U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON SPACE AND AERONAUTICS

Near-Earth Objects (NEOs)—
Status of the Survey Program and Review of NASA's
2007 Report to Congress

Thursday, November 8, 2007
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

Purpose

On Thursday, November 8, 2007 at 10:00 a.m., the House Committee on Science and Technology's Subcommittee on Space and Aeronautics will hold a hearing to examine the status of NASA's Near-Earth Object survey program, review the findings and recommendations of NASA's report to Congress, *Near-Earth Object Survey and Deflection Analysis of Alternatives,* and to assess NASA's plans for complying with the requirements of Section 321 of the NASA Authorization Act of 2005.

Witnesses

Panel 1

- The Honorable Luis G. Fortuño, Resident Commissioner, Puerto Rico

Panel 2

- Dr. James Green, Science Mission Directorate, NASA
- Dr. Scott Pace, Program Analysis and Evaluation, NASA
- Dr. Donald K.Yeomans, Jet Propulsion Laboratory
- Dr. Donald B.Campbell, Cornell University
- Dr. J. Anthony Tyson, University of California, Davis
- Mr. Russell "Rusty" Schweickart, B612 Foundation

Potential Issues

- ***What is the current status of NASA's Near-Earth Object (NEO) search program, and how urgent is the need to move ahead with the expanded search that was directed in the 2005 NASA Authorization Act? Is the timeline for achieving the goal appropriate or would changes in the "deadline" provide benefits in terms of technical approaches or costs?***

- ***What are the most important priorities to address relative to detecting, characterizing, and developing the means to deflect NEOs?***

- ***NASA submitted a 2007 report to Congress on NEO search and deflection options, but the report doesn't provide a recommended option, as required in the 2005 NASA Authorization Act. What approach does NASA recommend for complying with the legislated mandate and what steps has NASA taken to begin implementing any of the options identified in the report?***

- ***NASA's report to Congress mentions search options that would rely on planned ground-based telescopes that have been proposed for development under the auspices of other agencies. What role, if any, should NASA play in supporting the NEO-related operations of those telescopes? What alternatives exist if those assets are not funded and developed?***

- ***Planetary radar facilities have been cited as critical for providing more precise orbital determinations of potentially hazardous NEOs. However, the two radar facilities currently being used to obtain data on NEOs [Arecibo and Goldstone] may not be available in the future. What are the implications should existing planetary radar facilities become unavailable?***

- ***A NEO object, Apophis, has been identified and could pass as close as 23,100 kilometers from the Earth's surface in 2029 and return again for a close approach in 2036. What threat does this object pose in terms of a potential impact with Earth, and what is needed to improve our understanding of the threat?***

- ***How much time would be required to prepare a mitigation approach if a hazardous object were discovered to be on a collision course with Earth? How much time would likely be available?***

- ***How well understood are the potential approaches to deflecting asteroids? What is the confidence level in the technologies that would be required? What information is needed to assess the various approaches, and how will decisions be made on which mitigation strategy to take?***

- ***What is the degree of international involvement in searching for, characterizing, and studying deflection options for NEOs? What steps, if any, has NASA taken on potential collaboration or coordination of NEO-related initiatives?***

- ***How will policy and legal issues involved in addressing NEOs—e.g., when and how to warn the public and whether to use nuclear explosives to deflect an asteroid—be handled on national and international levels? What steps have NASA and other federal agencies taken to date to address such issues?***

Background

Astronomers estimate that millions of asteroids, comets, meteoroids, and other cosmic debris orbit within the vicinity of Earth and the Sun. The Earth is continually bombarded by these remnants from the formation of the solar system. Small objects ranging from the size of a dust particle up to a size of about 50 meters in diameter do not pose impact threats to Earth, because they burn up and disintegrate upon entry to the Earth's atmosphere. However, larger objects pose potentially catastrophic threats because they would not disintegrate before impacting the Earth. Near-Earth Objects (NEOs) are defined as asteroids and comets whose trajectories bring them within 45 million kilometers (km) of the Earth. NEOs larger than about 140 meters, whose orbits about the Sun bring them within 7.5 million km of the Earth's orbit, are classified as potentially hazardous objects (PHOs). Most of these objects are asteroids. According to NASA, there are currently 900 known Potentially Hazardous Asteroids (PHAs). NASA scientists estimate that the population of PHOs is about 20,000 objects.

The literature on NEOs is not entirely consistent on the threats posed by various sizes of objects. Information from NASA's Near Earth Object Program webpage [http://neo.jpl.nasa.gov] and other sources indicates the following:

- Objects larger than 50 meters can survive entry through the Earth's atmosphere, and could cause local disasters or events such as tsunamis upon impact. Estimates of the frequency of impacts of objects of this size range from once every 100 years to once every 500 years.

- Objects larger than 1 km in diameter that impact Earth would cause disasters on a global scale, and *"the impact debris would spread throughout the Earth's atmosphere so that plant life would suffer from acid rain, partial blocking of sunlight, and from the firestorms resulting from heated impact debris raining back down upon the Earth's surface."* Estimates of the frequency of these range from once every few hundred thousand years to once every million years.

- "Extinction-class" objects (10 km or greater in size) are estimated to occur on average once every 50 million to 100 million years.

Past NEO Impacts and Events

Evidence from past major NEO impacts or aerial explosions illustrates the catastrophic consequences that these objects can have:

- The impact of a NEO on the north side of Mexico's Yucatan Peninsula some 65,000,000 years ago that is thought to have helped bring about the extinction of the dinosaurs and to have destroyed 75 percent of life on Earth. Scientists estimate the frequency of an impact event of this magnitude to be about once every 50-100 million years.

- The Barringer Meteor Crater in Arizona is about 1 kilometer wide and is estimated to be 50,000 years old. The impact was caused by a nickel-iron meteorite, weighing about 300,000 tons and whose size was roughly 45 meters in diameter. The impact explosion was comparable to 20 million tons of TNT and created a hole 174 meters deep. Scientists estimate these types of impacts to occur once every 250-1000 years.

- The Tunguska Event took place in Siberia in 1908 when a NEO estimated to be 50-100 meters in size disintegrated about five-ten kilometers above the Earth's surface. That event unleashed energy comparable to an estimated 10-15 million tons of TNT. The explosion flattened trees and other vegetation over an area of roughly 2,000 square kilometers [about 500,000 acres]. Scientists estimate that this scale of impact would occur about once every 250-1000 years.

Within the last two decades, instances of objects that passed near Earth brought increasing interest in identifying NEOs and exploring options to protect Earth from a potential NEO impact. For example:

- On March 23, 1989, the 1989 FC asteroid with an estimated diameter of 0.3 miles came within 430,000 miles of Earth. 1989 FC carried the energy estimated to be more than 1000 one-megaton hydrogen bombs. The asteroid was only discovered after it had made its closest approach to Earth.

- Asteroid 99942 Apophis, discovered in 2004, is estimated to be roughly 300 meters in diameter, and could pass as close as 29,470 km [about 18,300 miles] from the Earth's surface [i.e., about the altitude that geosynchronous communications satellites orbit the Earth] in 2029. Radar observations conducted at the Arecibo Observatory in January 2005 significantly improved the understanding of the asteroid's orbit. The probability of impact in 2036, when the asteroid makes another close approach, is currently estimated to be 1/45,000. Scientists hope to use Arecibo again in 2012 to further refine the orbital coordinates when the asteroid is expected to be in a favorable viewing position.

Determining the population of NEOs, including those in the PHO category, can only be achieved by conducting a search campaign using ground-based or space-based telescopes, or a combination of the two.

<u>Previous Congressional Actions Related to NEOs</u>

Congress has taken a number of steps since 1990 to promote increased understanding of NEOs and the potential threat they pose, as well as potential options for protecting Earth from hazardous NEOs. In 1990 the National Aeronautics and Space Administration Multiyear Authorization Act of 1990 directed NASA to conduct two workshop studies on NEO detection and interception. In 1993 the House Science and Technology Committee held a hearing to review the results of the two reports, and in 1994 [by means of House Report 103-654, which accompanied the National Aeronautics and Space Administration Authorization and Space Policy Act for Fiscal Year 1995] gave further direction to NASA to coordinate with the Department of Defense and international space partners on identifying and cataloging NEOs greater than 1 kilometer in diameter that are in an orbit around the Sun that crosses Earth's orbit within the next decade. In 1998, NASA established a Near-Earth Object Program Office at the Jet Propulsion Laboratory and established its Spaceguard Survey. The Survey had the goal of detecting and cataloging 90 percent of NEOs 1 km or larger by the end of 2008.

<u>NASA's Current NEO Survey Program and Budget</u>

The Spaceguard Survey was housed in NASA's Exploration Systems Mission Directorate in recent years, but earlier this year it was moved to the Science Mission Directorate. NASA's report to Congress states that the current budget for the program is $4.1 million per year for Fiscal Years 2006 – 2012. NASA officials report that the annual budget is allocated as follows: $3 million are used to support the search teams and ground-based telescope facilities, $500,000 is allocated to JPL for studies on near-Earth objects, $400,000 is provided to the Minor Planets Center at the Smithsonian Center for Astrophysics to refine the orbital coordinates of NEOs that have been detected, and the remainder is allocated to additional NASA-funded studies.

NASA's report to Congress states that as of December 2006 the Spaceguard Survey had identified 701 of the estimated 1100 NEOs larger than 1 km that are believed to exist.

<u>Recent Congressional Action on NEOs</u>

Section 321 of the 2005 NASA Authorization Act directed NASA "*to plan, develop, and implement a Near-Earth Object Survey program to detect, track, catalogue, 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. It shall be the goal of the Survey program to achieve 90 percent completion…within 15 years after the date of enactment of this Act*." Section 321 also directed NASA to report to Congress on an analysis of ground-based and space-based alternatives to conduct the Survey; a recommendation on which Survey option to pursue and a proposed budget; and an analysis of options to divert an object that threatens impact with Earth.

NASA's Near-Earth Object Survey and Deflection Analysis of Alternatives Report to Congress

NASA's report, *Near-Earth Object Survey and Deflection Analysis of Alternatives, Report to Congress,* prepared in response to Sec. 321 of the NASA Authorization Act of 2005, was submitted to Congress in March 2007. The study was led and managed by NASA's Office of Program Analysis and Evaluation. The report is a condensed version of a longer, un-circulated version that included the analysis on which findings of the report to Congress were based. The 2007 report to Congress provides options for meeting the Survey goals by 2020, as required in the Act, and options for meeting the goals on a longer timeframe. However, the report does not provide Congress with NASA's recommended option for conducting the Survey or provide a cost estimate for that Survey.

The report's basic conclusion is that ***"NASA recommends that the program continue as currently planned, and we will also take advantage of opportunities using potential dual-use telescopes and spacecraft—and partner with other agencies as feasible—to attempt to achieve the legislated goal within 15 years. However, due to current budget constraints, NASA cannot initiate a new program at this time."***

In addition, the report contained a number of additional findings, including:

- *"The goal of the Survey Program should be modified to detect, track, catalogue, and characterize, by the end of 2020, 90 percent of all Potentially Hazardous Objects (PHOs) greater than 140m whose orbits pass within 0.05 AU of the Earth's orbit (as opposed to surveying for all NEOs)*

- *The Agency could achieve the specified goal of surveying for 90 percent of the potentially hazardous NEOs by the end of 2020 by partnering with other government agencies on potential future optical ground-based observatories and building a dedicated NEO survey asset assuming the partners' potential ground assets come online by 2010 and 2014, and a dedicated asset by 2015.*

- *Together, the two observatories potentially to be developed by other government agencies could complete 83 percent of the survey by 2020 if observing time at these observatories is shared with NASA's NEO Survey Program.*

- *New space-based infrared systems, combined with ground-based assets, could reduce the overall time to reach the 90 percent goal by at least three years. Space systems have additional benefits as well as costs and risks compared to ground-based alternatives.*

- *Radar systems cannot contribute to the search for potentially hazardous objects, but may be used to rapidly refine tracking and to determine object sizes for a few NEOs of potentially high interest. Existing radar systems are currently oversubscribed by other missions.*

- *Determining a NEO's mass and orbit is required to determine whether it represents a potential threat and to provide required information for most alternatives to mitigate such a threat. Beyond these parameters, characterization requirements and capabilities are tied directly to the mitigation strategy selected.*

The NASA report also describes the general advantages and disadvantages of using ground versus space-based search systems and analyzes an approach that includes a combination of ground-based and space-based NEO search capabilities:

- Ground-based Optical Systems. Ground-based telescopes are relatively easy to maintain and offer the flexibility for upgrades. They are limited by their nighttime or early morning viewing periods as well as the atmosphere's effects on observations.

- Space-Based Optical Systems. These systems can take advantage of proven space technologies, are not restricted in viewing hours and atmospheric interference, and can observe objects in inner Earth orbits or orbits similar to Earth's more easily than can ground-based systems. Space-based survey approaches however require access to space, data downlinks, and replacement spacecraft.

- Space-Based Infrared Systems. The technology for space-based infrared systems is less mature than space-based optical technology, however the infrared systems would require smaller aperture telescopes and could provide greater accuracy on the sizes of NEOs they detect.

The NASA report suggests that the goals of the Congressionally-mandated survey could be met by acquiring shared access to a proposed ground-based NSF/DOE, telescope system, the Large Synoptic Survey Telescope (LSST) and a potential Air Force telescope system, the Panoramic Survey Telescope and Rapid Response System (PanSTARRS). In addition, this exemplar search program would require an additional LSST-type telescope dedicated to the NEO survey effort.

LSST is proposed as a large-aperture, wide-field telescope. According to literature from the LSST project, the telescope will "*Conduct a survey over an enormous* *volume of sky; do it with a frequency that enables repeat exposures of every part of the sky every few nights in multiple colors; and continue this mode for ten years to achieve astronomical catalogs thousands of times larger than have ever previously been compiled*." LSST was recommended as a high priority initiative in the 2001 National Academies Astronomy and Astrophysics Decadal Survey. In addition, the 2003 National Academies Solar System Exploration Survey included the following recommendation: "*The SSE* [Solar System Exploration] *Survey recommends that NASA partner equally with the National Science Foundation to design, build, and operate a survey facility, such as the Large Synoptic Survey Telescope (LSST)... to ensure that LSST's prime solar system objectives are accomplished…*" LSST has not yet been approved as new project start by the National Science Foundation.

The director of the LSST project is expected to testify that LSST could complete the mandated survey within 12 years from the start of the telescope operations. This goal would involve modifications to the observing strategy and to the data processing procedures. The LSST project estimates that the cost of an LSST NEO survey over 12 years would be about $125M.

PanSTARRS is being developed by the University of Hawaii with funding from the U.S. Air Force. A main goal of PanSTARRS is to detect potentially hazardous objects. PanSTARRS is planned to be a system of four individual telescopes that will survey large areas of the sky at a high degree of sensitivity. The prototype one-mirror PanSTARRS telescope is complete; a full 4-telescope system has not yet been approved.

The NASA report to Congress also indicates that by using a space-based infrared telescope [along with the LSST and PanSTARRS systems], NASA could exceed the mandated requirement and detect an estimated 90 percent of the PHO population by 2017.

An additional capability that could be brought to bear on the NEO survey task is NASA's Wide-field Infrared Survey Explorer (WISE), which is scheduled for launch in 2009. The WISE spacecraft will survey the sky in the infrared band at high sensitivity. Asteroids, which absorb solar radiation, can be observed through the infrared band. NASA officials told Committee staff that NASA plans to use WISE to detect NEOs, in addition to performing its science goals. NASA expects that WISE could detect 400 NEOs [or roughly 2 percent of the estimated NEO population of interest] within the spacecraft's 6 month – 1 year mission.

It should be noted that the National Academies' 2001 report <u>New Frontiers in the Solar System</u> report [the solar system exploration decadal survey] commented on the potential value of ground-based observatories for detecting near-Earth objects: "*The SSE Survey's Primitive Bodies Panel endorses the concept of a large telescope capable of an all-sky search strategy that would reveal large numbers of near-Earth objects…also endorses a telescope that would enable the physical study of such objects by spectroscopic and photometric techniques. The panel heard* *recommendations for the Large Synoptic Survey Telescope (LSST) and the Next Generation Lowell Telescope (NGLT)…Other options, including the Panoramic Optical Imager concept, should be explored and a choice made that NASA can support in the next decade.*

According to the NASA report to Congress, once a NEO is identified, further characterization of its mass and orbit are required to "*assess the threat*" as required in the Act. Characterization involves observations that provide details on an object's structure, whether it is a single or binary NEO, its porosity, rotation rate, composition, and surface features. NASA's report to Congress discusses the need to characterize an object to inform decisions on mitigation.

According to NASA officials, characterization is usually focused on those objects that are identified as posing a potential threat. Both optical and radar ground-based systems can be used, however radar provides precise orbital determinations more quickly than optical systems. A dedicated in-situ mission to observe the object would provide the greatest detail on the character of the object and, according to the NASA report to Congress, help to "*confirm the probability of impact and characterize the potential threat if deflection is necessary*."

The report presents two broad strategies for diverting asteroids from a collision path with Earth. "Impulsive" options would involve the use of conventional or nuclear explosives and have immediate results. "Slow push" options would achieve deflection results over a period of time.

- *"Impulsive"* options include:
  - Surface conventional explosive (detonating on impact)
  - Subsurface conventional explosive
  - Standoff nuclear explosive (detonate on flyby with proximity fuse)
  - Surface nuclear explosive (detonate via impact with surface fuse)
  - Delayed nuclear explosive (surface lander, detonate at chosen time)
  - Subsurface nuclear explosive
  - Kinetic impact (high speed impact)

- *"Slow push"* approaches include:
  - Focused solar (focused beam to burn-off surface material)
  - Pulsed laser (rendezvous mission that burns-off material using laser)
  - Mass driver (rendezvous mission mines and ejects material)
  - Gravity tractor (large rendezvous mission flies in proximity to "pull" object off course)
  - Asteroid tug (rendezvous mission attaches to and pushes object)
  - Heating of surface material

The report includes the following findings on deflection alternatives:

- *"Nuclear standoff explosions are assessed to be 10-100 times more effective than the non-nuclear alternatives…. Other techniques involving the surface or subsurface of nuclear explosions may be more efficient, but they run the risk of fracturing the target NEO. They also carry higher development and operations risks.*

- *Non-nuclear kinetic impactors are the most mature approach and could be used in some deflection/mitigation scenarios, especially for NEOs that consist of a single, small solid body.*

- *"Slow push" mitigation techniques are the most expensive, have the lowest level of technical readiness, and their ability to both travel to and divert a threatening NEO would be limited unless mission durations of many years to decades are possible.*

- *30-80 percent of potentially hazardous NEOs are in orbits that are beyond the capability of current or planned launch systems. Therefore, planetary gravity assist swingby trajectories or on-orbit assembly of modular propulsion systems may be needed to augment launch vehicle performance, if these objects need to be deflected."*

Critics of NASA's analysis of deflection options argue that NASA's report focuses on atypical asteroid threats rather than the objects of size ranges that have a much higher probability of actually impacting the Earth. They argue that NASA's focus on the less likely scenarios results in a set of deflection requirements that are skewed towards nuclear explosives. If the focus would be placed on addressing the deflection requirements of the smaller, more common PHOs, the critics of NASA's analysis would assert that *"over 99 percent of them can be deflected using non-nuclear means."* One of the witnesses at the hearing, Mr. Russell "Rusty" Schweickart, will discuss issues related to NASA's analysis of deflection options, as well as identify what he believes are serious technical flaws in NASA's report to Congress.

Planetary Radar Facilities

Arecibo Observatory

The Arecibo Observatory in Puerto Rico, which has been described as "*the largest and most sensitive*" ground-based radar telescope on Earth, has been used to reduce the uncertainty of NEO collision estimates and refine the time period of when a NEO may pass near Earth. In addition, radar observations are more precise than data from optical telescopes in identifying details on the mass, shapes, trajectories, sizes, and on whether the NEO is a single object or part of a binary system. In 2005, Arecibo observations improved the estimates of the trajectory for the object, Apophis, which is on a path that will take it close to Earth in 2029. Research using the Arecibo Observatory also helps improve our understanding of how solar radiation influences near-Earth objects.

Arecibo is operated by Cornell University under a cooperative agreement with the National Science Foundation. A 2006 independent review of all NSF ground-based astronomy facilities recommended that "*The National Astronomy and Ionosphere Center* [Arecibo Observatory] …*should seek partners who will contribute personnel or financial support to the operation of Arecibo… by 2011 or else these facilities should be closed.*" At present, the planetary radar facility at Arecibo is funded through FY2008. Funding beyond that date is uncertain.

NASA's Goldstone Deep Space Tracking Station

The only planetary radar facility other than Arecibo is NASA's Goldstone Deep Space Tracking Station in Goldstone, California. Goldstone is less sensitive than Arecibo, however its steerable antenna allows it to see a larger portion of the sky. NASA is planning to replace the current Deep Space Network antennas and is looking at a number of options, including phased array antennas. The current replacement options do not appear to provide a planetary radar capability comparable to that of the existing Goldstone facility.

The 2003 National Academies Solar System Exploration Survey report contained the following recommendation: "*In addition, NASA should continue to support ground-based observatories for planetary science, including the planetary radar capabilities at the Arecibo Observatory in Puerto Rico and the Deep Space Network's Goldstone facility in California…as long as they continue to be critical to missions and/or scientifically productive…*"

NEO Contributions to Science, Human Exploration, and Resource Utilization

The NASA report notes that an increased search for and characterization of NEOs will benefit scientific discovery and study of Kuiper Belt Objects, as well as in determining whether certain comets originated in the Kuiper Belt. Further data on NEOs could also provide information that could be used to consider extracting and using asteroid resources and for considering a potential human mission to an asteroid. A 1998 National Academies Report on The Exploration of Near-Earth Objects notes that:

> "*Although it would be difficult to justify human exploration of NEOs on the basis of cost-benefit analysis of scientific results alone, a strong case can be made for starting with NEOs if the decision to carry out human exploration beyond low Earth orbit is made for other reasons. Some NEOs are especially attractive targets for astronaut missions because of their orbital accessibility and short flight duration. Because they represent deepspace exploration at an intermediate level of technical challenge, these missions would also serve as stepping stones for human missions to Mars. Human exploration of NEOs would provide significant advances in observational and sampling capabilities*."

NEO-Related Activities at the United Nations

The United Nation's Committee on the Peaceful Uses of Outer Space (COPUOS), Scientific and Technical Subcommittee has discussed and considered the issue of NEOs. In 2006, the subcommittee established a Working Group on Near-Earth Objects to focus on the issue over the 2006-2007 timeframe and also formed an Action Team. Over the next 1-2 years, the subcommittee plans to continue to obtain reports on NEO activities and to address the need for more international coordination on observations and follow-up studies. The subcommittee also plans to work on international procedures for handling NEO threats.

Space Science Missions to Comets and Asteroids

In addition to its ground-based Spaceguard Survey program, NASA and non-U.S space agencies have launched, or are planning to undertake a number of space science missions to study asteroids and comets. NASA's report to Congress notes that information gained from these missions benefits the agency's current NEO program. A number of past, current, and future missions of note include:

- NASA's Near Earth Asteroid Rendezvous (NEAR) mission, launched in 1996, flew by two asteroids and studied one, Eros;
- The Stardust mission collected dust samples from comet Wild 2;
- Deep Impact, launched in 2004, penetrated comet Tempel 1;
- The Dawn mission, launched in late September 2007 is en route to study, Ceres and Vesta, two of the largest known asteroids located in the main asteroid belt between Mars and Jupiter;
- Japan's Hayabusa mission had the objective of collecting a sample from the near-Earth asteroid Itokawa, and the sample carrier is en route back to Earth; and
- The European Space Agency's Rosetta mission to comet Churymov-Gerasimenko in late 2014 will rendezvous with and land on the comet.
- In addition, the European Space Agency has conducted studies on a potential space mission that could test and validate technologies for deflecting an asteroid.