SBAG Asteroid Redirect Mission Special Action Team

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SBAG ARM SAT: Timeline & Documents

- **January** – Opening discussion with ARM RCIT; discussion of initial task list
- **February** – Presentation to ARM Formulation Team
- **April** – Follow-on task list identified
- **June** – Additional specific questions added to task list
- **July** – Presentation at SBAG 11 meeting, draft posted to the web, solicitation of SBAG community feedback
- **August** – Finalize reports from SBAG ARM SAT

CURRENT DOCUMENTS:
- Slide set of July 30, 2014 – this slide set

- Findings relevant to ARM from open community SBAG meetings from July 10-11, 2013, and January 8-9, 2014, are available on the web and at the end of this slide package ([http://www.lpi.usra.edu/sbag/findings/](http://www.lpi.usra.edu/sbag/findings/))
- **The SBAG ARM SAT work does not negate those previous SBAG community findings.**
SBAG ARM Special Action Team Report: Summary

We request your technical assessment for the following areas to support assessments of the robotic mission concepts:

**Science:** What new science, beyond what's already planned for missions in development, could be done robotically at a large (>50 m) asteroid or small (<~10) asteroid? Or with crew at a captured and returned boulder from a large asteroid or at an entire small asteroid? As part of this assessment, we request your scientific assessment in sample selection and collection.

"What is the value to the Science community of characterization of a large >50 m NEA that hasn’t been visited before? Also what is the value of re-characterization of a previously visited NEA? What is the difference in value between the two options?"

**Planetary Defense:** What realistic impact threat mitigation techniques or strategies and what trajectory deflection demonstrations, if any, make sense to be performed by the asteroid redirect robotic mission?

**Resource Utilization:** What key resource utilization demonstrations could be done robotically at a large (>50 m) asteroid or small (<~10) asteroid? Or with crew at a captured and returned boulder from a large asteroid or at an entire small asteroid?
Science - summary

1) The type of asteroid sampled is of high scientific importance. Primitive asteroids associated with volatiles and prebiotic material are prioritized for science in the Decadal Survey, and such materials also may not be fully represented in meteorites, due to losses related to passage through Earth’s atmosphere. A substantial mass of asteroid samples are already available for scientific study by examination of meteorites, and thus the scientific priority is to sample asteroids that have the highest potential to provide new materials not available in meteorite collections. For science, target composition is a much higher priority than target mass returned.

2) Characterizing and returning a sample from an asteroid not already, or planned to be, sampled is of higher science priority than returning a sample from one that has been or will be. The asteroid population is numerous and diverse. Only samples collected from Itokawa are currently in our collections, and samples from Bennu and 1999 JU3 are planned. Samples from asteroids other than these three would provide new scientific insights and hence are of higher science value. The value to the science community is much higher for characterizing a previously unexplored NEA than re-characterizing one that has been previously visited.
Science - summary

3) Involvement of a science team is critically important to maximize the science, including during the concept development portion of the mission.

4) Ground-based characterization of the target asteroid is scientifically important.

5) Remote characterization prior to, during, and following sampling is required for scientific context.

6) The CAPTEM findings on sample selection and collection by the crew during EVA are very good assessments and supported by this report.
7) An asteroid sample return mission offers a wide range of possible science investigations, both with remote characterization and through study of the returned sample. Remote characterization scientific investigations to any asteroid would cover investigating physical properties, composition, mineralogy, heterogeneity, surface morphology, interior structure, and relating the sample to meteorites. Both options also have the potential to provide unique science. A few examples for each are provided below, but this list is not exhaustive.

• For capturing a small (~<10 m) asteroid: Much is unknown about this numerous population as it is very difficult to observe from Earth and has never been visited by spacecraft. What is the nature of such objects? Coherent monoliths or rubble piles? How homogenous/heterogeneous, for composition and physical properties? How does the surface compare to the interior?
• For capturing a boulder from a >50 m NEA: How strong is the boulder? How homogenous/heterogeneous is the boulder? How does the surface compare to the interior and what does this mean for space weathering? What are the characteristics of the surface below the boulder and how does the regolith move in response to the boulder being collected? How does the sampled boulder relate in the larger context of the whole asteroid?
Planetary Defense - summary

1) Involvement of the planetary defense community will be vital for optimal leveraging of the ARM mission for planetary defense studies. Involving the wider community in order to incorporate their expertise will help ensure that any planned demonstrations are correctly scoped for the available resources and allow the most efficient leveraging of independent programs already underway.

2) All mitigation technologies, except for the gravity tractor, will likely modify or transform the asteroid or boulder surface to some extent beyond that resulting from just the capture activities. The choice of a planetary defense demonstration will inevitably have implications for any subsequent science investigation, though we treat them as independent for the remainder of this report. This could be an issue for future interaction or interpretation of the body, however we will not limit our analysis with regard to this.
3) Neither the Option A target nor the block retrieved from the Option B target will be of a size *per se* relevant to planetary defense. While objects as small as only a few meters in diameter can produce meteorites, and bodies the size of the Chelyabinsk impactor (~15-20 m) can cause damage on the ground, the cost and effort required to mitigate such impactors combined with the likely very short warning time and limited damage they cause make them unlikely candidates for any future mitigation campaigns.

4) The Option B target from which the block would be retrieved is likely to be of a size of greater interest to the planetary defense community. The candidates we are aware of have diameters in the hundreds of meters range, large enough that mitigation would be seriously considered if such an object were threatening to impact Earth.
Planetary Defense - summary

5) Demonstrations of new technologies and deployment tests may be fruitfully conducted with either Option A or Option B, though specifics depend on the particular technology/test. The smaller size of the Option A target will lead to deflection measurements being completed more quickly than for Option B, however Option B studies may be more directly applicable to truly dangerous objects and may preserve the scientific integrity of samples more easily than Option A studies. It is noted that it is not necessary to carry out an end-to-end engineering demonstration of a mitigation technology in order to advance the technology level of any particular deflection approach.

Mitigation Techniques Discussed:
- Kinetic Impactor
- Gravity Tractor
- Ion Tractor
- Induced Surface Outgassing
- Surface Albedo Modification
Resource Utilization- summary

1) Simple small-scale demonstrations in a relevant environment are both feasible and invaluable to the community.

2) Knowledge of the asteroid composition may be critical to optimizing a resource extraction demonstration.

3) Knowledge of the surface properties may be critical to a resource extraction demonstration.

4) If the target composition (knowledge) is equivalent, there is no major differentiator between a small target, large target, or a boulder from a large target.

5) For resource utilization priorities, target composition is more important than target mass. A volatile-rich C-type target provides the greatest diversity for extraction method demonstrations.
Resource Utilization- summary

6) Techniques for small scale resource extraction demonstrations are likely not optimized and are potentially dissimilar from full scale industrial operational techniques.

7) ARM provides a unique opportunity, with advantageous power, and may provide an opportunity to jumpstart or focus asteroid ISRU investments.

8) There are no existing turn-key autonomous experiments readily available. It is unclear if an autonomous demonstration system can be matured for flight with appropriate testing and meet the baseline ARM launch date without immediate and modest investment. Crew-assisted extraction demonstrations may greatly simplify initial demonstrations.

9) Studies for simple demonstrations in the very near-term may be valuable to ARM secondary objectives.
SBAG ARM Special Action Team Report:

Full draft text available at:
http://www.lpi.usra.edu/sbag/documents/

Open for comment by the SBAG community, to contribute to final discussions by the SBAG ARM SAT.

Report to be finalized in ~mid-August.

Email any member of SBAG ARM SAT. Nancy.Chabot@jhuapl.edu
Other Task Lists Covered by the SBAG ARM SAT
Task List items addressed by SBAG ARM SAT in the February 19, 2014 slide set:

To inform mission formulation, we request your scientific assessment in these areas:

- Assessment of likely physical composition of near-Earth asteroids <10m mean diameter
- Assessment of likelihood and diversity of boulders on larger (>50 meter) near-Earth asteroids
  - Presence of “free-standing” boulders
  - Friability of boulders for various asteroid types
  - Also, assessment of <10m boulders on Itokawa
- Current relevant findings based on meteorites collected on Earth

Slides available on the SBAG website: http://www.lpi.usra.edu/sbag/documents/
Follow on request of April, 2014, based on the February SBAG ARM SAT presentation:

• Provide information/data regarding the range of expected regolith surface properties (surface cohesive, porosity, compaction, etc.) of large NEAs of various types to support analyses for assessing surface contact, interaction during boulder collection, and mechanical push planned for ARRM Option B.

Available in later section of this slide set
Additional questions, added June 2014:

1. In their 2/19/2014 presentation to the RCIT, on slide 26 they showed two small meteorites (Park Forest and Grimsby) that were estimated to be 1.8 meters and 0.13 meters diameter, respectively, that had very low compressive strengths at first breakup (~0.03 MPa). What does this imply about the lower limit on the strength of small NEAs or boulders on larger NEAs?

2. What do models of rubble piles say about their range of compressive strengths?

3. What does the latest paper on thermal cycling of NEAs (Delbo, M. et al. Nature 508, 233–236 (2014) ) say about the expected strengths of 10-m-class NEAs and 1- to 4-m sized boulders on 100-m-class NEAs?

4. What remote sensing instrumentation is available that is capable of determining the structural integrity of a boulder? What is the resulting uncertainty?

5. What is the effectiveness of C-type and S-type asteroid material for radiation shielding?

1. What is the maximum acceptable contamination level of an asteroid or boulder returned to lunar DRO?

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Slides addressing April 2014 and June 2014 Task List items
Provide information/data regarding the range of expected regolith surface properties (surface cohesive, porosity, compaction, etc.) of large NEAs of various types to support analyses for assessing surface contact, interaction during boulder collection, and mechanical push planned for ARRM Option B.
Meteorite Types

- **Chondrites (ordinary, enstatite)**
  - Stones, chondrules, olivine, pyroxene, metal, sulfides, usually strong

- **Volatile-rich Carbonaceous Chondrites**
  - CI, CM
  - Hydrated silicates, carbon compounds, refractory grains, very weak.

- **Other Carbonaceous**
  - CO, CV, CK, CR, CH
  - Highly variable, chondrules, refractory grains, often as strong as ordinary chondrites

- **Achondrites**
  - Igneous rocks from partial melts or melt residues

- **Irons**
  - Almost all FeNi metal

- **Stony-irons**
  - Mix of silicates and metal

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Cape York (IIIAB)
Bununu (Howardite)
Thiel Mountains (pallasite)
Allende (CV3)
Orgueil (CI)
Farmington (L5)
Farmville (H4)
Porosity

• Most NEAs are probably rubble piles with very weak cohesion
  – Bolide, spin rate, and bulk density observations support rubble pile structure
  – Inter-particle forces on small particles literally hold asteroids together.
  – Volatile-rich asteroids somewhat more likely to be rubble piles

• Macroporosities of ~ 25-50%

• Angle of Repose will depend on local gravity field, but should be in the range of ~ 45%
Soil Structure

- Relative to Lunar Soil NEAs have....
- Much higher thermal inertia, much lower gravity
- Expect courser soils, more boulders
- Micro-impacts and regolith gardening can result in size segregation. The solar wind may deplete the smallest size fraction and the larger materials are preferentially retained on the surface of the asteroid.
- Fine materials may be retained at depth in the soil profile.
Thermal inertia – NEOs are not bare rock and have regoliths likely coarser than the Moon, consistent with abundant boulders

**Itokawa**: $T_I \sim 750$ (Müller et al. 2005)

Boulder-rich, with finer-grained regions

**YU55**: $T_I \sim 600$ (Müller et al. 2013)

Many 8-m scale boulders

**Bennu**: $T_I \sim 310$ (Emery et al. 2014)

At most one 8-m scale boulder (Nolan et al. 2013)

**Eros**: $T_I \sim 150$ (Müller et al. 2007)

Fine regolith with boulders
Compaction

- **Lunar Regolith “Soil”**
  - Fine particles, very loose, very fluffy, created by micrometeorite bombardment.
  - About 20 cm deep
  - Density about 0.9-1.1 g/cm³. Increases with depth to about 1.9 g/cm³. Porosity about 45%.
  - The regolith becomes progressively more compacted with depth.

- **NEAs**
  - Lower gravity may make it harder to compact.
  - Interparticle forces may dominate.
  - Particle size profile with depth may be highly variable.
Provide information/data regarding the range of expected regolith surface properties (surface cohesive, porosity, compaction, etc.) of large NEAs of various types to support analyses for assessing surface contact, interaction during boulder collection, and mechanical push planned for ARRM Option B.

Summary:
Expected surface properties of “large” NEAs of various compositional types.

• **Porosity:** Mostly rubble piles, high macroporosities ~ 25-50%
• **Soil Structure:** Courser than lunar soils, more boulders, fines depleted.
• **Compaction:** Less compact relative to lunar soils, interparticle forces may dominate, particle size profile with depth may be highly variable.
Additional questions, added June 2014:

1. In their 2/19/2014 presentation to the RCIT, on slide 26 they showed two small meteorites (Park Forest and Grimsby) that were estimated to be 1.8 meters and 0.13 meters diameter, respectively, that had very low compressive strengths at first breakup (~0.03 MPa). What does this imply about the lower limit on the strength of small NEAs or boulders on larger NEAs?

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3. What does the latest paper on thermal cycling of NEAs (Delbo, M. et al. Nature 508, 233–236 (2014)) say about the expected strengths of 10-m-class NEAs and 1- to 4-m sized boulders on 100-m-class NEAs?

4. What remote sensing instrumentation is available that is capable of determining the structural integrity of a boulder? What is the resulting uncertainty?

5. What is the effectiveness of C-type and S-type asteroid material for radiation shielding?

1. What is the maximum acceptable contamination level of an asteroid or boulder returned to lunar DRO?
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<table>
<thead>
<tr>
<th>Meteorite</th>
<th>Comp. Strength range of Met. Type (MPa)</th>
<th>Initial Mass (Metric Tons) / Diameter (Meters)</th>
<th>Compressive Strength at First Breakup (MPa)</th>
<th>Max. Compressive Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pribram (H5)</td>
<td>77-247</td>
<td>1.3 / 0.9</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>Lost City (H5)</td>
<td>77-247</td>
<td>0.16 / 0.45</td>
<td>0.7</td>
<td>2.8</td>
</tr>
<tr>
<td>Innisfree (L5)</td>
<td>20-450</td>
<td>0.04 / 0.28</td>
<td>0.1</td>
<td>3</td>
</tr>
<tr>
<td>Tagish Lake (C2)</td>
<td>0.25-1.2</td>
<td>65 / 4.2</td>
<td>0.3</td>
<td>2.2</td>
</tr>
<tr>
<td>Moravka (H5-6)</td>
<td>77-327</td>
<td>1.5 / 0.93</td>
<td>&lt;0.9</td>
<td>5</td>
</tr>
<tr>
<td>Neuschwanstein (EL6)</td>
<td></td>
<td>0.3 / 0.55</td>
<td>3.6</td>
<td>9.6</td>
</tr>
<tr>
<td>Park Forest (L5)</td>
<td>20-450</td>
<td>10 / 1.8</td>
<td>0.03</td>
<td>7</td>
</tr>
<tr>
<td>Villalbeto de la Pena (L6)</td>
<td>63-98</td>
<td>0.6 / 0.7</td>
<td></td>
<td>5.1</td>
</tr>
<tr>
<td>Bunburra Rockhole (Ach)</td>
<td></td>
<td>0.022 / 0.24</td>
<td>0.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Almahata Sitta (Ure, OC)</td>
<td>70 / 4</td>
<td>0.2-0.3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Jesenice (L6)</td>
<td>63-98</td>
<td>0.17 / 0.45</td>
<td>0.3</td>
<td>3.9</td>
</tr>
<tr>
<td>Grimsby (H4-6)</td>
<td>77-327</td>
<td>0.03 / 0.13</td>
<td>0.03</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Note that all data are estimates that are inferred from observations of the bolide, breakup altitude, and the pattern of the breakup. From: Popova et al., 2011
• Park Forest and Grimsby are the lowest compressive strengths at first breakup (~0.03 MPa) in the current data.
• This is very weak cohesion and may be a lower bound for the weakest of small bodies.
• Remember that the individual pieces of Park Forest are very tough (note holes in roof). The model for this object may be a gravel or cobble bar in space.
2. What do models of rubble piles say about their range of compressive strengths?

Rubble piles are stronger in compression than in tension. When subject to uniaxial tension or compression, the compressive strength of a soil will be on the order of 4 times stronger than tensile strength. Minimum uniaxial tensile strength of rubble piles has been measured to range between 10-150 Pascals, but could be much larger depending on how strongly components are cemented to each other. If the compression is equal in all directions (i.e., is due purely to pressure), then the rubble pile will first go through a compaction stage. Following this phase, the final compressive strength can be on the order of the crushing strength of the material. The Table two slides prior to this one has detailed numbers on the compressive strength of various meteorites.
3. What does the latest paper on thermal cycling of NEAs (Delbo, M. et al. Nature 508, 233–236 (2014)) say about the expected strengths of 10-m-class NEAs and 1- to 4-m sized boulders on 100-m-class NEAs?

The Delbo et al. (2014) paper does not directly address the strengths of boulders. Application of their small-scale laboratory experiments to asteroid surfaces involves significant extrapolation (aided by numerical modeling). Furthermore, the process may only be applicable to a few cm length scale, so may only affect the outermost layer of boulders. While intriguing, the work is should not be used as a critical factor in any mission design.

Delbo et al. (2014) do not compute a "weakening rate" for boulders from the proposed thermal fatigue mechanism. Nevertheless, the focus of the paper is on crack formation, which will weaken an otherwise coherent rock. From a combination of laboratory experiments and numerical modeling of fracture mechanics, they conclude that a 10 cm rock would survive for less than 0.1 to 1 Myr on the surface of an asteroid at 1 AU (their Fig 1) and a 100m-sized asteroid with perihelion at 0.3 AU could be completely eroded in ~2 Myr. Their models are run for rotation periods of 2.2 and 6 hrs. Fast rotators and/or asteroids with high thermal inertia will tend toward isothermal surfaces, under which condition thermal fatigue would not operate at all since temperature cycling is required. Delbo et al. define fragmentation time as the time it takes a planar crack to propagate the length of the boulder, but do not quantitatively consider other cracks opening within the rock. Presumably this would occur, but different experiments and modeling would be required to quantify the weakening of boulders from thermal fatigue.
4. What remote sensing instrumentation is available that is capable of determining the structural integrity of a boulder? What is the resulting uncertainty?

The structural integrity of a boulder will be intimately tied to the presence and degree of fracturing within the boulder. To assess this requires methods that can sense the degree of fracturing within the boulder. Perhaps the most applicable approach in the space environment would be the use of radar tomography to probe the boulder and its interior. Radar tomography senses discontinuities within the material, either due to gaps or to changes in refractive index. The presence of such discontinuities will be diagnostic for the strength or competence of a boulder. Alternate ways to sense a boulder’s integrity exist, such as using ultrasonic waves to measure transmission of sound waves across the body, however such approaches would require direct interaction with the boulder. Ultimately, the best way to determine the strength of a boulder is to subject it to direct mechanical tests.
5. What is the effectiveness of C-type and S-type asteroid material for radiation shielding?

### Shielding Potential of Meteorites:

<table>
<thead>
<tr>
<th>Element (wt.%)</th>
<th>Volatile-rich Carbonaceous Chondrites (CI, CM)</th>
<th>Other Carbonaceous (CO, CV, CK, CR, CH)</th>
<th>Ordinary Chondrites (LL, L, H)</th>
<th>Enstatite Chondrites (EL, EH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>15.3</td>
<td>1.9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Carbon</td>
<td>2.7</td>
<td>0.7</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Iron</td>
<td>19.6</td>
<td>27.3</td>
<td>22.5</td>
<td>25.5</td>
</tr>
<tr>
<td>Magnesium</td>
<td>10.7</td>
<td>14</td>
<td>14.7</td>
<td>12.4</td>
</tr>
<tr>
<td>Nickel</td>
<td>1.1</td>
<td>1.4</td>
<td>1.3</td>
<td>1.5</td>
</tr>
<tr>
<td>Sulfur</td>
<td>4.6</td>
<td>1.5</td>
<td>2.2</td>
<td>4.6</td>
</tr>
<tr>
<td>Oxygen</td>
<td>31</td>
<td>32.7</td>
<td>38.2</td>
<td>29.5</td>
</tr>
<tr>
<td>Silicon</td>
<td>11.7</td>
<td>15</td>
<td>18.1</td>
<td>17.7</td>
</tr>
</tbody>
</table>

- In general, low atomic mass elements are better. More Hydrogen, the better.
- The response of individual elements complicates the analysis.
- CI & CM’s are about 30-40% less dense (fewer high atomic mass minerals), rich in water and OH. By far the best shielding material.
- All other stony meteorites are about the same.....
6. What is the maximum acceptable contamination level of an asteroid or boulder returned to lunar DRO?

Contamination control is vitally important. There are many types of contamination, and each would warrant a specific investigation, with scientists involved in the assessment, to arrive at an answer to this question. The January 2014 CAPTEM report also stresses the importance of contamination control, during all aspects of sampling. The OSIRIS-REx team has valuable expertise in this topic as well that could be beneficial to future contamination discussions.

From CAPTEM January 23, 2014 report:

Finding 4: Contamination Control is vitally important. There are several aspects of contamination control. Because in practice it is impossible to eliminate contamination entirely, it is important to use materials for tools and containers that are readily recognized in the laboratory after recovery by, for example, deliberately introducing cosmochemically rare elements at minor to trace levels. It is also important to use witness materials to serve as blanks, and to develop and curate a complete list of materials to which the asteroidal samples might be exposed. Storage containers should be sealable in space. The sample containers should be purged with high purity nitrogen if a vacuum-tight seal cannot be ensured. We highly recommend the Catalog of Apollo Lunar Surface Geological Sampling Tools and Containers (JSC-23454, LESC-26676, attached) compiled by Judy Allton as a reference. Finally, the sampling sites should not be disturbed by or contaminated by spacecraft operations (e.g., manoeuvring engine plumes).
References and Relevant SBAG Findings
References

Bus and Binzel (2002) Icarus v. 158 "Phase II of the Small Main-Belt Asteroid Spectroscopic Survey. A Feature-Based Taxonomy"


DeMeo et al. (2009) Icarus v. 202 "An extension of the Bus asteroid taxonomy into the near-infrared"


Kring et al. (1998) LPSC abs. 1526 "Gold Basin Meteorite Strewn Field: The 'Fossil' Remnants of an Asteroid that Catastrophically Fragmented in Earth's Atmosphere"


Mazrouei, S., M. G. Daly, O. S. Barnouin, C. M. Ernst, and I. DeSouza (2014) Block distributions on Itokawa; Icarus, Volume 229, pp. 181-189.


References


Rubin (1997) Meteoritics v 32 "Mineralogy of meteorite groups"


Stuart and Binzel (2004) Icarus v. 170 "Bias-corrected population, size distribution, and impact hazard for the near-Earth objects"

Tancredi et al. (2009) MAPS v. 44 "A meteorite crater on Earth formed on September 15, 2007: The Carancas hypervelocity impact"


Zolensky et al. "Flux of Extraterrestrial Materials" from Meteorites and the Early Solar System II
FINDINGS FROM SBAG MEETING, JANUARY 8-9, 2014:

Asteroid Redirect Mission. Though SBAG acknowledges that the Asteroid Redirect Mission (ARM) is continuing to evolve as the concept development matures, the current formulation has not resolved the issues detailed in previous SBAG findings of July, 2013. The objectives, requirements, and success criteria for the ARM are not clearly defined, including the relevance to planetary defense. There are substantial issues and challenges associated with the identification and characterization of potential targets. Together these combine for considerable schedule and cost uncertainty and risk for the ARM. As requested, SBAG in the near term will provide input for key small body science areas to inform NASA and the ARM formulation team, though we note that SBAG would be willing to provide input at earlier stages in the future.

Support of Target NEO 2 Findings. The Target NEO 2 workshop had widespread and broad community participation and enabled open discussion and debate of the Asteroid Redirect Mission (ARM) concept. The Target NEO 2 final report finds the need for: ARM requirements and mission success criteria to be clearly defined; an independent cost estimate; competition and peer review; reconsideration of the aggressive schedule; a well-constrained understanding of the target NEA population and the distribution of their physical characteristics; improvement of ground-based observatories and remote characterization follow-up procedures; and a robust NEO survey. SBAG finds that the Target NEO 2 workshop was highly valuable and successful at bringing together experts in the fields pertinent to the ARM concept, supports the well articulated findings in the final report, and urges that the report be used to inform and evaluate further ARM efforts.
FINDINGS FROM SBAG MEETING, JULY 10-11, 2013:

(a) **Planetary Science.** ARRM has been defined as not being a science mission, and it is not a cost effective way to address science goals achievable through sample return. Support of ARRM with planetary science resources is not appropriate.

(b) **Searching for Potentially Hazardous Objects.** There is great value in enhancing NASA's capabilities in small body discovery and characterization. The enhancement to NEO discovery and characterization efforts proposed as part of the Asteroid Initiative would be greater still if it were to be continued for more than one year. There is concern that a focus on acquiring ARRM targets can come at the expense of the detection rate and follow-up observations of 140m and larger asteroids.

(c) **Relevance of ARRM to Planetary Defense.** Given the size of the ARRM target (< 10m), ARRM has limited relevance to planetary defense.

(d) **Mission Objectives.** ARRM does not have clearly defined objectives, which makes it premature to commit significant resources to its development. Firm baseline and minimum requirements must be set. SBAG finds that formation of an independent Mission Definition Team (MDT) prior to commitment of significant resources and mission confirmation would allow for community participation in the relevant fields for the mission and provide a non-advocate peer review of the expected benefit if mission success criteria are met.
• **FINDINGS FROM SBAG MEETING, JULY 10-11, 2013:**

  • **(e) Target issues.** The population and physical characteristics of low delta-velocity targets having diameters less than 10m are poorly constrained by observations. It is impractical to begin the planning and design of any mission to capture such an asteroid in the absence of a pre-existing study on the population and the physical characteristics of its members. A robust characterization campaign is imperative. Target characterization will be challenging and is expected to be of the utmost importance to mission success.

  • **(f) Schedule risks.** Because of long-synodic periods, a missed launch window will not be recoverable for the same ARRM target. Therefore, multiple targets meeting orbital and physical characteristic requirements and having appropriately phased launch windows will need to be discovered. Given the poor knowledge of the population of these objects, this is a significant mission risk. The stated schedule for the ARRM, which posits funding of a ~$100M study in FY14 and launch in 2017, is unrealistic.

  • **(g) Cost risks.** As a mission that serves as a technology and operations demonstrator, the management approach and acceptance of risk needs to be better defined to determine the feasibility of the aggressive schedule and its impact on cost and mission success criteria. The full-cost target, funding profile, and funding sources are not provided and limit any credible assessment of the schedule and mission cost to the various directorates. Lack of clarity of both resources available and resources required limits any determination of mission value, merit, and/or whether the mission is the most efficient use of available resources to achieve NASA’s objectives.

Findings are summarized. Full findings available at: http://www.lpi.usra.edu/sbag/findings/