**Statement of**

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**before the**

**Subcommittee on Science, Technology and Space**
**Committee on Commerce, Science, and Transportation**
**United States Senate**

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Thank you, Mr. Chairman, for the opportunity to present to the subcommittee information on the important subject of Near Earth Objects. At the request of Congress, NASA conducts the Near Earth Object (NEO) Observation Program to discover the larger sized asteroids (greater than 1 kilometer or 0.62 miles in size) and periodic comets that pass relatively close to the Earth and may one day pose a collision hazard with our planet. Our NEO program has been quite successful in finding these larger objects in the first five years of the effort.

## BACKGROUND

The Earth orbits about the Sun in a cloud of planetary debris still left from the formation of the Solar System. This debris ranges from micron-sized dust particles, to meteoroids at sand grain to a few meters in size, and to asteroids and comets that are tens of meters to several kilometers in dimension. Collision with meter-sized meteoroids is almost a weekly event for the Earth, but the surface is well protected from these common events by its atmosphere, which will cause objects less than about 50 meters in size and of average density to disintegrate harmlessly before reaching the ground. However, even the relatively active surface of the Earth still bears scars of impacts from space, with 168 craters worldwide – some up to 300 kilometers in size – having been identified to date.

Though collisions with larger bodies are much less frequent now than in the early stages of planet formation in the Solar System, they do still occur. Very significant events, capable of causing damage at the surface, will happen on scales of a few hundred to a thousand years. But we do not know when the next impact of an object of sufficient size to cause widespread devastation at ground level may occur. At the current state of knowledge, it is about as likely to happen next week as in a randomly selected week a thousand years from now.

## The Survey

In an effort to gain better understanding of this hazard, NASA has been conducting a search of space near the Earth's orbit to understand the population of objects that could do significant damage to the planet should there be a collision. Commonly referred to as the "Spaceguard Survey", NASA's Office of Space Science conducts this research effort on "Near Earth Objects (NEOs)" -- that is, asteroids and comets that come within an astronomically close distance, <50 million kilometers of Earth. The objective of this survey is to detect, within a 10-year period, at least 90% of the NEOs that are greater than 1 kilometer in size and to predict their orbits into the future. The survey officially started in 1998 and to date, over 700 objects of an estimated population of about 1100 have been discovered, so the effort is believed to now be over 70% complete and well on the way to meeting its objective by 2008.

A few words of explanation on the parameters and limitations of the survey may be appropriate. The threshold of 1 kilometer in size was accepted for this survey because it is about the size asteroid that current research shows would border on having a devastating worldwide effect should an impact occur. Because of the orbital velocities involved, impact on Earth of an asteroid of this size would instantly release energies calculated to be equivalent to the detonation of almost a 100,000 megaton nuclear device, i.e., more than all the world's nuclear arsenals detonated at the same time. Not only would the continent or ocean where the impact occurs be utterly devastated, but the effects of the super-heated fragments of Earth's crust and water vapor thrown into the atmosphere and around the world would adversely affect the global weather for months to years after the event. Such an event could well disrupt human civilization anywhere from decades to a century after an impact.

A goal of 90% completeness was adopted as a compromise driven between the level of resources that could be dedicated to this effort and the time period practical to conduct the survey at this level of technical capability. Currently, slightly over $4M per year is budgeted to the NEO Observation Program within the Solar System Exploration Division's Supporting Research and Analysis Program. This funds modest search efforts, typically using refurbished, ground-based telescopes of about 1-meter aperture and wide-field-of-view, coupled with digital imaging in order to cover significant portions of the sky each month. Presently, five NEO search projects are either wholly or largely funded with this level of resource, along with significant support to central processing of observations, orbit determination and analysis. These five search projects are:

| PROJECT NAME | INSTITUTE | PRINCIPAL INVESTIGATOR |
|---|---|---|
| Lincoln Near Earth Asteroid Research (LINEAR) | MIT / Lincoln Laboratory, MA | Dr. Grant Stokes |
| Near Earth Asteroid Tracking (NEAT) | Jet Propulsion Laboratory, CA | Dr.Ray Bambery |
| Lowell Observatory Near Earth Object Search (LONEOS) | Lowell Observatory, AZ | Dr. Edward Bowell |
| Catalina Sky Survey | LPL, University of Arizona | Mr. Steve Larson |

| | | |
|---|---|---|
| Spacewatch | LPL, University of Arizona | Dr. Robert McMillan |

Both the LINEAR and NEAT projects operate using optical telescope facilities owned and supported by research components of the U.S. Air Force. This represents that service's entire contribution to the search effort, but utilization and direction of these assets must be coordinated with the cognizant Air Force Material Command offices. The Spacewatch Project also receives some modest private funding.

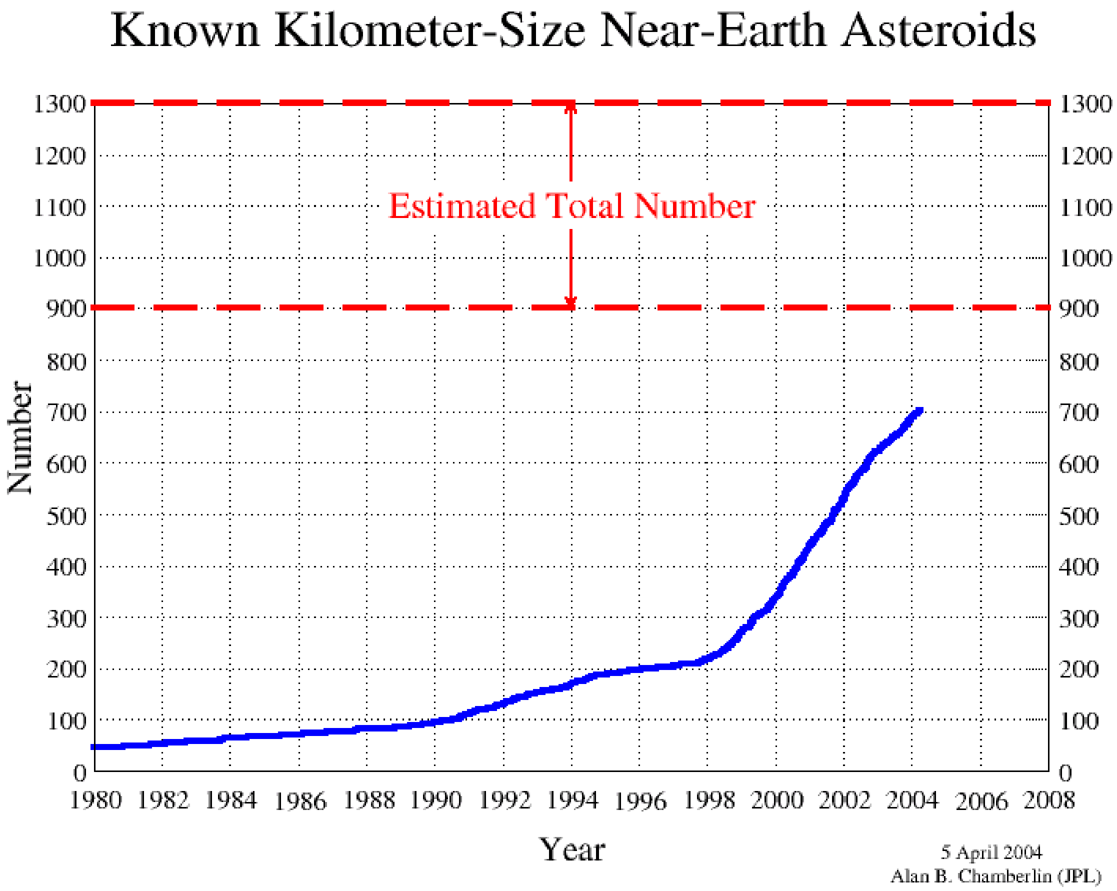
Ten years was considered a reasonable amount of time for this level of effort to bring the overall large asteroid population known to 90% completeness. No level of effort could ever be assured of achieving absolute 100% completeness, because of the vast difficulty in searching all possible orbit regimes and sources for generation of new NEOs. It should also be understood that the NEO Observation Program is merely a science survey and does not have the resources to provide a "leak-proof" warning network for impact of any size natural object, large or small. Such a comprehensive network would require an order of magnitude increase in funding and could require the cooperative efforts of several government departments and agencies.

## PROGRESS OF THE PROGRAM.

The NEO Observation Program continues to make steady progress toward the goal of finding at least 90% of the large NEO population. As of the end of March 2004, 513 of the 750 known NEOs (including 49 Earth-approaching comets) determined to be larger than 1 kilometer in size have been found by the program, of an estimated total population of about 1100. In addition, the program found 1862 of 2032 known Near Earth Asteroids (NEAs) of smaller sizes. The MIT/Lincoln Labs-led LINEAR project continues to be the leading search team, having found 40 large NEOs in 2003 along with 196 smaller objects. Significant contributions continue to be made by JPL's NEAT team (10 large and 58 smaller objects in the last year), Lowell Observatory's LONEOS project (10 and 44), and the University of Arizona's Spacewatch project (2 and 54). The Lunar and Planetary Laboratory Catalina Sky Survey has gotten back on line in the last few months of the year after an imager upgrade, obtaining 8 discoveries, 2 of them larger than 1 km.

The chart below summarizes the progress to date on finding the NEAs greater than 1 kilometer in size. A noticeable increase in the discovery rate occurs after the NEO Observation Program started in 1998.

**Budget.** The FY 2004 budget for this program is $4,062K, a 2.8% increase to the previous year.



5 April 2004
Alan B. Chamberlin (JPL)

## CURRENT SURVEY OPERATIONS

**Detection.** The NEO Observation Program wholly funds the operations of four search projects and partially funds another. Routine operation of these assets is highly automated, in order to maximize the sky coverage obtained each month. Ground-based telescopes can only effectively operate at night during the two to three weeks of the month opposite the full moon, due to the sky brightness it causes, and when weather (cloud cover) permits accessible clear sky. Telescope movement, pointing, and imaging operations are all computer controlled via pre-scripted software routines to optimize sky coverage and therefore maximize object detections.

The images taken each night are then post-processed to detect moving objects relative to the star background and obtain accurate measurements, called "observations", of any detected object's motion relative to the star background (a process called "astrometrics"). A group of these observations, usually a set taken from three to five images of the same patch of sky at slightly different times each night, is called a "track". These show the relative motion of an object, which can then be analyzed with other observations of the same object to determine its orbit. These observation tracks are then formatted for bulk telecommunications to the Minor Planet Center. On a productive night, a search project may extract hundreds of observations on moving objects from its imaging data, most of which will be on Main Belt Asteroids and only a small fraction, perhaps one or two if lucky, will be determined to be NEOs. The search teams also routinely find comets in their collected images.

**The Minor Planet Center.** All observations thought to be natural small bodies (asteroids, comets and now Kuiper Belt Objects in the outer Solar System) are sent to the Minor Planet Center (MPC), operated by the Smithsonian Astrophysical Observatory at Cambridge, Massachusetts, under the direction of Dr Brian Marsden. The MPC is internationally recognized and officially chartered by the International Astronomical Union to confirm the discovery of new objects in the Solar System and confer their official designations. A modest amount of NASA funding is sent to the MPC to support their work in confirming NEO detections.

The MPC receives observations from around the world, with a significant percentage coming from an informal international network of amateur asteroid hunters. The orbital analyst at MPC attempts to correlate them with the positions of tens of thousands of already known objects. Failing that, the MPC will provisionally designate the observations as a possible new object, determine an "initial" orbit for it, and place it on a list for objects awaiting "confirmation". This list of provisional objects, along with their predicted current positions, is available via the MPC web site for the community of observers to use in attempts to obtain additional "follow-up" observations to confirm the existence and orbit parameters of a new object.

The observation processing at the MPC is highly automated, as it must be with a staff of only three to four analysts operating with a very limited budget. However, initial orbit determination often requires some analyst's massaging of the orbit fit to obtain the lowest residuals across what may be observations with some inherent errors. Because individual search sites can only do the roughest of orbit calculations based on their own limited data, the MPC is, in most cases, the first place where it will be known if a newly found object poses an impact hazard to the Earth. Often a family of possible orbits is initially obtained which must be narrowed with additional observations. For newly found NEOs, the MPC solicits additional observations from the community via a web-based “NEO Confirmation Page”, and in the most critical cases, via phone calls to known observers in whatever part of the world is most likely to have the earliest accessibility to viewing the object.

**Follow-up Observations.** Additional observations, either obtained by another observer later the same night or on a subsequent night, even by the same facility that first discovers an object, are essential to confirming the objects existence and developing a more accurate orbit for the object. For the most accurate orbit, it is best for the observations to be obtained several days to a week or more after the initial set in order to obtain a longer observed “arc” of the orbit and, therefore, a broader fit of observation data. However, for NEOs, the time allowed to elapse must be traded off between obtaining a broader arc and getting an orbit established before the object is lost, either because the initial orbit was too far in error, or, more likely, the object is so small that it simply cannot be seen after only a few days of its closest approach to Earth.

The informal network of amateur astronomers does much of the follow-up observation work today. However, the search for NEOs is beginning to enter an era when the objects being detected are simply too faint to be seen by the equipment affordable to most amateurs. Therefore, in the future, search systems must ensure they have enough survey capacity available to do their own follow-up on new objects in a timely manner.

**High-accuracy Orbit Determination.** The best orbit determination requires enough observations spread over a sufficient arc of the orbit to provide the best resolution of motion for the object, and reduce the influence of subsets of data that may have some components of error. Again, getting the best results can be somewhat of an art form, but the best orbital modeling for this reside with the NEO Program Office established by NASA at the Jet Propulsion Laboratory in Pasadena, California, and managed by Dr. Donald Yeomans. This office also supports the orbit determination and navigation for NASA’s interplanetary missions to asteroids, comets, and moons of other planets. Its NEO work is fully funded by NASA, and the high-accuracy orbit determination capability is nicely complementary to the MPC’s observation processing and initial orbit determination abilities.

**The NEO Program Office** is able to use its orbital modeling capability to predict the position of any known NEO up to 200 years into the future, taking into account all the known gravitational influences and orbital perturbations of the Sun, planets, and moons in the Solar System. This can be done with a very high degree of precision for asteroids that have been tracked for extended periods, particularly multiple orbits, or for which high-precision observations have been taken by planetary radar. High-precision radar observations can greatly reduce the position and motion errors for the subset of objects that come close enough to the Earth to allow its use.

High-precision prediction of newly discovered NEO orbits allows them to be separated into those whose orbits will not be a collision hazard to Earth for the foreseeable future and those which are in orbits that pass close enough to Earth’s that they may someday pose a hazard. These “Potentially Hazardous Asteroids (PHAs)” are about a 20% subset of all NEOs found. Of course, known and unknown errors in the NEO’s orbital parameters can propagate out to significant uncertainty in the position when predictions are done decades into the future.

Therefore, periodic observation of known objects, especially those known to be in potentially hazardous orbits, must be done to update the last known position and reduce the orbit errors.

## Low Probability, High Consequence Events on Short Timelines

A central premise of the current survey effort is that in the relatively short 10-year period, the search teams would be able to find almost all asteroids of greater than 1 kilometer dimension that might pose a threat of impact – many years to multiple decades before any such event. It could perhaps even provide many centuries advanced notice, since this level of event is thought to happen only once or twice in a million years. Hypothetically, this would allow ample time to develop the techniques and technologies that may be required to deflect or mitigate a predicted disaster. But until the total population of these objects is known, there is always a chance that an object bound for a nearer term impact may be discovered, similar to the real-life scenario which unfolded when Comet Shoemaker-Levy 9 was discovered in March 1993 inbound for a July 1994 impact on Jupiter.

The results of a recent study by a Science Definition Team commissioned by NASA's Solar System Exploration Division show that it is entirely appropriate that we search for the larger NEOs first because, all factors considered, that is where the greatest risk for an undetected asteroid on an impact trajectory lies, principally due to the widespread devastation it would cause. It is orders of magnitude above what smaller, sub-kilometer sized impactors would produce. Completion of the current effort to find these large objects will do much to reduce the uncertain risk of which we have now become aware.

But more frequent would be the discovery of a relatively small asteroid on a potential impact trajectory with Earth, as these impacts occur more often. Since the optical sensors used in the survey detect the brightness of the object against the sky background, which can only be approximately related to an asteroid's size based on assumed reflectivity of light, the search systems are as capable of finding smaller asteroids at closer range as larger objects much farther away. They are designed to detect 1 kilometer sized asteroids at least 50 million kilometers distant but can also detect an asteroid a dozen meters in size within the Moon's distance from Earth.

Operational experience with the current systems shows that for every 1-kilometer or greater sized asteroid found, there are three to four smaller sized asteroids also discovered. But the true ratio of smaller asteroids, say 100-meter or larger objects to 1-kilometer or larger objects, is thought to be closer to 100 to 1. Because of the limitations of the search systems, the discovery of smaller asteroids is in a significantly smaller volume about the Earth -- an object one tenth the size of another must be about hundred times closer to be seen by the sensor, assuming equal reflectivity of their surfaces. If the sensor can detect a 1 kilometer sized asteroid at 50 million kilometers, it should theoretically also see a 100-meter asteroid at 500,000 kilometers.

However, at planetary relative orbital velocities, if the object is on collision course with the Earth, it may cover even this distance in less than one day. Thus the detection of a relatively small asteroid on a collision trajectory with Earth could also come with a relatively short reaction time. A 100 meter asteroid on direct collision with Earth could do significant damage at the surface as this is estimated to result in an approximately 50 megaton energy release at or perhaps slightly above the surface. This would result in much loss of life if the impact were in a populated area. It is therefore prudent that we begin to put in place some contingency plans, such as an internal NASA notification plan we are drafting, to deal with such a relatively unlikely but extremely high-consequence event.

Again I thank you for the opportunity to appear and would be happy to respond to any questions.

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