# Free Executive Summary

## Near-Earth Object Surveys and Hazard Mitigation Strategies: Interim Report

Committee to Review Near-Earth Object Surveys and Hazard Mitigation Strategies, National Research Council

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# Interim Report on
# Near-Earth Object Surveys and Hazard Mitigation Strategies

## SUMMARY

The United States is currently the only country with an active, government-sponsored effort to detect and track potentially hazardous near-Earth objects (NEOs). At congressional direction, NASA funds several ground-based observatories primarily dedicated to conducting NEO surveys. Several new or proposed observatories with other non-NEO objectives can also contribute to the NEO survey task. Congress has mandated that NASA detect[1] and track 90 percent of NEOs that are 1 kilometer in diameter or larger. These objects represent a great potential hazard to life on Earth and could cause global destruction. NASA is close to accomplishing this goal. Congress has more recently mandated that by 2020 NASA should detect and track 90 percent of NEOs that are 140 meters in diameter or larger, a category of objects that is generally recognized to represent a very significant threat to life on Earth if they strike in or near urban areas. Achieving this goal may require the building of one or more additional observatories, possibly including a space-based observatory.

Congress directed NASA to ask the National Research Council to review NASA's near-Earth object programs. This interim report addresses some of the issues associated with the survey and detection of NEOs. However, the committee continues its information collection and deliberations and will address a broader range of issues in its final report, due for delivery at the end of 2009. During its study so far, the committee has determined that the issues of survey and detection and characterization[2] and mitigation are closely linked and should be addressed as a whole. For example, NEOs detected by ground-based telescopes can be better tracked by the Arecibo Observatory when within its range. Thus this observatory plays a key role in determining physical characteristics of NEOs, important in determining how to mitigate the effects of NEOs on Earth. In part because of this interrelationship, and because the interim report does not address mitigation issues, the committee has deferred proposing an optimum approach to the survey and detection problem until its final report. The final report will contain findings and recommendations for survey and detection, characterization, and mitigation of near-Earth objects based on an integrated assessment of the problem.

This interim report contains five findings:

**Finding: Congress has mandated that NASA discover 90 percent of all near-Earth objects 140 meters in diameter or greater by 2020. The administration has not requested and Congress has not appropriated new funds to meet this objective. Only limited facilities are currently involved in this survey/discovery effort, funded by NASA's existing budget.**

**Finding: The current near-Earth object surveys cannot meet the goals of the 2005 NASA Authorization Act directing NASA to discover 90 percent of all near-Earth objects 140 meters in diameter or greater by 2020.**

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[1] The committee notes that although the statement of task includes the term "detect," this includes spotting asteroids that have previously been discovered. The committee therefore uses the more appropriate term "discover" to refer to the locating of previously unknown objects.

[2] Characterization of a near-Earth object involves determining its physical characteristics, such as mass, density, porosity, composition, and so on.

**Finding: The orbit-fitting capabilities of the Minor Planet Center are more than capable of handling the observations of the congressionally mandated survey as long as staffing needs are met.**

**Finding: The Arecibo Observatory telescope continues to play a unique role in characterization of NEOs, providing unmatched precision and accuracy in orbit determination and insight into size, shape, surface structure, multiplicity, and other physical properties for objects within its declination coverage and detection range.**

**Finding: The United States is the only country that currently has an operating survey/detection program for discovering near-Earth objects; Canada and Germany are both building spacecraft that may contribute to the discovery of near-Earth objects. However, neither mission will detect fainter or smaller objects than ground-based telescopes.**

## INTRODUCTION

In 2008, at congressional direction, NASA and the National Science Foundation asked the National Research Council to undertake a study of the nation's efforts to survey, discover and characterize, and develop mitigation strategies for NEOs. Near-Earth objects are defined as small solar-system objects whose orbits cross or nearly cross Earth's orbit.

To date the study's steering committee, survey/detection panel, and mitigation panel have each met twice. The panels remain in their information-gathering phases. This interim report addresses some issues contained in task 1 of the committee's charge (dealing primarily with survey and detection efforts) and does not address mitigation issues. The committee will evaluate the particular characteristics of survey strategies in terms of their implications for NEO discovery and/or characterization.

Currently, the U.S. government spends a relatively small amount of money funding a search and survey program to discover and track near-Earth objects, and virtually no money on studying methods of mitigating the hazards posed by such objects.[3] Although Congress has mandated that NASA conduct this survey program and has established goals for the program, neither Congress nor the administration has sought to fund it with new appropriations. As a result, NASA has supported this activity by taking funds from other programs, while still leaving a substantial gap between the goals established by Congress and the funds needed to achieve them.

## EVOLUTION OF THE STUDY OF NEAR-EARTH OBJECTS

Earth has been impacted by asteroids and comets for billions of years. In the 1980s, after Luis and Walter Alvarez suggested that a massive asteroid impact wiped out the dinosaurs, scientists began to consider the environmental effects—including widespread extinction—that could be caused by large impacts. By the 1990s, available research indicated that the impact of a 1.5- to 2-kilometer-diameter asteroid or comet anywhere on Earth had the potential to produce global effects that would seriously impact human civilization (e.g., a significant reduction in the total food yield, perhaps for several years). Because there were substantial uncertainties in the threshold impactor size needed to produce global effects, a team of NEO experts selected 1-kilometer-diameter objects as the threshold for the most dangerous objects to human civilization.

The uncertainties in the damaging effects of asteroids increase as the size of the asteroid increases. A 1-kilometer-diameter asteroid is generally accepted as the lower boundary for an impactor

[3] The threat posed by long-period comets is not part of the U.S. government effort. Mitigating the threat posed by such comets would be difficult due to the short warning times available for objects in such highly elliptical orbits; these objects are not often visible from Earth until a few months or so before reaching the vicinity of Earth's orbit.

with global consequences—asteroids below this size probably will not have globally catastrophic effects, although most estimates place the boundary for catastrophic effects starting at around 1.5 to 2 kilometers. Such an asteroid would be expected to produce a continent-sized fireball and form a crater approximately fifteen times the diameter of the asteroid, similar in size to many craters known from the geologic record; it could instead produce a devastating tsunami if it hit in an ocean. On average, such craters form at about 1-million-year intervals, but there is no known association between impact craters of this size and biologic extinctions. However, modern human civilization, with its strong dependence on agricultural crops and intricate distribution networks, is presumably much more fragile than the mere survival of humans or other animals as a species. We would thus want to avoid any impact that caused a large fraction of surviving humans to die of starvation, even though humans as a species would endure.

Although Congress's charge in 1998 to NASA was to discover 90 percent of objects 1 kilometer in diameter or greater that could potentially strike Earth, within a few years, as the surveys detected most of these larger objects, attention shifted to smaller-sized objects that could still cause substantial harm. Because NEOs are most often far from Earth, surveys must be conducted over a long period of time in order to detect a large fraction of them. See Figure 1 for an estimate of the populations of different sized near-Earth objects.

Based on scientists' estimates of the likely NEO population, the amount of damage that could be caused by different-sized NEOs, and an assessment of existing capabilities for detecting objects of different sizes, Congress directed NASA in 2005 to discover 90 percent of NEOs 140 meters in diameter or greater by 2020.

Estimates of the hazards associated with a given impact have changed substantially over the past few years. In 2003 there was extensive discussion of the role of tsunamis in magnifying the hazard from small objects striking the ocean. More recent studies suggest that this tsunami hazard may not yet be understood quantitatively with the desired (or needed) accuracy. Even the diameter of the asteroid that created the only known serious historically-recorded damage, the 1908 Tunguska explosion that leveled about 2000 $km^2$ of Siberian forest, has been recently revised downward—according to a single study—from 50-75 meters to about 30-40 meters, thus causing a reassessment of the apparent risk from airblast due to impacts by small asteroids.[4]

What this history demonstrates is that scientific understanding of both the population of near-Earth objects, and the damage that they can cause, has changed significantly in only the past fifteen years. More changes in our understanding of the potential threat can be expected as our understanding improves, but remaining changes are likely to be less dramatic given our improved knowledge on a broad front.

## LEGISLATION AND STUDY HISTORY: THE 1-KILOMETER-DIAMETER GOAL

The first NASA-sponsored NEO workshop, Collision of Asteroids and Comets with Earth: Physical and Human Consequences, took place in Colorado in 1981 shortly after the claim that an impact event ended the age of the dinosaurs. The NASA Multi-year Authorization Act of 1990 that was passed by Congress directed NASA to study both the discovery of potentially threatening asteroids and the technology for possible mitigation if an object on a collision course with Earth were to be found. The studies outlined in this legislation were prompted by recommendations to Congress in 1989 by the American Institute of Aeronautics and Astronautics shortly after asteroid 1989 FC passed close to Earth. The 1992 report of the NASA International Near-Earth-Object Detection Workshop (sometimes referred to as the "Spaceguard Survey")[5] increased attention to this issue. In 1994 the House Committee on Science, Space, and Technology requested that NASA develop a plan to "discover, characterize and

[4] M.B.E. Boslough and D.A. Crawford, "Low-altitude airbursts and the impact threat," *International Journal of Impact Engineering* 35:1441-1448, 2008.

[5] Morrison, D., ed. *The Spaceguard Survey—Protecting the Earth from Cosmic Impacts. Report of the NASA International Near-Earth-Object Detection Workshop,* NASA, Washington, D.C. 1992.

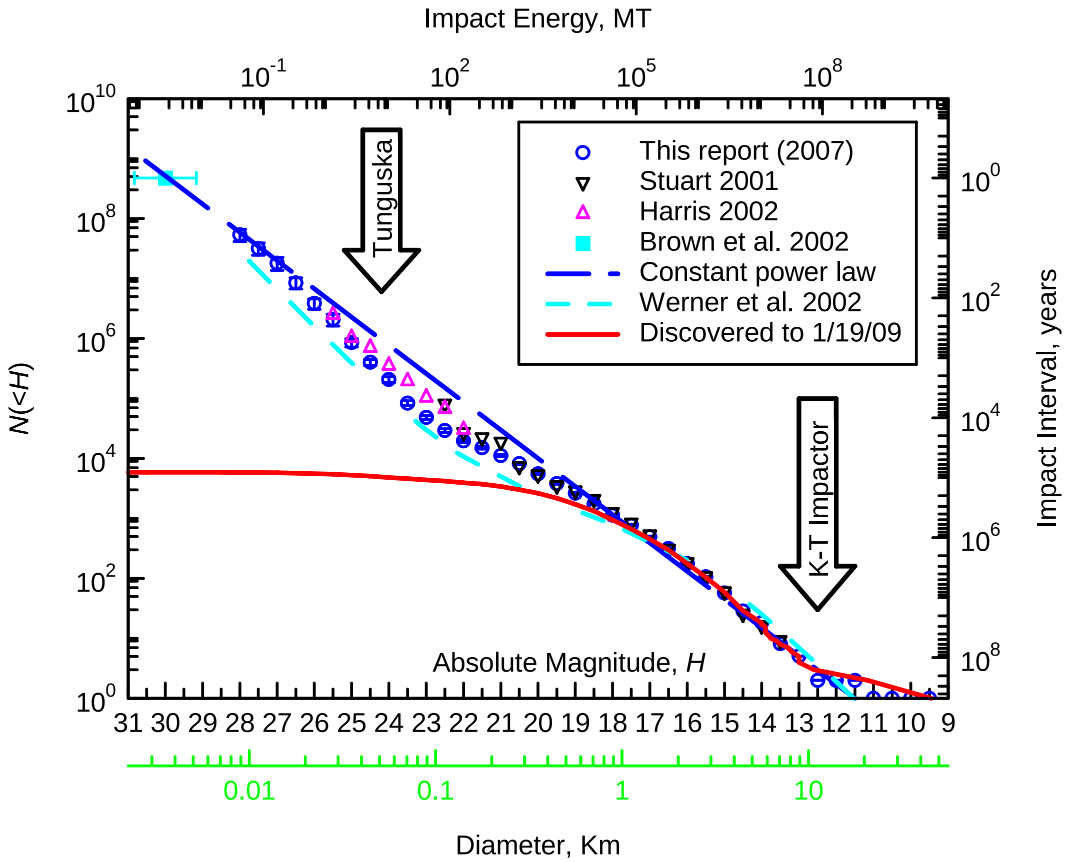


FIGURE 1 A modern estimate of the cumulative number of asteroids (y-axis) versus their brightness (x-axis) is show. At the left end, the brightness equivalent of ~1-meter-diameter objects, corresponds to a total number of asteroids (~$10^8$) that are this size or larger. The red curve (solid lower line) represents the results from observations through January 19, 2009; the other curves involve theoretical estimates whose uncertainties are not all well known. The dramatic deviations of the red curve from the others for small sizes is due to the insensitivity of present surveys to such small (and faint) objects. To use a curve to determine the estimate of the number of asteroids in a given size range, subtract the number on the y-axis corresponding to the upper end of that size range from the corresponding number for the lower end. NOTE: The conversion from brightness to size is only approximate; the brightness is itself defined for a standard configuration of Earth, Sun, and asteroid, and is reliably calculated from the observed brightness. SOURCE: Alan Harris, Space Science Institute, with data from "This Report (2007)" refers to A. Harris, in press; J.S. Stuart, A near-Earth asteroid population estimate from the LINEAR survey, *Science* 294:1691-1693, doi:10.1126/science.1065318, 2001; A.W. Harris, A new estimate of the population of small NEAs, *Bulletin of the American Astronomical Society* 34:835, 2002; P. Brown, R.E. Spalding, D.O. ReVelle, E. Tagliaferri, and S.P. Worden, The flux of small near-Earth objects colliding with the Earth, *Nature* 420:294-296, doi:10.1038/nature01238, 2002; S.C. Werner, A.W. Harris, G. Neukum, and B.A. Ivanov, The near-Earth asteroid size-frequency distribution: A snapshot of the lunar impactor size-frequency distribution, *Icarus* 156:287-290, doi:10.1006/icar.2001.6789, 2002.

catalog, within ten years (to the extent practicable), the potentially threatening comets and asteroids larger than 1 kilometer in diameter."

The 1995 NASA NEO Survey Workgroup Report *Asteroid and Comet Impact Hazards* was NASA's response to Congress.[6] The plan laid out by the workshop, if effective, would lead to discovery of 60 to 70 percent of NEOs larger than 1-kilometer diameter within one decade (i.e., by 2006). In 1997,

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[6] NASA, *Asteroid and Comet Impact Hazards. Report of the Near-Earth Objects Survey Workgroup Report,* Eugene Shoemaker, chair, Washington, D.C., June 1995.

NASA's annual funding level for NEO discovery programs was approximately $1 million. The following year, Congress directed NASA to conduct a program to discover at least 90 percent of 1-km or larger bodies, within ten years (i.e., by 2008). In fiscal year (FY) 1999, the House Committee on Appropriations gave NASA's NEO discovery and cataloguing effort $1.6 million in funding. However, after providing this money, and after NASA awarded multi-year grants, the line item was deleted from subsequent bills, causing NASA to obtain the money from other programs.

The search efforts were accompanied by study and evaluation. In 2003 a major scientific study of the issue concluded that with the goal of discovering 90 percent of 1-kilometer diameter or larger objects almost attained, and with new survey and discovery equipment becoming available, the goal should be revised.[7] This proposed change coincided with an increasing understanding of the potential threat posed by smaller objects.

## LEGISLATION AND STUDY HISTORY: THE 140-METER-DIAMETER GOAL

In the NASA Authorization Act of 2005, Congress called on NASA to provide an analysis of alternatives to discover, track, catalogue, and determine the physical characteristics of NEOs equal to or greater than 140 meters in diameter to assess the threat of such objects to Earth. The legislation also stipulated that NASA find 90 percent of all these NEOs within fifteen years. (The NASA analysis of alternatives is discussed in the next section.)

The NASA Authorization Act of 2008 stated that "near-Earth objects pose a serious and credible threat to humankind."[8] The 2008 act is more expansive than previous legislation dealing with NEOs. The act requested information from NASA on "a medium-sized space mission with the purpose of discovering near-Earth objects equal to or greater than 140 meters in diameter."[9] Furthermore, Congress requested information from NASA for "a low-cost space mission with the purpose of rendezvousing with, attaching a tracking device to, and characterizing the Apophis asteroid."[10]

In addition, this act details the follow-up to any NASA plan or input, explaining how the Office of Science and Technology Policy would spearhead coordinating roles and responsibilities of other federal agencies. Finally, the act discusses the role that planetary radar, especially the Arecibo telescope, and greater utilization of international cooperation might play in U.S. efforts to discover and characterize NEOs. Congress reaffirmed its support for the Arecibo telescope, but stated that its future is dependent on the recommendations from the National Research Council study on NEO discovery and mitigation efforts, and on planning analyses (i.e., this study).

## NASA ANALYSIS OF ALTERNATIVES

In 2006, in response to a request from Congress, NASA conducted a study on the state of NEO surveying and discovery efforts and methods to meet the goal mandated by Congress in the 2005

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[7] NASA, *Study to Determine the Feasibility of Extending the Search for Near-Earth Objects to Smaller Limiting Diameters,* Report of the Near-Earth Object Science Definition Team, Washington, D.C., 2003.

[8] National Aeronautics and Space Administration Authorization Act of 2008 (P.L. 110-422), October 15, 2008, Section 802.

[9] National Aeronautics and Space Administration Authorization Act of 2008 (P.L. 110-422), October 15, 2008, Section 803.

[10] The asteroid Apophis is a nearly 300-meter sized NEO. In 2029 Apophis will pass within about 25,000 km of Earth and though an impact at that time is effectively impossible, there is a remote chance of impact when Apophis comes by for another pass in 2036. Radar observation of Apophis in 2013 will indicate whether the object is or is not a threat to impact Earth in 2036 or in the following few decades.

authorization act. In March 2007, NASA published *Near-Earth Object Survey and Deflection Analysis of Alternatives Report to Congress*.[11]

In addition to evaluating ground-based survey/discovery options, NASA's study team analyzed various space-based alternatives that could be used independently or in tandem with ground-based observatories. Space-based telescopes could use either infrared or visible-light optics, and could operate, for example, in a Venus-like orbit, low-Earth orbit, or near one of Earth's Lagrange points. Observatories located in a Venus-like orbit could be more effective at finding objects inside Earth's orbit than ground-based observatories due to the glare of the Sun that affects the latter, but have disadvantages with respect to costs and risk.

These are only a few of the many options considered by the NASA team. The study named some advantages to employing space-based observation capabilities, including the ability to detect objects as small as ~80 meters in diameter, exceeding the 140-meter requirement set by Congress. The study assumed a start of October 1, 2007, for acquisition of new systems. This start did not occur, and none of the possible NEO search systems is fully funded.

Although Congress mandated as a goal the discovery of 90 percent of all NEOs 140 meters in diameter or greater by 2020, and NASA has studied possible methods for accomplishing this goal, neither the administration nor Congress has sought to provide the funding required to achieve this goal. Several possible solutions could be pursued to discover such NEOs and meet the goal, but all require the rapid construction of new hardware and facilities such as ground and/or space-based telescopes. Primarily because none of them has been explicitly funded since the goal was established in 2005, there is less time available to meet the 2020 date and it is consequently more difficult to meet this goal.

**Finding: Congress has mandated that NASA discover 90 percent of all near-Earth objects 140 meters in diameter or greater by 2020. The administration has not requested and Congress has not appropriated new funds to meet this objective. Only limited facilities are currently involved in this survey/discovery effort, funded by NASA's existing budget.**

## PAST NEO DISCOVERY EFFORTS

The survey/discovery effort for NEOs has proceeded through several phases. In recent years several previous NEO survey programs shut down or are being phased out primarily because more capable surveys have come online. This report discusses past efforts.

### Lowell Observatory Near-Earth-Object Search

The Lowell Observatory Near-Earth-Object Search (LONEOS), operated by the Lowell Observatory, had the capability to scan the entire sky accessible from Flagstaff, Arizona, every month. The 0.6-meter-diameter telescope could record objects about 100,000 times fainter than can be seen with the naked eye. The project, funded by NASA, began in 1993 and concluded at the end of February 2008. LONEOS discovered 288 NEOs.

### Near-Earth Asteroid Tracking

The Near-Earth Asteroid Tracking (NEAT) program began in 1995 and was initially a collaborative effort between NASA, the Jet Propulsion Laboratory, and the U. S. Air Force. This

[11] NASA, *Near-Earth Object Survey and Deflection Analysis of Alternatives Report to Congress,* Washington, D.C., March 2007; available at http://www.nasa.gov/pdf/171331main_NEO_report_march07.pdf.

program originally converted a Ground-based Electro-Optical Deep Space Survey (GEODSS) 1.02 meter telescope on Haleakala, Maui, Hawaii, to the world's first fully-automated search telescope. Operations on the GEODSS telescope ended in 1999. In 2000, the NEAT program completed both the conversion of the Maui Space Surveillance System 1.2 meter telescope on Haleakala, and the conversion of the 1.2 meter Oschin telescope at Mt. Palomar to become fully automated and to search for NEOs. NEAT ceased operations in 2007 after detecting ~20,000 objects, including discovery of more than 400 NEOs, 64 of them likely 1 kilometer in diameter or larger.

## PRESENT NEO DISCOVERY EFFORTS

In 2005, five programs were operational: Catalina Sky Survey (CSS); the Lincoln Near-Earth Asteroid Research (LINEAR) program; and Spacewatch, as well as LONEOS and NEAT. Today, only CSS, LINEAR and Spacewatch are still operational; these are discussed below. (No nation has had or currently operates a space-based observatory dedicated to the discovery and/or characterization of NEOs, but see below.) The size of NEOs that can be detected is related to the aperture of telescopes and their optics, cameras, and detection software, as well as the observing strategy of the teams performing the search. Naturally, local observing conditions also affect the ability of these telescopes to detect NEOs. In addition, the Milky Way can obscure targets. As most of the large objects have been discovered, less powerful systems have limited value for the continued search for smaller objects and have been retired from this role.

### Catalina Sky Survey

Of the three search programs currently in operation, CSS currently discovers NEOs at the highest rate. CSS is a system of three telescopes, located at the Mt. Lemmon Observatory in Arizona, the Mt. Bigelow Observatory, also in Arizona, and the Siding Spring Observatory in Australia (funded by NASA). The Mt. Lemmon Observatory is the largest and most productive of these telescopes, having a 1.5-meter-diameter mirror and 1.2-square-degree field of view, enabling it to detect asteroids as faint as visual magnitude (V) 22 (see Figure 2 and its caption). The Siding Spring facility has a 0.5 meter telescope for NEO discovery. The Mt. Bigelow Observatory houses the original CSS telescope, which is a 0.69 meter Schmidt. These telescopes work together to carry out sustained, highly productive searches for NEOs. Because two of these observatories are operating on opposite sides of Earth from the third, same night follow-up on a newly discovered object can usually be accomplished, facilitating the rapid determination of its orbit and thus an evaluation of the hazard posed by the object. In addition, CSS is successful in part because a human operator is actively involved in the observations and can spot faint moving objects in the data that automated software has not yet been developed to detect. CSS has discovered more than 855 NEOs.

### Lincoln Near-Earth Asteroid Research

The LINEAR program at Massachusetts Institute of Technology's Lincoln Laboratory is funded by the U.S. Air Force and NASA and was the most successful NEO search program from 1997 until 2004. The goal of LINEAR is to demonstrate the application of technology originally developed for the surveillance of Earth orbiting satellites to discovering and cataloguing of NEOs. LINEAR consists of a pair of Ground-based Electro-Optical Deep Space Surveillance telescopes at Lincoln Laboratory's Experimental Test Site at the White Sands Missile Range in Socorro, New Mexico. These two 1-meter telescopes were eventually joined by a third telescope used for confirmation of NEO orbits, and were able to detect asteroids as faint as V=20. LINEAR has discovered 2,210 NEOs. LINEAR accounted for more than 50 percent of all near-Earth asteroid discoveries from 1998 to 2004. In 2005 the rate of discoveries by CSS increased substantially and overtook LINEAR. The rate of near-Earth asteroid discoveries has continued to increase since the mid-1990s, and more were discovered in 2008 than in any previous year.

### Spacewatch

Spacewatch was one of the first NEO discovery systems, established in 1981 and run by the University of Arizona. Routine detections of asteroids and comets started in 1984 with a 0.9-meter telescope on Kitt Peak, Arizona, and a relatively small charge-coupled device (CCD) imaging array. Upgrades in 1989 enlarged the field of view and resulted in the first detection of an NEO. Automated software to identify NEOs was implemented in 1990; this was the first time automated, real-time software was used for detection of moving cosmic objects and proved the efficiency of such software. In 2001, a 1.8-meter-diameter telescope was added to the program. The smaller Spacewatch telescope typically detects NEOs brighter than V=21 over its field of view of 2.9 square degrees, while the larger telescope can potentially detect NEOs as faint as V=23 over a field of view of 0.7 square degrees.[12] The larger telescope is primarily used for recoveries of previously discovered, fainter NEOs, to confirm their orbits, while the smaller telescope is used primarily for NEO discovery surveys. The Spacewatch program is anticipating transitioning from a wholly recovery/characterization role as more powerful surveys come online, as discussed below.

According to the organizations that operate them, CSS, LINEAR, and Spacewatch are incapable of meeting the congressional goal of discovering 90 percent of NEOs 140 meters in diameter or greater by 2020. To achieve this goal, or to even come close to achieving it, new facilities capable of detecting fainter asteroids and having wider fields of view to cover larger portions of the sky each night are required. Existing large telescopes have very small fields of view and are therefore unsuitable for achieving the survey goal.

**Finding: The current near-Earth object surveys cannot meet the goals of the 2005 NASA Authorization Act directing NASA to discover 90 percent of all near-Earth objects 140 meters in diameter or greater by 2020.**

## FUTURE NEO DISCOVERY EFFORTS

Several ground-based telescopes have been proposed or are currently under development that could contribute substantially to meeting the goal established by Congress. However, none has yet been fully funded, nor principally dedicated to the NEO discovery goal. Most of these ground-based telescopes are primarily intended for detection of distant (time-varying) objects, but also have a role in discovering NEOs. In addition, some current spacecraft programs could contribute to the discovery goal.

### Discovery Channel Telescope

The 4.2-meter Discovery Channel Telescope (DCT) is a collaborative effort between Lowell Observatory and Discovery Communications. The telescope is being constructed on a cinder cone in Happy Jack, Arizona, southeast of Flagstaff. The telescope will be able to switch between operating in a wide-field survey mode and a more focused high-resolution imaging or optical and infrared spectroscopic

[12] The inference of an asteroid's size from its observed brightness depends on several factors that are usually not well known. This inference will be discussed in detail in the final report.

mode, and is designed to contribute to multiple astronomical search projects (e.g., for Kuiper Belt objects, those located beyond Neptune's orbit) and to characterization projects unrelated to NEOs. The telescope construction has been entirely privately funded; the ~$14.5 million prime-focus camera is not yet funded.

### Large Synoptic Survey Telescope

The Large Synoptic Survey Telescope (LSST) is planned to be an 8.4-meter telescope to scan the entire sky accessible from its planned location in Chile on El Pichon near the Gemini South and Southern Astrophysical Research telescopes. By repeating this scan every few days, using several different filters, LSST will produce a precisely calibrated (in both photometry and astrometry) catalog of millions of moving objects (asteroids and comets) brighter than approximately V=24.5, as well as measuring their colors and also, in some cases, their light curves. Results are to be publicly available soon after the data is acquired. With a 9.6-square-degree field of view (and three gigapixel camera), it would allow detection of NEOs using the same data acquired for other scientific purposes, such as studying cosmology or stellar variability. The efficiency of LSST in detecting NEOs could be boosted if it were solely dedicated to this purpose. Mirror fabrication for LSST has begun, and telescope design and development has been in progress for more than 4 years; however, the telescope is far from fully funded. Anticipated funding sources include NSF and the Department of Energy, as well as some private funding. Currently, first light is planned for 2015.

### Wide-field Infrared Survey Explorer and NEOWISE

The Wide-field Infrared Survey Explorer (WISE) is a NASA spacecraft mission scheduled for launch in November 2009. WISE will produce a high-sensitivity imaging survey of the entire sky in four wavelength bands centered at 3.3, 4.7, 12, and 23 microns. It will deliver a catalog of sources and a calibrated, position-registered image atlas. Using a cryogenically-cooled 0.4-meter-aperture telescope and always looking 90 degrees from the Sun, WISE will conduct an all-sky survey for 6 months following a 1-month in-orbit checkout. Imaging will be obtained simultaneously in the four bands, and every inertial location on the sky will be imaged at least eight times, with more coverage at the ecliptic poles.

NASA has funded an enhancement to the baseline WISE mission, called NEOWISE, to facilitate solar system science. NEOWISE is expected to discover hundreds of new NEOs with sizes as small as ~100 meters. The advantage of an infrared-selected sample is that it is inherently less biased against discovery of low-albedo objects than are optical surveys. However, NEOWISE is not a stand-alone NEO survey and requires coordination with other surveys to make full use of its data.

### Panoramic Survey Telescope and Rapid Response System

The Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) is expected to consist of four (henceforth PS4) 1.8-meter, 1.4-gigapixel camera telescopes, each with a 7-square-degree field of view. The telescope constellation will be situated in Hawaii and could be expanded to include more telescopes at additional sites.

Only the first telescope, the PS1 prototype, has been completed, but it is not yet fully operational. The PS1's major advance over previous telescopes is its combination of a very large imaging array, a very wide field of view, and advanced software for detecting moving objects. When fully operational, PS1 will be capable of making a substantial contribution to the discovery of NEOs. A second telescope, PS2, is currently in the initial phases of construction.

The telescopes' large cameras will produce enormous amounts of data that will require transmission, analysis, and storage—posing very significant software problems. The Pan-STARRS team is addressing this important, but difficult problem. Elements of the NEO-detection software developed for Pan-STARRS have already been adapted for NEOWISE and will also be used for LSST when the latter telescope is completed.

### Survey Spacecraft

The NASA Authorization Act of 2008 calls for NASA to report on "a medium-sized space mission with the purpose of detecting near-Earth objects equal to or greater than 140 meters in diameter."[13] Several possible spacecraft for conducting such a search have been proposed, although unlike the above discussed future discovery efforts, no mission has been approved. Such possible missions will be discussed in the final report.

## MINOR PLANET CENTER

The Minor Planet Center (MPC), located at the Harvard-Smithsonian Center for Astrophysics (CfA), works under the auspices of the International Astronomical Union and is now funded primarily by NASA. The MPC's main tasks are to take all observations that it receives from around the world, check them, match observations with corresponding predictions from orbits of known objects, determine orbits for newly discovered objects, continually update and improve orbit predictions, and archive this data in several places.

These observations and orbits are made publicly available but not as rapidly as current technology could allow. However, as of October 1, 2009, all of this information will be quickly available to anyone in the world on the MPC's website. The NEO observations and orbits will then be available on a daily basis.

The MPC's computer systems have been vastly improved in the last few years and are being improved yet further with the purchase of three high-speed LINUX machines. Also available is a few-hundred-node cluster at the CfA and a one-thousand-node cluster at the Smithsonian Institution for use as needed.

The projected increase in data rate from such telescopes as PanSTARRS can easily be handled by the MPC. At present, the MPC routinely calculates about 30,000 orbit improvements each day, has more than 60 million observations in its archives, and keeps track of nearly 500,000 objects, of which about 6,000 are NEOs.

The complex process of data analysis and reduction (for example, of the output from the PanSTARRS camera or other telescopes which is carried out at the observatories themselves, not the MPC) are necessary to distinguish moving objects from other data. The MPC in general has no problems with these processes at the observatories, although as advanced telescopes are developed, the observatories will face additional challenges in handling increasingly large amounts of data. As long as adequate funding is provided, the MPC appears to be capable of handling all of the observations generated, even beyond the congressionally mandated survey.

An example of MPC's present capabilities, was demonstrated following the October 2008 discovery of the NEO designated "2008 TC3" by CSS. From CSS observations and those of others who were alerted immediately, the MPC was able to determine that this NEO would strike Earth in the Sudan 19 hours after the discovery, with an uncertainty in location of ~100 kilometers and in time of ~1 minute—all in under 6 hours from the making of the first observations. An official in the chain of command at NASA was awakened with the news shortly thereafter, courtesy of the system in routine

[13] The National Aeronautics and Space Administration Authorization Act of 2008 (H.R. 6063, P.L. 110-422), October 15, 2008, p. 26.

operation. The prediction of impact location was later greatly refined based on further observations, allowing recovery of the resultant meteorites which were then subject to laboratory study.

**Finding: The orbit-fitting capabilities of the Minor Planet Center are more than capable of handling the observations of the congressionally mandated survey as long as staffing needs are met.**

## CHARACTERIZATION OF NEAR-EARTH OBJECTS

Since the ultimate goal is to mitigate the hazard posed by NEOs, it is insufficient to merely discover and track them. Those that pose a hazard are candidates to be characterized, and characterization of non-hazardous objects is useful for understanding the possible hazards. Some NEOs may be monolithic (i.e., solid), whereas others may be loose assemblies of materials (i.e., “rubble piles”). All of them spin, and some of them spin rapidly (for example, 2006 AM4, a 150-meter-diameter NEO, makes a complete rotation every 5 minutes). Further, about 25 percent have companions orbiting about them or attached to them (“contact binaries”).

There are several methods for characterizing NEOs, including ground observations at optical and infrared wavelengths with radar and via spacecraft-rendezvous missions. Currently one of the most effective methods involves radar observations when the NEO is within range for detailed study. Two radar telescopes are used in part to characterize and track NEOs—at the Arecibo Observatory in Puerto Rico and at the Goldstone Deep Space Communications Complex (GDSCC; referred to as the Goldstone Observatory) in California. These facilities’ declination coverages are given in Table 1.

Approximately 20 to 30 NEOs per year are observed from Arecibo and Goldstone. These radar observatories are crucial for very precise initial orbit determination and for characterizing the shape and physical properties of those objects within their range. However, these telescopes cannot be used to discover new objects, because they must be precisely pointed at an object for an extended period of time in order to achieve a useful signal-to-noise ratio.

TABLE 1 Minimum and Maximum Declination Coverage of the Two Active Planetary Radar Facilities

| Radar Facility | Minimum Declination | Maximum Declination | Sky Coverage |
|---|---|---|---|
| Arecibo Observatory | −1 degrees | +38 degrees | 32% |
| Goldstone Observatory | −35 degrees | +90 degrees | 79% |

## THE ARECIBO OBSERVATORY

The Arecibo Observatory radar is a uniquely powerful instrument for the characterization and orbital refinement of NEOs. Arecibo is the world’s most capable planetary radar, but it does have a restricted sky coverage, as noted above. It is about 20 times more sensitive than NASA’s Goldstone Solar System Radar, the world’s only other operational planetary radar; and it can resolve features on NEOs down to several meters in size. Arecibo can obtain this resolution on NEOs that are millions of kilometers from Earth and unresolved by the largest ground- and space-based optical telescopes. Arecibo thus plays an important role in investigation of NEO sizes, shapes, spin states, and surface properties, as well as in discovering companions that often orbit NEOs. Its highest spatial resolution is surpassed only by spacecraft during rendezvous or flyby missions. Figure 2 shows an example of the quality of imagery that can be obtained with Arecibo’s radar. Because of its greater sensitivity, Arecibo provides more frequent opportunities for high-resolution imaging than does Goldstone.

Within its declination coverage, Arecibo has twice the detection range of Goldstone for similarly sized objects and has contributed two-thirds of all radar-determined NEO orbits obtained in the last

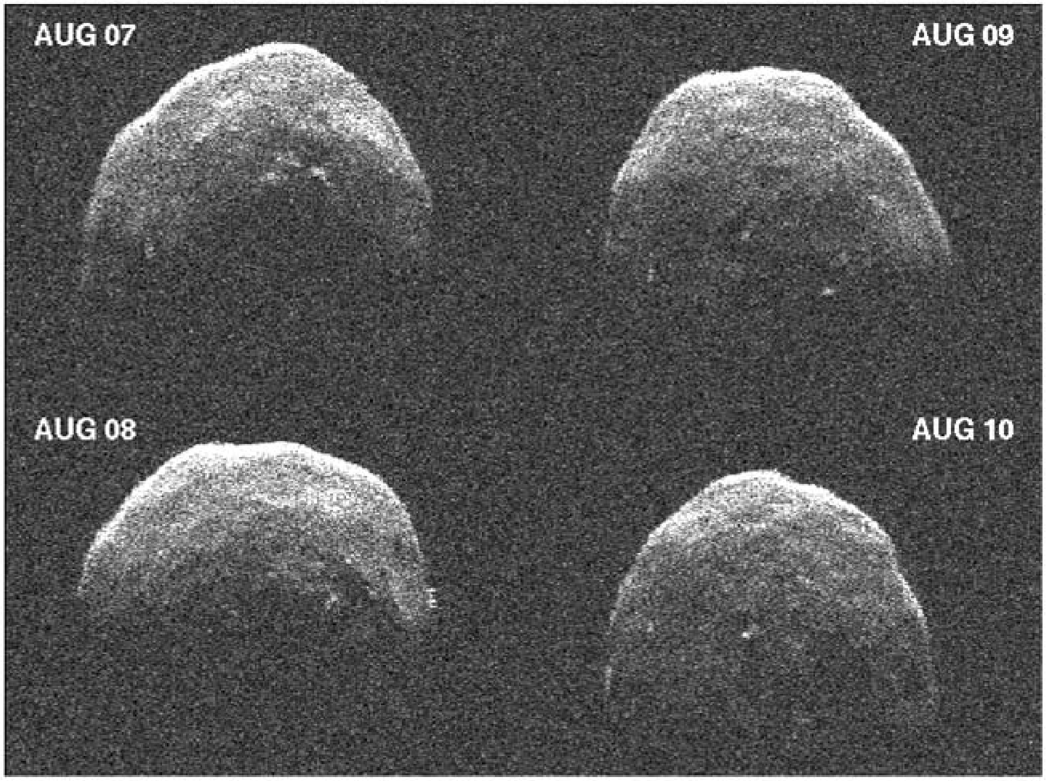


FIGURE 2 Arecibo radar images of 2-kilometer-diameter asteroid 1992 UY4 made from four days' observations in August 2005. Radar images are unusual in that the coordinates are not spatial ones on the plane of the sky. Rather, radar images are in delay and Doppler coordinates, corresponding for each pixel to its (relative) distance from us and its (relative) radial velocity, determined, respectively, by the time delay and Doppler shift of the echo. The delay (distance) resolution for these images is ~5 nanoseconds (7.5 meters, one-way), and the Doppler (velocity) resolution is 0.029 Hertz (~0.2 centimeters/second). The delay coordinate is vertical and the Doppler coordinate is horizontal. SOURCE: Lance Benner, Jet Propulsion Laboratory, California Institute of Technology.

decade. Radar observations can reduce initial NEO orbital uncertainties by factors of up to 100,000, which can very substantially extend reliable prediction estimates. Range measurements can achieve fractional accuracies as high as a part in a billion—orders of magnitude better than optical angle observations. Since completion of a major upgrade in 1999, Arecibo has detected radar echoes from more than 210 NEOs.

Radar is also an effective technique for determining that an NEO is a member of a binary system and for estimating the masses and bulk densities of the binary system members. Arecibo and Goldstone radar observations revealed that at least 25 percent of NEOs larger than 200 meters in diameter are either "contact binaries" or binary systems, as stated above. The only confirmed NEO triple system, 2001 SN263, was discovered at Arecibo.

Arecibo observations of 1950 DA revealed that NEO physical properties are intimately coupled with long-term orbit prediction through the interaction of rotation states and differential thermal emission (the Yarkovsky effect) and through solar radiation pressure, the importance of which depend on asteroid densities, thermal properties, sizes, shapes, and spin vectors. In fact, Arecibo radar observations led to the first detection of the Yarkovsky effect.[14]

[14] NEOs absorb sunlight; as they rotate, they re-radiate infrared energy asymmetrically, producing a net "push" on the NEO, which alters its orbit. This is known as the Yarkovsky effect. It has a greater influence on the orbits of

**Finding: The Arecibo Observatory telescope continues to play a unique role in characterization of NEOs, providing unmatched precision and accuracy in orbit determination and insight into size, shape, surface structure, multiplicity, and other physical properties for objects within its declination coverage and detection range.**

## OTHER CHARACTERIZATION EFFORTS

The Spitzer Space Telescope, currently in solar orbit, can also be used for NEO observation, although it was not designed for this task and is not effective for NEO discovery. Spitzer has recently run out of cryogen and has begun its Warm Mission. Only its 3.6- and 4.5-micron imaging channels are still available. A large program to image all observable known NEOs with Spitzer (~700 objects) at these two wavelengths is scheduled to begin soon. This program will allow improved knowledge of diameters and albedos to be obtained for these NEOs. A project to mine the Spitzer archive for observed NEOs is ongoing and is expected to eventually recover several thousand NEOs. These NEOs will have been previously discovered by other surveys, then located in the Spitzer archive through their known orbits.

## SPACECRAFT MISSIONS TO SMALL PLANETARY OBJECTS

NASA has launched several missions to asteroids and comets over the years. For example, in 1996 NASA launched the Near Earth Asteroid Rendezvous (NEAR Shoemaker) mission which orbited the asteroid Eros for a year and touched down on the surface in February 2001. In early 2005 NASA launched the Deep Impact spacecraft which used an impactor to eject material from the comet Tempel 1 in July 2005. Deep Impact is now part of the EPOXI mission, which is scheduled for a flyby of the comet Hartley 2 in late 2010. NASA's Stardust-NExT mission is heading for a flyby of the Tempel 1 comet in order to image the crater created by Deep Impact. In 2003 the Japanese Aerospace Exploration Agency launched the Hayabusa spacecraft that rendezvoused with the asteroid Itokawa in 2005 and is returning to Earth by 2010, possibly carrying samples from the asteroid. Japan currently has plans for a Hayabusa 2 mission. The European Space Agency (ESA) has launched the Rosetta spacecraft which is scheduled to rendezvous with a comet in 2015 and deploy a lander to touch down on its surface. ESA was also working on a study of the Marco Polo mission for rendezvous with a small asteroid; however, this mission was recently canceled.

## OPTIONS FOR MEETING THE 140-METER-DIAMETER OBJECT DISCOVERY GOAL

The 2007 NASA analysis of alternatives report[15] outlined several alternatives for achieving the discovery goals established in the 2005 NASA Authorization Act. Figure 3 indicates how these alternatives would meet or approach the congressionally mandated goals.[16] The report stated that

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smaller asteroids than of larger ones. Because every NEO has a different shape, composition, and spin state, the Yarkovsky effect is different for every object and therefore complicates the prediction of the long-term orbits of NEOs, particularly small ones.

[15] NASA, *Near-Earth Object Survey and Deflection Analysis of Alternatives Report to Congress*, Washington, D.C., March 2007; available at http://www.nasa.gov/pdf/171331main_NEO_report_march07.pdf.

[16] In common usage, NEOs are asteroids and comets in orbits that allow them to enter Earth's neighborhood, defined by astronomers as having the closest approach to the Sun (known as perihelion) of less than 1.3 astronomical units (AU; 1 AU is approximately 150 million kilometers, the mean distance between the Sun and Earth). A PHO is an object in our solar system that passes within 0.05 AU (about 7.5 million kilometers) of Earth's orbit and is large enough to pass through Earth's atmosphere and cause significant damage on impact, estimated as

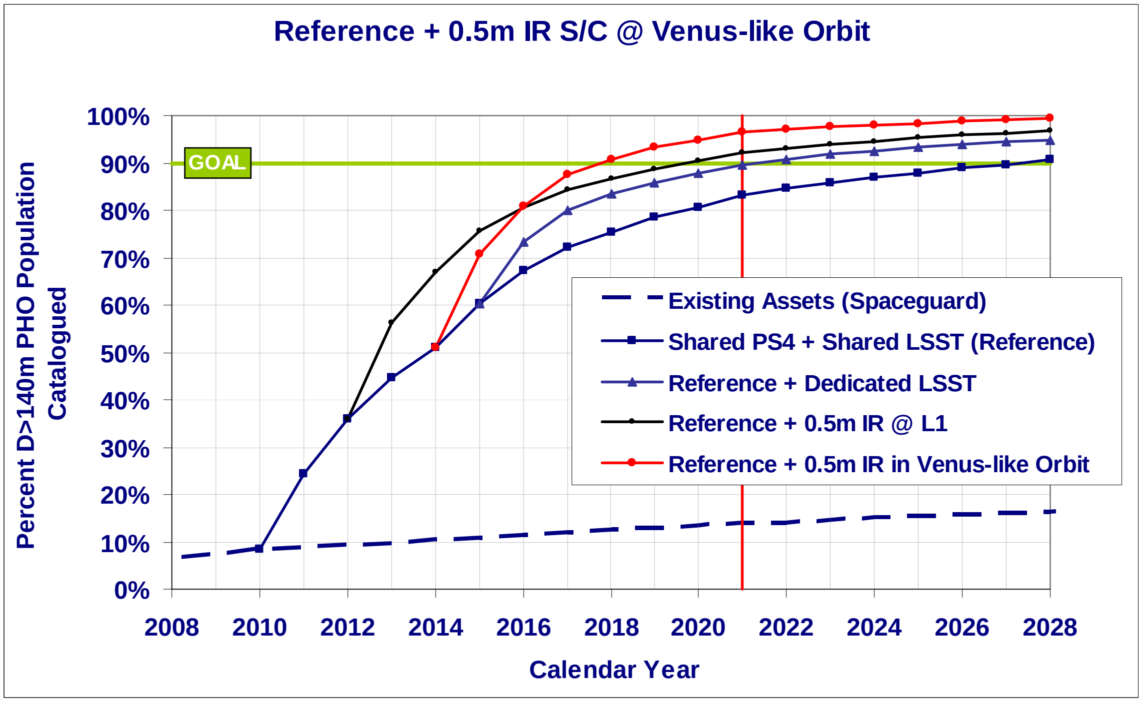


FIGURE 3 A 2006 estimate of ability to meet congressional goal established in the 2005 NASA Authorization Act. The spacecraft options utilize a 0.5-m infrared telescope. Because none of these solutions has been funded, the entire chart should slip to the right by at least 3 years. In addition, the considerable uncertainty for each point on each curve was not included in the chart. NOTE: The vertical axis should be labeled PHA for "potentially hazardous asteroids" instead of PHO for "potentially hazardous objects," which includes comets. SOURCE: Lindley Johnson, NASA, "Near Earth Object Program" presentation to the Committee to Review Near-Earth Object Surveys and Hazard Mitigation Strategies, December 9, 2008.

budgetary constraints precluded any new NASA initiatives for NEO discovery and characterization. The committee notes that this chart does not include the uncertainties for any of these options. In addition, it does not fully take into account the time required to implement each of these options. Figure 3 also assumes that funding for these options would be included in the FY 2010 budget; however, no funding was provided.

The committee sought input from several knowledgeable sources about the accuracy of NASA's predictions for meeting the congressionally mandated goal using various methods. Based on this input, the committee concluded that the chart was likely a good *general indication* of the ability of various alternatives to accomplish this goal, demonstrating that in order to achieve the 90 percent goal, additional resources are required. However, there remains considerable uncertainty about how effective each option would be at discovering the required percentage of NEOs. The primary issue is that *none* of these alternatives is currently fully funded.

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about 50 meters or larger in diameter. PHAs are currently defined based on parameters that measure the asteroid's potential to make threatening close approaches to Earth. Specifically, all asteroids with an Earth minimum orbit intersection distance of 0.05 AU or less and an absolute magnitude of 22.0 or less are considered PHAs. In other words, asteroids that *cannot* get any closer to Earth than 0.05 AU (roughly 7,480,000 kilometers or 4,650,000 miles) or are smaller than about 150 meters (500 feet) in diameter (i.e., H=22.0, with assumed albedo of 13%) are *not* considered PHAs.

## INTERNATIONAL EFFORTS

Despite expressions of interest in various countries around the globe, the majority of search efforts and funding for discovering NEOs comes from the United States. Several smaller projects, such as the Beijing Schmidt CCD Asteroid Program (no longer operational) and the Asiago DLR Asteroid Survey (an ongoing joint venture between the German Aerospace Agency's [DLR's] Institute of Space Sensor Technology and Planetary Exploration, the University of Asiago, and the Astronomical Observatory of Padua in Italy), have made some inroads on detecting NEOs, but not on the scale of the U.S. projects. In addition, with the notable exception of Canada, through its Near-Earth Object Surveillance Satellite (NEOSSat) mission, and Germany, via its AsteroidFinder mission, which are both relatively limited in scope, no other countries have committed funding for a "next generation" NEO-discovery program.

### AsteroidFinder

The German Aerospace Agency has selected AsteroidFinder as the first payload to be launched under its new national compact satellite program. Currently the spacecraft is planned to launch sometime in 2012 with a 1-year baseline-mission duration and the possibility of an extension; this mission is funded through the development stage. It will be equipped with a 30-cm telescope mirror. Its primary science goals are to estimate the population of NEOs interior to Earth orbit, their size-frequency distribution, and their orbital properties. AsteroidFinder will also aid in the assessment of the impact hazard due to NEOs and provide a space-based platform detecting space debris from artificial satellites. This mission will be part of ESA's Cosmic Vision Program and the soon-to-be-developed ESA Space Situational Awareness initiative.

### Near-Earth Object Surveillance Satellite

NEOSSat is currently in development and is being constructed in Canada as a joint venture between the Canadian Space Agency (CSA) and Defense Research and Development Canada, an agency of the Canadian Department of National Defence. NEOSSat is based on a previous satellite, MOST, launched in 2003, that remains operational long after completion of its initial mission. Set to launch in mid 2010, NEOSSat is scheduled to operate continuously for at least one year and should operate considerably longer.

NEOSSat will conduct two simultaneous projects during its operational lifetime—High-Earth Orbit Surveillance System (HEOSS), which will monitor and track human-made satellites and orbital debris, and Near-Earth Space Surveillance (NESS), which will discover and track NEOs. NEOSSat will be the first satellite to be built on Canada's Multi-Mission Microsatellite Bus and will be roughly the size of a large suitcase with a mass of approximately 75 kg. It will have a 15-cm mirror. This microsatellite will operate in a Sun-synchronous orbit at an altitude of ~700 km.

NEOSSat will be the first dedicated space platform designed to obtain observations on both human-made and natural objects in near-Earth space. The NESS project will focus primarily on discovering NEOs whose orbits are partially or fully inside Earth's. NEOSSat will expand overall knowledge of NEOs, monitor them for cometary activity, perform follow-up tracking of newly discovered targets, aid in the development of asteroid search and tracking algorithms for space-based sensors, and explore the synergies between ground- and space-based facilities involved in NEO discovery and characterization.

**Finding: The United States is the only country that currently has an operating survey/detection program for discovering near-Earth objects; Canada and Germany are both building spacecraft**

**that may contribute to the discovery of near-Earth objects. However, neither mission will detect fainter or smaller objects than ground-based telescopes.**

## QUESTIONS THE COMMITTEE INTENDS TO ADDRESS IN THE FINAL REPORT

The committee's final report, due by the end of 2009, will address the survey/detection, characterization, and mitigation issues associated with NEOs. Although mitigation scenarios frequently attract the most attention in the press and from the public, the committee notes that the discovery of NEOs is the nearer-term problem and also will ultimately shape and constrain the options for mitigation. However, the committee is still exploring these various aspects of the problem and their interrelationships. Below are some, but certainly not all, of the questions that the committee hopes to address in its final report.

### *Are the congressional deadline (90 percent by 2020) and object size (~140 meters) appropriate? Or should they be changed?*

Congress has charged the committee to recommend ways to provide discovery and (partial) characterization of 90 percent of NEOs exceeding 140 meters in diameter by the year 2020. These parameters represent a reasonable compromise in addressing a complex problem. The committee was instructed by congressional staff to consider whether or not the congressionally established discovery goals should be modified. One possible issue is that smaller NEOs, ranging down to 20 meters in diameter, may pose serious regional threats to urban areas, and their impacts are far more frequent than those of larger objects. Therefore, the committee will keep the parameters open while continuing to study the tradeoffs among detection efficiency and object size and lethality.

In short, the committee continues to study whether the goal of discovering 90 percent of NEOs exceeding 140 meters in diameter by the year 2020 represents an optimal response to the NEO impact threat.

### *What could we do to ensure that our existing resources for conducting survey programs maximize the warning times for imminent impacts?*

Imminent impacts (i.e., those with very short warning times of hours or weeks) may require an improvement in current discovery capabilities. Existing surveys are not designed for this purpose; they are designed to discover more-distant NEOs and to provide years of advance notice for possible impacts. In the past, objects with short warning times have been discovered serendipitously as part of surveys having different objectives. Search strategies for discovering imminent impacts need to be considered, and current surveys may need to be changed.

### *How do mitigation approaches differ for large versus small impactors and for short versus long warning times?*

Different mitigation approaches will be required for different cases. The key parameters appear to be the kinetic energy (i.e., mass times impact velocity squared divided by two), the physical characteristics of the NEO, and the time from recognition of the threat until impact. The committee will be considering which mitigation techniques make the most sense in various cases and will also be considering which techniques should be developed first. This priority for development will require an understanding of the relative risk associated with various scenarios.

Because asteroid impacts can occur with warning periods ranging from hours to many centuries, and dangerous impacting objects can range from a few tens of meters to many kilometers in diameter, and can be composed of ice, rock, or metallic iron, it is unlikely that any one mitigation strategy will offer a universal defense. Instead, each plausible strategy (and others yet to be conceived) should have its own place in a matrix of possible responses whose elements depend on the parameters of the particular threat. The effectiveness of various technologies could be evaluated by demonstration experiments as budgets permit.

***Given experience to date with international collaboration on surveys, how should international collaboration play a role in the future to address NEO issues?***

The committee notes that there is worldwide interest in the issue of the hazard from NEOs, both among scientists and among governmental agencies. However, virtually no international funds are spent supporting ground-based NEO surveys, and international NEO discovery efforts are largely conducted on an ad hoc, voluntary, or amateur basis. NASA is the agency that has funded more than 97 percent of the discoveries of NEOs in the last decade.

Survey/detection is the non-controversial part of addressing the potential NEO threat and yet international activity is extremely limited. In contrast, mitigation raises many important international issues—for example, the possibility of partially deflecting an object so that it falls somewhere else on Earth.

## CONCLUSION

Although the threat posed to human life by near-Earth objects has received much attention in the media and popular culture, with numerous movies and television documentaries devoted to the subject, to date there has been relatively little effort by the U.S. government to survey, discover, characterize, and mitigate the threat. Requirements have been imposed on NASA in this area without the provision of funds to address them. Despite this problem, the United States is still the most significant actor in this field with few exceptions,, if only because other countries have devoted negligible resources to it. If the threat of NEOs and solutions to deal with that threat are to be further explored, additional resources will be required, such as for completion of dedicated telescopes and increased funding for existing key facilities and research and analysis programs.

# Appendixes

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# Near-Earth Object Surveys and Hazard Mitigation Strategies

## Interim Report

Committee to Review Near-Earth Object Surveys and Hazard Mitigation Strategies
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Aeronautics and Space Engineering Board
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[1] Major General Bolden became NASA administrator on July 17, 2009, after writing and review of this report was completed.

# Preface

The Consolidated Appropriations Act, 2008,[1] required NASA to ask the National Research Council (NRC) to conduct a study of near-Earth object (NEO) surveys and hazard mitigation strategies. Near-Earth objects orbit the Sun and approach or cross Earth's orbit. In a June 2, 2008, letter, James L. Green, director, Planetary Science Division, NASA, and Craig Foltz, acting director, Astronomical Sciences Division, National Science Foundation (NSF), wrote to Lennard Fisk, then chair of the Space Studies Board, requesting that the Space Studies Board, in cooperation with the Aeronautics and Space Engineering Board conduct a two-part study to address issues in the detection of potentially hazardous NEOs and approaches to mitigating identified hazards (See Appendix A). The ad hoc Committee to Review Near-Earth Object Surveys and Hazard Mitigation Strategies consists of a steering committee, a panel on survey/detection, and a panel on mitigation. (See Appendix B for the committee's statement of task.)

The statement of task requires the committee to include an assessment of the costs of various alternatives, using independent cost estimating. Options that blend the use of different facilities (ground- and space-based) or involve international cooperation may be considered. Each study phase will result in a report to be delivered on the schedule provided below. Key questions to be addressed during each phase of the study are the following:

**Task 1: NEO Surveys**

What is the optimal approach to completing the NEO census called for in the George E. Brown, Jr. Near-Earth Object Survey section of the 2005 NASA Authorization Act[2] to detect, track,[3] catalogue, and characterize the physical characteristics of at least 90 percent of potentially hazardous NEOs larger than 140 meters in diameter by the end of year 2020? Specific issues to be considered include, but are not limited to, the following:

- What observational, data-reduction, and data-analysis resources are necessary to achieve the Congressional mandate of detecting, tracking, and cataloguing the NEO population of interest?
- What physical characteristics of individual objects above and beyond the determination of accurate orbits should be obtained during the survey to support mitigation efforts?
- What role could be played by the National Science Foundation's Arecibo Observatory in characterizing these objects?
- What are possible roles of other ground- and space-based facilities in addressing survey goals, e.g., potential contributions of the Large Synoptic Survey Telescope (LSST) and the Panoramic Survey Telescope and Rapid Response System (Pan STARRS)?

[1] Consolidated Appropriations Act, 2008 (H.R. 2764; P.L. 110-161), Division B—Commerce, Justice, Science, and Related Agencies Appropriations Act, 2008. December 26, 2007.

[2] National Aeronautics and Space Administration Authorization Act of 2005 (P.L. 109-155), S. 1281, January 4, 2005, Section 321, George E. Brown, Jr. Near-Earth Object Survey Act.

[3] The committee notes that although the statement of task includes the term "detect," which includes spotting asteroids that have previously been discovered. The committee therefore uses the more appropriate term "discover" to refer to the locating of previously unknown objects.

**Task 2:  NEO Hazard Mitigation**

What is the optimal approach to developing a deflection capability, including options with a significant international component?  Issues to be considered include, but are not limited to, the following:

- What mitigation strategy should be followed if a potentially hazardous NEO is identified?
- What are the relative merits and costs of various deflection scenarios that have been proposed?

NASA and NSF requested an initial report for the first task no later than September 30, 2009. This interim report responds to that requirement, although the committee's work on this task is not yet complete.

Congress has charged the committee to recommend ways to discover and (partially) characterize 90 percent of NEOs exceeding 140 meters in diameter by the year 2020 (smaller objects are not discarded, once found).  However, during its first meeting, the committee was explicitly asked by congressional staff to consider whether or not the congressionally established discovery goals should be modified.  The committee's work on this task is also incomplete.

In addition to evaluating the capability of currently available resources, the committee is studying a range of proposals for future surveys. The committee will evaluate these proposals in terms of their implications for NEO discovery and/or characterization. These proposals range from space-based missions in the infrared to ground-based surveys in the visible spectrum, to be conducted with various aperture sizes and numbers of telescopes. The committee will also consider combinations of these proposed projects, including combinations of ground- and space-based approaches. This consideration of projects and of the costs associated with them is necessary to formulate recommendations for possible future congressional action.

The committee has thus deferred most of its findings and all of its recommendations for the final report, due at the end of 2009.

# Acknowledgments

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the Report Review Committee of the National Research Council (NRC). The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Erik Asphaug, University of California, Santa Cruz,
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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Louis J Lanzerotti, New Jersey Institute of Technology. Appointed by the NRC, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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