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NASA's Efforts to Identify Near-Earth Objects and Mitigate Hazards

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Acronyms

ATLAS	Asteroid Terrestrial-impact Last Alert System
DARPA	Defense Advanced Research Projects Agency
FY	Fiscal Year
JPL	Jet Propulsion Laboratory
KaBOOM	Ka-Band Objects Observation and Monitoring Project
LINEAR	Lincoln Near-Earth Asteroid Research
LSST	Large Synoptic Survey Telescope
NEA	Near-Earth Asteroid
NEO	Near-Earth Object
NEOCam	NEO Camera
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
NRC	National Research Council
NSF	National Science Foundation
OIG	Office of Inspector General
OSIRIS-Rex	Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer Project
Pan-STARRS	Panoramic Survey Telescope and Rapid Response System 1 and 2
PHO	Potentially Hazardous Object
SST	Space Surveillance Telescope
WISE	Wide-field Infrared Survey Explorer

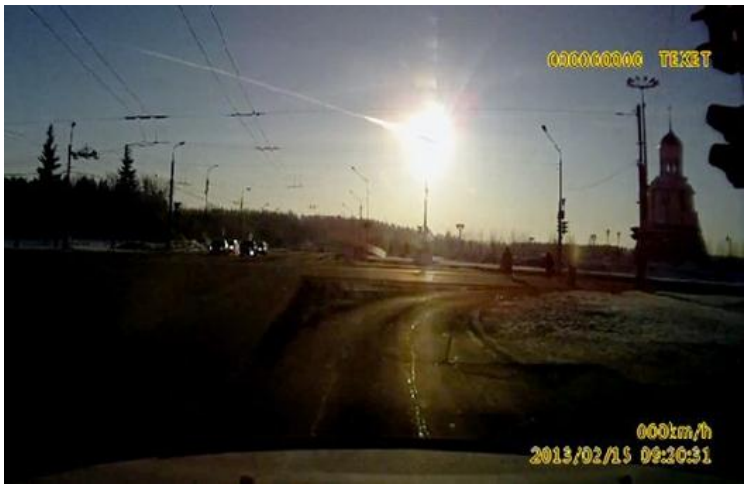
OVERVIEW

NASA'S EFFORTS TO IDENTIFY NEAR-EARTH OBJECTS AND MITIGATE HAZARDS

The Issue

Scientists classify comets and asteroids that pass within 28 million miles of Earth's orbit as near-Earth objects (NEOs). Asteroids that collide and break into smaller fragments are the source of most NEOs, and the resulting fragments bombard the Earth at the rate of more than 100 tons a day. Although the vast majority of NEOs that enter Earth's atmosphere disintegrate before reaching the surface, those larger than 100 meters (328 feet) may survive the descent and cause destruction in and around their impact sites. Furthermore, even smaller objects that disintegrate before reaching Earth's surface can cause significant damage. For example, in February 2013 an 18-meter (59 foot) meteor exploded 14.5 miles above the city of Chelyabinsk, Russia, with the force of 30 atomic bombs, blowing out windows, destroying buildings, injuring more than 1,000 people, and raining down fragments along its trajectory (see Figure 1). Recent research suggests that Chelyabinsk-type events occur every 30 to 40 years, with a greater likelihood of impact in the ocean than over populated areas, while impacts from objects greater than a mile in diameter are predicted only once every several hundred thousand years.

Figure 1. Photograph of Chelyabinsk Meteor



Source: AP Photo/AP Video, February 15, 2013.

In 1992, NASA began conducting scientific workshops and research into the identification, characterization, and tracking of NEOs, as well as into potential mitigation strategies. NASA reported NEOs with a diameter greater than 1 kilometer (0.62 miles) posed the greatest hazard to Earth and predicted a comprehensive survey could identify most NEOs of this size within a decade.[1] In 1994, the House Committee on Science, Space, and Technology requested NASA identify and catalogue within 10 years the orbital characteristics of all comets and asteroids greater than 1 kilometer in diameter and

[1] The Spaceguard Survey, "Report of the NASA International Near-Earth-Object Detection Workshop," January 25, 1992.

in an orbit around the Sun that crosses the orbit of the Earth.[2] Four years later, NASA established a NEO Program Office to coordinate these efforts.[3] In addition, the NASA Authorization Act of 2005 required the Agency to implement a "program to detect, track, catalogue, and characterize the physical characteristics of near-Earth objects equal to or greater than 140 meters in diameter" and established a goal of cataloging 90 percent of these objects by 2020.[4] However, even with a ten-fold increase in the NEO Program budget in the past 5 years – from $4 million in fiscal year (FY) 2009 to $40 million in FY 2014 – NASA estimates that it has identified only about 10 percent of all asteroids 140 meters and larger. Moreover, given its current pace and resources, the Agency has stated that it will not meet the goal of identifying 90 percent of such objects by 2020.

We initiated this review to examine NASA's NEO Program and assess the Agency's progress toward meeting statutory and other Program goals. Specifically, we reviewed NASA's allocation and use of resources and plans for the future of the Program. Details of the review's scope and methodology are in Appendix A.

Results

NASA has organized its NEO Program under a single Program Executive who manages a loosely structured conglomerate of research activities that are not well integrated and lack overarching Program oversight, objectives, and established milestones to track progress. In addition, NASA is undertaking NEO-related activities not managed by the Program and not sufficiently integrated into ongoing Program activities. Furthermore, NASA lacks formal agreements or procedures for NEO-related activities it conducts with other Federal agencies and foreign governments and has not taken advantage of possible partnership opportunities. Consequently, managers could not identify the level of resources required to adequately support the Program or explain how activities to which the NEO Program is contributing further Program goals. Even though the Program has discovered, categorized, and plotted the orbits of more than 11,000 NEOs since 1998, NASA will fall short of meeting the 2005 Authorization Act goal of finding 90 percent of NEOs larger than 140 meters in diameter by 2020. We believe the Program would be more efficient, effective, and transparent were it organized and managed in accordance with standard NASA research program requirements.

Lack of Structure and Limited Resources Hinders the NEO Program. Since creation of the NEO Program, the number of identified NEOs has increased from less than 500 in 1998 to over 11,000 as of July 2014. Most of this work occurred while the Program was relatively small – receiving only $4 million annually from FYs 2002 through 2009 and funding less than 20 individual efforts – and focused on identifying the largest NEOs.

[2] United States Congress, H. R. 4489, Report No. 103–654, August 3, 1994.

[3] In various documents, NASA refers to this research effort as the Near-Earth Object Observations Program. For ease of reference, we use "NEO Program" or "the Program" in this report.

[4] Pub. L. No. 109–155, December 30, 2005 (codified at 42 U.S.C. § 16691).

However, with the directive to identify 90 percent of NEOs larger than 140 meters, substantially increased budget beginning in FY 2011, and additional projects, the NEO Program's existing structure and resources are inadequate to provide efficient, effective, and transparent program management.

In FY 2013, the Program Executive oversaw a budget of $20.5 million and 64 funding instruments that included grants, purchase orders, and contract task orders to observatories and other facilities. With the Program budget growing to $40 million in FY 2014, the number of funding instruments will likely also increase and with it the Program Executive's oversight responsibilities.

In addition to limited personnel, the NEO Program lacks a plan with integrated milestones, defined objectives, and cost and schedule estimates to assist in tracking and attaining Program goals. To implement the goals of the 2005 Authorization Act, the Program provided funding to more ground-based observatories and obtained additional observation time at observatories such as the Panoramic Survey Telescope and Rapid Response System in Hawaii and the Arecibo Observatory in Puerto Rico (see Figure 2). In addition, the Program supports the work of NASA initiatives such as the Asteroid Redirect Mission and NEO Program personnel provide technical support for a Space Act Agreement with the B612 Foundation to assist in the development of a privately funded, space-based infrared telescope.[5] Despite this increased activity, NASA has not changed or improved the NEO Program's management structure and the Program has not established a plan to integrate the additional initiatives or track their contributions to attainment of NEO Program goals.

Figure 2. Arecibo Observatory

Source: NASA.

In our judgment, the NEO Program would be better equipped to meet its goals if the Program followed NASA's programmatic policies for research projects and if Program management established clear and verifiable requirements for processes pertaining to NEO detection, characterization, and mitigation.[6]

[5] The Asteroid Redirect Mission, developed by NASA's Human Exploration and Operations Mission Directorate, aims to fulfill the President's call to send astronauts to a near-Earth asteroid. The mission objective is to identify, capture, redirect into a stable lunar orbit, and sample an asteroid with a mass up to 1,000 tons by the first half of the next decade.

[6] NASA Procedural Requirements (NPR) 1080.1A, "Requirements for the Conduct of NASA Research and Technology (R&T)," May 30, 2008. NPR 7120.8, "NASA Research and Technology Program and Project Management Requirements (w/change 3 dated 04/18/13)," February 5, 2008.

NASA Needs to Improve its Oversight of NEO Grants and Task Orders. NASA's controls for managing and overseeing costs associated with the NEO Program are inadequate to ensure proper accounting of Agency-funded grants and task orders. First, we found that contrary to effective internal control standards, the NEO Program Executive is responsible for or has significant input into all the primary elements of the award process, including overseeing, monitoring, and evaluating the progress of awards.[7] Having the Program Executive perform all these tasks increases the risk of error or fraud in the Program.

We also reviewed the 10 awards that exceeded $900,000 the NEO Program funded in FY 2013 and found the Program did not adequately oversee, monitor, or evaluate the progress of the work performed. For example, NASA recently awarded the Lincoln Near-Earth Asteroid Research Program a $6.5 million, 5-year grant via an interagency transfer in spite of a steep decline in its ability to provide NEO detection. In addition, we identified three instances in which NASA awarded grants when contracts would have been the more appropriate instrument for achieving Program goals. Although these grants supported some research, the majority of funds supported operations and maintenance on observatory facilities and therefore, pursuant to Federal law, NASA should have used a contract.[8] Furthermore, a contract would have provided greater visibility into awardee operations and ensured the level of funding and awardee performance was commensurate with requirements and deliverables.

Lack of Formal Agreements with Federal and International Partners Hampers NASA's Ability to Accomplish Program Goals. Although NASA has established two formal partnerships with domestic, nongovernmental research organizations and several informal partnerships, a lack of planning and resources has prevented the NEO Program from developing additional partnerships that could help achieve Program goals. For example, establishing formal partnerships with the Department of Defense and the National Science Foundation could give the Program access to additional Earth-based telescopes, thereby increasing its ability to detect, track, and characterize a greater number of NEOs. Moreover, the NEO Program has not taken advantage of experience gained by other NASA programs, such as the International Space Station, that have formed international partnerships. Such expanded partnerships could accelerate discovery of NEOs, aid in development of global mitigation strategies, and help ensure that the burden of mitigating NEO threats does not disproportionately fall on NASA and the United States.

[7] Government Accountability Office, "Standards for Internal Control in the Federal Government" (AIMD-00-21.3.1, November 1999).

[8] 31 U.S.C. § 6303, "Using Procurement Contracts."

Management Action

To improve NASA's efforts to discover, characterize, and catalog NEOs and develop mitigation strategies, we recommended the Associate Administrator for the Science Mission Directorate develop a formal NEO Program with a strategic plan, integrated master schedule, and cost estimates. We also recommended the Associate Administrator direct the NEO Program Executive to develop and implement requirements, procedures, and internal controls to address deficiencies; perform a full-time equivalent analysis to determine the staff required to manage, oversee, and administer the Program; develop a plan to establish formal partnerships with domestic and international agencies to leverage resources and complementary technologies; and establish a systematic oversight process pursuant to which NASA-funded observatories are required to coordinate to avoid duplication of effort.

In response to a draft of this report, the Associate Administrator concurred with our recommendations and agreed to establish a formal NEO Program in accordance with NASA guidance. He also stated the Program will conduct a full-time equivalent analysis, develop a plan to establish formal partnerships, and establish a coordination plan between observatories – all of which he promised will be documented in the NEO Program Plan.

We consider NASA's planned actions responsive and will close the recommendations upon verification of their completion. We also reviewed management's comments regarding the technical accuracy of the draft and made changes as appropriate. Management's full response to the draft report is reprinted in Appendix D.

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INTRODUCTION

Background

Scientists classify comets and asteroids that pass within 28 million miles of Earth's orbit as near-Earth objects (NEOs).[9] Composed of rock, ice, and organic compounds, comets are thought to originate from an area beyond the orbit of Pluto but occasionally have orbits that bring them closer to the Sun where they heat up and may display a visible atmosphere and tail due to the effects of solar wind and radiation. Asteroids are primarily rocky or metallic bodies that orbit the Sun, with most residing in the main asteroid belt between Mars and Jupiter. Asteroids that collide and break into smaller fragments are the source of most NEOs. Fragments of comets or asteroids that enter the Earth's atmosphere are known as meteors. Most meteors are small and vaporize in the Earth's atmosphere as "shooting stars" before reaching the planet's surface. A meteor that reaches the Earth's surface is known as a meteorite.

Every day more than 100 tons of meteors bombard the Earth. Although the vast majority of these objects disintegrate before reaching the planet's surface, objects larger than 100 meters (328 feet) may survive the descent, hit the ground, and cause destruction in and around the impact site. Moreover, even smaller objects that enter the Earth's atmosphere and disintegrate before reaching the surface can cause significant damage. For example, on February 15, 2013, an 18-meter (59 foot) meteor exploded 14.5 miles above the city of Chelyabinsk, Russia, with the force of 30 atomic bombs, blowing out windows, destroying buildings, injuring more than 1,000 people, and raining down fragments along its trajectory.[10] Recent research suggests that Chelyabinsk-type events occur every 30 to 40 years with a greater likelihood of impact in the ocean than over populated areas.

Although the probability of a meteor 1 kilometer (3,280 feet) or larger striking the Earth is extremely remote, the consequences of such an impact would be severe. On May 31, 2013, a massive asteroid 2.7 kilometers (1.6 miles) in diameter passed within 5.8 million kilometers (3.6 million miles) of Earth or about 15 times the distance from the Earth to the Moon. Had an object this size struck the Earth, the resulting debris would likely have contaminated the Earth's atmosphere, causing partial obstruction of sunlight, acid rain, and firestorms. In a dramatic example of this phenomenon, scientists believe that a 10-kilometer wide (6.2 mile) meteorite struck Mexico's Yucatan Peninsula about 66 million years ago, perhaps contributing to the extinction of the dinosaurs. Table 1 summarizes impact frequencies based on meteor size.

[9] Astronomers Carl Gustav Witt and Auguste Charlois are credited with discovering the first NEO in 1898.

[10] The Chelyabinsk meteor was the largest reported since 1908 when a meteor hit Tunguska, Siberia, and flattened more than 772 square miles of forest. Scientists believe that between 9,000 and 13,000 pounds of the Chelyabinsk meteor fell to Earth in various size fragments. One fragment weighing approximately 1,400 pounds was recovered from a lake about 45 miles east of the city.

Table 1. Approximate Impact Frequencies and Consequences from Near-Earth Objects

Type of Event	Diameter of Object (meters)	Impact Energy (megatons)[a]	Average Impact Interval (years)
High altitude break-up	< 30	<5	1–50
Tunguska-like event	> 30	>5	250–500
Regional event	> 140	~150	5,000
Large sub-global event	> 300	~2,000	25,000
Low global effect	> 600	~30,000	70,000
Medium global effect	> 1,000	>100,000	1 million
High global effect	> 5,000	> 10 million	6 million
Extinction-class event	> 10,000	>100 million	100 million

[a] A megaton is a unit of measurement describing the amount of energy released from an explosion. One megaton equals the amount of energy released from one million tons of TNT.

Source: NASA.

Legislative Directives and National Research Council Findings. NASA conducts scientific workshops and performs research into identifying and characterizing the physical and orbital properties of and tracking NEOs.[11] The Agency also funds and conducts research into mitigating potentially hazardous NEOs. In 1992, NASA issued a report concluding NEOs with a diameter larger than 1 kilometer posed the greatest hazard to Earth and posited that a comprehensive survey could identify most NEOs of this size within a decade.[12] In 1994, the House Committee on Science, Space, and Technology requested NASA identify and catalogue within 10 years the orbital characteristics of all comets and asteroids that are greater than 1 kilometer in diameter and are in an orbit around the Sun that crosses the orbit of the Earth.[13] Thereafter, NASA's Authorization Act of 2005 required the Agency to implement a "program to detect, track, catalog, and characterize the physical characteristics of near-Earth objects equal to or greater than 140 meters in diameter in order to assess the threat of such near-Earth objects to the Earth" and set a goal of cataloguing 90 percent of these objects by 2020.[14] The law also amended the National Aeronautics and Space Act of 1958 and additionally required NASA use its skills to "provide warning and mitigation of the potential hazard of such near-Earth objects to the Earth."[15]

In 2010, the National Research Council (NRC) issued a report finding NASA would not meet the goal of identifying 90 percent of NEOs larger than 140 meters by 2020 due to insufficient resources.[16] The NRC identified two approaches to reach the goal by

[11] As discussed in more detail later in this report, characterizing the physical and orbital properties of a NEO is required to determine its threat potential and to plan any necessary mitigation efforts.

[12] The Spaceguard Survey, "Report of the NASA International Near-Earth-Object Detection Workshop," January 25, 1992.

[13] United States Congress, H. R. 4489, Report No. 103–654, August 3, 1994.

[14] Pub. L. No. 109–155, December 30, 2005 (codified at 42 U.S.C. § 16691).

[15] 42 U.S.C. § 2451(g).

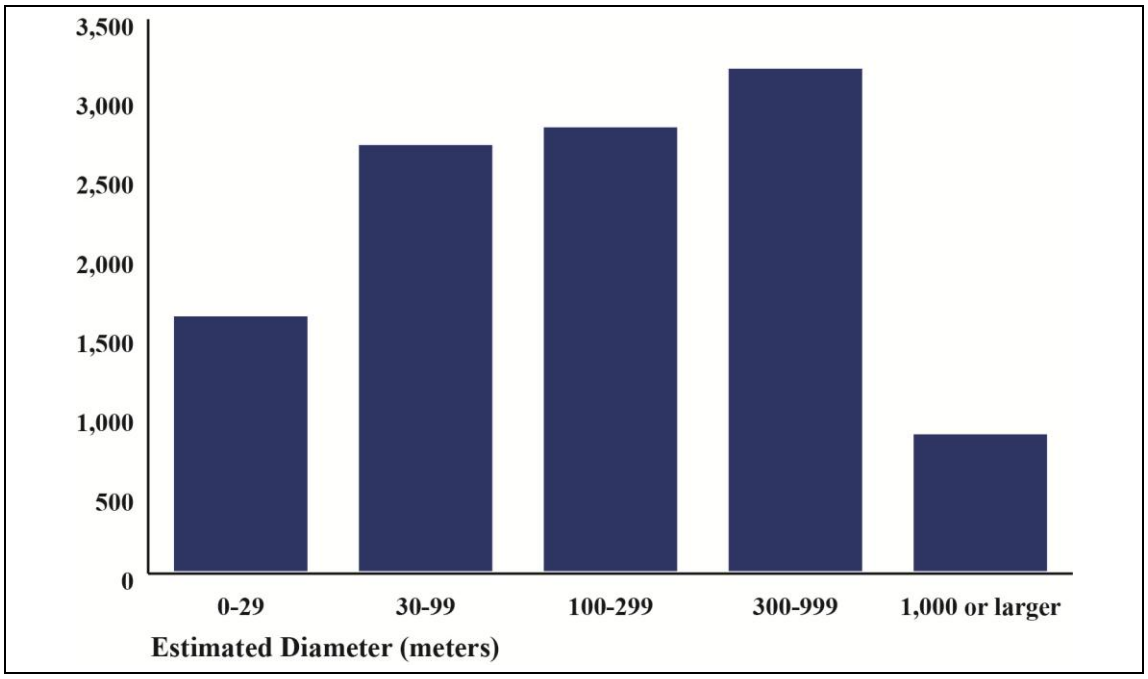
[16] NRC, "Defending Planet Earth: Near Earth Object Surveys and Hazard Mitigation Strategies," 2010.

2030 depending on the priority policymakers attached to the issue. Specifically, if finishing the survey as soon as possible was most important, the NRC recommended using a space-based telescope in concert with observations from suitable ground-based telescopes. If conserving costs was a higher priority, the NRC suggested using only large ground-based telescopes.

The NRC report recommended NASA be directed to monitor objects as small as 30 to 50 meters in diameter. In addition, the NRC suggested the United States organize an international entity to develop a detailed plan for addressing NEO hazards and NASA and the National Science Foundation (NSF) support a vigorous program of observation at the Arecibo Observatory in Puerto Rico (Arecibo) and Goldstone Deep Space Communications Complex in California (Goldstone), both of which play an important role in determining the orbits and characterizing the properties of NEOs.

NASA has surveyed about 95 percent of the known population of NEOs 1 kilometer or larger and significantly increased efforts to locate and characterize NEOs between 140 meters and 1 kilometer. As of July 2014, approximately 11,230 NEOs have been identified of which 862 have diameters of approximately 1 kilometer or larger. In addition, NASA estimates that it has identified approximately 10 percent of all asteroids 140 meters and larger. Moreover, NASA has classified 1,492 NEOs as potentially hazardous objects (PHOs), meaning they have orbits predicted to come within roughly 4.6 million miles of Earth's orbit and exceed about 150 meters (500 feet) in diameter. Figure 3 illustrates the quantity of known asteroids by size as of July 2014.

Figure 3. Sizes of Near-Earth Asteroids Discovered



Note: Comet size is unknown; therefore, the 94 known near-Earth comets are not included.
Source: NASA.

NASA's NEO Program. In 1998, NASA established a NEO Program Office in the Science Mission Directorate's Planetary Science Division to coordinate its NEO-related efforts.[17] The Program Executive sits at NASA Headquarters and is responsible for overall execution of the NEO Program and oversight of related grants and contracts. The Executive is the only NEO Program employee at Headquarters. The other major parts of the Program are the Minor Planet Center in Cambridge, Massachusetts, and the NEO Program Office at the Jet Propulsion Laboratory (JPL).

NASA funds the Minor Planet Center through a 5-year, $6.3 million grant. Hosted by the Harvard-Smithsonian Center for Astrophysics, the Center is an international clearinghouse for small body observational data under the authority of the International Astronomical Union. A director, two investigators, and three information technology employees staff the Center.

The NEO Program Office receives, refines, and publishes data on the orbits and impact likelihood of objects reported to the Minor Planet Center. NASA funds the Office through a 14-year, $8.9 million task order issued pursuant to NASA's larger contract with the California Institute of Technology to operate JPL. The Office has six employees – a manager, four research scientists, and an information technology specialist.[18]

[17] NASA refers to this research effort in various documents as the Near-Earth Object Observations Program. For ease of reference, we use "NEO Program" or "the Program" in this report.

[18] The JPL NEO Office works with the European Space Agency's Near Earth Objects - Dynamic Site on issues of mutual interest.

Since 1998, NASA has spent about $100 million in NEO-related efforts using funds from the Science Mission Directorate's Planetary Science Research Program. Over the past 5 years, the annual budget has grown from approximately $4 million in fiscal year (FY) 2009, to $20 million in FYs 2011 through 2013, to $40 million in FY 2014.[19]

NEO Program Operations. NEO Program operations consist of three major elements: detection and notification, characterization and cataloging, and mitigation (see Appendix B for more detail on the Program assets that support these elements).

- *Detection and Notification*. The ability to detect a NEO is dependent on the object's distance from the Earth; its size and location relative to the Sun; and how well light reflects from its surface, also known as its "albedo." It is extremely difficult, if not impossible, to detect a NEO that is near or, as observed from Earth, positioned in front of the Sun. The NEO Program provides funds to three survey teams that operate five ground-based telescopes to detect NEOs – the Catalina Sky Survey (Catalina), Lincoln Near-Earth Asteroid Research (LINEAR), and Panoramic Survey Telescope and Rapid Response System 1 and 2 (Pan-STARRS). Together these teams have reported approximately 73 percent of all NEO observations recorded by the Minor Planet Center. To supplement these Earth-based surveys, in September 2013 NASA reactivated and reprogrammed its Wide-field Infrared Survey Explorer (WISE) telescope to search for NEOs.[20] Renamed NEOWISE, this space-based infrared telescope is particularly useful for discovering dark-colored asteroids that are extremely difficult to detect with ground-based telescopes.

- *Characterization and Cataloging*. To determine threat potential and plan any necessary mitigation efforts, scientists must characterize the composition, size, shape, and orbital properties of a NEO. For example, a NEO composed of iron is denser than one composed of rock and therefore more likely to survive the descent through Earth's atmosphere. Moreover, to plan effective mitigation efforts authorities need to know a NEO's path and likely impact site. The NEO Program provides funding to Arecibo and Goldstone to assist in the effort to characterize NEOs and the Minor Planet Center and the NEO Program Office maintain a catalog of the characteristics of specific NEOs.

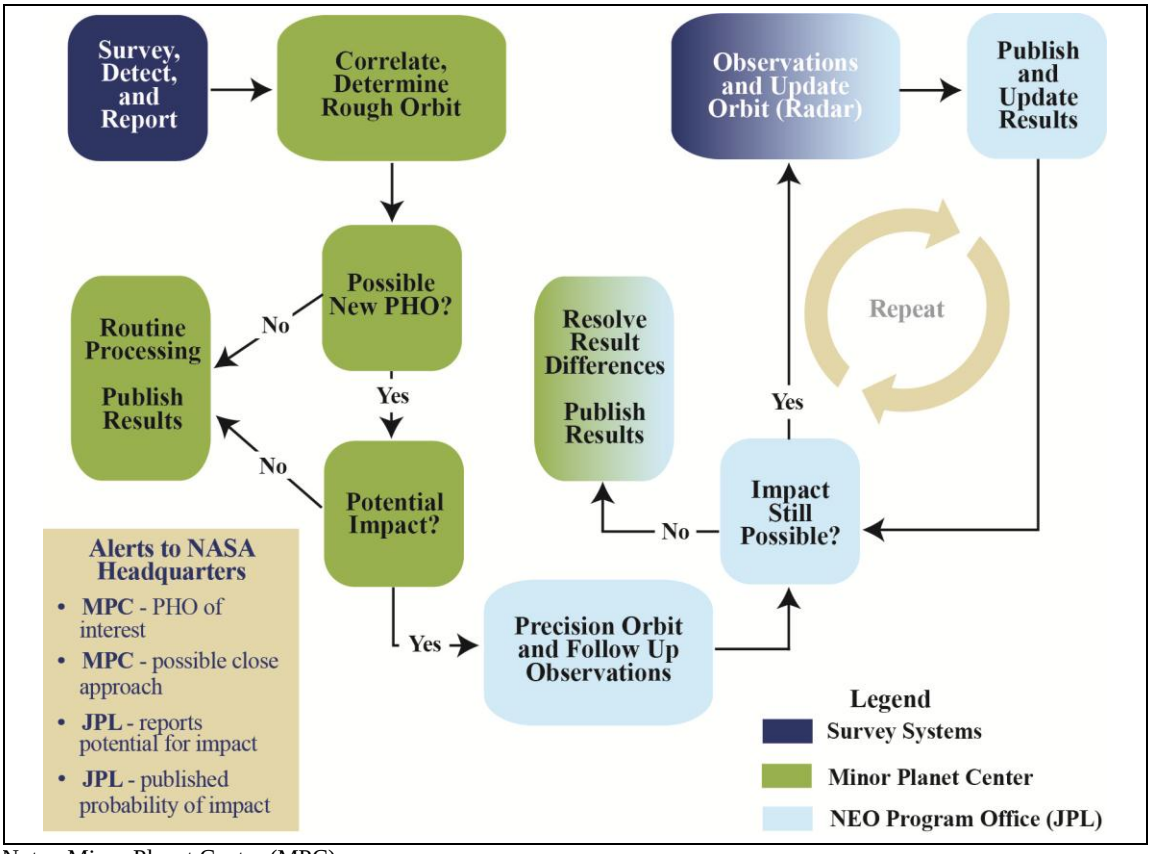
[19] In FY 2009, the NEO Program received an additional $1.9 million from the Science Mission Directorate's Planetary Research and Analysis budget.

[20] Launched in December 2009, NASA placed WISE into hibernation in February 2011 after it had completed its original mission of surveying the sky in infrared light to look for dwarf stars and undiscovered asteroids.

- *Mitigation*. Mitigation is the means of defending Earth and its inhabitants from the effects of NEO impacts. Mitigation may take the form of civil defense efforts such as emergency evacuations or efforts to deflect the trajectory of an object such as "slow-push" or "slow-pull," kinetic impact, or nuclear explosions in space.[21] The NEO Program devotes about $1 million annually or 7 percent of its overall funding to the study of mitigation strategies.

The NEO Program implemented the process illustrated in Figure 4 to meet the goal of identifying, characterizing, and mitigating NEOs of 140 meters or larger.

Figure 4. NEO Program Operation Process



Note: Minor Planet Center (MPC).

Source: NASA.

Generally, professional and amateur astronomers report their observations of possible NEOs to the Minor Planet Center, which acts as a repository for this information (see Appendix C for a list of NASA-funded and other observatories). The Center collects, catalogs, and disseminates for further analysis information about NEOs so that scientists

[21] The "slow-push" and "slow-pull" methods involve a propulsion device or other large body positioned near an object to change its orbit and avoid collision with Earth. The technique takes considerable time to implement – on the order of decades – and would only be effective for objects with diameters no larger than 100 meters. Kinetic impactors change a NEO's orbit by striking it directly at high speed. The nuclear option is the last resort because of concerns over uncontrolled fragmentation.

can characterize the objects and authorities can plan any necessary mitigation efforts. Accordingly, the Center is a critical element in NASA's NEO Program and vital to the Program's success. By comparing reported objects to a database of known orbits, the Center's automated computer system verifies and validates reported objects to determine if they represent a new discovery. In the case of a new discovery, the Center calculates and publishes an initial orbit so that observatories throughout the world can search for and confirm the object's existence. If a NEO is determined to be an unidentified PHO with a potential for impact, NEO Program Office personnel use the Sentry System, an automated collision monitoring system, to continually scan the most current asteroid catalog and conduct a more detailed and refined analysis. The Program attempts to determine the precise orbit of NEOs, publishes results of its research, and requests follow-up observations from the scientific community. Previously reported data is continually refined to determine whether a PHO has the potential to affect the Earth in the next 100 years. If the Program Office determines there is no potential for harm, it works with the Minor Planet Center to refine and reconcile any differences in orbital calculations.

An example of this process is Asteroid 2014 AA, a 2–3 meter (7–10 foot) asteroid first detected by a team at California's Catalina Sky Survey Lunar and Planetary Laboratory between 1:18 a.m. and 1:46 a.m. Eastern Standard Time on January 1, 2014. The Catalina team quickly determined a potential impact trajectory of the asteroid and reported their findings to the Minor Planet Center. The Center and the NEO Program Office each performed independent orbit calculations and correctly predicted Asteroid 2014 AA would enter the Earth's atmosphere and travel along an arc extending from Central America to East Africa, with impact most likely to occur off the coast of West Africa at approximately 9:00 p.m. Eastern Standard Time that same day.

Related NASA and Federal Government Initiatives. The NEO Program provides funding to several other related NASA projects, including the Ka-Band Objects Observation and Monitoring Project (KaBOOM), the Asteroid Terrestrial-impact Last Alert System (ATLAS), and the NEO Camera (NEOCam) infrared space telescope.[22] In addition, Program personnel contribute to NASA's Asteroid Redirect Mission and Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer Project (OSIRIS-Rex).[23] Other Federal agencies are also involved in NEO-related initiatives, including the Defense Advanced Research Projects Agency (DARPA), the NSF, and the Department of Energy. See Appendix B for more detail on these initiatives.

[22] The KaBOOM Project is an array of radar dishes that could provide tracking and characterization of NEOs at much further distances and far higher resolution than currently available. ATLAS is a NEO detection system comprised of eight ground-based telescopes. NEOCam uses heat to detect NEOs. See Appendix B for more detail on these systems.

[23] The objective of the Asteroid Redirect Mission is to identify, capture, and redirect by the first half of the next decade a small asteroid into a stable lunar orbit for further exploration. In 2016, NASA intends to launch OSIRIS-Rex to an asteroid and use a robotic arm to collect samples that could better explain our solar system's formation and how life began. Because the spacecraft will spend a significant amount of time at the asteroid – up to 2.5 years – the mission could help improve asteroid orbit predictions.

Objectives

We initiated this review to examine NASA's NEO Program and assess the Agency's progress toward meeting statutory and other Program goals. Specifically, we reviewed NASA's allocation and use of resources and plans for the Program's future. See Appendix A for details of the review's scope and methodology, our review of internal controls, and a list of prior coverage.

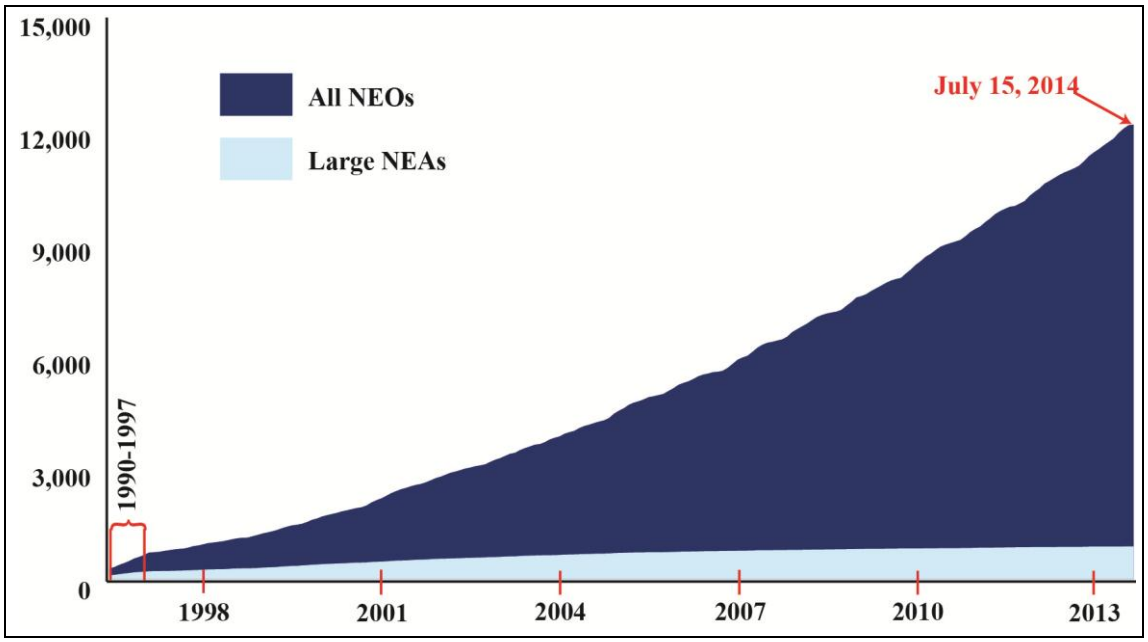
EXISTING NEO PROGRAM MANAGEMENT STRUCTURE NOT COMMENSURATE WITH INCREASED RESOURCES AND EXPANDED RESPONSIBILITIES

We found that NASA has organized its NEO Program under a single Program Executive who manages a loosely structured conglomerate of research activities that are not well integrated and lack an overarching framework with Program oversight, objectives, and established milestones to track progress. In addition, NASA is undertaking NEO-related activities not managed by the Program and not sufficiently integrated into Program activities. Furthermore, NASA lacks formal agreements or procedures for NEO-related activities it conducts with other Federal agencies and foreign governments and has not taken advantage of some partnership opportunities. Consequently, Program managers could not identify the level of resources required to support the Program adequately or explain how some activities to which the NEO Program is contributing further Program goals. Even though the Program has discovered, categorized, and plotted the orbits of more than 11,000 NEOs since 1998, NASA will fall short of meeting the 2005 Authorization Act goal of finding 90 percent of NEOs larger than 140 meters in diameter by 2020. In sum, we believe the Program would be more efficient, effective, and transparent were it organized and managed in accordance with standard NASA research program requirements.

Lack of Structure and Limited Resources Hinders the NEO Program

Since implementation of the NEO Program, the number of identified NEOs has increased dramatically from less than 500 in 1998 to over 11,000 as of July 2014, including nearly 900 objects larger than 1 kilometer in diameter (see Figure 5). Most of this work occurred while the Program was relatively small – receiving only $4 million annually from FYs 2002 through 2009 and funding less than 20 individual efforts – and focused on identifying the largest NEOs. However, with the 2005 statutory directive to identify 90 percent of NEOs larger than 140 meters, a substantially increased budget beginning in FY 2011, and additional research projects, the existing programmatic structure and resources are not sufficient to provide for efficient, effective, and transparent program management.

Figure 5. Number of Near-Earth Objects Discovered



Note: Near-Earth asteroids (NEA). Comet size is unknown; therefore, 94 known near-Earth comets are only accounted for in the total population of all NEOs.

Source: NASA.

NASA has placed overall Program responsibility in a single Program Executive at Headquarters who has no dedicated staff to assist with Program oversight. In FY 2013, the Program Executive oversaw a budget of $20.5 million and 64 funding instruments, including grants, purchase orders, and contract task orders to observatories and other facilities. More than half of these instruments exceeded $100,000, and nine involved more than $1 million in annual funding. With the Program budget growing to $40 million in FY 2014, the number of funding instruments will likely also increase, and with it the Program Executive's oversight responsibilities.

In addition to limited personnel, the NEO Program lacks a plan with integrated milestones, defined objectives, and cost and schedule estimates to assist in tracking and attaining Program goals. Although the Program Executive described the NEO Program's primary objective as finding as many asteroids as possible as quickly as possible, NASA has no structure or metric to evaluate the Program's effectiveness in reaching this objective.

Moreover, to meet the 2005 Authorization Act goal, the NEO Program provided support for ground-based telescopes with larger cameras and more sophisticated data acquisition, processing, and dissemination systems and obtained additional observation time at Pan-STARRS for detection of objects and at Arecibo for characterization. In addition, the Program funded research studies related to the mitigation of NEO hazards and supported demonstration projects such as ATLAS and the KaBOOM Project.

In addition to NEO-specific activities, the Program supports the work of other NASA initiatives, including the Asteroid Redirect Mission. NEO Program personnel also provide technical support for a Space Act Agreement with the B612 Foundation to help develop a privately funded, space-based, infrared telescope. In FY 2014, the Program also began funding the Antarctic Search for Meteorites Project (together with the NSF and the Smithsonian Institution) that sends researchers to Antarctica to collect and deliver meteorites to the Smithsonian Institution for permanent storage. Despite this increased activity, NASA has not changed or improved the NEO Program management structure and the Program has not established a plan to integrate the additional initiatives or demonstrate and track their contributions to attainment of NEO Program goals.

NASA Policy Directive (NPD) 7120.4D sets forth requirements for planning, tracking the progress of, and accomplishing mission objectives for Agency programs and projects.[24] In addition, NASA Procedural Requirements (NPR) 1080.1A requires research and technology program leads to demonstrate the relevance, quality, and performance of their program investments; demonstrate that their programs have well-conceived plans identifying goals, priorities, and linkages to national and stakeholder or beneficiary needs; and justify how funds will be allocated to ensure quality.[25] The NPR also requires programs to establish plans and processes to monitor and document performance, including appropriate outcome measures and milestones to track progress toward goals and assess whether funding needs to be increased or redirected.

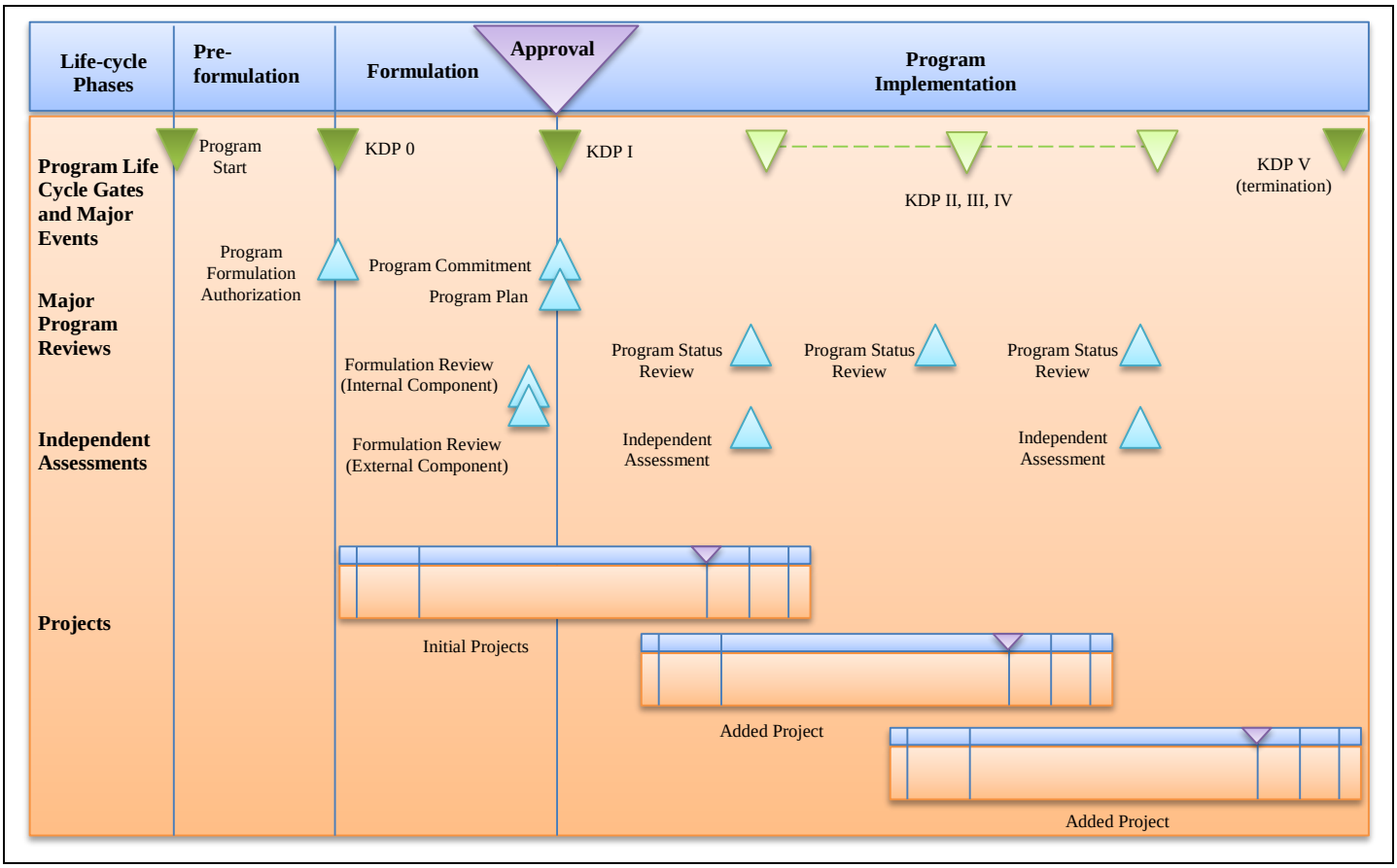
Further, to achieve technical objectives within cost and schedule constraints, NPR 7120.8 requires project leads to establish a Work Breakdown Structure, a project schedule with milestones for each element in the Structure, and an allocation of the project's available resources necessary to achieve each milestone.[26] In addition, the milestones should be set at intervals sufficient to demonstrate steady progress toward achieving overall key decision points, as shown in Figure 6.

[24] NPD 7120.4D, "NASA Engineering and Program/Project Management Policy," March 16, 2010.

[25] NPR 1080.1A, "Requirements for the Conduct of NASA Research and Technology (R&T)," May 30, 2008.

[26] NPR 7120.8, "NASA Research and Technology Program and Project Management Requirements (w/change 3 dated 04/18/13)," February 5, 2008.

Figure 6. Research and Technology Program Life Cycle



Note: Key decision point (KDP).

Source: NPR 7120.8.

Because it lacks a program plan with associated cost estimates, NASA could not identify resources required to adequately support the Program, explain how some of the efforts to which the NEO Program contributes further Program goals, or predict when statutory goals would be met. For example, the NEO Program does not have an integrated plan for how it will contribute to the development or use NEOCam, the KaBOOM radar array, or information from the OSIRIS-Rex mission. Moreover, the manner in which the developmental paths for these projects are coordinated with NEO Program requirements is not clear since there is no integrated timeline or requirement for the projects to report milestones.

We believe the NEO Program would be better equipped to manage its various funding initiatives, support related NASA initiatives, and meet Program goals if it utilized clear, concise, verifiable, and valid requirements pertaining to NEO detection, characterization, and mitigation and followed NASA's policies for research programs and projects. Without an appropriate management and staffing structure, the Program Executive is unable to evaluate needs compared to requirements and effectively communicate those needs to stakeholders.

NASA Needs to Improve its Oversight of NEO Grants and Task Orders

NASA's controls for managing and overseeing costs associated with the NEO Program are inadequate to ensure proper accounting of NASA-funded grants and task orders. Specifically, due to a lack of personnel and internal controls the Program lacks adequate segregation of duties and sufficient oversight of grants and contracts by management. In addition, the Program used grants when contracts were the more appropriate procurement vehicle, thereby reducing NASA's ability to monitor grantees' performance and deliverables.

Inadequate Segregation of Duties. We found that contrary to effective internal control standards, the NEO Program Executive is responsible for or has significant input into all the primary elements of the award process. The Science Mission Directorate Management Handbook directs the Program Executive to review proposals for compliance with solicitations, identify and select panel members to review proposals, review panel recommendations, and make a recommendation for selection to the selection official – the Planetary Science Division Director.[27] According to the Program Executive, neither the Director nor the NASA Shared Services Center have ever deviated from his award recommendations. In addition to these responsibilities, the Program Executive also serves as the Contracting Officer's Technical Representative for all NEO Program awards. In that role, the Executive oversees, monitors, and evaluates the progress of all awards. Furthermore, the Executive reviews grantees' annual progress reports and approves requests for additional funding as necessary. Although we did not find any instances, this multi-responsibility role increases the risk of error and fraud in the NEO Program.

Government Accountability Office internal control standards provide that no single individual should control all important aspects of an event and key duties and responsibilities need to be divided among different individuals to reduce the risk of error or fraud in Federal programs.[28] This includes separating responsibility for authorizing, processing, recording, and reviewing transactions, as well as handling any related assets. Furthermore, an Association of Certified Fraud Examiners study reviewing 1,843 cases of occupational fraud in the United States and more than 100 other countries involving more than $18 billion in losses found that a lack of internal controls, including failure to segregate duties, contributed to fraud in 37.8 percent of cases.[29] Accordingly, having the Program Executive perform all of the duties outlined above increases the risk of error or fraud in the NEO Program.

[27] Final awards are typically made by the NASA Shared Services Center – a partnership between NASA and a contractor that consolidates certain support functions such as financial management, human resources, information technology, and procurement.

[28] Government Accountability Office, "Standards for Internal Control in the Federal Government" (AIMD-00-21.3.1, November 1999).

[29] Association of Certified Fraud Examiners, "Report to the Nations on Occupational Fraud and Abuse: 2010 Global Fraud Study" (2010).

Inadequate Oversight and Inappropriate Use of Funding Instruments. We reviewed all awards exceeding $900,000 funded by the NEO Program during FY 2013. These six grants, three task orders (contracts), and one interagency transfer accounted for 67 percent of the NEO budget that year (see Table 2).[30]

Table 2. Summary of Reviewed Grants, Task Orders, and Interagency Transfer

Task Title	Task Organization	Award Type	FY 2013 Funding
Near Earth Object Program Office	JPL	Task Order	$1,131,936
Primitive Body Navigation	JPL	Task Order	1,061,736
NEOWISE Data Analysis	JPL	Task Order	900,000
Lincoln Near Earth Asteroid Research Program	Massachusetts Institute of Technology/Lincoln Lab	Interagency Transfer	1,220,524
Minor Planet Center Continued Operations	Smithsonian Astrophysical Observatory	Grant	1,155,869
Arecibo Radar Observations of NEO and Other Solar System Bodies	Universities Space Research Association	Grant	1,966,453
Expanded Arecibo Radar Observation of NEAs	Universities Space Research Association	Grant	1,500,000
Catalina Sky Survey: A Comprehensive Survey for Near Earth Objects	University of Arizona	Grant	1,585,049
Augmentation of Pan-STARRS for Pan-STARRS-2	University of Hawaii	Grant	1,750,000
ATLAS – Asteroid Terrestrial-impact Last Alert System	University of Hawaii Institute for Astronomy	Grant	1,373,226
Total			**$13,644,793**

Source: NASA Office of Inspector General analysis of NEO Program data.

We found NASA did not adequately oversee, monitor, or evaluate the progress of the work performed pursuant to these awards. We also found three of the instruments issued as grants should have been contracts.

In July 2013, the NEO Program Executive awarded the LINEAR Program a $6.5 million, 5-year grant via an interagency transfer in spite of a steep decline in the Program's ability to provide detection and follow-up observations. According to the LINEAR Principal Investigator, this decline relates to the decommissioning of the Program's primary telescope, which was becoming increasingly ineffective in detecting smaller objects. The NEO Program Executive stated that the grant is also funding testing of a new Space Surveillance Telescope (SST) designed and operated by DARPA.[31] However, the SST will transfer to Australia in 2015 and there is no official agreement with DARPA or

[30] Interagency transfer is the transfer of funds from one Federal agency to another for the purpose of conducting research.

[31] The SST is primarily intended to detect and track small objects in geosynchronous orbit, approximately 22,000 miles above Earth.

Australia for the NEO Program to use the telescope after the transfer. Without such an agreement, it is uncertain what if any benefits the NEO Program will receive from this grant going forward.

In another example, in 2012 NASA awarded a 5-year, $6.3 million grant to the Harvard-Smithsonian Center for Astrophysics to operate the Minor Planet Center. The Minor Planet Center Director told us that the Director of the Center for Astrophysics did not provide sufficient institutional support and infrastructure, citing the lack of an emergency generator and sufficient uninterruptable power supplies to allow for continued operations during a power outage or for routine maintenance. However, we found that the grant had limited requirements with respect to the grantee's roles and responsibilities, and as a result the Program Executive was not in a position to remedy these issues.

We also identified three instances in which the Program Executive awarded grants when contracts would have been the more appropriate instrument for achieving Program goals. Specifically, in October 2011 and September 2013 NASA awarded grants worth more than $10 million and $6 million, respectively, to the Universities Space Research Association for Program costs, operations, and maintenance of Arecibo. In January 2013, NASA awarded a 5-year, $5 million grant to the University of Hawaii System for construction and operational costs related to ATLAS. When we asked the Program Executive about these grants, he noted the difficulty of going through the formal procurement process required for contracts given his lack of staff support.

Under Federal law, the Government may use a grant to "carry out a public purpose of support or stimulation," and NASA often issues grants to obtain research related to its science and space activities.[32] While grants offer greater flexibility and reduced administrative burden to the Government, they also provide less certainty in terms of performance and deliverables. In contrast, contracts provide greater visibility into awardees operations and ensure the level of funding and performance is commensurate with requirements and deliverables and when the purpose is to acquire property or services for the Government.[33]

Although part of the awards to Arecibo and ATLAS supported research, the majority of the funds were directed to facility construction, operations, and maintenance. During review of the Arecibo proposal, NASA Headquarters Office of Procurement and the Goddard Space Flight Center's Office of Chief Counsel informed the Program Executive that a contract was the more appropriate procurement instrument. In May 2012, the Program Executive received contradictory advice from the NASA Headquarters Office of General Counsel that stated, "…there is a basis to keep it a grant. In fact, it would be unnecessary and counterproductive to shift to a contract mechanism," and "…because NASA is supplementing support of a federal activity that is primarily funded and managed by NSF [National Science Foundation], which has chosen a grant mechanism."

[32] 31 U.S.C. § 6304, "Using Grant Agreements."

[33] 31 U.S.C. § 6303, "Using Procurement Contracts."

However, in October 2011 the NSF did not use a grant, but awarded a 5-year, $42 million cooperative agreement to the Stanford Research Institute to manage, operate, and maintain the Arecibo Observatory. In our judgment, using contracts in these instances would have benefitted the Program and provided greater visibility into Arecibo's operations as well as provide assurance that the level of funding and performance was commensurate with contractual requirements. Moreover, given that funding for the NEO Program has grown ten-fold since 2009, we believe the Program needs more personnel to ensure proper oversight of associated research and procurement awards. The Program Executive agreed, suggesting the Program requires a minimum of four to six full-time equivalent positions to be fully effective.[34]

Lack of Formal Agreements with International and Federal Partners Hampers NASA's Ability to Accomplish Program Goals

Pursuant to Presidential Policy Directive, NASA is required to "[p]ursue capabilities, in cooperation with other departments, agencies, and commercial partners, to detect, track, catalog, and characterize near-Earth objects to reduce the risk of harm to humans from an unexpected impact…."[35] Although NASA has established two formal partnerships related to NEOs, lack of planning and resources has prevented the NEO Program from developing additional partnerships that could help achieve Program goals. Moreover, the NEO Program has not taken advantage of existing knowledge within NASA regarding forming partnerships. Expanded partnerships could increase the number of NEOs discovered, aid in development of mitigation strategies, and help ensure the burden of mitigating NEO threats does not fall disproportionately on NASA and the United States.

Existing Partnerships. Partnerships are an increasingly important component of NASA's overall mission strategy. With regard to NEOs, NASA has established formal partnerships with two organizations – the B612 Foundation and Planetary Resources. Through these partnerships, NASA supported development of a privately funded, space-based, infrared telescope by the B612 Foundation and an effort by Planetary Resources to create a crowdsourcing algorithm related to NEO survey work.

In addition to these formal partnerships, NASA has also entered into a number of informal international partnerships. For example, the NEO Program is a leading participant in the United Nations Committee on the Peaceful Uses of Outer Space. Over the past several years, a working group of the Committee's Scientific and Technical Subcommittee has studied NEOs and recently made recommendations to broaden and strengthen international cooperation and collaboration and called for national space

[34] Full-time equivalent refers to the number of hours worked that add up to one full-time employee working an 8-hour day, 5 days a week for 52 weeks.

[35] Presidential Policy Directive 4, "National Space Policy of the United States of America," June 28, 2010.

agencies to form a group focused on designing a set of standard, agreed upon missions for deflecting NEOs.[36]

NEO Program initiatives have also resulted in informal partnerships. For example, the Catalina and Pan-STARRS observatories have taken first steps towards coordinating their survey efforts to ensure they are not duplicating efforts. In our judgment, the NEO Program Executive should replicate this model and establish a systematic process to improve observational efficiency and telescope utilization among international entities, intergovernmental organizations, and Program participants.

The NEO Program Could Leverage Agency Experience to Form Partnerships. A number of NASA programs and offices, including the International Space Station Program, NASA's Office of International and Interagency Relations, and the Office of the Chief Technologist, have formal agreements or help promote partnerships with international and domestic partners regarding various aspects of their goals and respective missions. The NEO Program may be able to leverage the knowledge of these organizations to establish agreements of its own. For example, NASA established the Global Exploration Roadmap with foreign space agency members of the International Space Exploration Coordination Group.[37] One of the Global Exploration Roadmap's goals is "Enhancing Earth Safety" by contributing to the "collaborative pursuit of planetary defense and orbital debris management mechanisms." Citing the NEO Program as one of NASA's efforts in fulfilling this goal could create opportunities for partnerships between member countries and maximize access to and development of technology as well as augment mitigation investments.

Partnerships Could Expand Access to Technological Assets and Spread the Burden of Detection and Mitigation. The 2005 Authorization Act directed NASA to detect NEOs and develop mitigation strategies to determine how to alter the path of or destroy PHOs. However, NASA's lack of NEO Program partnerships and insufficient staff to pursue such partnerships limits the Nation's ability to discover NEOs and weakens the Agency's ability to plan for effective mitigation. For example, establishing formal partnerships with the Department of Defense and the NSF could give the NEO Program access to additional Earth-based telescopes, thereby enhancing sky-viewing capabilities and the ability to detect, track, and characterize a greater number of NEOs and PHOs and increasing the Program's ability to plan for and implement effective mitigation strategies. Although, the NEO Program Executive told us he has had informal discussions with these agencies regarding use of their telescopes, we believe the Program Executive should leverage NASA's Office of International and Interagency Relations and the Office of Chief Technologist to expedite formation of agreements.

[36] United Nations Committee on the Peaceful Uses of Outer Space, *Report of the Scientific and Technical Subcommittee on its fifty-first session, held in Vienna from 10 to 21 February 2014* (Vienna: United Nations, 2014), available from http://www.oosa.unvienna.org/pdf/reports/ac105/AC105_1065E.pdf (last accessed July 28, 2014).

[37] The International Space Exploration Coordination Group is comprised of 14 space agencies with the goal to advance a long-range human space exploration strategy.

The NEO Program lacks a plan for establishing agreements with domestic and foreign entities to leverage capabilities or mitigate NEO threats and has not developed milestones to measure progress toward established goals. Due to the variety of possible sizes, trajectories, and warning times for PHOs, developing an appropriate mitigation response is extremely challenging. For example, PHOs larger than a few hundred meters in diameter would require enormous energies to deflect or fragment, as well as cooperation on the part of multiple nations. Although NEO Program managers stated they would alert the Federal Emergency Management Agency in the event of an impending PHO threat to the United States or the Department of State if predicted impact was outside the United States, there is no interagency agreement or formal procedure between the NEO Program and either agency, or with the Department of Defense and Department of Energy in the event a nuclear option is required.

NEO Program management told us that if given the opportunity, they would like to form partnerships with the Russian and the European space agencies. The Russian Space Agency is considering forming a separate agency to monitor NEOs and the European Space Agency is building a 1-meter telescope intended to cover the entire sky every few nights to search for NEOs. Other countries have similar initiatives in planning or development.

Recommendations, Management's Response, and Evaluation of Management's Response

To improve NASA's efforts to discover, characterize, and mitigate NEO threats, we recommended the Associate Administrator for the Science Mission Directorate:

Recommendation 1. Develop a formal NEO Program in accordance with NASA policies that includes a strategic plan to obtain statutory and programmatic goals, integrated master schedule, and cost estimates.

Management's Response. The Associate Administrator concurred and agreed that managing the Program in accordance with NASA policies will maximize results and may reduce costs. The Associate Administrator expects the new Program plan will be in place by September 1, 2015.

Evaluation of Management's Response. Management's comments are responsive; therefore, the recommendation is resolved and will be closed upon verification and completion of the proposed corrective actions.

In addition, we recommended the Associate Administrator direct the NEO Program Executive to:

Recommendation 2. Develop and implement requirements, procedures, and internal controls to address program deficiencies.

Management's Response. The Associate Administrator concurred and expects to develop requirements, procedures, and internal controls consistent with Agency policy by March 1, 2015.

Evaluation of Management's Response. Management's comments are responsive; therefore, the recommendation is resolved and will be closed upon verification and completion of the proposed corrective actions.

Recommendation 3. Perform a full-time equivalent analysis to determine the appropriate number of staff needed to manage, oversee, and administer the Program and associated funding instruments.

Management's Response. The Associate Administrator concurred, stating that a full-time equivalent analysis will be conducted by March 1, 2015.

Evaluation of Management's Response. Management's comments are responsive; therefore, the recommendation is resolved and will be closed upon verification and completion of the proposed corrective actions.

Recommendation 4. Develop a plan to establish formal, documented partnerships with domestic and international agencies to leverage resources and complementary technologies.

Management's Response. The Associate Administrator concurred, stating that the Program is on the proper course to establish the appropriate domestic and international partnerships and that a plan to establish formal, documented partnerships with domestic and international agencies will be developed by September 1, 2015.

Evaluation of Management's Response. Management's comments are responsive; therefore, the recommendation is resolved and will be closed upon verification and completion of the proposed corrective actions.

Recommendation 5. Establish a systematic oversight process pursuant to which NASA-funded observatories are required to coordinate with each other in order to avoid duplication of efforts.

Management's Response. The Associate Administrator concurred, stating the Program has already taken steps to ensure project activities are coordinated and will continue to do so. He also stated that a strategy for coordination of activities will be documented in the NEO Program Plan by September 1, 2015.

Evaluation of Management's Response. Management's comments are responsive; therefore, the recommendation is resolved and will be closed upon verification and completion of the proposed corrective actions.

APPENDIX A

Scope and Methodology

We performed this audit from September 2013 through August 2014 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

We reviewed research and technology program requirements, grant and cooperative agreement requirements contained in the following NASA policies, as well as Center-specific policies that corresponded with NASA guidance, and public laws:

- National Aeronautics and Space Act, Pub. L No. 111–314, December 18, 2010.
- NPD 1080.1B, "Policy for the Conduct of NASA Research and Technology (R&T)," July 9, 2008.
- NPD 7120.4D, "NASA Engineering and Program/Project Management Policy," March 16, 2010.
- NPR 7120.8, "NASA Research and Technology Program and Project Management Requirements, (w/change 3 dated 04/18/13)," February 5, 2008.
- NPR 1080.1A, "Requirements for the Conduct of NASA Research and Technology (R&T)," May 30, 2008.
- NPR 9680.1A, "NASA Financial Management of Grant and Cooperative Agreements," November 10, 2011.
- Headquarters Science Mission Directorate (SMD) Handbook, February 8, 2008.
- Pub. L. No. 109–155, Subtitle C – George E. Brown, Jr., Near Earth Objects Survey Act, December 30, 2005.
- House of Representatives 6063, National Aeronautics and Space Administration Authorization Act of 2008 (Enrolled as Agreed to or Passed by Both House and Senate), Title VIII – Near Earth Objects, Section 801, "Reaffirmation of Policy."
- 31 U.S.C. § 6303, "Using Procurement Contracts."
- 31 U.S.C. § 6304, "Using Grant Agreements."
- 14 C.F.R. § 1260.13, Section A, "Grants and Cooperative Agreements."

We reviewed internal control requirements contained in the Government Accountability Office's "Standards for Internal Controls in the Federal Government," November 1999, and Office of Management and Budget Circular A-123, "Management Responsibility for Internal Controls," December 21, 2004.

To determine whether the NEO Program devised an effective strategy to meet the findings and recommendations of the NRC, we interviewed NASA personnel, scientists, and astrophysicists about their roles and responsibilities. We assessed the NEO Program oversight procedures to determine whether oversight reviews were conducted as required. We also conducted fieldwork at the Minor Planet Center in Cambridge, Massachusetts, the Catalina Sky Survey in Arizona, and the KaBOOM Project at Kennedy Space Center. Further, we attended two conferences:

- Small Bodies Assessment Group, Washington, DC, January 2014
- International Asteroid Warning Network hosted by the Minor Planet Center, January 2014

To assess whether funding and resources were adequately allocated, we judgmentally selected for review 10 funding instruments that exceeded $900,000, which included 6 grants, 3 task orders, and 1 interagency transfer.

To determine whether the NEO Program's monitoring systems were adequately maintained and updated and that the data was effectively processed, communicated, and tracked, we reviewed the Minor Planet Center and JPL systems and databases.

To assess NEO Program mitigation and partnership strategies, we interviewed scientists receiving NEO grants to determine whether any plans for mitigation existed and any agreements executed to form partnerships within the Federal Government or with international partners.

Use of Computer-Processed Data. We used data from the Research and Analysis Program Tracking of Resources system to perform this audit.[38] Although we did not test the general or application controls of the system, we did compare the information in the key data fields with our sample of funding instruments and supporting documents for the data and determined that the data was valid and reliable to support our objectives and conclusions.

[38] The Research and Analysis Program Tracking of Resources system is a Science Mission Directorate web-based tool for tracking approved investigations and specifying the award funding vehicles and amounts.

Review of Internal Controls

We performed an assessment of the internal controls associated with NASA's NEO Programs. Throughout the audit we reviewed controls associated with the audit objectives and determined that NASA's internal controls and program oversight were inadequate to ensure proper segregation of duties and oversight and monitoring of NEO funding instruments.

Prior Coverage

During the past 5 years, the NASA Office of Inspector General (OIG) and the Government Accountability Office have not issued any reports of particular relevance to the subject of this report. However, we issued NASA OIG, "NASA's Grant Administration and Management" (IG-11-026, September 12, 2011), which identified systemic deficiencies in the administration and management of NASA's grant program. We also relied on NASA OIG, "Federal Information Security Management Act: Fiscal Year 2013 Evaluation" (IG-14-004, November 13, 2013), to review systems and databases at JPL. Unrestricted reports can be accessed over the Internet at http://oig.nasa.gov/audits/reports/FY14.

NEO PROGRAM ASSETS AND RELATED INITIATIVES

The NEO Program operations consist of detection and notification, characterization and cataloging, and mitigation.

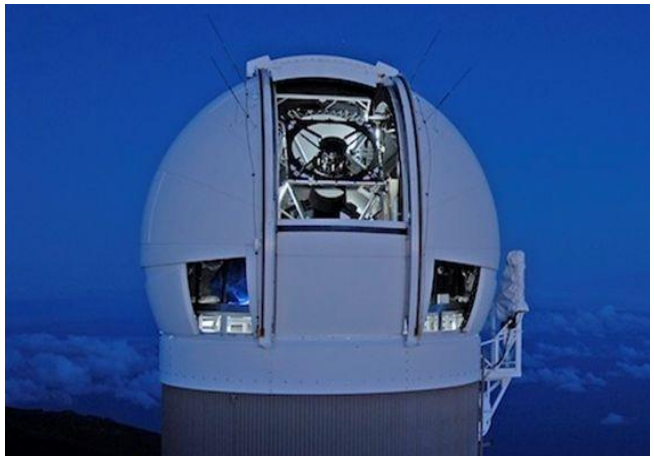
Detection and Notification. The NEO Program provides funds to three survey teams that operate five ground-based telescopes to detect NEOs. The majority (73 percent) of the observations reported to the Minor Planet Center come from three survey teams:

- The *Catalina Sky Survey (Catalina)*, including the Mount Lemmon Survey and the Siding Spring Survey, is based at the University of Arizona. A successful discovery program due to its comprehensive sky coverage and on site follow-up observation capabilities, in 2013, Catalina discovered more than 600 NEOs. Catalina observation time is split between detection and follow-up with approximately 20 percent devoted to post-discovery, follow-up observations that allow computation of an object's orbit.

- The *Lincoln Near-Earth Asteroid Research (LINEAR)* program at White Sands, New Mexico, is run by the Massachusetts Institute of Technology and leads in the discovery of NEOs larger than 1 kilometer. LINEAR uses electro-optical sensor technology developed for U.S. Air Force space surveillance applications to discover NEOs and is largely responsible for NASA successfully meeting the goal of finding 90 percent of the 1-kilometer and larger NEOs. LINEAR is fully dedicated to the NEO Program and schedules 20 to 25 nights per month for observations.

- The *Panoramic Survey Telescope and Rapid Response System 1 and 2 (Pan-STARRS)* discovery telescope, run by the University of Hawaii's Institute for Astronomy, is a 1.8-meter telescope with a wide field of view and incorporating a very large camera on Haleakala in Maui, Hawaii (see Figure 7). The NEO Program funds approximately 11 percent of its total available observation time.

Figure 7. Pan-STARRS



Source: Institute for Astronomy, University of Hawaii. Photo by Rob Ratkowski.

To supplement the three Earth-based surveys, in September 2013, NASA reactivated and reprogrammed the Wide-field Infrared Survey Explorer (WISE) telescope to search for NEOs.[39] The telescope – renamed NEOWISE – is a space-based infrared telescope that can detect the ambient heat from asteroids. It is particularly useful for discovering dark colored asteroids that are extremely difficult to detect with ground-based conventional telescopes.

Characterization and Cataloging. The interaction of radar signals with the surface of a NEO yields information about its physical characteristics, such as the NEO's size, shape, rotation characteristics, and whether it has any moons. For example, radar observations can be used to estimate the roughness of the top layer of a NEO's surface, which could distinguish between stony and metallic compositions and may be used to estimate the porosity of a NEO's surface and help in understanding its composition for developing mitigation strategies.[40]

The NEO Program provides funding to two radar systems:

- *Goldstone Solar System Radar (Goldstone)*, located in the Mojave Desert in Southern California, is part of NASA's Deep Space Network and is operated by JPL under contract with NASA (see Figure 8). Comprised of a fully steerable 70-meter-diameter antenna, this radar has a significant capability for observing NEOs in 80 percent of the sky north of -35° latitude over the course of a day. The Goldstone antenna's primary mission is spacecraft communications and therefore is available for astronomy observations only a few percent of its time.

Figure 8. Goldstone 70-meter Telescope

Source: NASA.

- *The Arecibo Observatory (Arecibo)* in Puerto Rico is part of the National Astronomy and Ionosphere Center, a national research center operated by the Stanford Research Institute under a cooperative agreement with NSF. NASA provides additional support through grants with Universities Space Research Association. Its chief feature is a fixed 305-meter-diameter spherical antenna that allows coverage directly overhead. Observing time at Arecibo is awarded on a competitive basis from proposals that

[39] WISE launched in December 2009 and was placed in hibernation in February 2011 after completing its mission of surveying the sky in infrared light and discovering dwarf stars and new asteroids.

[40] Porosity is the ratio of the volume of space to the total volume of a rock.

are normally submitted quarterly. Arecibo is also available for "urgent" target-of-opportunity observations on short notice and, in a small number of instances, has been used for radar observations of NEOs within 24 hours of their discovery.

Mitigation. The NEO Program allocated about $1 million per year to study mitigation strategies, such as:

- NEO Observations Program Mitigation Effects grant, which is a comprehensive study of impact and explosion mitigation technologies for threatening asteroids;
- NASA Innovative Advanced Concepts Program, which studies entirely new or radically different mitigation strategies from American innovators and entrepreneurs; and
- Kinetic Impactor Demonstration Mission Studies, which include a mission concept for the use of two independent spacecraft, one impactor and one rendezvous probe, where the rendezvous probe would observe the impact of an asteroid and measure any change in the asteroids relative orbit.

Other Related NASA and Federal Government NEO Initiatives

The KaBOOM Project is a capability demonstration project at Kennedy Space Center (see Figure 9). KaBOOM technology would be complimentary to other radar technologies by providing tracking and characterization at Ka-band frequencies for NEOs at much further distances and far higher resolution than currently available. Compared to NASA's Goldstone 70-meter antenna, which can track an object that is about 9 million miles away (in X-band frequencies) using an array of multiple radar dishes, KaBOOM may be able to track objects 47 million miles or more away – potentially providing more time for a mitigation strategy to be developed in the event of a PHO threat. However, Project managers stated development of the technology and system would take approximately 7–8 years before it would be ready to deploy in a 24/7 operational radar array.

Figure 9. KaBOOM Radar Array

Source: NASA.

The Asteroid Terrestrial-impact Last Alert System (ATLAS) is being developed by the University of Hawaii and intended to be operational in 2016. The array of eight telescopes is designed to offer a 1-week warning for a 50-yard-diameter asteroid, or "city killer," and 3 weeks for a 150-yard-diameter "county killer," which provides sufficient

time to evacuate the area, take measures to protect buildings and other infrastructure, and be alert to a tsunami danger generated by ocean impacts.

The NEO Camera (NEOCam) is a wide-field camera operating at thermal infrared wavelengths being developed at JPL and intended to be integrated onto a space-based telescope for the purpose of improving NEO detection capabilities. NEOcam is intended to be launched to a position about four times the distance between Earth and the moon, where it could observe NEOs without the impediments of cloud cover or daylight. However, there is presently no funding available to design and manufacture a spacecraft to carry the NEOCam payload.

The Asteroid Redirect Mission that is being developed by NASA's Human Exploration and Operations Mission Directorate aims to fulfill the President's call to send astronauts to a near-Earth asteroid by 2025. The mission objective is to identify, capture, redirect, and sample an asteroid with a mass of up to about 1,000 tons into a stable lunar orbit by the first half of the next decade. NASA has stated that the mission would provide invaluable new data on the threats asteroids pose to Earth and how they could be mitigated.

The Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer (OSIRIS-Rex) mission, planned for launch in 2016, is designed to rendezvous with an asteroid and use a robotic arm to collect samples that could better explain our solar system's formation and how life began. The mission will be the first U.S. mission to carry samples from an asteroid back to Earth. Because the spacecraft will spend a significant amount of time at the asteroid – up to 2.5 years – the mission could help improve asteroid orbit predictions.

The Defense Advanced Research Projects Agency's Space Surveillance Telescope (SST) is a 3.5-meter telescope located within the White Sands Missile Range in New Mexico designed to enhance the nation's deep space and small object surveillance capabilities. SST could improve the ability to determine the orbits of newly discovered objects and provide rapid observations of transient events and improvements in orbital prediction. NASA is testing the capability of SST and seeking to incorporate SST asteroid detections into the NEO Program.

The Large Synoptic Survey Telescope (LSST), funding for which is provided by NSF, the Department of Energy, and private organizations, is being designed to produce a wide-field astronomical survey of our universe using an 8.4-meter ground-based telescope in Chile. From its mountaintop position, LSST will image the entire visible sky every few nights, thus capturing changes that could enable the detection of smaller NEOs. The LSST system is the only proposed astronomical facility that can detect 140-meter objects in the main asteroid belt in less than a minute. However, the LSST is currently in its design and development phase and full science operations will not begin until approximately 2020.

SUMMARY OF OBSERVATORY STATISTICS

Summary of Top 20 Observatory Statistics for October 2013

Observatory Site	NEOs Observed	NASA Funded
Astronomical Research Observatory, Westfield, Illinois	237	Yes
Mt. Lemmon Survey, Tucson, Arizona	201	Yes
Catalina Sky Survey, Tucson, Arizona	184	Yes
Lunar Planetary Laboratory/Spacewatch II, Tucson, Arizona	149	Yes
Tenagra II Observatory, Nogales, Arizona	143	No
Pan-STARRS 1, Haleakala, Hawaii	106	Yes
Cerro Tololo Observatory, La Serena, Chile	86	Yes
Desert Moon Observatory, Las Cruces, New Mexico	71	No
Southern Observatory for NEAs Research Observatory, Oliveira, Brazil	66	No
Purple Mountain Observatory, XuYi Station, China	41	No
Steward Observatory, Kitt Peak-Spacewatch, Tucson, Arizona	32	Yes
Palomar Mountain, Palomar Mountain, California	29	No
Klet Observatory, Czech Republic	25	No
Arkansas Sky Observatory, Petit Jean Mountain South, Morrilton, Arkansas	22	No
McDonald Observatory-Las Cumbres Observatory Global Telescope, Goleta, California	15	Yes
International Scientific Optical Network-New Mexico Observatory, Mayhill, New Mexio	14	No
International Scientific Optical Network-Kislovodsk Observatory, Russia	12	No
Volkssternwarte Drebach, Schoenbrunn, Germany	12	No
University of Szeged, Piszkesteto Stn. (Konkoly), Hungary	7	No
Mobile Astronomical System of the Telescope-Robots-II Observatory, Tunka, Russia	4	No

MANAGEMENT COMMENTS

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

SEP 11 2014

Reply to Attn of: Science Mission Directorate

TO: Assistant Inspector General for Audits

FROM: Associate Administrator for Science Mission Directorate

SUBJECT: Response to OIG Draft Report "NASA's Efforts to Identify Near-Earth Objects and Mitigate Hazard" (Assignment A-13-016-00)

The Science Mission Directorate (SMD) appreciates the opportunity to review your draft report entitled "NASA's Efforts to Identify Near-Earth Objects and Mitigate Hazard" (Assignment A-13-016-00), dated August 14, 2014.

In the report, the Office of Inspector General (OIG) makes five recommendations intended to improve NASA's efforts to discover, characterize, and mitigate near-Earth orbit (NEO) threats. NASA's response to the OIG's recommendations outlined in the report, including planned corrective actions, follows.

To improve NASA's efforts to discover, characterize, and mitigate NEO threats, the OIG recommends that the Associate Administrator for the Science Mission Directorate (SMD):

Recommendation 1: Develop a formal NEO Program in accordance with NASA policies that includes a strategic plan to obtain statutory and programmatic goals, integrated master schedule, and cost estimates.

Management's Response: SMD concurs with this recommendation. The assets currently used, as well as additional capabilities needed, to detect, track, and characterize the hazardous NEO population can best be described as a loosely coupled system of systems that are managed, designed, and operated by a variety of science institutions and personnel – almost all within a scientific research background and setting. These elements operate at or very near the forefront of our scientific understanding of these smallest constituents of our solar system and the engineering of the systems is likewise at the edge. We agree that the proposed approach to manage this effort, in accordance with NPR 7120.8, NASA Research and Technology Program and Project Management Requirements, will maximize the results and offer the potential to reduce contractual costs while providing the flexibility to maintain individually customized research approaches under over-arching strategies established at a program level.

Estimated Completion Date: The new program will be established by September 1, 2015.

The OIG also recommends that the Associate Administrator for SMD should direct the NEO Program Executive to:

Recommendation 2: Develop and implement requirements, procedures, and internal controls to address program deficiencies.

Management's Response: SMD concurs with establishing a program that follows the Agency's requirements, procedures, and internal controls in exercising the Agency's fiduciary responsibilities and firmly believes that the NEO Observations projects that are currently funded already follow NASA's standard procedures for awarding research grants and contracts, with multiple levels of review and independent internal controls in the award and funding of our research activities.

Estimated Completion Date: Requirements, procedures, and internal controls for the new program will be identified by March 1, 2015.

Recommendation 3: Perform a full-time equivalent (FTE) analysis to determine the appropriate number of staff needed to manage, oversee, and administer the Program and associated funding instruments.

Management's Response: SMD concurs with this recommendation.

Estimated Completion Date: An FTE analysis will be conducted by March 1, 2015 and incorporated into plans for the program.

Recommendation 4: Develop a plan to establish formal, documented partnerships with domestic and international agencies to leverage resources and complementary technologies.

Management's Response: SMD concurs with this recommendation, and it will be incorporated into the NEO Program Plan. It is our view that the program is on the proper course to establish both the appropriate domestic and international partnerships. While NEO activities are very new to our potential partners, there have been considerable efforts within U.S. Government interagency working groups, and international coordination efforts within the constructs of the United Nations Committee On Peaceful Uses of Outer Space Working Group on NEOs are highly documented, all of which are worked in coordination with the NASA Office of Interagency and International Relations.

Estimated Completion Date: This plan will be developed by September 1, 2015.

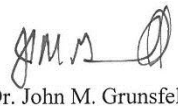
Recommendation 5: Establish a systematic oversight process pursuant to which NASA-funded observatories are required to coordinate with each other in order to avoid duplication of effort.

Management's Response: SMD concurs with the intent of this recommendation. As noted in the audit report, SMD has already taken steps to ensure project activities are coordinated and will continue to do so in the future. Strategy for coordination of activities will be documented in the program plan. This is not the same as coordinating nightly observations of survey teams, where we believe the existing competitive environment across all of our assets is maximizing the identification of new NEOs through continuous improvement for increased sky coverage, improved detection limits, moving object algorithms and astrometric accuracy.

Estimated Completion Date: This oversight process will be in place by September 1, 2015, when the new program is established.

At the request of the OIG, we have reviewed the draft report for information that we believe should not be publicly released and have not identified any concerns in this regard.

Again, thank you for the opportunity to review and comment on the subject draft report. If you have any questions or require additional information regarding this response, please contact Peter Meister at (202) 358-1557.



Dr. John M. Grunsfeld

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