in the Arena. The competition attempts will be chosen at NASA's discretion.

2) 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. In each of the two official competition attempts, the teams will score cumulative Mining Points.

3) See Table 1 for the Mining Category Scoring Sheet. The teams' 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 100 Mining points.)
- c) During each competition attempt, the team will earn 15 Mining points for each kilogram of simulated icy regolith (gravel) deposited in the Collector Bin. The gravel will be sieved out at the Collector Bin and weighed separately from the BP-1.
- d) During each competition attempt, the team will lose 1 Mining point for each 50 kilobits/second (kb/s) of average data used.
- e) During each competition attempt, the team will lose 200 kb/s of data for each situational awareness camera used (Camera Bandwidth Usage 200kb/camera)
- f) 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).
- g) During each competition attempt, the team will lose 1 Mining point for each watt-hour of energy consumed. The electrical energy consumed must be displayed by an (commercial off the shelf or "COTS") electronic data logger and verified by a judge.
- h) 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.
- i) **DUST-TOLERANT DESIGN** - The 30 points for dust-tolerant design will be broken down as follows:
- |      |  |           |
|------|--|-----------|
| i.   | Drive train components enclosed/protected and other component selections | 10 points |
| ii.  | Custom dust sealing features (bellows, seals, etc.)                      | 10 points |
| iii. | Active dust control (brushing, electrostatics, etc.)                     | 10 points |
- j) **DUST-FREE OPERATION** - The 70 points for dust-free operation will be broken down as follows:
- |      |  |           |
|------|--|-----------|
| i.   | Driving without dusting up crushed basalt  | 20 points |
| ii.  | Digging without dusting up crushed basalt  | 30 points |
| iii. | Transferring crushed basalt without dumping the crushed basalt on your own Robot | 30 points |

- k) **AUTONOMOUS OPERATION** - During each competition attempt, the team will earn up to 500 Mining points for autonomous operation. Mining points will be awarded for successfully completing the following activities autonomously:
- i. Crossing the obstacle field (two times only, Outbound and back): 50 points
  - ii. Crossing the obstacle field, excavate and returning to the collection bin: 150 points
  - iii. Crossing the obstacle field, excavate and depositing regolith (two times): 250 points
  - iv. Fully autonomous run for 10 minutes: 500 points
- l) The points earned for autonomy are not cumulative. Levels 1 through 4 points will be incrementally achieved. For example if level 2 is achieved then the points for level 1 are not counted. The autonomy points are awarded for the whole competition attempt and not for each run across the obstacle zone. If the robot fails to achieve autonomy during the competition attempt, and manual control is regained, then only autonomy points achieved to that point in time will be allowed.
- m) 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.
- n) The walls of the Caterpillar Mining Arena shall not be used for sensing by the robot to achieve autonomy. The team must explain to the inspection judges how their autonomous systems work and prove that the autonomy sensors do not use the walls. There are no walls on Mars and teams shall operate as closely as possible to a Mars scenario of operations. Integrity is expected of all team members and their faculty advisors. Failure to divulge the method of autonomy sensing shall result in disqualification from the competition.
- 4) All excavated mass deposited in the Collector Bin during each official competition attempt will be weighed after the completion of each competition attempt. All gravel will be sieved out from the BP-1 at the Collector Bin and weighed separately.
- 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 and gravel 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 by the front end of the robot.
- 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 and gravel 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 5 minutes to place the mining robot in its designated starting position within the Caterpillar Mining Arena; and remove the mining robot from the Caterpillar Mining Arena after the 10-minute competition attempt has concluded and as directed by the Mining Judge.
- 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 Mining Judge.

- 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 while the RoboPits 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 trough/sieve top front edge will be placed so that it is in the vertical plane of the adjacent end wall of the Caterpillar Mining Arena. The top edge of the sieve will be approximately 0.55 meter +/- 0.05 m from the top of the BP-1 surface directly below it. The sieve screen frame will have the same opening dimensions and internal slope angles as the trough but will be suspended above it. See Diagram 3.
- The top opening inner dimensions for both the trough and the sieve screen placed above it are the same: 1.575 m long by 0.457 m deep with the same slope angles of 44 degrees long sides and 51 degrees at the ends.
  - With the addition of the sieve screen, the effective height of the collector trough lip is raised by 3.8 cm above the trough alone. The sieve screen is 6.4 cm below the sieve frame top. See Diagrams 1 – 3.
  - Target(s) or beacon(s) may be attached to the collector trough (not the sieve frame) 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 trough, it must not exceed the length of the Collector trough and it must not weigh over 9 kg.
  - The outside dimensions of the collector trough and sieve frame are 1.65 meters long and .48 meters wide.
  - The navigational aid system may not be higher than 0.25 m above the Collector Trough, and cannot be permanently attached or cause alterations (ex: no drilling, nails, etc.).
  - 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).
- 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 Arena and the Collector Bin during each competition attempt. The BP-1 and/or gravel 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 and/or gravel 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 not be used for the purposes of mapping autonomous navigation and collision avoidance (there are no walls on Mars). Touching or having a switch sensor springwire that may brush on a wall as a collision avoidance sensor is not allowed.

18) The mining robot must not use the wall as support or push/scoop BP-1 and/or gravel 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 5 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. The energy consumed must be recorded with a "Commercial Off-The-Shelf" (COTS) electronic data logger device. Actual energy consumed during each competition run must be shown to the judges on the data logger immediately after the competition attempt.

22) The mining robot must be equipped with an easily accessible **red** emergency stop button or "kill switch". The spirit and intent of the kill switch is that it is easily accessible and can be safely activated by anyone in an easy and quick manner. Use good engineering practices and principles in placing the kill switch on your robot, failure to do so may result in a safety disqualification. The kill switch is required to be on the robot and enabled at all times during the competition week. Disabling the kill switch without authorization from the Competition Staff shall result in a safety disqualification. The emergency stop button or kill switch shall have a 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. This rule is to save 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 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 mass is limited to a maximum of 80.0 kg. During the excavated mass dumping operations only, the mining robot may deploy itself and exceed 1.5 m in height, but must be lower than the height of the ceiling of the tent, which is less than 2.5 m above the surface of the regolith. 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. Multiple mining robot(s) systems are allowed but the total mass and starting dimensions of the whole system must comply with the volumetric dimensions given in this rule.

24) 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. Pneumatic mining systems are permitted if the gas is supplied by the robot and self-contained.

25) 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 or off-world mission.

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

27) 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.

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

29) 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** kill switch or emergency stop button at any time.