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ASTEROID REDIRECT MISSION
BROAD AGENCY ANNOUNCEMENT

PROPOSALS DUE
May 5, 2014

Release Date: March 21, 2014
Notice of Intent: April 4, 2014

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, DC 20546

Table of Contents

1 FUNDING OPPORTUNITY DESCRIPTION 3

2 INFORMATION FOR PARTICIPANTS 4
2.1 General Information 4
2.2 Eligible Participants 6
2.3 Guidelines for Foreign Participation 6
2.4 China Funding Restriction 7
2.5 Export Control 7
2.6 Data Rights 8
2.7 Process for Appeals 8
2.7.1 Ombudsman Program 8
2.7.2 Protests 8

3 INSTRUCTIONS FOR PROPOSALS 9
3.1 Proposal Submittal 9
3.2 Proposal Content 9

4 PROPOSAL EVALUATION AND SELECTION 10
4.1 Process 10
4.1.1 Compliance Check 10
4.1.2 Evaluation 10
4.1.3 Selection and Award 11
4.1.4 Selection Officials 11
4.1.5 Personnel 11
4.2 Evaluation Criteria 11

APPENDIX A: ASTEROID CAPTURE SYSTEMS 12

APPENDIX B: RENDEZVOUS SENSORS 15

APPENDIX C: ADAPTING COMMERCIAL SPACECRAFT FOR THE ASTEROID REDIRECT VEHICLE 22

APPENDIX D: STUDIES OF POTENTIAL FUTURE PARTNERSHIP OPPORTUNITIES FOR SECONDARY PAYLOADS 25

APPENDIX E: STUDIES OF POTENTIAL FUTURE PARTNERSHIP OPPORTUNITIES FOR THE ASTEROID REDIRECT CREWED MISSION (ARCM) ... 28

APPENDIX F: PRICE PROPOSAL FORMAT 30

1 FUNDING OPPORTUNITY DESCRIPTION

NASA is developing two mission concepts for the Asteroid Redirect Mission (ARM): one concept uses a robotic spacecraft to capture a whole small near-Earth asteroid, and the second concept uses largely the same robotic spacecraft to capture a cohesive mass from a larger asteroid. In both mission concepts, the asteroid mass would be redirected into a stable orbit around the Moon. Astronauts aboard the Orion spacecraft launched on the Space Launch System (SLS) would rendezvous with the captured asteroid mass in lunar orbit and collect samples for return to Earth.

NASA's activities in human exploration, space technology, and space science are being leveraged and integrated in order to make progress toward a range of objectives, including:

- Conduct a human exploration mission to an asteroid in the mid-2020's, providing systems and operational experience required for human exploration of Mars.
- Demonstrate an advanced solar electric propulsion system, enabling future deep-space human and robotic exploration with applicability to the Nation's private and public sector space needs.
- Enhance the detection, tracking, and characterization of near-Earth asteroids (NEAs), enabling an overall strategy to defend our home planet.
- Demonstrate basic planetary defense techniques that will inform impact threat mitigation strategies required to defend our home planet.
- Pursue a target of opportunity that benefits scientific and partnership interests, expanding our knowledge of small celestial bodies, and enabling the mining of asteroidal resources for commercial and exploration needs.

This Broad Agency Announcement (BAA) builds upon the over 400 ideas that were gathered from the broad community through a Request for Information (RFI) issued in June 2013, and the synthesis of the 96 most promising ideas in a two-part public workshop held in September and November 2013.

This Announcement solicits proposals for system concept studies, technology development activities, and partnership opportunities to support the goals of the Asteroid Initiative. Specific topics of interest are described in the appendices of this Announcement. The following topics were identified as the highest priority near-term system development activities through the RFI process:

- Asteroid capture system concepts including using deployable structures and autonomous robotic manipulators.
- Rendezvous sensors that can be used for a wide range of mission applications including automated rendezvous and docking and asteroid characterization and proximity operations.
- Commercial spacecraft design, manufacture, and test capabilities that could be adapted for development of the Asteroid Redirect Vehicle (ARV).
- Studies of potential future partnership opportunities for secondary payloads on

either the ARV or the SLS.

- Studies of potential future partnership opportunities for the Asteroid Redirect Crewed Mission, or other future missions, in areas such as advancing science and in-situ resource utilization, enabling commercial activities, and enhancing U.S. exploration activities in cis-lunar space after the first crewed mission to an asteroid.

Additional topics may be solicited in future amendments to this Announcement.

2 INFORMATION FOR PARTICIPANTS

2.1 General Information

Agency:	National Aeronautics and Space Administration
Announcement Title:	Asteroid Redirect Mission Broad Agency Announcement
Responsible Office:	Advanced Exploration Systems Division Human Exploration and Operations Mission Directorate NASA Headquarters Washington, DC 20546
Proposal Due Date:	Proposal due dates for each solicitation topic are specified in the appendices to this Announcement.
Notice of Intent:	To assist in the planning of the proposal evaluation process, NASA strongly encourages the submission of a Notice of Intent (NOI) to propose by all prospective offerors. NOI due dates for each solicitation topic are specified in the appendices to this Announcement. The NOI should contain the following information: name, address, telephone number, e-mail address, and institutional affiliation of the offeror, and the solicitation topic in which you intend to propose. NOIs shall be submitted electronically to the Point of Contact e-mail address below. **Please note that NOIs are strongly encouraged, but are not required**. **Not submitting an NOI will not impact the selection process.**
Proposal Submittals:	Proposals shall be submitted electronically in Adobe pdf format to the Point of Contact e-mail address below. Hard copies will not be accepted.

Point of Contact: All questions shall be directed to the following NASA official:

Dr. Chris Moore
Deputy Director, Advanced Exploration Systems
Human Exploration and Operations Mission Directorate
NASA Headquarters
E-mail: HQ-Asteroid-BAA@mail.nasa.gov

Award Information: NASA reserves the right to select for award multiple, one, or none of the proposals in response to this Announcement. NASA reserves the right to negotiate, with selected offerors, cost/price terms and any other terms, as appropriate. The overall number of awards will be dependent upon funding availability and evaluation results. Maximum individual award amounts for each solicitation topic are specified in the appendices to this Announcement, and are summarized in the table below:

Appendix	Solicitation Topic	Total Available Funding	Anticipated Number of Awards	Maximum Individual Award
A	Asteroid Capture Systems	$2M	4-5	$500,000
B	Rendezvous Sensors	$1.8M	4-6	$450,000
C	Adapting Commercial Spacecraft for the Asteroid Redirect Vehicle	$1.8M	4-6	$450,000
D	Studies of Potential Future Partnership Opportunities for Secondary Payloads	$0.2M	4	$50,000
E	Studies of Potential Future Partnership Opportunities for the Asteroid Redirect Crewed Mission	$0.2M	4	$50,000

Web Site for Reference Information: http://www.nasa.gov/asteroidinitiative

This solicitation constitutes a BAA as contemplated by Federal Acquisition Regulation (FAR) Part 35 and NASA FAR Supplement (NFS) Part 1835.

NASA will not issue paper copies of this Announcement. The Announcement, related documents, and other information may be obtained and downloaded from the above Web site. Proposers are encouraged to refer regularly to this site for updates and other information. Responses to submitted questions concerning the Announcement will be posted periodically on this Web site.

An Asteroid Initiative Opportunities Forum will be held at NASA Headquarters on March 26, 2014, and proposers will have a chance to ask questions about this Announcement. The meeting agenda and related information will be posted on the above Web site.

2.2 Eligible Participants

Eligible participants and partnerships for each solicitation topic are specified in the appendices to this Announcement.

2.3 Guidelines for Foreign Participation

The NASA FAR Supplement clause 1835.016-70(a) foreign participation under BAAs policy provides guidelines for this activity. NASA seeks the broadest participation in response to broad agency announcements, including foreign proposals or proposals including foreign participation. NASA's policy is to conduct research with foreign entities on a cooperative, no-exchange-of-funds basis (see NPD 1360.2, Initiation and Development of International Cooperation in Space and Aeronautics Programs). NASA does not normally fund foreign research proposals or foreign research efforts that are part of U.S. research proposals and will not do so pursuant to this BAA. Rather, cooperative research efforts are implemented via international agreements between NASA and the sponsoring foreign agency or funding/sponsoring institution under which the parties agree to each bear the cost of discharging their respective responsibilities. NASA funding may not be used for subcontracted foreign research efforts.

All foreign proposals must be typewritten in English and comply with other submission requirements stated in the Announcement. All foreign proposals will undergo the same evaluation and selection process as those originating in the U.S. All proposals must be received before the established closing date. Sponsoring foreign government agencies or funding institutions may, in exceptional situations, forward a proposal without endorsement if endorsement is not possible before the announced closing date. In such cases, the NASA sponsoring office should be advised when a decision on endorsement can be expected.

NASA's Office of International and Interagency Relations (OIIR), in consultation with other interested NASA offices, will review for eligibility for selection all foreign proposals and U.S. proposals with foreign participation to ensure consistency with all applicable statutes (including the Iran, North Korea, and Syria Nonproliferation Act, P.L. 106-178, as amended), regulations, Executive Orders, and policies governing export control, nonproliferation, trade, and foreign policy.

Should a foreign proposal or a U.S. proposal with foreign participation be selected, NASA's OIIR will arrange with the sponsoring foreign agency or funding/sponsoring institution for the proposed participation on a no-exchange-of-funds basis, in which NASA and the non-U.S. sponsoring agency or funding/sponsoring institution will each bear the cost of discharging their respective responsibilities.

2.4 China Funding Restriction

Proposals must not include bilateral participation, collaboration, or coordination with China or any Chinese-owned company or entity, whether funded or performed under a no-exchange-of funds arrangement. Grant Information Circular 12-01A instructs NASA, when issuing new BAAs, to add the "Assurance of Compliance – China Funding Restriction" to the current proposal requirements set forth at 14 CFR § 1260.10 (c)(1).

The Department of Defense and Full-Year Appropriation Act, Public Law 112-10 Section 1340(a) and the Consolidated and Further Continuing Appropriation Act of 2012, Public Law 112-55, Section 539 state that:

(1) NASA is restricted from using funds appropriated in the Acts to enter into or fund any grant or cooperative agreement of any kind to participate, collaborate, or coordinate bilaterally with China or any Chinese-owned company, at the prime recipient level and at all subrecipient levels, whether the bilateral involvement is funded or performed under a no exchange of funds arrangement.
(2) Definition: "China or Chinese-owned Company" means the People's Republic of China, any company owned by the People's Republic of China, or any company incorporated under the laws of the People's Republic of China.
(3) The restrictions in the Acts do not apply to commercial items of supply needed to perform a grant or cooperative agreement.
(4) By submission of its proposal, the offeror represents that the offeror is not China or a Chinese-owned company, and that the proposer will not participate, collaborate, or coordinate bilaterally with China or any Chinese-owned company, at the prime recipient level or at any subrecipient level, whether the bilateral involvement is funded or performed under a no-exchange of funds arrangement.

NASA anticipates this restriction will be contained in future appropriation acts. Active Procurement Information Circular (PIC) 12-01A instructs Contracting Officers to add certification NFS 1852.225-72 entitled "Restriction on Funding Activity with China – Representation" as well as NFS clause 1852.225-71 entitled "Restriction on Funding Activity with China" in all contract awards.

2.5 Export Control

Performance of activities under this Announcement may require access to data that is subject to export control regulations. Any entity proposing for a contract under this BAA in order to be considered for award shall comply with all U.S. export control laws and regulations, including the International Traffic in Arms Regulations (ITAR), 22 CFR Parts 120 through 130, and the Export Administration Regulations (EAR), 15 CFR Parts 730 through 799, and must demonstrate their compliance and process in the performance of this contract.

2.6 Data Rights

The objective of the contract is to obtain data for NASA's use in defining, deriving, and validating system requirements and a baseline mission concept. Any limitations to use of data, including pre-existing data, for these purposes are discouraged. The Government may incorporate elements of the offeror's mission concept into a baseline mission concept that will be used to define system requirements for future solicitations. The Government will not disclose the cost data outside the Government except to Government support contractors with non-disclosure agreements. The offeror shall identify in the proposal areas of limited rights. The Government strongly encourages the provision of unlimited rights in all data delivered pursuant to the resulting contract.

2.7 Process for Appeals

2.7.1 Ombudsman Program

The NASA Procurement Ombudsman Program is available under this solicitation as a procedure for addressing concerns and disagreements. The clause at NASA FAR Supplement (NFS) 1852.215-84 ("Ombudsman") is incorporated into this solicitation. The cognizant ombudsman is: Director, Contract Management Division, Office of Procurement, NASA Headquarters, Washington, DC 20546-0001.

2.7.2 Protests

Only prospective offerors seeking contract awards under this solicitation have the right to file a protest, either at the Government Accountability Office (GAO) or with the Agency, as defined in FAR 33.01. The provisions at FAR 52.233-2 ("Service of Protest") and NFS 1852.233-70 (Protests to NASA") are incorporated into this solicitation. Under both of these provisions, the designated official for receipt of protests to the Agency and copies of protests filed with the GAO is:

Assistant Administrator for Procurement
Office of Procurement
NASA Headquarters, Mail Stop 5G70
Washington, DC 20546-0001

3 INSTRUCTIONS FOR PROPOSALS

3.1 Proposal Submittal

Proposals must comply with the following requirements.

Proposal Section	Page Limitations
Title Page	1
Executive Summary (Section I)	1
System Concept & Technical Approach (Sections II-III)	15
Capabilities (Section IV)	2
Data Rights (Section V)	1
Price Proposal (Section VI)	No limit
Attachments	No limit

Attachments
Resumes of Key Personnel
Draft Statement-of-Work

A page is defined as one side of a sheet, 8 1/2" x 11" with at least one-inch margins on all sides, using not smaller than 12-point font, with the exception of tables and figures, which may use 8-point font. Pages in excess of the page limits for each section will not be evaluated.

Proposals received by the Government after the published date and time for receipt will not be accepted.

3.2 Proposal Content

Respondents must provide enough detail in the proposal for NASA to make informed assessments against the criteria in section 4.2 of this Announcement.

All proposals must contain the following information organized in the following outline format:

Title Page: Include any Notice of Restriction on Use and Disclosure of Proposal Information. An optional graphic image may be included. Also, include the following information:

- The title and number of this Announcement.
- Organization name and address.
- Point of Contact name, title, e-mail address, and phone number.

Section I: Executive Summary: Describe the proposal's prominent and distinguishing features.

Section II: System Concept: The offeror shall describe the system concept and its functions, how it addresses the objectives and requirements in this Announcement, and its maturity (Technology Readiness Level).

Section III: Technical Approach: The offeror shall describe the approach and schedule for designing, analyzing, and testing the proposed system concept, including the plans to mature key technologies.

Section IV: Capabilities: The offeror shall provide evidence of existing capabilities for designing and developing space-qualified systems applicable to the objectives of this Announcement.

Section V: Data Rights: The offeror shall describe the approach for data rights and how they meet the objectives outlined under Section 2.5, Data Rights.

Section VI: Price Proposal: The price proposal shall include the overall firm fixed price for the mission concept study. The offeror shall provide total direct labor hours by skill mix, travel, and subcontracts in accordance with the format set forth in Appendix F.

Section VII: Draft Statement-of-Work: The offeror shall provide a draft statement-of-work that includes a work breakdown structure and a description of the major tasks, products, and schedule milestones.

4 PROPOSAL EVALUATION AND SELECTION

NASA reserves the right to select for negotiations all, some, or none of the proposals received in response to this Announcement.

4.1 Process

4.1.1 Compliance Check

All proposals will be screened to evaluate whether they comply with the eligibility criteria (Section 2.2) and proposal requirements (Section 3) of this Announcement. Proposals that do not comply may be declared noncompliant and rejected without further review.

4.1.2 Evaluation

A NASA Evaluation Panel will evaluate proposals deemed compliant according to the evaluation criteria described in Section 4.2. The Evaluation Panel will summarize the strengths and weaknesses of each proposal and assign an overall consensus rating (Excellent, Very Good, Good, or Poor). Only proposals that are rated as either Excellent or Very Good will be in the selectable range.

NASA may request clarification of a specific point or points in a proposal. Such a request and the Respondent's response shall be in writing.

4.1.3 Selection and Award

Upon selection, final contract terms and conditions will be negotiated. Activities under the contract will commence after the parties execute the contract.

4.1.4 Selection Officials

The Associate Administrators for the Human Exploration and Operations Mission Directorate and the Space Technology Mission Directorate at NASA Headquarters will jointly make selections.

4.1.5 Personnel

NASA may use contractor support personnel to provide technical, business, and investment expertise when evaluating proposals. Any support contractor involved in the evaluation process will be bound by appropriate nondisclosure agreements to protect proprietary and competition sensitive information and must have accepted limitations on future contracting.

4.2 Evaluation Criteria

NASA will use the following evaluation factors, with each factor having equal weight:

Factor 1 - Relevance: The Government will evaluate the relevance of the proposal to the overall objectives of the Asteroid Initiative and the system requirements specified in each specific appendix.

Factor 2 – Technical Merit: The Government will evaluate the quality, depth, and thoroughness of the proposed technical approach and the organization's capabilities and the qualifications of key personnel.

Factor 3 - Price: The Government will evaluate the overall cost reasonableness of the firm fixed price to the Government and the extent to which the offeror complied with the specified dollar limits in this Announcement. The Government will evaluate the total direct labor hours by skill mix, travel, and subcontracts.

APPENDIX A: ASTEROID CAPTURE SYSTEMS

1 Description of Solicitation Topic

One concept for the Asteroid Redirect Robotic Mission (ARRM) would use a cylindrical inflatable structure deployed from the robotic spacecraft to capture a small (4-10 m mean diameter), slow spinning (< 0.5 rpm) asteroid in a bag. Winches in the capture system would cinch cables attached to the inflatable structure to collapse the bag around the asteroid and restrain it firmly against the spacecraft. Key technical challenges are capturing and despinning an asteroid that has uncertainty in its mass, shape, and spin rate, and containing asteroid material that may be a loose agglomeration of rocks and regolith (rubble pile). It can be assumed that the spacecraft will match the spin state such that there remains a residual surface velocity < 1 cm/s. The capture system must be able to accommodate relative motion and irregular asteroid shapes until the capture process is completed.

Since an asteroid capture system has never been developed before, it has low technology readiness. To mitigate risk, NASA is interested in developing alternate designs for packaging, deploying, closing, and restraining the asteroid inside the capture bag in parallel with the inflatable concept and then down selecting to a single concept for flight system development. The asteroid material inside the bag needs to be accessible by extra-vehicular activity (EVA).

NASA is also interested in a second concept for the ARRM, utilizing autonomous robotic systems, to capture and firmly restrain a cohesive boulder-like mass (1-5 m diameter) from the surface of a larger asteroid. The system may combine sensor inputs, image processing, and other situational awareness information to create the autonomous sequences. The system will require a software system that can evaluate the sensor inputs and determine the proper action for the robot to accomplish the boulder capture. This concept may use robotic manipulators, articulated trusses, or other types of systems (including inflatables) to grasp and capture the boulder. Although the boulder will be characterized prior to capture operations, its precise friability will likely be unknown until the capture process is underway. The asteroid material needs to be accessible by EVA.

NASA is particularly interested in the following capture system concepts:

- Capture systems that use noninflatable methods to deploy a bag to capture an entire small NEA, or hybrid capture systems that use both inflatable and non-inflatable elements. Concepts should emphasize material compatibility with long-duration deep space mission environments.
- Innovative approaches to retrieve a boulder from the surface of a large near-Earth asteroid, including autonomous capture systems, effectors and grippers, supporting sensors (e.g., ground-penetrating radar), approaches for determining the mechanical strength of the boulder prior to capture, and simple, low-cost regolith and contingency sample collection concepts.

Systems for acquiring a whole small NEA shall be capable of capturing and de-spinning an asteroid with the following characteristics:

- Asteroid size: 4 m < mean diameter < 10 m; maximum dimension is 13 m.
- Asteroid mass: 100 to 1,000 metric tons
- Asteroid rotation rate: up to 0.5 revolutions per minute.
- Asteroid composition, internal structure, and physical integrity will likely be unknown until after rendezvous and capture.

Systems for acquiring a boulder from a larger NEA shall be capable of capturing and controlling a boulder with the following characteristics:

- Boulder size: 1-5 meter extent in any dimension with capture systems scalable to larger boulders (up to 10 meters) also of interest; aspect ratio < 3:2:1.
- Boulder mass: typically up to 30 metric tons, but up to 1,000 metric tons for 10 meter size.
- Boulder assumed to be coherent with compressive strength of at least 0.3 MPa (corresponding to lowest expected strength of carbonaceous chondrite).
- The design should account for the forces needed to overcome cohesion and separate the boulder from the asteroid's surface.
- System should be tolerant of possible boulder break-up during the capture process by being able to release the boulder and without damaging the capture system. The system shall be capable of multiple attempts.
- Parent asteroid rotation rate: up to 0.33 revolutions per hour about any axis or all axes, with up to 1 revolution per hour also of interest.

The proposals shall provide a detailed technical approach for the design, analysis, fabrication, and laboratory testing of a proof-of-concept, subscale capture system.

NASA may use the data resulting from this effort in the ARM Mission Concept Review (MCR), which is planned for late 2014 or early 2015.

Depending on the results from the initial Phase 1 study, NASA may decide to award a follow-on Phase 2 contract option for further development of the system concept. A proposed statement-of-work for the Phase 2 contract option shall be developed during the Phase 1 study.

2 **Eligible Participants:** This solicitation topic is open to non-Government U.S. institutions (companies, universities, nonprofit organizations), and foreign institutions. NASA civil servants and JPL employees may not propose to this solicitation topic. Proposals from foreign organizations must comply with Section 2.3, Guidelines for Foreign Participation.

3 **Notice of Intent to Propose:** NOI to propose are due by April 4, 2014, at 4:00 PM Eastern Time

4 **Proposal Due Date:** May 5, 2014, at 4:00 PM Eastern Time.

5 **Period of Performance:** Period of performance for the initial phase of the contracts will be for 180 calendar days (approximately six months) following the authorization to proceed effective date.

6 **Award Date:** Award is anticipated on or about July 1, 2014. The price proposal should be based on this anticipated award date.

7 **Funding Allocation**: Individual award amounts may range from $400,000 to $500,000. NASA anticipates making up to four-five awards for a total of approximately $2M. Contracts shall be firm fixed price. NASA will select the entire proposed effort only. The Government's obligation to make awards is contingent upon the availability of appropriated funds from which payments can be made and the receipt of proposals that NASA determines are acceptable.

8 **Reporting Requirements:** The resultant contract awards will include the following deliverable requirements:

Month	Deliverable
1	Kickoff meeting at NASA Johnson Space Center.
4	Interim briefing to support the ARM Mission Concept Review.
6	Final technical report and accompanying briefing; Statement-of-work, schedule, and cost estimate for optional Phase 2 contract.

APPENDIX B: RENDEZVOUS SENSORS

1 Description of Solicitation Topic

NASA needs automated rendezvous and docking/capture (AR&D/C) sensors for both the robotic and crewed segments of the ARM. NASA recently conducted a commonality assessment of the concept of operations for the robotic Asteroid Redirect Vehicle (ARV) and the crewed mission segment using the Orion crew vehicle. The commonality assessment also considered several future exploration and science missions requiring an AR&D/C capability such as asteroid sample return, satellite servicing, and planetary entry, descent, and landing. This assessment determined that a common sensor suite consisting of one or more visible wavelength cameras, a three-dimensional LIDAR along with long-wavelength infrared cameras for robustness and situational awareness could be used on each mission to eliminate the cost of multiple sensor developments and qualifications. By choosing sensor parameters at build time instead of at design time and, without having to requalify flight hardware, a specific mission can design overlapping bearing, range, relative attitude, and position measurement availability to suit their mission requirements with minimal nonrecurring engineering costs. The resulting common sensor specification provides the union of all performance requirements for each mission and represents an improvement over the current systems used for AR&D/C today.

Offerors are welcome to propose a single sensor or multiple sensors including the whole suite. NASA is interested in all current technology types that can address the common specification and support an ARV launch scheduled in approximately 2019.

Under this Announcement, NASA intends to fund selected sensor vendors' design, risk reduction, and technology maturation tasks to upgrade their current visible and infrared cameras and LIDAR sensors to satisfy and validate the common specification. Proposals may cover improvements or upgrades to one or more of a proposer's sensors to the required performance and qualification levels discussed below.

Proposals shall provide the following information:

- A response—either validation or alternative approach—as to whether the common specification defined below will meet the navigation concept of operations for both ARV mission concepts (capturing a small asteroid and removing a boulder from an asteroid's surface) and Orion.
- A detailed technical approach for the design, analysis, integration, and laboratory testing of a prototype common sensor system (single sensor or multiple sensors including the whole suite).
- A detailed cost and schedule estimate for development of a prototype common sensor system, including details on how proposers' existing sensors would be modified to meet the common specification.

- A list of specific risk reduction activities – long-lead or high-value technical tasks– that are needed to increase the likelihood of successful flight system development.
- A strategy or plan to perform component or block upgrades of the defined sensor suite to keep pace with technology advancements in decreasing size, mass, and power resources and increasing performance.
- A list of previous flight missions or ground test demonstrations, along with meaningful results, that show the validity of the proposed approach.

NASA may use the data resulting from this effort to inform the ARM Mission Concept Review (MCR), which is planned for late 2014 or early 2015.

Depending on the results from the initial Phase 1 study, NASA may decide to award a follow-on Phase 2 contract option for further development of the system concept. A proposed statement-of-work for the Phase 2 contract option shall be developed during the Phase 1 study.

ARV Mission Concept of Operations: Capturing a Whole Small Asteroid

The purpose of the **Rendezvous Phase,** starting when the spacecraft is within a range of 50,000 km to the asteroid, is to first search and acquire the asteroid with the narrow field of view (FOV) camera, to image the asteroid to enable the determination of the position of the spacecraft relative to the asteroid, to identify the spin state and refine the shape of the asteroid, and finally, to compute and execute a series of burns to bring the spacecraft to a proximity within ~1 km of the asteroid, to start the next phase.

The next phase is the **Asteroid Characterization Phase**, which starts when the asteroid is acquired by the 3D LIDAR at a range of 1 km. The purpose of this phase is to “orbit” the asteroid at a safe distance, and at different ranges and illumination angles and scanning angles to allow the full characterization of the asteroid’s shape, rotational dynamics, and mass properties.

The final phase is the **Approach and Capture Phase**, which starts at ~100 meters, and approaching the asteroid at a low velocity (~0.1 m/sec). When the spacecraft reaches a distance of ~50 m to the asteroid, it stops and station-keeps at a fixed position. Under some scenarios, the spacecraft will match the spin state of the asteroid to minimize relative motion. The approach phase continues until the capture system has “docked” to the asteroid with the spacecraft velocity relative to the asteroid at zero. The attitude control system is disabled and the capture system sequence starts. More details of the ARV mission concept of operations can be found on the BAA Web site (http://www.nasa.gov/asteroidinitiative).

ARV Mission Concept of Operations: Capturing a Boulder from an Asteroid's Surface

The **Rendezvous Phase** starts well beyond 10,000 km when the target asteroid first becomes visible in the narrow FOV camera. At this time, the narrow FOV camera and the stellar background provide enough information to determine the relative bearing to the target, which is required to maneuver closer to the asteroid. As the ARV nears the target, a medium FOV camera will also provide usable images of the asteroid while the narrow FOV camera produces detailed images of asteroid surface features that can be used for relative navigation.

The **Asteroid Characterization Phase** then begins with a series of flybys of the asteroid, approaching to within 1 km of the surface. The objective is to navigate using two cameras—the medium and wide FOV cameras—and using images from the narrow FOV camera to monitor the asteroid spin rate, build a 3D map of the asteroid surface, and perform a detailed survey of potential boulder collection sites. This phase ends with the spacecraft station keeping about a designated home point approximately 5 km from the asteroid center of mass in the asteroid orbital plane.

The purpose of the **Boulder Collection Phase** is to perform a closed loop descent to the asteroid and grab a large boulder (typically ~2-5 m maximum extent) off the surface. Here, the medium and wide FOV camera images are fed into a real-time, onboard algorithm to determine relative position and attitude (or pose) between the spacecraft and the target boulder. Additionally, a 3D LIDAR is brought online at altitudes below 1 km to provide direct range measurements to the boulder, along with 3D range images that are used to compute another onboard pose measurement that is processed by the navigation filter. By using a two-axis gimbal to point the medium FOV camera relative to the wide FOV camera, the medium FOV camera could be slewed to areas along the horizon that are feature rich for pose, while the wide FOV camera provides dedicated images of the boulder collection site.

The final phase of operations is the **Enhanced Gravity Tractor Phase** where the spacecraft will orbit near the asteroid and use its mass, augmented by the acquired boulder, to alter the orbit of the asteroid using gravitation attraction. This phase begins by precisely determining the current orbit of the asteroid using measurements from the narrow and wide FOV cameras in conjunction with Deep Space Network measurements of the spacecraft during free drift motion near the asteroid (at ~10 km). Afterwards, the spacecraft enters and maintains a halo orbit about the asteroid velocity vector at a safe distance, dependent on the target asteroid (typically ~500-700 m from the asteroid center of mass), using measurements from the narrow and medium FOV cameras.

Orion Concept of Operations

As with ARV, the rendezvous sensors for the Orion spacecraft must also operate in multiple mission phases: rendezvous, proximity operations, final approach, and docking with the ARV. The **Rendezvous Phase** for Orion uses bearing measurements derived from optical sensor images but also includes RF-based range and range-rate measurements, which are required because the higher relative approach speeds required for the shorter crewed timeline, as compared to the longer-duration robotic timeline. Orion also switches to a **Proximity Operations Phase** once the LIDAR starts providing additional range information to the navigation solution. During **Final Approach and Docking Phase**, Orion requires an on-board measurement of the relative attitude and position of the ARV, which is provided by advanced pose estimation algorithms using data from both the optical cameras (visible and infrared) and the LIDAR. More details of the Orion concept of operations can be found on the BAA Web site.

Common Rendezvous Sensor Specification

The common specification identified a set of environmental requirements common to each concept of operation. These values are shown below in Table B-1. Where possible, we note where an attribute could be instantiated in a modular fashion, or where the sensor design includes build-time options that can change its intended use. One example is target albedo: a sensor built for the ARV could be assembled differently than one assembled for Orion in order to meet the low albedo of the asteroid as opposed to the potentially highly reflective target on the ARV. While such modularity works for the asteroid applications covered here, extension to other future missions such as satellite servicing may require both ends of the attribute spectrum. Items such as size, weight, and power goals can be found in the supporting documentation on the BAA Web site.

Table B-1: Environmental Commonality Specification

Attribute	Units	Specification	Notes
Operational Regime	NA	Deep space and cis-lunar	
Mission Duration	Years	> 7	
Sensor On-time	Hours	> 1600 (not for all sensors in the suite)	The suite is used as described in the supporting materials on the BAA Web site. Accounting for duty cycling, the on-time could be shorter.
Operational Thermal Range	deg C	-30 to +50	Survival temperature range should be wider than the operational.
Tested Partial Pressure	Pa	< 1e-5	The actual environment will be a hard vacuum.
Total Ionizing Dose (*)	kRad Si	> 100	Computed TID should account for sensor on-time and mission elapsed time, which are different from each other.

Single Event Upset Rate	Upsets/day	< 1e-2	Computed rates should be for functional upsets only that require a power cycle or configuration reload from stored memory.
Asteroid Size	Meters	2-500	Small sizes apply to capturing an entire asteroid, and larger sizes apply to removing a boulder from an asteroid's surface.
Asteroid visible albedo (*)	%	> 3	Depends on material make up with 3 precent being a minimum.
Docking target reflectance (*)	%	> 90	Docking target to use retro-reflectors.
Sun Exposure Survival	Hours	Indefinite	No requirement to operate with Sun in view.

* = Modular specification

The top-level performance attributes required to meet all three of the mission concept of operations, for each type of sensor, is given in Table B-2.

Table B-2: Commonality Specification for Each Sensor Type

	Visible Camera	**Infrared Camera**	**LIDAR**	**Notes**
Minimum Operational Range	1 m	1-2 m	1 m	Ranges closer than 1 m are being explored for Orion and may be addressed by proposers.
Maximum Operational Range	> 50,000 km (bearing only)	100m to 200 km (bearing only)	2-3 km (range and bearing)	LIDAR: ~2-3 km initial detection range.
Operational Field of View	Rendezvous: 0.5 – 1.5 deg Prox Ops: 30 – 45 deg	Typically max of 30 and min of 20º, but is application dependent. Ability to utilize appropriate lenses required.	±30º ARV ±10º Orion	LIDAR: ARV requires ±30º to "capture" target, ensuring bag does not snag. Orion requires ±10º to ensure relative measurement accuracy throughout AR&D/C.
Angular Resolution	Rendezvous: < 8 urad/pixel Prox Ops: < 300 urad/pixel	Prox Ops: < 300 urad/pixel	< 1.5 mrad /measurement	
Range Accuracy	NA	NA	Precision: 2 cm (1-sigma) within a frame Accuracy: 2 cm (1-sigma) at 2 m separation	

Wavelengths (*)	400 – 700 nm	8 – 14 um	ARV: no restrictions Orion: Eye safe	Eye safety could be met with system protections or laser output frequency.
Frame Rates	5 – 10 Hz	3 – 5 Hz	5 – 10 Hz	
Dynamic Range	> 1000:1	> 1000:1	NA	For a single exposure.

* = Modular specification

NASA acknowledges that as technology improves, changes, and matures, the common sensor suite will need to change and adapt. NASA invites innovative ideas for how to incrementally improve this sensor suite as technology improves and advances. Examples include advances in the regime of noise radar, computing, and other technologies that could enable new approaches to AR&D. New technologies could result in savings on size, weight, power, and complexity. NASA would like to establish incremental growth in AR&D/C capability including the ability to operate in parallel to other solutions to demonstrate the technology prior to integrating it into the primary solution set.

2 **Eligible Participants:** This solicitation topic is open to non-Government U.S. institutions only (companies, universities, nonprofit organizations), and foreign institutions. NASA civil servants and JPL employees may not propose to this solicitation topic. Proposals from foreign organizations must comply with Section 2.3, Guidelines for Foreign Participation.

3 **Notice of Intent to Propose:** NOI to propose are due by April 4, 2014 at 4:00 PM Eastern Time

4 **Proposal Due Date:** May 5, 2014 by 4:00 PM Eastern Time

5 **Period of Performance:** Period of performance of the initial phase of the contracts will be for 180 calendar days (approximately six months) following the authorization to proceed effective date.

6 **Award Date:** Award is anticipated on or about July 1, 2014. The price proposal should be based on this anticipated award date.

7 **Funding Allocation**: Individual award amounts may range from $300,000 to $450,000. NASA anticipates making up to four-six awards for a total of approximately $1.8M. Contracts shall be firm fixed price. NASA will select the entire proposed effort only. The Government's obligation to make awards is contingent upon the availability of appropriated funds from which payments can be made and the receipt of proposals that NASA determines are acceptable.

8 Reporting Requirements: The resultant contract awards will include the following deliverable requirements:

Month	Deliverable
1	Kickoff meeting at NASA Johnson Space Center.
4	Interim briefing to support the ARM Mission Concept Review.
6	Final technical report and accompanying briefing; Statement-of-work, schedule, and cost estimate for optional Phase 2 contract.

APPENDIX C: ADAPTING COMMERCIAL SPACECRAFT FOR THE ASTEROID REDIRECT VEHICLE

1 Description of Solicitation Topic

To reduce development costs, NASA is interested in studying the feasibility of adapting and leveraging existing commercial spacecraft design, manufacture, integration, and testing capabilities for developing the ARV and its main components such as the Solar Electric Propulsion (SEP) module. The major elements of the ARV configuration are the SEP module, the mission module, and the asteroid capture system.

The current baseline conceptual SEP module consists of the solar arrays and a high-voltage power management and distribution subsystem; a propulsion subsystem including Hall thrusters, Power Processing Units (PPUs), tanks for xenon storage, and a propellant distribution and control subsystem; a thermal control subsystem; a reaction control subsystem; and a mechanical subsystem. The mechanical subsystem includes mechanisms for launch vehicle separation and for docking with the Orion spacecraft.

The mission module contains the ARV attitude control system, a command and data handling system, a communications subsystem, an energy storage subsystem, a low-voltage power distribution subsystem, a thermal control subsystem, all the instrumentation required for navigation, asteroid characterization, and asteroid capture, and a separation mechanism to enable ejection of the capture system if necessary.

The capture system could be either an inflatable or deployable structure that captures the asteroid in a bag or robotic manipulators that capture a boulder from the asteroid's surface (see Appendix A). Alternatively, the capture system may also contain the navigational sensors used during asteroid rendezvous, proximity operations, and capture (see Appendix B). In this case, a control and data system interface would exist between the mission module and capture system.

The mission module interfaces with the solar electric propulsion module and the asteroid capture system. A docking mechanism attached to aft end of the ARV will allow it to dock with the Orion spacecraft.

The ARV must be capable of meeting the following additional requirements:

- Capable of being launched on a single launch vehicle, including Atlas V, Delta IVH, Falcon Heavy, or SLS.
- Solar electric propulsion system input power approximately 40 kW at end of life.
- Thruster specific impulse between 2,000 and 3,000 seconds.
- Capable of operating over the range of 0.7 AU to 1.7 AU, including temperature control and communications
- System capable of carrying 2,000 to 10,000 kg of xenon.

- An operational lifetime of at least six years in deep space, including radiation tolerance.
- System must be demonstrated high reliability, including appropriately redundant critical systems and operability through fault conditions that include proximity operations with a potentially hazardous noncooperating body.

NASA seeks proposals for industry-led studies of how existing commercial capabilities could be used to reduce the development cost of either the ARV solar electric propulsion module, the mission module, or a combined propulsion and mission module. NASA is particularly interested in developing a standalone high-power SEP tug with an initial capability of approximately 40 kW that could not only permit direct application as a component of the ARV, but also extend to other compelling government and commercial mission applications. NASA is also interested in block upgrade approaches to accommodate higher power (50-300 kW) SEP systems for future exploration missions.

The proposals shall describe the overall system development plan, including any modifications required to existing commercial designs, the leveraging of commercial development and fabrication capabilities, and integration and testing facilities. During the study, the selected companies will perform conceptual systems design, analysis, and engineering, and estimate the cost and schedule required for flight systems development. Special consideration of innovative procurement approaches, such as NASA purchase of commercial services or a fixed price milestone-based contract is desired.

NASA may use the data resulting from this effort to inform the ARM Mission Concept Review (MCR), which is planned for late 2014 or early 2015.

Depending on the results from the initial Phase 1 study, NASA may decide to award a follow-on Phase 2 contract option for further development of the system concept. A proposed statement-of-work for the Phase 2 contract option shall be developed during the Phase 1 study.

2 **Eligible Participants:** This solicitation topic is open to U.S. commercial organizations only. NASA civil servants and JPL employees may not propose to this solicitation topic.

3 **Notice of Intent to Propose:** NOI to propose are due by April 4, 2014, at 4:00 PM Eastern Time

4 **Proposal Due Date:** May 5, 2014, by 4:00 PM Eastern Time

5 **Period of Performance:** Period of performance of the initial phase of the contracts will be for 180 calendar days (approximately six months) following the authorization to proceed effective date.

6 **Award Date:** Award is anticipated on or about July 1, 2014. The price proposal should be based on this anticipated award date.

7 **Funding Allocation**: Individual award amounts may range from $300,000 to $450,000. NASA anticipates making up to four-six awards for a total of approximately $1.8M. Contracts shall be firm fixed price. NASA will select the entire proposed effort only. The Government's obligation to make awards is contingent upon the availability of appropriated funds from which payments can be made and the receipt of proposals that NASA determines are acceptable.

8 **Reporting Requirements:** The resultant contract awards will include the following deliverable requirements:

Month	Deliverable
1	Kickoff meeting at NASA Jet Propulsion Laboratory.
4	Interim briefing to support the ARM Mission Concept Review.
6	Final technical report and accompanying briefing; Statement-of-work, schedule, and cost estimate for optional Phase 2 contract.

APPENDIX D: STUDIES OF POTENTIAL FUTURE PARTNERSHIP OPPORTUNITIES FOR SECONDARY PAYLOADS

1 Description of Solicitation Topic

NASA would like to study potential future commercial and international partnership opportunities for launch of secondary payloads on the ARM robotic spacecraft and its launch vehicle, or the SLS during human exploration missions (e.g., Exploration Mission-1). These payloads may address commercial interests such as asteroid resource prospecting, demonstration of planetary defense capabilities, or Strategic Knowledge Gaps (SKGs) for future human exploration. The potential types of missions for these launch opportunities could include precursor missions to potential target asteroids or the moons of Mars, ride-along missions on the ARV, or independent small body missions for commercial or planetary defense purposes.

The SKGs represent the unknown environments or availability of resources at potential destinations that could impact the design of human spaceflight systems. NASA uses the SKGs to guide the planning of robotic precursor missions. For NEAs, it is important to know the uncertainty in the target asteroid's orbital position; to measure its size, shape, and spin rate; to map its gravity field and infer its internal structure; and to determine if it is a binary system or has hazardous debris orbiting around it that could limit crew vehicle operations.

NASA is also interested in robotic precursor missions to the moons of Mars, Phobos and Deimos, which may be captured asteroids. The Martian moons may have accessible resources such as water that could enable human exploration of Mars. The SKGs can be found at: http://www.nasa.gov/exploration/library/skg.html.

NASA is particularly interested in the following types of secondary payloads:

- Cubesat-class payloads (1U to 6U) deployed from the ARV in proximity to the target asteroid. A 1-unit (1U) Cubesat has a volume of 10 cm x 10 cm x 10 cm, and its mass is typically 1.33 kg per 1U.
- Cubesat-class payloads (6U or 12U) deployed from SLS, sent as precursor missions to potential target asteroids.
- Science instruments, such as spectrometers. Representative volume (50 cm x 50 cm x 50 cm), mass (10 kg), power (100 W), and data interfaces (8 Gbps) could be provided on the ARV.
- Microspacecraft launched on the same launch vehicle as the ARV for robotic precursor missions to NEAs and the moons of Mars.
- Kinetic impactors launched with the ARV or launched on a separate launch vehicle for demonstrating planetary defense capabilities at the target NEA.
- Simple, low-cost regolith, and contingency sample collection concepts that would work in conjunction with the capture system or proximity operations (see Appendix A).

Proposals for initial mission feasibility studies to assess compatibility of the proposed secondary payload with the primary vehicle and mission will be selected and funded under this Announcement.

Proposals shall describe the secondary payload concept, the relevancy to commercial interests, planetary defense, or SKGs, the type of launch opportunity requested, and the capabilities of the partner organization to provide space flight hardware. The proposals shall also outline the approach for the initial mission feasibility study. NASA will work with selected partner to define interface requirements and payload accommodations on the primary vehicle.

NASA may use the data resulting from this effort to inform the ARM Mission Concept Review (MCR), which is planned for late 2014 or early 2015.

Any future partnership agreement will be selected under a separate solicitation. NASA intends to award no-exchange-of-funds partnership agreements in which NASA may contribute payload integration, launch, and mission operations support to secondary payloads provided by the partner. NASA would not provide any funds to the partner for development of the secondary payload.

2 **Eligible Participants:** This solicitation topic is open to all U.S. and foreign institutions (companies, universities, non-profit organizations, other Government agencies) except NASA civil servants and JPL employees**.** Proposals from foreign organizations must comply with Section 2.3, Guidelines for Foreign Participation.

3 **Notice of Intent to Propose:** NOI to propose are due by April 4, 2014, at 4:00 PM Eastern Time

4 **Proposal Due Date:** May 5, 2014, by 4:00 PM Eastern Time.

5 **Period of Performance:** Period of performance of the initial feasibility study will be for 180 calendar days (approximately six months) following the authorization to proceed effective date.

6 **Award Date:** Award is anticipated on or about July 1, 2014.

7 **Funding Allocation:** Individual award amounts shall not exceed $50,000. NASA anticipates making up to four awards for a total of approximately $200,000. Contracts shall be firm fixed price. NASA will select the entire proposed effort only. The Government's obligation to make awards is contingent upon the availability of appropriated funds from which payments can be made and the receipt of proposals that NASA determines are acceptable.

8 Reporting Requirements: The resultant contract awards will include the following deliverable requirements:

Month	Deliverable
1	Kickoff meeting at NASA Headquarters.
4	Interim briefing to support the ARM Mission Concept Review.
6	Final technical report and accompanying briefing summarizing the initial mission feasibility study.

APPENDIX E: STUDIES OF POTENTIAL FUTURE PARTNERSHIP OPPORTUNITIES FOR THE ASTEROID REDIRECT CREWED MISSION (ARCM)

1 Description of Solicitation Topic

To maximize utility of the ARCM and reduce the costs of meeting mission objectives, NASA is interested in studying concepts for potential partnerships for crewed mission activity to the redirected asteroid in the Lunar Distant Retrograde Orbit (LDRO), and to further utilize the asteroid. The potential partnerships may include both technical concepts and innovative business models. Specifically, concepts are requested that are responsive to the secondary mission objectives of science, advancing in-situ resource utilization (ISRU), and enabling commercial activities. NASA is also interested in concepts to enhance and inform U.S. exploration activities in cis-lunar space after the first crewed mission to an asteroid.

The ARV should be assumed to be in a LDRO of approximately 71,000 km altitude. The overall concept of operations envisioned for the NASA crewed mission to the asteroid is as follows:

- A crew of two astronauts aboard the Orion vehicle arrives in the LDRO to spend no more than five days.
- After rendezvous and docking with the ARV, two EVA's of approximately four hours are envisioned.
- After undocking, the ARV and asteroid remain in the LDRO.
- Additional visits to the asteroid may be considered, as well as other activities that leverage this capability.
- Proposers should be aware that mass on Orion on the first crewed mission is reserved for requirements to implement the asteroid exploration and sampling mission. Additional mass, power, and volume may be available on the ARV.

NASA seeks proposals to study partnership concepts for crewed activities or to leverage crewed activities in the vicinity of the redirected asteroid. For example, astronauts could deploy scientific instruments or resource prospecting and ISRU experiments provided by commercial or international partners on the surface of the captured asteroid.

Proposals for initial concept feasibility studies to assess compatibility of the proposed activity with the ARCM will be selected and funded under this Announcement. The proposals shall describe the overall concept for the partnership, including benefits and potential cost sharing, and any modifications required to the robotic spacecraft.

NASA may use the data resulting from this effort to inform the ARM Mission Concept Review (MCR), which is planned for late 2014 or early 2015.

Any future partnership agreement will be selected under a separate solicitation. NASA intends to award no-exchange-of-funds partnership agreements

in which NASA may contribute engineering expertise, test facilities, payload integration, launch, mission operations support, and other services at no cost to the partner.

2 **Eligible Participants:** This solicitation topic is open to all U.S. and foreign institutions (companies, universities, nonprofit organizations, other Government agencies) except NASA civil servants and JPL employees**.** Proposals from foreign organizations must comply with Section 2.3, Guidelines for Foreign Participation.

3 **Notice of Intent to Propose:** NOI to propose are due by April 4, 2014, at 4:00 PM Eastern Time

4 **Proposal Due Date:** May 5, 2014, by 4:00 PM Eastern Time

5 **Period of Performance:** Period of performance of the initial feasibility study will be for 180 calendar days (approximately six months) following the authorization to proceed effective date.

6 **Award Date:** Award is anticipated on or about July 1, 2014. The price proposal should be based on this anticipated award date.

7 **Funding Allocation:** Individual award amounts shall not exceed $50,000. NASA anticipates making up to four awards for a total of approximately $200,000. Contracts shall be firm fixed price. NASA will select the entire proposed effort only. The Government's obligation to make awards is contingent upon the availability of appropriated funds from which payments can be made and the receipt of proposals that NASA determines are acceptable

8 **Reporting Requirements:** The resultant contract awards will include the following deliverable requirements:

Month	Deliverable
1	Kickoff meeting at NASA Johnson Space Center.
4	Interim briefing to support the ARM Mission Concept Review.
6	Final technical report and accompanying briefing summarizing the initial mission feasibility study.

APPENDIX F: PRICE PROPOSAL FORMAT

FIRM FIXED PRICE	
ELEMENTS	6 months
Direct Labor Price from Labor Template	**$ -**
Overhead (List)	
1. (Name & Description of Base)	$ -
Overhead Rate	0.00%
Overhead Price	$ -
2. (Name & Description of Base)	$ -
Overhead Rate	0.00%
Overhead Price	$ -
Total Overhead Price	**$ -**
Subcontract Price	
1. (Subcontractor Name);(provide detailed description of work proposed)	$ -
2. (Subcontractor Name); (provide detailed description of work proposed)	$ -
Total Subcontract Price	**$ -**
'Other Direct Costs (ODCs)'	
1. ODCs from ODC Breakdown Section (following page)	$ -
2. Travel (provide separate breakdown of proposed travel price)	$ -
3. Other ODCs; (provide description)	$ -
Total Price for Other Direct Costs	**$ -**
G&A Price	
1. (Description of G&A Base)	$ -
G&A Rate	0.00%
G&A Price	**$ -**
Subtotal	**$ -**
1. (Description of Profit Base)	$ -
Profit Rate	0.00%
Profit	**$ -**
Total Price	**$ -**

LABOR PRICE BREAKDOWN

Labor Category Name	WYEs	Labor Hours	Labor Rate	Labor Price
	0.00	0.00	$0.00	$0.00
	0.00	0.00	$0.00	$0.00
	0.00	0.00	$0.00	$0.00
	0.00	0.00	$0.00	$0.00
	0.00	0.00	$0.00	$0.00
	0.00	0.00	$0.00	$0.00
	0.00	0.00	$0.00	$0.00
	0.00	0.00	$0.00	$0.00
	0.00	0.00	$0.00	$0.00
	0.00	0.00	$0.00	$0.00
	0.00	0.00	$0.00	$0.00
	0.00	0.00	$0.00	$0.00
	0.00	**0.00**		**$0.00**

OTHER DIRECT COSTS PRICE BREAKDOWN

Item Name & Description	Quantity	Unit Price	Total Price
	0.00	0.00	$0.00
	0.00	0.00	$0.00
	0.00	0.00	$0.00
	0.00	0.00	$0.00
	0.00	0.00	$0.00
	0.00	0.00	$0.00
	0.00	0.00	$0.00
	0.00	0.00	$0.00
	0.00	0.00	$0.00
	0.00	0.00	$0.00
	0.00	0.00	$0.00
	0.00	0.00	$0.00
			$0.00