Citizen Forum Background Information

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Asteroid Detection: Finding Potentially Hazardous Asteroids

Asteroids may not seem like a big problem compared to all of our everyday concerns, but the potential consequences of a major asteroid collision are devastating. Scientists estimate that asteroids with the power to devastate a city impact Earth about once every 100 years on average. What, if anything, should we do to protect the Earth from this threat?

The threat of an Asteroid Impact
Asteroids have impacted Earth throughout its history. A massive asteroid impact was responsible for the extinction of the dinosaurs 65 million years ago. In 1908, a huge object exploded over a remote location in Siberia, killing thousands of reindeer and killing an estimated 80 million trees over 1000 square miles. Had it struck a more populated location, the effects could have been catastrophic.

The world got a reminder of the potentially devastating consequences of an asteroid collision in February of 2013, when a previously undetected meteor measuring approximately 20 meters in diameter entered Earth's atmosphere and exploded in a large airburst over Chelyabinsk, Russia with the force of many atomic bombs. The shockwave from the explosion led to widespread damage and an estimated 1,500 injuries to residents from secondary impacts such as shattered glass.

16 hours later on the same day, an asteroid about twice the size of the one above Chelyabinsk (estimated diameter: 45 meters) that had been previously detected and tracked by astronomers made the closest approach to Earth that had ever been observed for an asteroid of its size. Although the two events were completely unrelated, this coincidence raised awareness about the potential threat to Earth among the public.

What are our current capabilities for detecting potentially hazardous asteroids?

There is currently no planetary defense agency for the United States, but NASA funds a number of scientific research teams to track Near-Earth Objects (NEOs) such as asteroids and comets. An observer network of asteroid-hunting astronomers works loosely together to find asteroids from the ground, and to share data with one another about the asteroids that they find. Much of the coordination among this group is overseen by the Minor Planet Center at the Smithsonian Center for Astrophysics, which is funded by NASA.

NASA and the Minor Planet Center observe a "6x6" rule, in which if an object comes within 6 Earth radii (about 40,000 kilometers or 25,000 miles) within the next six months, a protocol is activated to share the risk with stakeholders. Astronomers and governments in other countries have their own policies for sharing what they find.

What do we know and communicate about the asteroids that are out there?

Scientists estimate that they have identified well over 95% of the largest "planet-killer" asteroids of over 1 kilometer in diameter, and none of these are likely to threaten earth in the next few centuries. We know far less, though, about smaller asteroids that could cause destruction at regional or urban scales. Congress has charged NASA with the task of finding 90% of all asteroids that are 140 meters in diameter or larger by 2020, but this goal is unlikely to be achieved with current capabilities.

What could be done to improve asteroid detection capabilities?

Right now, we depend on ground-based systems from a global network of observers. But this system has a lot of weaknesses. First, detection is only possible at night, and we don't have coverage in much of the Earth's Southern hemisphere. Also, looking up at space through the Earth's atmosphere makes detection much more difficult than it is from outer space. Weather, moonlight, and distortion from the atmosphere all present challenges to better detection. Finally, looking from Earth makes it very hard to find asteroids that are in orbit similar to our own.

We could augment our existing capabilities from the ground by building new observatories that would increase our coverage area and allow for more standardized detection around the world. This policy might cost about $50 million annually for several decades, and could lead to new breakthroughs in other areas of astronomical research. However, it would still suffer from some of the challenges that come from hunting while down on the ground.

Many experts argue for a space-based detection system. NASA's WISE (wide-field infrared survey system) satellite provides some data about asteroids, but it wasn't really designed for the task and many researchers use it for other purposes. A system of one or two spacecraft could be designed and launched, with a mission of using infrared detection capabilities to identify potentially hazardous asteroids. These space-based telescopes would provide coverage of the whole sky, and being above the Earth's atmosphere allows for more accurate detection. Experts from NASA estimate that this would allow them to find and characterize over 90% potentially hazardous asteroids within a decade. The estimated cost of such an effort would be around $500 million per telescope, which is much more than NASA currently receives for its ground-based detection efforts.

Who Should Guard the Earth?

NASA currently leads most asteroid detection efforts, but there are others who could be part of efforts going forward. With a heightened focus on planetary defense, some people are calling for an international Planetary Defense Agency to be overseen by the United Nations or some other authority. A non-governmental agency called the B612 foundation (named after the asteroid in the story *The Little Prince*) has proposed creating a "Sentinel" satellite within 5 years that would significantly enhance our detection capabilities. Other groups such as the European Space Agency are also working on ways to improve detection. Asteroids also present the potential for space research missions and commercial benefits, and some private industry groups are getting involved.

Your Asteroid Detection Decision at the Forum

During the Forum, you and other participants will consider what the policies for asteroid detection should look like in the future. You will discuss and weigh the tradeoffs, costs, and risks of several potential policy options and recommend what should be done to detect potentially hazardous asteroids. You'll also consider and share your opinion about what groups and institutions should be charged with the task of asteroid detection.

Mitigation And Preparedness: Responding to the Threat of an Asteroid Impact

Asteroid detection (meaning finding and identifying asteroids that present a potential threat to Earth) is an important component of planetary defense. Another essential decision point is mitigation. Mitigation refers to what actions (if any) that people might decide to take to prepare and protect the Earth, after an asteroid threat to Earth is identified. There are a number of potential responses that people could decide to take, ranging from. Each of these possible responses carries a unique mix of tradeoffs, uncertainties, risks, and costs.

Your Mitigation Decision at the Forum

During the Forum, you and other participants will consider two scenarios that describe a threat to Earth from an approaching asteroid. You will discuss and decide what actions you would recommend. There is no one correct answer in any of these cases, because the decision to take (or not take) any particular action depends on individual perspectives and values that will not be the same for everyone. For each scenario, you and your fellow participants will consider and recommend what mitigation option(s) (if any) to enact and who should implement them.

To help inform the best possible decisions, it is important to understand the mitigation options that are available to decision-makers, and how each of these options might be applied.

Risk factors for Asteroid Impact

Impacts from near-Earth object (NEO's) have occurred throughout Earth's history, and we know that these impacts are inevitably going to continue. Potential negative consequences of an asteroid collision range from harmless fireballs in the atmosphere (which occur very often with asteroids that are only a few meters across in diameter) to airbursts or dust clouds all the way to catastrophic events with the potential for massive loss of life. The decision of whether and how people should respond a detected asteroid threat will depend upon a number of factors. These include: the severity of the collision's impacts upon Earth, where and how it is predicted to impact, and the cost, uncertainty, and time associated with all of the potential mitigation responses.

The process for assessing and characterizing potential impacts from an asteroid collision is complex and involves many factors. But the three most important factors affecting the potential danger to people on Earth, and the ones that we will focus on to inform your discussions are:

- The mass of the asteroid. In general, the more massive the asteroid, the greater the potential threat. The mass of the asteroid depends largely on the size of the asteroid and what materials it is made of.
- The speed of the object as it approaches Earth.
- The estimated distance and time to Earth impact after the asteroid threat is identified. Detection time can range from hours or days to decades or centuries.

Potential actions for mitigation

Many ideas have been proposed for preparing and protecting the Earth from the threat of an imminent asteroid collision. These mitigation options vary tremendously from one another in terms of how much each would cost, how much warning time each would require, what the risks and potential unanticipated consequences are, and how close each of techniques is to being ready to deploy if needed. Some could be deployed rapidly if an asteroid were detected tomorrow, while others would require huge programs to establish their readiness.

For the Asteroid Forum, you and your fellow participants will consider four potential options for mitigation: civil defense, nuclear explosives, kinetic impactors, and gravity tractors. We explain the concept and tradeoffs around each of these proposed strategies below. These strategies could be adopted by themselves, or in some cases could be combined together to respond to a threat of an asteroid collision. Your group will have the option of recommending all, some, or none of the actions for each of the scenarios you will consider at the Asteroid Forum.

Civil Defense: Communication and Preparation. Civil defense does not actually reduce the probability of asteroid collision, but rather involves notifying citizens and decision-makers, and preparing people and infrastructure on Earth for the asteroid's impact. It is likely that civil defense would be adopted to some degree in response to any imaginable asteroid threat, but the scale and timeframe for communication and preparation would depend on the specific situation. Civil defense actions may involve communicating risks, so residents and decision-makers can plan and prepare for the impact. Disaster preparedness actions may include preparing buildings or infrastructure for increased resilience, planning and preparing for the evacuation and/or sheltering of at-risk populations, stockpiling food and energy resources, and could also lead to agreements between global or national governments to help groups of people adapt. Civil defense strategies can be implemented on the scale of weeks or years, depending on what policies have been put into place before the asteroid is detected.

Important considerations include: the costs and logistics required for preparation, the dynamics of international or regional agreements to prepare for collision, the risks of causing an unnecessary panic if the asteroid does not actually impact the planet, and the tradeoffs between preparing the Earth and taking other kinds of actions to actually prevent the asteroid from reaching the Earth.

Kinetic Impactors: Ramming an asteroid. Kinetic impaction involves sending one or more large, high-speed spacecraft into the path of an approaching near-earth object. This could deflect the asteroid into a different trajectory, steering it away from the Earth's orbital path. NASA demonstrated on a small scale with the Deep Impact mission of 2005. If preparations were made in advance so that kinetic impactors were available upon detection, the National Academy of Sciences would require a warning time of at least 1 to 2 years for smaller asteroids. If an approaching asteroid were detected tomorrow, perhaps 20 years would be required to build and launch an impactor, to reach and impact the target, and to nudge the asteroid from Earth's path. However, decades or more might be required to deflect larger asteroids (hundreds of kilometers in diameter) that present the most catastrophic threats. If time allows, a mission to study the asteroid up close and send information back to Earth before sending the impactor could greatly increase the chance of success. Kinetic impactors may not be effective in changing the orbit of the very largest asteroids.

Important considerations for kinetic impactors include: the potential for mission failure, the need for prolonged detection times, the risk of breaking the asteroid into smaller pieces that could still threaten Earth, the cost and factors needed to accomplish the mission, and the tradeoffs with other potential mitigation and/or civil defense actions.

Blast deflection: Earth has an arsenal of many nuclear or other kinds of explosives, held by nations around the world. Some experts have proposed launching nuclear explosives from the Earth to disrupt, destroy, or redirect an approaching near-earth object. This may be the only strategy that would be effective for the largest and most dangerous "planet-killer" asteroids (over 1 kilometer in diameter). Blast deflection could also be used if one of the other approaches are attempted and are unsuccessful. A NASA study from 2007 concluded that nuclear standoff explosions were likely to be the most effective method for diverting an approaching near-Earth object. However, nuclear explosives are a controversial technology, are technically banned from use in outer space, and are the subject of many geopolitical disputes. Blast deflection could result in fracturing the asteroid into smaller pieces that could still threaten the Earth. However, it may be more appropriate for dealing with an approaching rubble pile than kinetic impactors would be. Important considerations for blast deflection include the potential for mission failure, the need for international cooperation, and the readiness of the techniques.

Gravity Tractors: If an approaching asteroid were detected early enough, it could be possible to divert its path using the gravity of a spacecraft. Instead of sending an impactor to ram into an approaching object, a gravity tractor device would fly alongside the asteroid for a long period of time (years to decades) and slowly pull it out of Earth's path. Gravity tractors would be most likely to work on any shape or composition of approaching asteroid, even if it were just a pile of rubble. However, gravity tractors might not be effective for the largest asteroids of over 500 meters in diameter which might be the greatest threat to Earth. Gravity tractors offer the greatest control and could perhaps even divert an approaching asteroid to other locations in space where people could theoretically use them for research or commercial purposes. However, these techniques have never been tried and would require decades for building, launching, and carrying out a mitigation mission.

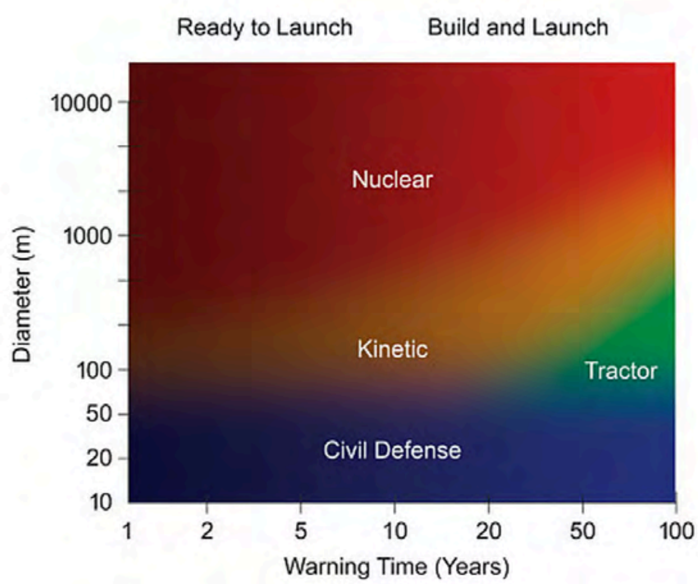

Figure 5.5 from *Defending Planet Earth: Near-Earth-Object Surveys and Hazard Mitigation Strategies,* National Academies of Science report (2010)

Asteroid Redirect Mission: A Stepping Stone to Mars

In what is being called the 'Proving Ground', NASA is taking aim at the future of deep space exploration by demonstrating technologies necessary for extending our reach in the Solar System. The Asteroid Redirect Mission is a key milestone on this path. By relocating an asteroid to orbit the Moon and then sending crewed missions to that asteroid, many of the techniques and capabilities that are needed for eventually exploring Mars and beyond will be proven in a space environment.

What is a Capability-Driven Framework?

One of the development strategies for the advancement of human exploration of the Solar System is to follow a capability-driven framework. NASA's capability-driven framework is a departure from the traditional space mission model. Instead of selecting a destination – like the moon or the International Space Station – and building the transportation vehicles to get there, this approach develops the vehicles and capabilities that can go to a broad range of destinations. As these vehicles and capabilities mature, increasingly complex missions can be selected to destinations farther and farther into the solar system.

This means that missions are funded, designed, and carried out as NASA's budget and capabilities dictate. Rather than a detailed start-to-end plan, such as the Apollo Program had for lunar exploration in the 1960s, this approach does not need final, fixed goals in place before initial missions are carried out.

This method has the potential to be more efficient and cost-effective, as the path towards the eventual goal of Mars exploration is flexible. Technologies can be developed, tested, refined, and perfected in a lower-risk environment than a crewed Mars mission.

What is Proving Ground?

Merriam-Webster defines "proving ground" as a place where things or people are tested or tried out for the first time; a place where scientific testing is done. NASA refers to the Proving Ground as a phase of human and robotic missions that prepare for and prove our ability to safely live and work away from Earth for extended periods of time. The proving ground is centralized in cis-lunar space, but encompasses activities conducted aboard the International Space Station, and robotic missions on and around the moon, Mars, and farther into the cosmos.

NASA's capabilities will continue to mature through missions in the Proving Ground, leading to the ability to go to Mars. As such, the Proving Ground and the Capability Driven Framework are related, as the final destination and mission concept for human exploration is not defined for the Proving Ground. The Proving Ground can be viewed as a method of moving NASA from earth-dependent to earth-independent in smaller increments and in full before attempting a mission to Mars.

What is the Asteroid Redirect Mission?

The Asteroid Redirect Mission or ARM will be the first major Proving Ground Mission. There have been other proposed Proving Ground missions to destinations in cis-lunar space and Mars. ARM will capture a small near-Earth asteroid and place it into orbit around the Moon. Once the object is in lunar orbit, a crewed mission will be sent to rendezvous with the asteroid and obtain samples for Earth-based analysis. Many new technologies and techniques will be demonstrated, including propulsion systems and crew habitats. In addition, other mission components will advance parallel fields such as planetary defense capabilities. ARM is just one of a series of Proving Ground missions that will 'pave the road' for the future, including the eventual exploration of Mars. There are two robotic mission options being considered.

What are the two potential robotic mission scenarios, and how do they differ?

Option A involves the capture of a single asteroid approximately 10 meters in diameter. A large, inflatable bag will be deployed around the object, and the entire asteroid will be redirected to lunar orbit. This will result in a much larger object being available for study, increasing the volume of samples available to astronauts and also eventually yielding more material.

There is a possibility that this technique will be relevant to clearing space junk and other debris from low Earth orbit or orbits around other bodies. Due to the uncertainties in characterizing such a small object, the asteroid might be a loosely held together 'rubble pile' rather than a solid object.

Option B instead aims to retrieve a 2-3 meter boulder from the surface of a much larger asteroid. The "much larger object" referred to in Option B is relative to the size of the asteroid/object that would be targeted in Option A. Option A targets a ~10m, free-flying monolithic asteroid. Option B targets an asteroid that is hundreds of meters in size, covered with boulders that could be retrieved from its surface.

Using a type of grabbing device, the spacecraft would land on the asteroid's surface, attach itself to the target boulder, and then lift off in order to place the boulder in lunar orbit. Ground-based observations will be more able to identify the composition of this larger asteroid, and the added mass of the boulder will have more of an impact in the planetary defense demonstration element of the robotic mission.

The additional maneuvering required by Option B could also be more relevant in informing engineers about similar future missions, such as landing on the moons of Mars. The mission would have a multitude of target boulders to choose from, but removing any boulder could prove challenging.

How does the Asteroid Redirect Mission advance planetary defense technologies?

During the capture phase of the mission, a gravity tractor demonstration will be performed on the target asteroid. The gravity tractor method leverages the mass of the spacecraft to impart a gravitational force on the asteroid, slowly altering the asteroid's trajectory. In both Options A and B, the robotic spacecraft will initiate an orbit around the asteroid to transmit the required impulse to the asteroid. For Option A, the robotic spacecraft will be empty, conducting the demonstration on the target asteroid before enveloping it. For Option B, the robotic spacecraft will conduct the demo on the large asteroid, with the small boulder in its clutches. The boulder's additional mass enhances the gravitational force that the spacecraft can transmit to the asteroid.

Before making the capture, the orbital path of the asteroid around the Sun will be altered. This demonstration will be the first attempt to change the trajectory of a near-Earth object. While the final selected target will not be considered hazardous in terms of size or location, testing this mitigation technology will help us better prepare for deflecting future hazardous objects.

Your Asteroid Redirect Decision at the Forum

During the Forum, you and other participants will discuss the merits and advantages of the two finalist mission scenarios with regards to relevance to planetary defense, benefits in terms of scientific and material gains, and usefulness in terms of furthering human exploration. You will consider both of the options and ultimately choose one that you feel would provide the most benefit to NASA's future plans. There is no one correct answer in any of these cases, because the decision to take (or not take) any particular action depends on individual perspectives and values that will not be the same for everyone. Below is a summary of the two options.

Option A - Pro	***Option A - Con***
Larger object being available for study: Option A is targeting a ~10m asteroid, while Option B is targeting a 2-3m boulder. Therefore, the returned asteroidal mass in Option A will result in a larger object being available for study **Relevant to clearing space junk**: When the capture mechanism is deployed, it is essentially a large, inflatable bag with a strong yet flexible frame. As envisioned with the ARM mission, it is capable of enveloping free-flying objects. At increased scales, the concept could be extended to clear "space junk" from Earth's orbit. Space junk could include spent rocket stages, old satellites, or other fragments that could collide with operational spacecraft.	**The asteroid might be a loosely held together 'rubble pile' rather than a solid object**: Objects that are within the size range of Option A (~10 m) are difficult to characterize from Earth. What may seem like a monolith may actually be a clump of rubble, held together by gravitational forces. Approaching the rubble could disrupt the debris, resulting in a smaller sample collected than anticipated. Additionally, for the crewed segment of the mission, approaching the debris for investigation and sampling could prove more challenging due to debris mitigation protocols for astronauts.

Option B - Pro	***Option B - Con***
Ground-based observations will be more able to identify the composition of this larger asteroid: As stated above, the larger asteroids are easier to characterize, so the advanced knowledge of the target's composition, rotation, shape, precise orbit, and spectral class will help to inform mission planning. **The added mass of the boulder will have more of an impact in the planetary defense demonstration element of the robotic mission:** Please see answer to question above about "greater mass" **The additional maneuvering required by Option B could also be more relevant in informing engineers about similar future missions, such as landing on the moons of Mars**: The robotic	**The mission would have multiple target boulders to choose from, but removing any boulder could prove challenging:** The boulders on a large asteroid could be loosely adjacent to the surface of the asteroid, or may have over the years bonded to the asteroid surface. Plucking the boulder from the surface could be as easy as land-grab-go, but it could also require agitation or drilling to free it from the surface.

spacecraft would have to rendezvous with the large asteroid, adjusting its propulsion and trajectory to the asteroid's, possibly performing real-time investigation of boulder options before selecting the best one to retrieve. It will descent to the surface in a low-gravity environment while the asteroid is on its rotational axis. The surface landing will have to be precise, positioning the robotic arms sufficiently around the boulder in order to be able to lift it from the surface. This advanced maneuvering will be greatly informative for future missions, particularly those to Mars' moons, Phobos or Deimos, because they share similar traits with large asteroids – in fact many people believe they are asteroids that were caught in Mars's gravitational pull.	

For more information about the options for the Asteroid Redirect Mission, please see the presentations at this link:

Option A:
http://www.lpi.usra.edu/sbag/meetings/jul2014/presentations/1030_Wed_Muirhead_ARM_OptionA.pdf

Option B:
http://www.lpi.usra.edu/sbag/meetings/jul2014/presentations/1030_Wed_Mazanek_ARM_OptionB.pdf

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Journey to Mars: Planning the Future of Human Space Exploration

The complexities and challenges that need to be faced when planning a crewed mission to the planet Mars are vast. The incredible distances and harsh conditions render such an endeavor many times more difficult than any previous space initiative. While developing a plan for what a Mars mission would look like is important, it is also of critical importance to look towards the more immediate future and decide what agencies like NASA can be doing in preparation for the most ambitious exploration agenda in human history. What are the problems that engineers and astronauts must solve when planning for Mars, and what framework will result in the most rapid, cost-effective, and successful navigating of those challenges?

What considerations need to be addressed when planning a mission to Mars?

- **Timeframes** While the Earth and Moon vary in distance very little over time, the position of Mars relative to Earth can change quite drastically on the timescale of months. This limits the windows of opportunity for launching spacecraft and also constrains the time it takes to reach Mars. A typical travel time for the spacecraft that have been launched to Mars is 5 months; compare this to 3 days for astronauts to reach the Moon. Advanced propulsion technologies could cut this down significantly.

- **Radiation** Mars lacks a magnetic field. On the Earth, this shields us from much of the Sun's harmful radiation. While traveling to Mars for many months and once at the red planet, astronauts can expect to receive a significant amount of radiation. Spacecraft and habitats that are capable of protecting the astronauts will need to be developed, but even with such technology, the risk of negative health effects remains significant.
- **Surface conditions** The atmosphere of Mars is two hundred times thinner than that of the Earth and composed primarily of carbon dioxide. The surface temperatures can drop as far as -200^0 Fahrenheit. Advanced habitats and space suits would need to be designed in order to maintain survivable conditions on the surface of Mars for many months at a time.
- **Supplies and fuel** Due to the distances involved, resupplying a Mars mission from Earth is impractical unless planned out months in advance. If critical habitat components fail, relying on backup parts to arrive from Earth may not be possible. With the advance of technologies such as 3D printing and in-situ resource utilization, astronauts may be able to manufacture their own fuel, air, water, and other supplies from resources found on Mars.
- **Phobos and Deimos** Mars has two small moons which are thought to be captures asteroids. While the Earth's moon is over 3,000 kilometers in diameter, neither Phobos nor Deimos is larger than 27 kilometers in any dimension. Even though the distance required to travel to these moons is the same as traveling to Mars, their much lower mass results in a far easier landing/takeoff procedure. For this reason, a crewed mission to Phobos or Deimos would necessitate a lower level of capability than a crewed mission to the surface of Mars.

Options for a Crewed Mars Initiative

- **Robotic and Orbital/Moon Missions** This scenario involves a much larger array of robotic explorers being sent to Mars than NASA currently has. In addition, crewed missions would be sent to orbit Mars and possibly to Phobos and Deimos. While this option does not involve a crewed landing on the surface of Mars, the astronauts in orbit would be able to remotely operate robots on the surface in a much more efficient and directed manner than teams on Earth.

Since this is the least intensive option in terms of scale, it is also the least expensive and involves the smallest amount of risk. Without the need for human-rated landing and takeoff vehicles, the amount of research and engineering that would need to be undertaken is a fraction of a mission involving a crewed landing, lowering cost and making this scenario possible on a fairly short timescale.

The absence of setting humans on Mars also results in a substantial reduction in the risk to the astronauts in many respects. The amount of science that can be done pales in comparison to any mission with a crewed landing on the surface of Mars. This option also may be less exciting to the public than full human exploration missions.

- **Viking Strategy** This scenario involves a small-scale crewed exploration mission that would set down on the surface of Mars and operate for several months before the crew would return to Earth. Eight astronauts would be selected to make the journey, and it would be launched at a time that would provide for not only a short travel time but also the shortest possible stay on the surface to minimize risk to the astronauts.

Having astronauts on the surface of Mars would greatly increase the relevance and amount of science data that the mission would yield compared to remote operation of robots. However, the technical and engineering hurdles that need to be addressed result in a major cost and timeframe increase. While risk would be minimized, it would still be substantial for all of the astronauts involved.

Without a permanent habitation plan, there is the risk that the mission will suffer a fate similar to the Apollo Program. That is, once we accomplish a crewed landing on Mars, interest and support in the Mars program may wane to the point of cancelling any future missions.

- **Pioneer Strategy** This scenario involves a permanent settlement on the surface of Mars. This colony would be preceded by a fleet of robotic and supply ships that would deposit food, fuel, and materials on the surface. These robots would also begin preparations for constructing permanent habitats. An initial large crew of human explorers would be refreshed every few months both in terms of supplies and personnel.

A mission of this scale and duration would be able to unlock a large number of the mysteries we have concerning the history of Mars and the entire Solar System. Multiple locations could be settled or scouted, offering opportunities for an abundance of diverse scientific research. Humanity would become 'Earth-Independent', meaning that such a mission might no longer require support from our home planet and may become self-sustaining.

The technology and techniques required for such an undertaking would be extremely challenging. Methods of dealing with radiation, extracting water, producing fuel and air, propulsion, habitat construction, and a number of other techniques would need to be vastly improved before this scenario becomes feasible. It would involve a colossal increase over a smaller-scaled surface exploration mission in terms of cost, risk, and timeframe.

The Asteroid Redirect Mission and the Proving Ground

With the challenges for a crewed Mars mission defined and potential exploration scenarios outlined, it is obvious that the engineers and scientists of today need a framework that will allow for a successful Mars campaign. While some advocate laying an entire plan down from test missions through final exploration plans from the very beginning, there are other options for organizing the efforts that must be made. One of these options is the Proving Ground concept, which allows for missions to be designed, funded and carried out as NASA's budget and capabilities dictate.

An example of the Proving Ground approach to Mars exploration was seen in the last discussion - NASA's upcoming Asteroid Redirect Mission. While there is merit in the mission itself, it really serves primarily as a stepping stone towards the overarching goal of crewed Mars exploration. Many missions such as this would allow for the capabilities necessary for Mars exploration to be designed, tested, improved, and perfected on an increasing level of complexity and distance from the Earth. Smoothly transitioning from our current capabilities to the set of technologies and techniques necessary for a large-scale Mars initiative will likely be more cost-effective than planning an entire Mars mission start to end.

Your Path to Mars Decision at the Forum

During the Forum, you and other participants will discuss the different options for an eventual Mars exploration mission with a focus on the Proving Ground strategy. You will consider the options for a crewed Mars initiative in terms of scale, science benefits, cost, and even whether each option would be exciting or worthwhile. However, the main part of the discussion will focus on the more immediate future, and how the plan for Mars should be laid out as we move forward – would you like to see an entire strategy laid out now, or are you comfortable with a series of Proving Ground missions (such as the Asteroid Redirect Mission) that are undertaken as budgets and capabilities dictate?