S. HRG. 108–1020

NEAR EARTH OBJECTS

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED EIGHTH CONGRESS

SECOND SESSION

APRIL 7, 2004

Printed for the use of the Committee on Commerce, Science, and Transportation

U.S. GOVERNMENT PUBLISHING OFFICE

21–399 PDF WASHINGTON : 2016

For sale by the Superintendent of Documents, U.S. Government Publishing Office
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ONE HUNDRED EIGHTH CONGRESS

SECOND SESSION

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NEAR EARTH OBJECTS

WEDNESDAY, APRIL 7, 2004

U.S. SENATE,
SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Committee met, pursuant to notice, at 2:30 p.m. in room SR–253, Russell Senate Office Building, Hon. Sam Brownback, presiding.

OPENING STATEMENT OF HON. SAM BROWNBACK, U.S. SENATOR FROM KANSAS

Senator BROWNBACK. The hearing will come to order. Thank you all very much for coming today. My apologies for being nearly a half hour late. We had two votes scheduled back to back and I had to go over and vote. I apologize for that to our witnesses and to others.

We appreciate people being able to come particularly on this Holy Week of Passover and Easter. It's quite a week and I appreciate our witnesses are willing to come into town for this particular important hearing that we're having.

Most people have watched Hollywood movies about asteroids, or more correctly "Near-Earth Objects"—NEOs for short—striking the Earth. Yet few know what is real and what is not. Fewer still know what your government is doing about this threat, or not doing for that matter.

Asteroid 2004FH, approximately 100 feet wide, passed within about 25,000 miles of the Earth on March 18, 2004. This is equivalent to riding in an airliner and seeing a small plane suddenly pass a few hundred feet off the wing. It's a pretty scary occurrence. Had this asteroid hit the Earth, as a somewhat bigger one did in 1908, it would have released over a megaton of energy. This is the explosive yield of a large nuclear weapon. Yet we had only a few days warning of Asteroid 2004FH. Other similar objects just missed us in the past few years and we didn't even see them until they were past.

Scientists tell us that a big asteroid, ten miles in diameter, destroyed the dinosaurs 65 million years ago. Asteroids are the small bits left over from the formation of the solar system billions of years ago. If we look up at the moon we can see the results of billions of years of bombardment in its shattered face. The Earth suffered similar hits but most have healed due to Earth's weather and geological processes.

Small asteroids hit the Earth every year; about thirty struck the upper atmosphere last year. They each release as much energy as a small atomic bomb. Fortunately the atmosphere protects us from these little asteroids. But ones such as the March 18 object could devastate a large city. Experts tell us that we run about the same risk of dying in an airline crash as we do dying from an asteroid strike. This is serious and warrants serious attention by our government.

The President's new space exploration vision mandates that we focus our attention on the opportunities inherent in moving human presence into the solar system. But it also raises the question as to potential threats out there. Panels of experts have met over the past few years. All tell us that the threat of NEO impact is real. At the smallest scale, those that strike us several times a month could be confused in a crisis as a nuclear attack. Asteroids the size of the one a few weeks ago hit Earth several times a century. The experts also tell us that we could have the ability to detect these objects before they hit and do something about it.

Today we are meeting to consider whether Congress should pass legislation to do something about this threat from space. We will hear from program managers within NASA and the National Science Foundation on what is being done now and what is planned.

We will hear from the experts in our scientific community on what they recommend we do to find the threatening objects before they hit. We will hear from space development experts on how we could build spacecraft quickly and cheaply to meet threatening objects deep in space to find out about them and divert them as necessary.

And finally, we will hear from former and current astronauts how these objects might fit into the President's exciting new space exploration vision, both as targets for scientific exploration and commercial use, as well as how to divert the threatening ones.

For the first time in this planet's long history, the life that lives here can take control of its own long-term destiny in this regard. The clockwork of the solar system eliminated dinosaurs. Humans were one result of that event. The question before us is to whether and how humans will deal with this aspect of our collective future.

I want to enter into the record then as well, a statement from Congressman Dana Rohrabacher who could not be here with us today. They are on break on the House side and he has proposed a bill to deal with Near Earth Objects and that will be put into the record.

[The information referred to follows:]

108TH CONGRESS
2D SESSION

H. R. 3813

To provide for a Near-Earth Object Survey program to detect, track, catalogue, and characterize certain near-earth asteroids and comets.

IN THE HOUSE OF REPRESENTATIVES

FEBRUARY 11, 2004

Mr. ROHRABACHER introduced the following bill; which was referred to the Committee on Science

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A BILL

To provide for a Near-Earth Object Survey program to detect, track, catalogue, and characterize certain near-earth asteroids and comets.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "George R. Brown Near-Earth Object Survey Act".

SEC. 2. FINDINGS.

The Congress makes the following findings:

(1) Near-Earth objects pose a serious and credible threat to humankind, as scientists are certain that a major asteroid or comet was responsible for

the mass extinction of the majority of the Earth's species, including the dinosaurs, nearly 65,000,000 years ago.

(2) Similar objects have struck the Earth or passed through the Earth's atmosphere several times in the Earth's history and pose a similar threat in the future.

(3) Several such near-Earth objects have only been discovered within days of the objects' closest approach to Earth, and recent discoveries of such large objects indicate that many large near-Earth objects remain undiscovered.

(4) The efforts taken to date by the National Aeronautics and Space Administration for detecting and characterizing the hazards of Earth orbit-crossing asteroids and comets are not sufficient to the threat posed by such objects to cause widespread destruction and loss of life.

SEC. 3. DEFINITION.

For purposes of this Act, the term "Administrator" means the Administrator of the National Aeronautics and Space Administration.

SEC. 4. NEAR-EARTH OBJECT SURVEY.

(a) SURVEY PROGRAM.—The Administrator shall plan, develop, and implement a Near-Earth Object Survey program to detect, track, catalogue, and characterize the physical characteristics of near-Earth asteroids and comets equal to or greater than 100 meters in diameter in order to assess the threat of such near-Earth objects in striking the Earth.

(b) AMENDMENTS.—Section 102 of the National Aeronautics and Space Act of 1958 (42 U.S.C. 2451) is amended—

(1) by redesignating subsection (g) as subsection (h);

(2) by inserting after subsection (f) the following new subsection:

"(g) The Congress declares that the general welfare and security of the United States require that the unique competence of the National Aeronautics and Space Administration in science and engineering systems be directed to detecting, tracking, cataloguing, and characterizing near-Earth asteroids and comets in order to provide warning and mitigation of the potential hazard of such near-Earth objects impacting the Earth."; and

(3) in subsection (h), as so redesignated by paragraph (1) of this subsection, by striking "and (f)" and inserting "(f), and (g)".

(c) ANNUAL REPORT.—The Administrator shall transmit to the Congress, not later than February 28 of each of the next 5 years beginning after the date of enactment of this Act, a report that provides the following:

(1) A summary of all activities taken pursuant to subsection (a) for the previous fiscal year.

(2) A summary of expenditures for all activities pursuant to subsection (a) for the previous fiscal year.

(3) A detailed plan and budget request for all activities pursuant to subsection (a) for the next five fiscal years from the year that the annual report is submitted.

(d) AUTHORIZATION OF APPROPRIATIONS.—There are authorized to be appropriated to the National Aeronautics and Space Administration for the Near-Earth Object Survey program described in subsection (a) $20,000,000 for each of the fiscal years 2005 and 2006. Amounts appropriated under this subsection shall remain available for 2 fiscal years.

○

Senator BROWNBACK. I'm delighted you all could join us today. I look forward to this informative hearing giving the Senate some idea of what all is being done and what needs to be done.

Our first panel is Dr. Wayne Van Critters—Citters?

Dr. VAN CITTERS. Van Citters.

Senator BROWNBACK. Van Citters, excuse me. That's a near miss for me on the pronunciation. Division Director, Division of Astronomical Sciences, National Science Foundation. I'm delighted you're here.

Dr. Lindley Johnson, Program Manager, Near Earth Objects Observation Program at NASA.

Gentlemen. We're delighted to have both of you here. I apologize for being late. Your full statement will be placed in the record and so you're free to summarize or to present however you'd like to. Dr. Van Citters.

STATEMENT OF DR. WAYNE VAN CITTERS, DIRECTOR, DIVISION OF ASTRONOMICAL SCIENCES, NATIONAL SCIENCE FOUNDATION

Dr. VAN CITTERS. Thank you sir. Chairman Brownback, Ranking Member Breaux, and distinguished Members of this Subcommittee.

We appreciate the opportunity to present the position of the National Science Foundation on the important subject of Near Earth Objects this afternoon and in responding, I'll present a picture of NSF's current activities in this area. We are supporting research into the nature and origin of these objects as well as potential important contributions that NSF support, instrumentation and techniques could make to an expanded discovery and characterization effort.

As I'm sure the Committee is aware, NSF supports a wide range of basic research in astronomy from solar system studies to cosmology all the way to the very nature of matter and energy and what we support is driven by the interest of the scientific community that we support and our merit review process.

The Committee is probably also aware of the formation of the Astronomy and Astrophysics Advisory Committee. This is after the study that was done on possibly combining astronomical research at NSF and NASA and the purpose of this Committee is to advise both NSF and NASA and to some extent DOE on areas of common interest and cooperation. And in this recent March 15 report, the first report that this Joint Advisory Committee made, they underscored along with a number of other issues the number and nature of Near Earth Objects as an important and fundamental question to be investigated over the coming decade.

We support a wide range of individual investigator grants and operations at Arecibo, the National Astronomical and Ionospheric Center, in particular the Planetary Radar Program there, and these investigations look at the nature of Near Earth Objects and I've given a few examples of those investigations in the written testimony.

In general, they concentrate on the internal structure and origin of the objects whether they're binary in nature. If they are binary or multiple in nature, how that came to be and for some of the brighter ones, with more modern instrumentation or even capable of doing some rather detailed mineralogical analysis of the actual composition of the objects themselves.

We've seen an increasing interest in this area in the scientific community through the proposals presented to us over about the past 2 to 3 years and are making choices of which areas to support through our normal merit review of the proposals.

Looking to the future. I detailed in the statement the results of the NASA study which was reported out in late 2002, I believe, which outlines the current status of the Space Guard Program which I'm sure Lindley will talk about in much more detail and recommends next steps.

Very briefly, this treats the post-2008 period and in its conclusions urges that a catalogue of objects larger than 140 meters in diameter, so considerably larger than the one that passed by us a few weeks ago, be completed which would give a complete census at about the 90 percent certainty level.

The study estimates that the same approaches would provide 60 to 90 percent uncertainty—or 60/90 percent completion for objects larger than 50 meters. An object of this size would provide quite a large air burst but not anything like a dinosaur extinction event.

The study sets out several approaches both ground and space based to consider in reaching the above goal and it gives a cost and benefit analysis. So we think it provides a rather solid basis for looking at how to go forward in the future.

In that regard, our plans at NSF we are considering building on that NASA study and charging a Subcommittee of our Joint Astronomy and Astrophysics Advisory Committee with looking at an appropriate effort following on the Space Guard effort that would span both agencies and in particular for NSF how we would increase our ground based effort in this area.

We would foresee that it would certainly involve an increase in the support of individual investigator efforts looking into the nature and origin of the object themselves provided that our community interests and the proposal quality warrants it.

It would also however I think look at what's being proposed and highly rated in three of the National Research Council and the Department of Defense looking at trade studies and relative merit of these two possible instrumentation efforts for contributions to the future of the detection effort. And in particular there are estimates that the LSST and possibly Pan-STARRS could indeed respond to the challenge of cataloguing all of the 140 meter diameter or larger asteroids within seven to twenty years.

In conclusion, we're pursuing a significant amount of basic research in this area and we are laying plans for new facilities and expanded research activity that speak to many of the basic questions about the objects themselves and are confident that the body of knowledge that we gain by this effort will have important application to any eventual risk mitigation effort.

Again, I thank you for the opportunity to appear and we'd be happy to respond to any questions.

[The prepared statement of Dr. Van Citters follows:]

PREPARED STATEMENT OF G.W. VAN CITTERS, DIRECTOR, DIVISION OF ASTRONOMICAL SCIENCES, NATIONAL SCIENCE FOUNDATION

Chairman Brownback, Ranking Member Breaux, and distinguished members of the Subcommittee. Thank you for the opportunity to present the position of the National Science Foundation on the important subject of Near Earth Objects. In responding to the questions that the Committee has presented to us, I will present a picture of NSF's support of research into the nature and origin of these objects, as well as potential important contributions that NSF-supported instrumentation and techniques could make to an expanded discovery and characterization effort.

Background and Context

The Division of Astronomical Sciences supports basic research in astronomy covering a very wide range of subjects—from studies of objects in our own solar system to investigations of the beginning of the universe, including the very nature of matter and energy. In planning and conducting its programs, the Division benefits from the advice of the scientific community in many ways, including the recently established Astronomy and Astrophysics Advisory Committee (AAAC, jointly advising NSF, NASA, and DOE). The establishment of the AAAC recognizes the value of an integrated strategy to address national efforts to answer questions about our origins and our future. The number and nature of NEOs are clearly fundamental questions about both our origins and our future. In their March 15, 2004 report the AAAC recommended a coordinated implementation effort to ensure timely development of the Large Synoptic Survey Telescope, calling it a key facility for the detection of potentially hazardous earth-intersecting objects as small as 300 meters.

Current Activity

A number of awardees in our Planetary Astronomy Program are investigating Near Earth Objects (NEOs). The proposals funded by our program are determined by the interest of the research community, as reflected in the number and subject matter of proposals that we receive, and the results of our merit review of these proposals.

As one example, Dr. Derek Richardson at the University of Maryland will be modeling the tidal disruption of near Earth asteroids (NEAs) by the Earth's gravitational field to determine the frequency of binary NEA formation and the typical characteristics of the resulting binary asteroids. The results from this research will give insight into the internal structure of NEAs and may have implications for hazard mitigation strategies.

In another effort, Richard Binzel at MIT will measure the near-infrared spectral properties of 40–60 NEOs per year. The observations will balance measurements that push the state-of-the-art limits of the technology for the smallest and faintest objects and measurements that provide sufficient detail for detailed mineralogical analysis.

Research in this area also represents a substantial fraction of the use of the Arecibo planetary radar system, characterizing sizes, shapes, rotation rates, and configurations (single or binary, *e.g.*). The smallest system yet observed (a binary of 120m and ~40 m diameter components) was discovered in 2003. Measurements from a combination of Arecibo and NASA's Goldstone antenna from 1991 through 2003 demonstrated the existence of the Yarkovsky effect. This effect is an acceleration of the body related to the time delay between the absorption of solar radiation and the re-emission in the infrared. The observations clearly indicated that the acceleration must be included in orbit predictions.

We have observed that the number of proposals to investigate NEOs has been increasing annually for the last few years. Of the proposals we receive on this topic, those that do best in our merit review competition are those proposing to characterize the physical properties of the objects. What are they made of? How were they formed and when?

I believe NSF is currently playing the role for which it is best suited. It is funding individual investigators to further our understanding of the physical make-up of NEOs. The proposals for these investigations are subject to our normal merit review, thus insuring high quality basic research on these objects. In addition, it provides access to tools such as Arecibo that can enhance the discovery process.

Looking to the Future

In recent years, there has been an increasing appreciation for the hazards posed by near-Earth objects, those asteroids and periodic comets (both active and inactive) whose motions can bring them into the Earth's neighborhood. In August of 2002, our colleagues at NASA chartered a Science Definition Team to study the feasibility of extending the search for near-Earth objects to smaller limiting diameters. The formation of the team was motivated by the good progress being made toward achieving the *Spaceguard* goal of discovering 90 percent of all NEOs with diameters greater than 1 km by the end of 2008. This raised the question of what, if anything, should be done with respect to the much more numerous smaller, but still potentially dangerous, objects. The team was tasked with providing recommendations to NASA as well as the answers to seven specific questions. We believe that the answers to these questions could form a solid basis for the direction of our research efforts and for more detailed studies of the best integrated strategy to carry on at the end of *Spaceguard* in 2008.

What are the smallest objects for which the search should be optimized? The Team recommends that the search system be constructed to produce a catalog that is 90 percent complete for potentially hazardous objects (PHOs) larger than 140 meters.

Should comets be included in any way in the survey? The Team's analysis indicates that the frequency with which long-period comets (of any size) closely approach the Earth is roughly one-hundredth the frequency with which asteroids closely approach the Earth and that the fraction of the total risk represented by comets is approximately 1 percent. The relatively small risk fraction, combined with the difficulty of generating a catalog of comets, leads the Team to the conclusion that, at least for the next generation of NEO surveys, the limited resources available for near-Earth object searches would be better spent on finding and cataloging Earth-threatening, near-Earth asteroids and short-period comets. A NEO search system would naturally provide an advance warning of at least months for most threatening long-period comets.

What is technically possible? Current technology offers asteroid detection and cataloging capabilities several orders of magnitude better than the presently operating systems. This report outlines a variety of search system examples, spanning a factor of about 100 in search discovery rate, all of which are possible using current technology. Some of these systems, when operated over a period of 7–20 years, would generate a catalog that is 90 percent complete for NEOs larger than 140 meters.

How would the expanded search be done? From a cost/benefit point-of-view, the report concludes that there are a number of attractive options for executing an expanded search that would vastly reduce the risk posed by potentially hazardous object impacts. The Team identified a series of specific ground-based, space-based and mixed ground-and space-based systems that could accomplish the next generation search. The choice of specific systems would depend on the time allowed for the search and the resources available.

What would it cost? For a search period no longer than 20 years, the Team identified several systems that they felt would eliminate, at varying rates, 90 percent of the risk for sub-kilometer NEOs, with costs they estimate to range between $236 million and $397 million for both ground and space components. They conclude that all of these systems have risk reduction benefits which greatly exceed the costs of system acquisition and operation.

How long would the search take? The Team concludes that a period of 7–20 years is sufficient to generate a catalog 90 percent complete to 140-meter diameter, which will eliminate 90 percent of the risk for sub-kilometer NEOs. The specific interval would depend on the choice of search technology and the investment allocated.

Is there a transition size above which one catalogs all the objects, and below which the design is simply to provide warning? The Team concluded that, given sufficient time and resources, a search system could be constructed to completely catalog hazardous objects with sizes down to the limit where air blasts would be expected (about 50 meters in diameter). Below this limit, there is relatively little direct damage caused by the object. Over the 7–20 year interval (starting in 2008) during which the next generation search would be undertaken, the Team suggests that cataloging is the preferred approach down to approximately the 140-meter diameter level and that the search systems would naturally provide an impact warning of 60–90 percent for objects as small as those capable of producing significant air blasts.

The path from where we are today to where we should be in 2014 is not defined in the conclusions of the study that NASA sponsored. Clear goals are defined; how one might reach them is wisely left to the scientific and technical community. At the national level, we must now examine these goals in detail, validate the conclusions, and determine how they might best be achieved.

NSF Plans for the Future

We are considering asking the AAAC to form a subcommittee to advise on the effort that would be appropriate beyond *Spaceguard.* Broadly based in the scientific and technical community, this subcommittee would consider the conclusions of recent studies, extract necessary research directions that would help us better understand the origin and nature of the objects known to date and help to chart the most productive course into the future. By the very nature of the charge to the AAAC, this would be an integrated look at the ground-based and space-based efforts that would make the most effective scientific advances in this area.

Of particular interest to NSF would be the expansion of the individual investigator-driven basic research that we currently support, and a more detailed understanding of how such projects as the Large Synoptic Survey Telescope (LSST) and Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) might best contribute to the discovery and characterization effort in the future.

The LSST is a proposed single 8.4meter aperture, very wide field telescope capable of surveying the entire sky visible from one hemisphere every two weeks. It has a variety of science drivers including the characterization of dark matter and dark energy, the discovery of many classes of transient objects such as supernovae and gamma-ray burst counterparts, and NEOs.

Pan-STARRS, an Air Force funded project under construction in Hawaii, will be composed of 4 individual telescopes of 1.8meter aperture observing the same region of sky simultaneously. In survey mode, *i.e.,* searching for NEOs, Pan-STARRS will cover 6,000 square degrees per night. The whole available sky as seen from Hawaii will be observed 3 times during the dark time in each lunation.

The LSST's ability to make fast, wide, and faint observations may make it uniquely suited to detecting small NEOs. A model LSST survey covering 9,000 square degrees of sky along the ecliptic, three or four times a month, to a limiting V magnitude of 24.0, achieved a ten-year completeness of about 90 percent for NEOs larger than 250 m, and about 80 percent for NEOs down to 140 m as called for by the NASA study. The requirements placed on the telescope, telescope operations, data system and detectors by the NEO detection challenge are considerable.

By reaching objects 100 times fainter than those currently observed in the NEO surveys, Pan-STARRS is being designed to help complete the Congressional mandate to find and determine orbits for the 1-km (and larger) threatening NEOs. Further, it should push the detection limit for a complete (99 percent) sample down to objects as small as 300-meters in diameter.

Design studies over the next several years will be needed to determine the strategy for attacking the NEO problem and whether it is best carried out with a single telescope like the LSST or whether an array of smaller telescopes such as Pan-STARRS is more appropriate for this particular problem. NSF's Division of Astronomical Sciences has begun planning for such studies and we have been actively joined by our colleagues at NASA, who will contribute their knowledge and experience in the handling of large data bases and archives.

Conclusion

In conclusion, Mr. Chairman, NSF is already pursuing a significant amount of basic research in this important area. We are guided, as always, by the scientific community through our merit review process. We are laying plans for new facilities and expanded research activity that speak to many basic questions about the nature and origin of these objects, and are confident that the body of knowledge so gained will have important application to any eventual risk-mitigation effort.

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

STATEMENT OF DR. LINDLEY N. JOHNSON, PROGRAM SCIENTIST, NEAR EARTH OBJECT OBSERVATION PROGRAM, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. JOHNSON. Thank you, Mr. Chairman, for the opportunity to present to the Subcommittee information on this important subject on NEOs.

At the request of Congress, NASA conducts the NEO observation program to research the population of the larger asteroids 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 5 years of its effort.

In the effort to gain a better understanding of this hazard, NASA's Office of Space Science 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 a "Space Guard Survey," this research seeks those asteroids and periodic comets that come within an astronomically close 50 million kilometers of the Earth. The objective of this survey is to detect within a 10-year period at least 90 percent of the NEOs that are greater than one kilometer in size and predict their orbits into the future.

Currently, slightly over 4 million per year is budgeted for the program. This funds modest search efforts, typically using refurbished ground based telescopes of about one meter aperture and wide field of view coupled with digital imaging in order to cover significant portions of the sky each month.

Presently 5 NEO search projects are either wholly or largely funded with this resource. Also important to the effort is the observation correlation and initial orbit determination done by the Minor Planet Center which is operated by the Smithsonian Astrophysical Observatory and the High Accuracy Orbit Propagation and Project Coordination done by NASA's NEO Project Office at the Jet Propulsion Lab.

The chart you've been handed summarizes the progress to date in finding the Near Earth Asteroids or NEAs greater than one kilometer in size. The program continues to make steady progress since it started in 1998 to the goal of finding at least 90 percent of these NEOs. As of the end of March, 514 of the 702 known NEAs determined to be larger than one kilometer have been found by the program out of an estimated total population of about 1,100.

We have also found 11 of 49 known Earth approaching comets. In addition, 1,866 of the 2,032 known Near Earth Asteroids of smaller size have been found. Because the projects are always refining the detection techniques, the discovery of smaller objects is becoming more frequent.

None of these objects found to date are on impact trajectories with the Earth in the next 100 years.

The results of the recent study by the Science Definition Team which Dr. Van Citters referred to which was commissioned by my office and you'll hear more about it from Grant Stokes, will show that it is entirely appropriate that we search for the larger NEOs first, because all factors considered, that is where the greatest risk from an undetected asteroid on an impact trajectory lies. This is principally due to the worldwide devastation it would cause. It is orders of magnitude above what a smaller few hundred meter sized impact would create and could well disrupt human civilization for decades after an impact.

Completion of the current effort to find these large objects will do much to reduce this uncertain risk and find the objects many decades before any impact threat. But until the total population of these objects is known, there is always the chance that an object bound for a near term impact maybe discovered similar to the real life scenario which unfolded 10 years ago, when comet Shoemaker-Levy 9, was discovered only in March 1993 inbound for a July 1994 impact on Jupiter.

It should be understood that the NEO Observation Program is merely a science survey and does not provide a leakproof warning network for impact of any size natural object large or small. Such a comprehensive network would require an order of magnitude increase in our funding and the cooperative efforts of several government departments and agencies like with NSF.

Operational experience with the current system shows that for every one kilometer of greater size asteroid found, there are three to four smaller size asteroids also discovered.

But the true ratio of the small to larger asteroids is thought to be over 100 to one. Because of the limitations of the current search systems, the discovery of smaller asteroids is only possible in a significantly smaller volume around the Earth. If our sensors can detect a one kilometer sized asteroid at 50 million kilometers, they can also see a 100 meter asteroid, but at perhaps only half a million kilometers or a little beyond the moon's orbit.

But at planetary orbital velocities, if the object is on impact trajectory of the Earth, it would cover even this distance in less than a day.

Thus, the detection of a relatively small asteroid on a destiny with Earth could also come with relatively short reaction time. The impact of a 100 meter asteroid on Earth could do significant damage at the surface as this is estimated to result in an approximately a 50 megaton energy release at or perhaps slightly above the surface. This will result in much loss of life if the impact were in a populated area.

It is therefore prudent that we begin to put into place contingency plans such as an internal NASA notification plan we are drafting to deal with such a relatively unlikely but extremely high consequence event.

Thank you for the opportunity to speak at this hearing and I'd be happy to respond to any questions you have.

[The prepared statement of Dr. Johnson follows:]

PREPARED STATEMENT OF LINDLEY N. JOHNSON, PROGRAM SCIENTIST, NEAR EARTH OBJECT OBSERVATION PROGRAM, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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 percent 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 percent 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 percent 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 percent completeness. No level of effort could ever be assured of achieving absolute 100 percent 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.*

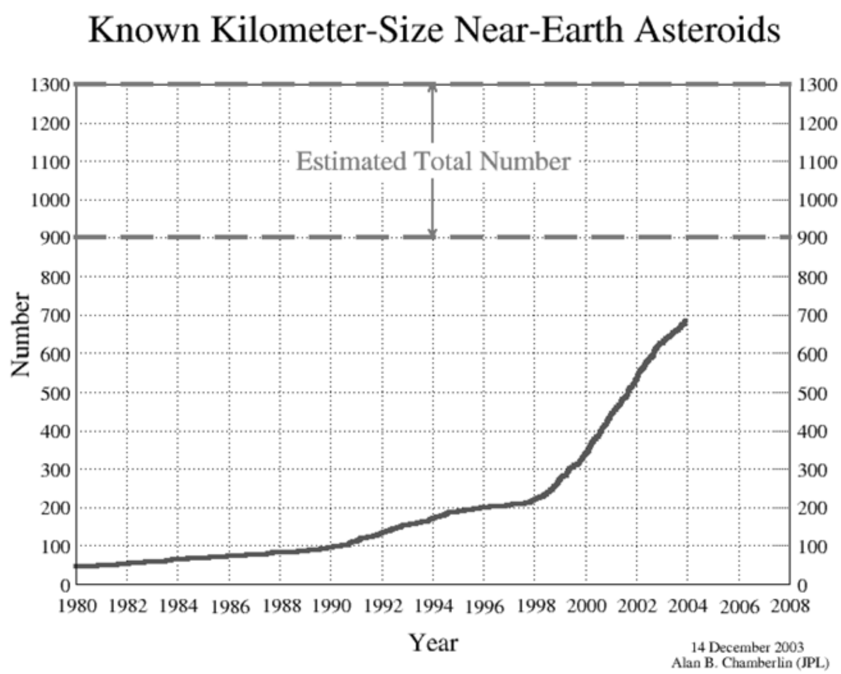
Such a comprehensive network would require an order of magnitude increase in funding and could require the cooperative efforts of several government departments and agencies.

Progress of the Program

The NEO Observation Program continues to make steady progress toward the goal of finding at least 90 percent 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 percent increase to the previous year.



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 prescripted 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 website 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 with 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 percent 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 this occurs 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.

Senator BROWNBACK. Thank you, gentlemen. I'm sorry that Astronaut Nelson had to leave, but he submitted a series of questions for the record that I would like to submit to you gentlemen if you could get back to him in a timely time, I would appreciate you doing that and I'll put that into the record.

As you look at that, what are the chances of Earth being hit by a substantial near earth target? I put forward the chance is the same as being involved in an airliner crash. Is that an accurate assessment? Do you think that's inaccurate? Or where would you place it?

Dr. JOHNSON. From the studies that we've had, yes, that is about the probability that is equivalent to about a million to one—a million—or one in 500,000 somewhere in that range.

Senator BROWNBACK. We're talking about a substantial size object. What would you categorize as a substantial size object to hit us in that chance range?

Dr. JOHNSON. Anything that's large enough to make it through the atmosphere, anything larger than 80 meters or 200 feet in size.

Senator BROWNBACK. I was looking at your chart and you're saying that we're catching right about 700, that we've got categorized and you've placed the estimated total at around 1,100, is that correct?

Dr. JOHNSON. Yes. That's based upon the distribution that we've seen to date. We've actually lowered that estimate through the course of the program by about 40 percent. We were thinking the overall population was about 2,000, but what we've seen so far, we think that population is somewhat less than the original estimates and it's about 1,100 plus or minus 100 or so, the large one kilometer size.

Senator BROWNBACK. OK, these are the large one kilometer size, right? And I thought you said there was 100 to one ratio of the large to the small.

Dr. JOHNSON. Yes. We believe it's kind of a power law of the numbers. As you get smaller, you know, a 100 to one ratio of sizes——

Senator BROWNBACK. You're not worried about their impact on the Earth should they hit, the smaller ones. Is that correct?

Dr. JOHNSON. No. We are worried about it. Until you get down to a size that Earth's atmosphere will dissipate, and that's down to about 50 meters, you have to worry about damage all the way to the surface of the Earth of anything that's larger than about 50 meters.

Senator BROWNBACK. OK. So what I hear you saying and you've made substantial progress on the one kilometer or larger——

Dr. JOHNSON. Yes.

Senator BROWNBACK.—ones, but we're still somewhere—you think there's 1,100—you think there's 400 or so out there that we have not found yet.

Dr. JOHNSON. Of the large ones, the ones that would do worldwide devastation if they were to hit.

Senator BROWNBACK. But you're at 100 to one times of others than that could do substantial damage. Depending upon their size and we don't have any idea where they are?

Dr. JOHNSON. Right. The original charter of the NEO Observation Program was to find the large ones that would have worldwide global consequences, but there's kind of a big elephant out there. We're taking it a bite at a time.

Senator BROWNBACK. So if you've got one that's half a kilometer in size—let's say what kind of damage could that do? Do you have any estimates of what that would be?

Dr. JOHNSON. Well, that devastation on the order of the continent if it were to hit on land, pretty much the continent that it hits would be affected. However, if it were to hit in the ocean the ocean wave that would be caused, the tsunami, would probably impact on both coasts. If it were hit in the Middle Atlantic, both the Eastern seaboard of the United States and the European seaboard would be affected by a large tsunami of several meters, if not a 100 meters in height.

Senator BROWNBACK. And we're not even tracking those yet?

Dr. JOHNSON. No, we're not tracking those yet. We are finding them when they come close to Earth, come close enough to Earth for our sensors to see it, but we know that there are a lot more out there.

Senator BROWNBACK. So when you say we're finding them when they come close enough to Earth, how close and how much time do we have between when we're finding them now and when they would impact Earth?

Dr. JOHNSON. Well, as I said, so far those that we've found, none of them are on impact trajectories. It all depends on what the orbit is. It could be as rapidly as a day or two if it's on a direct impact, or it could be decades or centuries into the future until the orbits intersect.

Senator BROWNBACK. Well, how much—you say we're finding virtually all of them now that are coming in close to the Earth. Did I understand or did I ask that correctly?

Dr. JOHNSON. We're finding virtually all the large ones that come close enough.

Senator BROWNBACK. Kilometer or larger?

Dr. JOHNSON. Yes.

Senator BROWNBACK. What about those that are a half a kilometer?

Dr. JOHNSON. I would give you no guarantee on what the coverage is for those.

Senator BROWNBACK. Of what we're finding at all?

Dr. JOHNSON. Right. What we're currently using are not designed to find the small ones.

Senator BROWNBACK. Are you comfortable with what we're doing to date on this topic?

Dr. JOHNSON. As I said, it's a pretty big elephant and you've got to take it a chunk at a time. I'm comfortable that we are finding the large ones, but there is a hazard out there still of the small ones.

Senator BROWNBACK. It sounds like to me it's a large hazard.

Dr. JOHNSON. Yes, it is.

Senator BROWNBACK. And that we're not going through that set at all? I mean, I understand that there are costs associated with this and there's user resources that you've got to do. I trying to assess what's the nature of the damage potential?

Dr. JOHNSON. I think that's an accurate assessment. We are finding the ones that would have global consequence if they were to impact, but it's only serendipitously that we find the smaller ones that could still do significant damage if they were to impact.

Senator BROWNBACK. What's the likelihood, the odds of us being hit by a smaller object, say that's a half a kilometer in size. Do we have any projections on the odds of being hit by one of those in the next 100 years?

Dr. JOHNSON. In the next 100 years, it'd be very, very small. Our estimates are that one 500 meters in size or so would impact maybe once in 100,000 years. Something like that. But we also believe that small ones, those on the order of 100 meters or so, impact once every few hundred to a thousand years.

Senator BROWNBACK. What kind of damage could those cause?

Dr. JOHNSON. The energy release from a 100 meter object that's of average density would be about 50 megatons at the surface, or slightly above the surface of the Earth. That's larger than any nuclear weapon that we have.

Senator BROWNBACK. So you're talking about a catastrophic event wherever it occurs?

Dr. JOHNSON. The region that it impacts in, yes.

Senator BROWNBACK. And what are the odds of that taking place?

Dr. JOHNSON. Well, if on the average it happens once in 1,000 years that's your probability. Maybe once in 1,000 years.

Senator BROWNBACK. Do we know when the last time one of these hit the Earth was?

Dr. JOHNSON. Well, close to that size was the Tunguska Event in 1908. That one was probably slightly smaller somewhere in the 70 meter range. Something like that.

Senator BROWNBACK. What was the impact of that event?

Dr. JOHNSON. Well, it actually exploded above the Earth's surface probably at five to seven kilometers, but it still devastated several hundred square kilometers of forest in Siberia. The over pressure just blew the forest down and so if it were to hit in a populated area it would be like a nuclear device going off.

Senator BROWNBACK. And this is an item of 100 meters in size. Is that correct?

Dr. JOHNSON. That's correct.

Senator BROWNBACK. And we don't have any idea of the quantity of those that are out there that might be on some orbital pattern toward the Earth?

Dr. JOHNSON. We believe they're in the hundreds of thousands.

Senator BROWNBACK. Hundreds to thousands?

Dr. JOHNSON. Hundreds of thousands.

Senator BROWNBACK. Hundreds of thousands?

Dr. JOHNSON. Objects, yes.

Senator BROWNBACK. And that those hit the Earth you say once every how often?

Dr. JOHNSON. Once every thousand years.

Senator BROWNBACK. Are we doing enough, Dr. Van Citters?

Dr. VAN CITTERS. I think we could do a lot more. I think that the study that NASA commissioned identified a very reasonable set of parameters for future searches to carry on from the one kilometer on down. We have a little more technology development to do in terms of large area detectors and so on, but the ideas that our community has presented to us and to Lindley's program and so on and how you might continue from here, I think are very credible.

I think there's a fair amount of trade study that we need to do to look at how one might best carry out an extended search whether it's in one instrument or a series of instruments or if it's assigning parts of the search different instruments and so on, but I think we could do a better job as I indicated in things like the large Synoptic Survey Telescope will quite naturally in the way they operate, catalogue tens of thousands of these objects and provide the kind of completeness that the expert committee has put in front of us.

Senator BROWNBACK. These would be objects of much smaller in size than the one kilometer?

Dr. VAN CITTERS. Yes, this would be we—our sense of the estimates, and these are of course just estimates, would be that the surveys would be complete within—and it depends a little bit on how you do them, but it's somewhere between 7 years and 20 years of operation, the surveys would be 90 percent complete down to 140 meters, which is of course a substantial increase in our knowledge of the objects.

Senator BROWNBACK. Let me ask you on the other side of this, just the knowledge we could learn from these Near Earth Objects. We've got a *Scientific American* article I think we'll have some people testifying about, about using these as tugboats for information of hooking probes on them, of what we could gain from asteroids. Have either of you dealt with that side of this equation or thought?

Dr. JOHNSON. Not too much. We do have studies going on what we call, "characterization studies," to find out what these things are made of and that would help us to determine what kind of resources are present on these and so theoretically if there are resources there that are of benefit to either us on Earth or in the exploration of the solar system, one could think of mining operations going on on Near Earth Asteroids.

Senator BROWNBACK. What about using—that we put probes on to carry the probe out further into the galaxy.

Dr. JOHNSON. Ones that are on the right kinds of orbits that do go out into the solar system, potentially that's an idea.

Senator BROWNBACK. Dr. Van Citters?

Dr. VAN CITTERS. There's certainly a lot of interest in our community and indeed in the research that we re funding, because these objects are—as you indicated in your opening remarks, left over from the formation of the solar system. And so as we catalogue more of them, look at their orbits, where they lie in the solar system, we get more spectroscopy to characterize what they're made of, whether they're binary in nature and so on, we have a very good probe of the very early days of our own solar system. And add to our knowledge of basic research in that area.

I should say too that there are, I think, we concentrate on the astronomical aspects of this problem, there are other areas that I think are very valid areas of research that would be supported by other areas of the Foundation. And as we are talking this afternoon, it ran through my mind that we have a very active area, for instance, in mathematical sciences, looking at the propagation of uncertainty in very complex models.

And as we go through a study like the one that NASA commissioned, the uncertainties in the prediction of what the population of the asteroids is, what they're made of, uncertainties in observation and so on, propagation of those into an analysis of the risk at the end which we must then use as a parameter to size systems and so on is a very active area of mathematical research and something that would apply there.

Two, there's also the evaluation and the public perception of risk. You characterized the risk, or tried to draw the parallel between the risk of being struck by a large asteroid and riding in an airplane. There are certainly different perceptions among the populace of the risk of riding in an airplane versus the risk of riding in a car in certain cases. And I think the social sciences are extremely interested in how that sort of risk analysis and risk perception plays out, particularly in something like this, which is not something within our—perhaps should be, but not something within everyone s everyday thought process.

Senator BROWNBACK. That's very interesting, gentlemen, and I appreciate your work. How do you sleep at night, Dr. Johnson, with this knowledge?

Dr. JOHNSON. I sleep very well at night. But it's not something I worry about on a daily basis, but over time, it's something we need to be concerned with.

Senator BROWNBACK. That's what it looks like to me. It's one of those things that we need to know the information for safety purposes first. Protection is the reason the initial Federal Government was created, was to provide for the security of the people. And so you're always out there searching, what's the security issue. And you could say, well, the odds are this or that, but if something happens, it's significant. So you really want to do everything you can.

And then on the flipside, it seems like there's some real exploration and research that could be done if we knew more of just what all was out there. There's a security issue here which is of paramount concern. And then there's a curiosity/research issue that seems like a significant benefit if we knew a lot more of what all was out there.

Dr. JOHNSON. These objects are the building blocks of the planets. They're the building blocks of Earth. So the more we learn about these objects, the more that we will learn about the Earth.

Senator BROWNBACK. Gentlemen, thank you very much. I appreciate your coming in and I hope everybody listening in sleeps well tonight.

We have a second panel. Dr. Grant Stokes, Associate Head of Aerospace Division at MIT in Massachusetts; Dr. Michael Griffin, Head of the Space Department at Johns Hopkins University, Applied Physics Lab; Mr. Rusty Schweickart, Chairman of the Board, B612 Foundation; and Dr. Ed Lu, President, and NASA Astronaut, of the B612 Foundation.

Gentlemen, I appreciate very much your coming and joining in the panel and discussion today on Near Earth Objects. All of your written statements will be placed into the record. Dr. Stokes, we'll start with you and then we'll proceed down the list as I announced it.

Welcome to the Committee. You might pull that microphone up kind of close to you. It's fairly directional.

STATEMENT OF DR. GRANT H. STOKES, CHAIRMAN, NEAR EARTH OBJECT SCIENCE DEFINITION TEAM, MIT LINCOLN LABORATORY

Dr. STOKES. All right. Thank you, Mr. Chairman, for the opportunity to present to the Subcommittee information on NEOs this afternoon. I'm here to represent the findings of the Near Earth Object Science Definition Team, which I led recently for NASA. And you've heard a little bit from the previous folks about that.

The team was tasked to address a series of specific questions intended to explore the technical possibilities of searching for asteroids smaller than the current one kilometer goal, and the efficacies of those searches. The study team which was composed broadly of experts through the community addressed the question by performing an exhaustive analysis along two parallel paths.

First, the team established the current estimates of the Near Earth Object population, estimated the collision rates over time as functions of size, and then the damage expected from those types of collisions.

Second, the team evaluated the technologies available to be built into systems intended to search for asteroids, and estimated their implementation costs and the effectiveness of discovering and cataloguing potentially dangerous asteroids.

Combining that information from those two paths of analysis systems and strategies on a cost/benefit basis. The cost of investment in a search system balanced against the benefit of providing awareness of potential short or long term threats.

The team specifically did not address issues related to mitigation approaches in the highly unlikely event that we find an object, a substantial object, on a collision course with Earth, but the view was that if one was coming, we certainly wanted to know.

The team estimated the annual nominal average risk remaining in 2008, associated with an asteroid impact would be approximately 300 casualties per year, that's worldwide, plus the attendant property damage and destruction. That breaks down to about 17 percent of that risk is attributed to smaller objects doing regional damage for land impacts, about 53 percent of that is due to water impacts and the tsunamis that ensue, and 30 percent of that risk is global climatic disruption caused by large impacts. So those are the physical objects left over, undiscovered by the Space Guard Survey in 2008.

Senator BROWNBACK. You re saying 300 deaths per year?

Dr. STOKES. That's the average rate. Now, remember, that's composed of events that happen over long intervals, but some of them can be quite destructive. That average risk is composed of devastating events that may occur only once over periods very long compared to the life of an individual.

Senator BROWNBACK. So if there's another like 1908 event that occurs in 2030, you re calculators add——

Dr. STOKES. Right.

Senator BROWNBACK. The large number of casualties of that event, but you're calculating it over a period of time.

Dr. STOKES. Correct.

Senator BROWNBACK. All right.

Dr. STOKES. In any particular year, the most likely number of casualties due to an asteroid impact is zero. Now, in fact, over periods of millions of years, there have been extinction events like the dinosaurs 65 million years ago, which would essentially cause the loss of civilization. And that is some part of the average rate.

The 300 casualties per year that I mention is the left over after we execute the current surveys. The actual yearly rate, much of which has already been taken care of by the surveys, would have been about 1,200 per year, if we started with no information.

In addition, the team concluded that current technology offers asteroid detection and cataloguing capabilities several orders of magnitude better than presently operating systems. It is resources rather than technology that is the current limitation on NEO search performance. The team identified a variety of search system examples which, when operated over periods ranging from 7 to 20 years, would generate a catalogue. That catalogue would contain hundreds of thousands of asteroids and would be 90 percent complete for Near Earth Objects larger than 140 meters. Construction and operation of these systems to achieve the level of completeness is estimated by us to cost somewhere between $296 million and $397 million, that's in Fiscal Year 2003 dollars.

All of those systems——

Senator BROWNBACK. Is that a total figure, or is that over——

Dr. STOKES. That's a total figure including building the system and operating it to that level of completeness, which would take 7 to 20 years, depending on how aggressive—if one is in a hurry, one should look at space-based systems. If one wants to take longer, it can be done from the ground.

All of those systems that I mentioned have a favorable cost/benefit pay back when measured in the unknown risk eliminated by the dollars invested in the asteroid search system. Based on those findings, the team recommended three things for NASA.

First, we recommended that future goals related to search for potential Earth-impacting objects should be stated explicitly in terms if the statistical risk eliminated or characterized, and should be firmly based in a cost/benefit analysis.

Second, we recommend that NASA develop and operate a NEO search program with the goal of discovering and cataloguing the potentially hazardous population sufficient to eliminate 90 percent of the risk due to the sub-kilometer objects. That would imply 90 percent completeness in the catalogue to the 140 meter level.

Third, to get things rolling, we suggest that NASA release an announcement of opportunity, or an AO, to allow system implementers to recommend a specific approach to satisfy the goal stated in recommendation two, which we are sure is technically possible.

Thank you and I would be happy to respond to questions.
[The prepared statement of Dr. Stokes follows:]

PREPARED STATEMENT OF DR. GRANT H. STOKES, CHAIRMAN, NEAR-EARTH OBJECT SCIENCE DEFINITION TEAM, MIT LINCOLN LABORATORY

Thank you, Mr. Chairman, for the opportunity to present to the subcommittee information on the subject of Near Earth Objects. In recent years, there has been an increasing appreciation for the hazards posed by near-Earth objects (NEOs), those asteroids and periodic comets (both active and inactive) whose motions can bring them into the Earth's neighborhood. In August of 2002, NASA chartered a Science Definition Team to study the feasibility of extending the search for near-Earth objects to smaller limiting diameters. The formation of the team was motivated by the good progress being made toward achieving the so-called Spaceguard goal of discovering 90 percent of all near-Earth objects (NEOs) with diameters greater than 1 km by the end of 2008. This raised the question of what, if anything should be done with respect to the much more numerous smaller, but still potentially dangerous, objects. The team was tasked with providing recommendations to NASA as well as the answers to the following 7 specific questions:

1. What are the smallest objects for which the search should be optimized?
2. Should comets be included in any way in the survey?
3. What is technically possible?
4. How would the expanded search be done?
5. What would it cost?
6. How long would the search take?
7. Is there a transition size above which one catalogs all the objects, and below which the design is simply to provide warning?

Team Membership

The Science Definition Team, which I lead, was composed of experts in the fields of asteroid and comet search, including the Principal Investigators of two major asteroid search efforts, experts in orbital dynamics, NEO population estimation, ground-based and space-based astronomical optical systems and the manager of the NASA NEO Program Office. In addition, the Department of Defense (DOD) community provided members to explore potential synergy with military technology or applications. The Team members are listed in the following table along with their institutions.

Dr. Grant H. Stokes (Chair)	MIT Lincoln Laboratory
Dr. Donald K. Yeomans (Vice-Chair)	Jet Propulsion Laboratory/Caltech
Dr. William F. Bottke, Jr.	Southwest Research Institute
Dr. Steven R. Chesley	Jet Propulsion Laboratory/Caltech
Jenifer B. Evans	MIT Lincoln Laboratory
Dr. Robert E. Gold	Johns Hopkins University, Applied Physics Laboratory
Dr. Alan W. Harris	Space Science Institute
Dr. David Jewitt	University of Hawaii
Col. T.S. Kelso	USAF/AFSPC
Dr. Robert S. McMillan	Spacewatch, University of Arizona
Dr. Timothy B. Spahr	Smithsonian Astrophysical Observatory
Dr./Brig. Gen. S. Peter Worden	USAF/SMC
Ex Officio Members	
Dr. Thomas H. Morgan	NASA Headquarters
Lt. Col. Lindley N. Johnson (USAF, ret.)	NASA Headquarters
Team Support	
Don E. Avery	NASA Langley Research Center
Sherry L. Pervan	SAIC
Michael S. Copeland	SAIC
Dr. Monica M. Doyle	SAIC

Analysis Process

The Team approached the task using a cost/benefit methodology whereby the following analysis processes were completed:

Population estimation—An estimate of the population of near-Earth objects (NEOs), including their sizes, albedos and orbit distributions, was generated using the best methods in the current literature. We estimate a population of about 1100 near-Earth objects larger than 1 km, leading to an impact frequency of about one in half a million years. To the lower limit of an object's atmospheric penetration (between 50 and 100 m diameter), we estimate about half a million NEOs, with an impact frequency of about one in a thousand years.

Collision hazard—The damage and casualties resulting from a collision with members of the hazardous population were estimated, including direct damage from land impact, as well as the amplification of damage caused by tsunami and global effects. The capture cross-section of the Earth was then used to estimate a collision rate and thus a yearly average hazard from NEO collisions as a function of their diameter. We find that damage from smaller land impacts below the threshold for global climatic effects is peaked at sizes on the scale of the Tunguska air blast event of 1908 (50–100 m diameter). For the local damage due to ocean impacts (and the associated tsunami), the damage reaches a maximum for impacts from objects at about 200 m in diameter; smaller ones do not reach the surface at cosmic speed and energy.

Search technology—Broad ranges of technology and search systems were evaluated to determine their effectiveness when used to search large areas of the sky for hazardous objects. These systems include ground-based and space-based optical and infrared systems across the currently credible range of optics and detector sizes. Telescope apertures of 1, 2, 4, and 8 meters were considered for ground-based search systems along with space-based telescopes of 0.5, 1, and 2 meter apertures. Various geographic placements of ground-based systems were studied, as were space-based telescopes in low-Earth orbit (LEO) and in solar obits at the Lagrange point beyond Earth and at a point that trailed the planet Venus.

Search simulation—A detailed simulation was conducted for each candidate search system, and for combinations of search systems working together, to determine the effectiveness of the various approaches in cataloging members of the hazardous object population. The simulations were accomplished by using a NEO survey simulator derived from a heritage within the DOD, which takes into account a broad range of "real-world" effects that affect the productivity of search systems, such as weather, sky brightness, zodiacal background, etc.

Search system cost—The cost of building and operating the search systems described herein was estimated by a cost team from SAIC. The cost team employed existing and accepted NASA models to develop the costs for space-based systems. They developed the ground-based system cost estimates by analogy with existing systems.

Cost/benefit analysis—The cost of constructing and operating potential survey systems was compared with the benefit of reducing the risk of an unanticipated object collision by generating a catalog of potentially hazardous objects (PHOs). PHOs, a subset of the near-Earth objects, closely approach Earth's orbit to within 0.05 AU (7.5 million kilometers). PHO collisions capable of causing damage occur infrequently, but the threat is large enough that, when averaged over time, the anticipated yearly average of impact-produced damage is significant. Thus, while developing a catalog of all the potentially hazardous objects does not actually eliminate the hazard of impact, it does provide a clear risk reduction benefit by providing awareness of potential short-and long-term threats. The nominal yearly average remaining, or residual, risk in 2008 associated with PHO impact is estimated by the Team to be approximately 300 casualties worldwide, plus the attendant property damage and destruction. About 17 percent of the risk is attributed to regional damage from smaller land impacts, 53 percent to water impacts and the ensuing tsunamis, and 30 percent to the risk of global climatic disruption caused by large impacts, *i.e.,* the risk that is expected to remain after the completion of the current Spaceguard effort in 2008. For land impacts and all impacts causing global effects, the consequences are in terms of casualties, whereas for sub-kilometer PHOs causing tsunamis, the "casualties" are a proxy for property damage. According to the cost/benefit assessment done for this report, the benefits associated with eliminating these risks justify substantial investment in PHO search systems.

PHO Search Goals and Feasibility

The Team evaluated the capability and performance of a large number of ground-based and space-based sensor systems in the context of the cost/benefit analysis. Based on this analysis, the Team recommends that the next generation search system be constructed to eliminate 90 percent of the risk posed by collisions with sub-kilometer diameter PHOs. Such a system would also eliminate essentially all of the global risk remaining after the Spaceguard efforts are complete in 2008. The implementation of this recommendation will result in a substantial reduction in risk to a total of less than 30 casualties per year plus attendant property damage and destruction. A number of search system approaches identified by the Team could be employed to reach this recommended goal, all of which have highly favorable cost/

benefit characteristics. The final choice of sensors will depend on factors such as the time allotted to accomplish the search and the available investment.

Answers to Questions Stated in Team Charter

What are the smallest objects for which the search should be optimized? The Team recommends that the search system be constructed to produce a catalog that is 90 percent complete for potentially hazardous objects (PHOs) larger than 140 meters.

Should comets be included in any way in the survey? The Team's analysis indicates that the frequency with which long-period comets (of any size) closely approach the Earth is roughly one-hundredth the frequency with which asteroids closely approach the Earth and that the fraction of the total risk represented by comets is approximately 1 percent. The relatively small risk fraction, combined with the difficulty of generating a catalog of comets, leads the Team to the conclusion that, at least for the next generation of NEO surveys, the limited resources available for near-Earth object searches would be better spent on finding and cataloging Earth-threatening near-Earth asteroids and short-period comets. A NEO search system would naturally provide an advance warning of at least months for most threatening long-period comets.

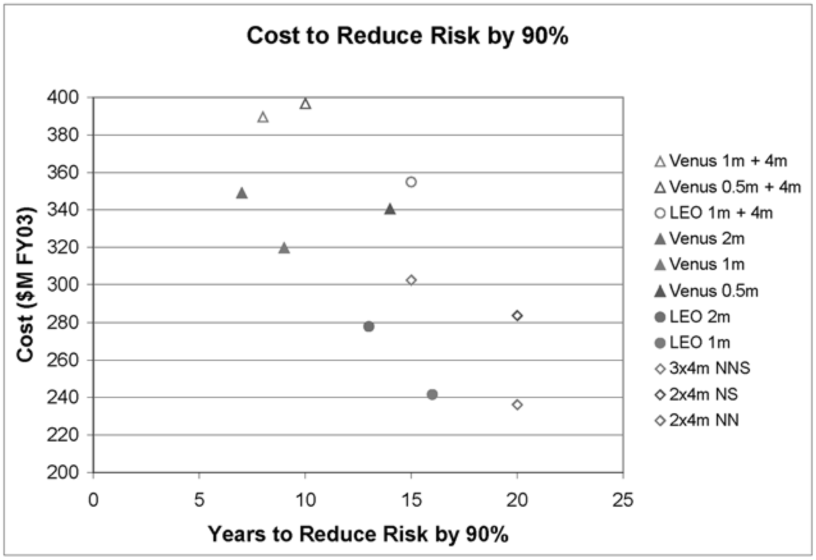
What is technically possible? Current technology offers asteroid detection and cataloging capabilities several orders of magnitude better than the presently operating systems. NEO search performance is generally not driven by technology, but rather resources. This report outlines a variety of search system examples, spanning a factor of about 100 in search discovery rate, all of which are possible using current technology. Some of these systems, when operated over a period of 7–20 years, would generate a catalog that is 90 percent complete for NEOs larger than 140 meters.

How would the expanded search be done? From a cost/benefit point-of-view, there are a number of attractive options for executing an expanded search that would vastly reduce the risk posed by potentially hazardous object impacts. The Team identified a series of specific ground-based, space-based and mixed ground-and space-based systems that could accomplish the next generation search. The choice of specific systems will depend on the time allowed for the search and the resources available.

What would it cost? For a search period no longer than 20 years, the Team identified several systems that would eliminate, at varying rates, 90 percent of the risk for sub-kilometer NEOs, with costs ranging between $236 million and $397 million. All of these systems have risk reduction benefits which greatly exceed the costs of system acquisition and operation.

How long would the search take? A period of 7–20 years is sufficient to generate a catalog 90 percent complete to 140-meter diameter, which will eliminate 90 percent of the risk for sub-kilometer NEOs. The specific interval depends on the choice of search technology and the investment allocated, as shown in the figure below.

The cost of various space-based and ground-based search systems are plotted against the number of search years required to reduce by 90 percent the sub-global risk from impacts by sub-kilometer sized objects.



The cost of various space-based and ground-based search systems are plotted against the number of search years required to reduce by 90 percent the sub-global risk from impacts by sub-kilometer objects.

Is there a transition size above which one catalogs all the objects, and below which the design is simply to provide warning? The Team concluded that, given sufficient time and resources, a search system could be constructed to completely catalog hazardous objects with sizes down to the limit where air blasts would be expected (about 50 meters in diameter). Below this limit, there is relatively little direct damage caused by the object. Over the 7–20 year interval (starting in 2008) during which the next generation search would be undertaken, the Team suggests that cataloging is the preferred approach down to approximately the 140-meter diameter level and that the search systems would naturally provide an impact warning of 60–90 percent for objects as small as those capable of producing significant air blasts.

Science Definition Team Recommendations

The Team makes three specific recommendations to NASA as a result of the analysis effort:

Recommendation 1—Future goals related to searching for potential Earth-impacting objects should be stated explicitly in terms of the statistical risk eliminated (or characterized) and should be firmly based on cost/benefit analyses.

This recommendation recognizes that searching for potential Earth impacting objects is of interest primarily to eliminate the statistical risk associated with the hazard of impacts. The "average" rate of destruction due to impacts is large enough to be of great concern; however, the event rate is low. Thus, a search to determine if there are potentially hazardous objects (PHOs) likely to impact the Earth within the next few hundred years is prudent. Such a search should be executed in a way that eliminates the maximum amount of statistical risk per dollar of investment.

Recommendation 2—Develop and operate a NEO search program with the goal of discovering and cataloging the potentially hazardous population sufficiently well to eliminate 90 percent of the risk due to sub-kilometer objects.

The above goal is sufficient to reduce the average casualty rate from about 300 per year to less than 30 per year. Any such search would find essentially all of the larger objects remaining undiscovered after 2008, thus eliminating the global risk from these larger objects. Over a period of 7–20 years, there are a number of system approaches that are capable of meeting this search metric with quite good cost/benefit ratios.

Recommendation 3—Release a NASA Announcement of Opportunity (AO) to allow system implementers to recommend a specific approach to satisfy the goal stated in Recommendation 2.

Based upon our analysis, the Team is convinced that there are a number of credible, current technology/system approaches that can satisfy the goal stated in Recommendation 2. The various approaches will have different characteristics with respect to the expense and time required to meet the goal. The Team relied on engineering judgment and system simulations to assess the expected capabilities of the various systems and approaches considered. While the Team considers the analysis results to be well grounded by current operational experience, and thus, a reasonable estimate of expected performance, the Team did not conduct analysis at the detailed system design level for any of the systems considered. The next natural step in the process of considering a follow-on to the current Spaceguard program would be to issue a NASA Announcement of Opportunity (AO) as a vehicle for collecting search system estimates of cost, schedule and the most effective approaches for satisfying the recommended goal. The AO should be specific with respect to NASA's position on the trade between cost and time to completion of the goal.

The complete Science Definition Team Report may be accessed online at: *http://neo.jpl.nasa.gov/neo/neoreport030825.pdf*

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

Senator BROWNBACK. Thank you very much. Dr. Griffin.

STATEMENT OF MICHAEL D. GRIFFIN, HEAD OF THE SPACE DEPARTMENT, APPLIED PHYSICS LAB, JOHNS HOPKINS UNIVERSITY

Dr. GRIFFIN. Thank you, Senator Brownback. I am here this afternoon, representing the Johns Hopkins Applied Physics Laboratory, which is so far the only laboratory which has carried out the mission of visiting a Near Earth Object with a robotic spacecraft.

Thank you for providing me with this opportunity to comment on the greatest natural threat to the long-term survivability of mankind, which is an asteroid impact with the Earth.

Throughout its history, Earth has been continuously bombarded by objects ranging in size from dust particles to asteroids or comets greater than 10 kilometers in diameter. You've heard that although the probability of the Earth being hit by a large object in this century is low, the effects of such an impact are so catastrophic that it is essential to prepare a defense against such an occurrence.

The first step in that defense is a system to identify and catalogue all potential impacters above the threshold of significant damage, approximately 100 meters in diameter. Later, the remainder of a comprehensive Earth protection system could be assembled so that it would be ready to deflect a potential impacter shortly after it is identified.

NEOs also represent a tremendous opportunity in the context of the President's exploration initiative. They are potential suppliers of resources for future manned space exploration, but in order to use these resources a much more detailed knowledge of their composition and physical characteristics will be required before the technologies to produce fuels or construction materials from Near Earth Objects can be developed.

In 1998, NASA embraced the goal, as you've heard, of finding and cataloguing within 10 years 90 percent of all the Near Earth Objects with diameters greater than 1 kilometer. It is estimated that on the order of a thousand such objects exist. Population counts show, however, that there could likely be 150,000 Near Earth Objects larger than 100 meters, the threshold of significant damage on Earth.

For reference, the Tunguska Event in Siberia in 1908 destroyed an area 50 kilometers in diameter and is believed to have been caused by an impacter on the order of 50 meters in diameter.

Again, you have already heard that the average—at the average speed of these objects, the energy released by the impact of 100 meter Near Earth Object is about equivalent to that of a 50 megaton bomb.

The frequency of impacts over the last century can be estimated by noting the Tunguska Event in 1908, the Sikhote-Alin Event in Siberia about 270 miles northeast of Vladivostok in February 1947, and the several recently identified objects that have had very near misses with the Earth.

All this evidence confirms that impacts with the ability to wipe out a large metropolitan area can be expected within the next 100 years. It is also worth noting that within living—or at least recent memory, there is a 12 mile wide crater under the sea floor near the island of New Zealand, the impact of which lives on in Maori legends in the area. The impact is estimated to have occurred in the 1700s. These are not terribly infrequent events on human time scales.

It is estimated that a 30 year advance warning would be required to have a reasonable assurance of deflecting a Near Earth Object from a collision with the Earth. If a future impacter were identified today, the time to explore the characteristics of the object, to develop a deflection system, deliver it to the NEO, and apply the deflection early enough to prevent an impact requires about a three decade lead time from the initial discovery.

An overall Earth protection system must have three components. A search system is needed to identify any potential impacters, a series of detailed investigation missions are needed to understand the structure, composition, rotational state, and other physical properties of the impacter. And finally, deflection technologies are needed to change the speed of the object so that it will not impact Earth.

At the current rate of discovery, the group of observatories that are finding and cataloguing Near Earth Objects will come close to achieving their goal of identifying 90 percent of the greater than 1 kilometer diameter objects by 2008. More than 50 percent of the population has already been discovered.

The very large number of undiscovered, small to modest sized objects, the greater than 100 meters that I spoke of, represents the greatest remaining threat to regional safety not currently being addressed.

A NASA Near Earth Object Science Definition Team recently examined the requirements for extending this search to smaller diameters and showed that a system to accomplish the discovery and cataloguing of 90 percent of these objects within 10 years could be accomplished with a single discovery class spacecraft in a heliocentric orbit, about seven-tenths of an AU out from the sun, or about at the orbit of Venus, relative to the sun. This modestly priced system could be constructed and launched in 4 to 5 years.

My time is running out, and so I will conclude that in summary, the threat to life on Earth from Near Earth Objects is real, even though the likelihood of a severe impact during the next few years is low. The space exploitation opportunities of these objects are equally real. The most important thing needed at this time is an improved search system for smaller objects. Recent studies have shown that a search spacecraft can catalogue 90 percent of the remaining objects within 10 years and can be launched within the next 4 or 5 years.

Thank you very much, and I'm ready to take any questions you may have.

[The prepared statement of Dr. Griffin follows:]

PREPARED STATEMENT OF MICHAEL D. GRIFFIN, HEAD OF THE SPACE DEPARTMENT, APPLIED PHYSICS LAB, JOHNS HOPKINS UNIVERSITY

Mister Chairman and members of the subcommittee, thank you for giving me this opportunity to comment on the greatest natural threat to the long-term survivability of mankind, an asteroid impact with the Earth. Throughout its history, the Earth has continuously been bombarded by objects ranging in size from dust particles to comets or asteroids greater than 10 km in diameter. Although the probability of the Earth being hit by a large object in this century is low, the effects of an impact are so catastrophic that it is essential to prepare a defense against such an occurrence. The first step in that defense is a system to identify and catalog all potential impactors above the threshold of significant damage, approximately 100 meters in diameter. Later, the remainder of a comprehensive Earth-protection system could be assembled so that it would be ready to deflect a potential impactor shortly after it is identified.

In 1998, NASA embraced the goal of finding and cataloging, within 10 years, 90 percent of all near-Earth objects (NEOs) with diameters greater than 1 km. Impacts by objects of this size and larger could result in worldwide damage, and the possible elimination of the human race. The current system is not sufficient to catalog the population of smaller NEOs. While there are thought to be nearly a thousand objects with diameters greater than 1 km, there are a great many smaller NEOs that could devastate a region or local area. The exact NEO size distribution is not known; however a good current estimate is that there are more than 5 times as many objects with diameters greater than 1/2 km than there are with diameters greater than 1 km. This multiplication of numbers for smaller diameters continues for all sizes at least down to those just large enough to make it through the atmosphere. Thus, if there are about 700 NEOs of 1 km or greater, there are more than 150,000 NEOs with diameters greater than 100 m. The Tunguska event in Siberia in 1908 destroyed an area 50 km in diameter and is believed to have been caused by an impactor less than 50 m in diameter.

The average speed of objects colliding with Earth is about 20 km/s (about 45,000 miles per hour). At these speeds the energy of impact is 44 times the explosive power of the same mass of TNT. Thus, the energy released by the impact of a 100 m object is about equivalent to a 50 megaton bomb. The impacts at Tunguska in 1908, Sikhote-Alin (about 270 miles northeast of Vladivostok) in February 1947, and the recently identified objects that have had near misses with Earth, all show us that impacts with the ability to wipe a large metropolitan area can be expected during the next 100 years.

A great deal has been learned about the nature of the threat in the last decade. It is vital to understand the characteristics of NEOs to know how to defend against a potential impactor. An improved theoretical understanding of the population of NEOs has clarified their evolution through interactions with the planets of our solar system. It has helped us understand their numbers and their distribution in the different classes of orbits. On the practical side, the progress of several space missions has greatly improved our understanding of the physical and chemical characteristics of these objects. A great deal still needs to be done since only a handful of these objects have been observed from sufficiently close distances to see their surface structure, and only one asteroid has been orbited. The Near Earth Asteroid Rendezvous (NEAR) mission orbited and landed on 433-Eros and was able to get the first estimates of the internal structure and composition of a NEO. However, there is still a great deal more that will have to be known about an object if it becomes necessary to deflect it from a collision course with Earth.

Opportunities

In addition to the threat that NEOs represent, they are also potential suppliers of resources for future manned space exploration. In order to use these resources, a much more detailed knowledge of their composition and physical characteristics will be required before the technologies to produce fuels or construction materials from NEOs can be developed.

Current and Future Technologies for Earth Protection

It is estimated that a 30-year advance warning would be required to have a reasonable assurance of deflecting a NEO from a collision with Earth. Thus, if a future impactor were identified today, the time to explore the characteristics of the NEO, develop a deflection system, deliver it to the NEO, and apply the deflection early enough to prevent an impact, requires about a 3-decade lead time.

The deflection technologies available today, which are chemical rockets and nuclear weapons, both have limited abilities to slow down or speed up an asteroid. A 100 m object has a mass of the order of 1 million tons, and a 1 km object has a mass of the order of 1 billion tons. To prevent an object from colliding with Earth, it must be sped up or slowed down by about 7 cm/s (about ⅙ of an mile per hour) divided by the number of years in advance that the change is applied. The fuel that can be contained in a medium-sized scientific spacecraft could successfully deflect a 100 m body if it were pushed about 15 years in advance. The Space Shuttle's main engines and the fuel contained in the large external tank could successfully deflect a 1 km diameter object if it were applied about 20 years in advance. Nuclear weapons carry much greater impulse for their mass. However, they deliver that impulse so quickly that they are more likely to break up the body than to deflect it. Because NEOs are in their own orbits around the Sun, the pieces of a disrupted object will tend to come together one half of an orbital period later. Therefore, the successful use of nuclear weapons for deflection will require the development of techniques for slowing the delivery of the impulse to the NEO and will probably also require many small weapons to be used to deflect a single NEO.

The orbital mechanics required to approach a potential impactor also require it to be identified early. It may take 5 years or more for any deflector mission to rendezvous with a NEO in an arbitrary Earth-crossing orbit.

What Remains to be Done

An overall Earth protection system must have three components. First, a search system is needed to identify any potential NEO impactors. Second, a series of detailed investigation missions are needed to understand the structure, composition, rotational state, and other physical properties of potential impactors. And finally, deflection technologies are needed to change the speed of a NEO to ensure that it will not impact Earth.

Search systems

The United States and other countries around the world have concentrated on the first part of the Earth-protection system. At the current rate of discovery, the group of observatories that are finding and cataloging NEOs will come close to achieving their goal of identifying 90 percent of the greater than 1-km diameter NEO population by 2008. More than 50 percent of the expected population has already been discovered and discoveries continue to be made each month. While this effort will retire most of the risk of a global catastrophe, the size distribution of NEOs shows us that there are a great many more small objects than larger ones. Their numbers increase by a factor of about 220 for a diameter that is reduced by a factor of 10. This very large number of small-to-modest sized objects represents the greatest remaining threat to regional safety that is not being addressed. The equipment used by current NEO surveys is sized to find the largest objects. Some sub-kilometer objects are found serendipitously; however, these telescope systems are not optimized to find the smaller objects.

A NASA NEO Science Definition Team recently examined the requirements for extending the NEO search to smaller diameters and showed that a system to accomplish the discovery and cataloging of 90 percent of all NEO greater than 100 m diameter within 10 years could be accomplished with a single Discovery-class spacecraft in a heliocentric orbit at about 0.7 AU. This modestly priced system (the Discovery class is about $300 million full mission cost) could be constructed and put on-station in four to five years.

Detailed Examination of NEOs

Several space missions that are contributing to the detailed investigations of NEOs and comets have been launched and others are currently in development. As stated above, the NEAR mission provided the first detailed information on the mass, shape, structure, and composition of an asteroid. However, we know from ground-based spectroscopic data that there is a great deal of variability among these objects.

The Giotto and Deep Space 1 missions took close images of comets Halley and Borelli. The Stardust mission will be returning with dust particles from comet Wild 2 in January of 2006. The Deep Impact mission will create a crater in comet Tempel 1 to learn about the internal composition of comets. And the DAWN mission will examine the composition of asteroids 1 Ceres and 4 Vesta, two of the largest planetoids in the solar system. These missions are making steady progress in our understanding of the formation of the solar system and the characteristics of the small bodies within it. Continuation of this series of investigations is vital to our future ability to deal with the threat and opportunities of NEOs.

Deflection Technologies

While there has been a great deal of theoretical examination of deflection techniques, no practical systems exist at this time. As the search systems and detailed examination missions progress, it is important to continue the development of deflection system technologies so that a full Earth-protection system could be deployed rapidly if a future impactor is discovered by the search systems.

Summary

The threat to life on Earth from NEOs is real even though the likelihood of a severe impact during the next few years is low. The most important thing that is needed in order to deal with this risk is an improved search system. Recent studies have shown that a search spacecraft that can catalog 90 percent of the remaining NEOs larger than 100 m in diameter over 10 years of operation can be launched within 4 or 5 years at the cost of a NASA Discovery-class mission. In addition, the pace of mission developments for detailed examination of small solar system bodies should continue undiminished. This is clearly summarized by the cartoon below, originally published in New Yorker magazine in 1998.

"All I'm saying is now is the time to develop the technology to deflect an asteroid"

WITNESS BIOGRAPHY

Michael D. Griffin is Space Department Head, Johns Hopkins University Applied Physics Laboratory.

Prior to joining APL, Mike served in a variety of executive positions with industry, including: President and Chief Operating Officer of In-Q-Tel, Inc., CEO of the Magellan Systems Division of Orbital Sciences Corporation, General Manager of Orbital's Space Systems Group, and Executive Vice President and Chief Technical Officer at Orbital. He has previously served as both the Chief Engineer and the Associate Administrator for Exploration at NASA, and as the Deputy for Technology of the Strategic Defense Initiative Organization.

Before joining SDIO in an executive capacity, Mike played a key role in conceiving and directing several "first of a kind" space tests in support of strategic defense research, development, and flight testing. These included the first space-to-space intercept of a ballistic missile in powered flight, the first broad-spectrum spaceborne reconnaissance of targets and decoys in midcourse flight, and the first space-to-ground reconnaissance of ballistic missiles during the boost phase.

Mike holds seven degrees in the fields of Physics, Electrical Engineering, Aerospace Engineering, Civil Engineering, and Business Administration, has been an Adjunct Professor at the George Washington University, the Johns Hopkins University, and the University of Maryland, and is the author of over two dozen technical papers and the textbook *Space Vehicle Design*. He is a recipient of the NASA Exceptional Achievement Medal, the AIAA Space Systems Medal, the DOD Distinguished Public Service Medal, and is a Fellow of the AIAA and the AAS. Mike is a Registered Professional Engineer in Maryland and California, and a Certified Flight Instructor with instrument and multiengine ratings.

Senator BROWNBACK. Dr. Griffin, just a couple real quick. That's the best way it's felt within the scientific community to do this, is to put a space-based observatory of sorts in an orbit out and around, to be able to categorize——

Dr. GRIFFIN. I wouldn't—that is one way. I wouldn't want to go so far as to say that the scientific community would regard it as the best way. The task can equally well be accomplished with a series or a set of ground-based telescopes spread as widely as possible on the Earth.

And indeed, I believe NASA is open to both possibilities through the announcement of opportunity to which the previous witness alluded. So either ground-based—either several ground-based observatories or a single space-based observatory could probably accomplish the same job.

Senator BROWNBACK. And what about the exploration opportunity and the research opportunity. What do you see as the biggest things we can learn from NEOs?

Dr. GRIFFIN. Well, I am an engineer by profession, and not a scientist. So my primary interest in Near Earth Objects would be for the exploration, exploitation, and development of a spacefaring infrastructure.

Many Near Earth Objects will be found to be of the class of so-called carbonaceous chondrites from which volatile material, to include water, can likely be extracted. A small fraction of them, 1 or 2 percent, a few percent, will have heavy useful metals. Others will be merely rock and stone.

But all of those together can provide construction materials, possibly fuel supplies. And those materials do not have to be lifted out of the gravity well of this planet or any other.

This is a pursuit which should occupy us in the coming decades of space exploration. It will not be the first thing that we do, but it should be allowed to be the last thing we think of.

Senator BROWNBACK. Mr. Schweickart. Good to have you here.

Mr. SCHWEICKART. Thank you, sir. With your permission, I'd like to defer to Mr. Lu first, sir. Sequences would be better that way.

The CHAIRMAN. That'll be just fine. Dr. Lu.

STATEMENT OF DR. EDWARD LU, NASA ASTRONAUT AND PRESIDENT, B612 FOUNDATION

Dr. LU. Thank you for the opportunity to discuss a bold new proposal to demonstrate—actually demonstrate altering the orbit of an asteroid. I wanted to talk today about sort of a different aspect than what you've been hearing about which is searching for asteroids and that's the necessary first step. But once you find asteroids, particularly if you find one on a collision course, the question is, "What do you do? Or what can we do?"

I represent the B612 Foundation and we're a group of astronomers, engineers and astronauts concerned about the issue of asteroid impacts. Recent developments have now given us the potential to defend the Earth against these natural disasters and I'll talk about that.

To develop this capability, we have proposed a spacecraft mission to significantly alter the orbit of an asteroid in a controlled manner by 2015 and we think it's important that there be an actual demonstration and I'll talk about why that is later.

First off. Why would you want to move an asteroid? I think we've been hearing a little bit about that and I want to put some of these odds that you've been hearing about in a different way; their equivalent numbers. You've been asking about what are the odds of getting hit by an asteroid? Well, rather than saying once per thousand years or so—another way to say that is that during your lifetime, during my lifetime, everyone in this room, there's a 10 percent chance that there will be a 60 meter asteroid that impacts the Earth with an energy of a 10 megatons and that's about 700 simultaneous Hiroshima sized bombs going off. It's 10 percent.

It's kind of like a bad lottery but—in that most days are—nothing's going to happen, but occasionally you get a bad day and there's a one in 50,000 chance that your death, my death, everyone in this room along with most of humanity and human civilization is going to end all on the same day with the impact with a greater than kilometer sized asteroid; one to 50,000 is pretty small, but that would be the end of it.

We think that we now have the potential to change these odds and what we propose is again actually trying a demonstration mission to deflect an asteroid because there's a lot of unknown surrounding this. You've been hearing about that but the surest way to actually attack any of these unknowns is to try something.

The first time that you attempt to deflect an asteroid shouldn't be on the real day because there's going to be many surprises in store. The first few missions may not work at all. You want to learn those ahead of time before you actually have to use such a system.

So why do we suggest by 2015? Well, again, the time to test, learn and experiment is now because we have just recently developed or are developing new advances in space nuclear power and high efficiency propulsion that we think makes it possible. 2015 is challenging, but we think doable and having a clear goal, a clear date will, we think, serve to focus the development efforts.

So how big of an asteroid are we proposing to move? The demonstration asteroid that you try this test mission on ought to be large enough to represent a real risk and also what you test should be applicable to larger size asteroids because you want to start out fairly small, but you want what you learn to be useful through larger asteroids.

So we're suggesting an asteroid of about 200 meters and a 200 meter asteroid if it impacts, would be about a 600 megaton explosion and as we heard that if that lands in an ocean that will likely destroy most coastal cities in that ocean. So that's large enough to be a threat.

Asteroids of about 150 meters across or larger are thought to be not single pieces, but rather conglomerations or loosely held together groups called, "rubble piles," and so if you pick something that's a rubble pile, what you learn will be applicable to larger size asteroids. So again, we're picking something that's of moderate risk—of major risk but is doable we think. Large enough to be doable.

So what do we mean by significantly alter it? It turns out that you don't really need to give an asteroid very much of a push to prevent a collision. If you have several decades of warning which we expect if these proposed searches are carried out, then all you really need to do is if you have several decades of notice is to give an asteroid a small impulse. Maybe about a centimeter a second. That's about 1/50th of a mile an hour.

Even though the typical asteroid moves around the sun at about 70,000 miles per hour, making it 70,000.002 is enough to prevent a collision if you've got a decade or so of warning, but even though that's a small change in velocity, that's still pretty hard because even a 200 meter asteroid weights about 10 million tons.

So why do you need to move it in a controlled manner? Well, if you don't make it a highly controlled thing, you risk making the problem worse. You've seen *Armageddon,* or movies like that where they talk about blowing up an asteroid with a nuclear weapon. Well, you stand as much of a chance of making your problem worse as making it better and you split the asteroid up and what you've done then is turned this rifle bullet heading at you into a shotgun blast and now your life has just gotten worse.

Furthermore, you won't really quite know where you're going to end up pushing the asteroid and that's not a good situation if you're trying to avert a catastrophe. So we are suggesting doing this in a controlled slow manner which also has the advantage that you can use the same technology for commercial reasons—commercial and exploration reasons which has also been brought up. So how can you do this?

Well, first off, conventional rockets like we use today, like I've launched on the Space Shuttle and Rusty's flown on the Saturn Five, those use chemical propellants. Well, chemical propellants basically don't have the umph to move objects of this size. So what we are proposing to use is a nuclear powered spacecraft using high energy propulsion such as an ion or plasma engine. Those are currently in development at NASA today as part of the Prometheus Project.

In fact, the thrust and power requirements that we've discussed for moving a 200 meter asteroid are about the same as the Jupiter Icing Moons Orbiter and that's a spacecraft that's currently planned for launch in around 2012. So we're suggesting that you could use similar hardware to do this demonstration mission.

So this spacecraft would fly to an asteroid rendezvous and land on and attach to this small asteroid and push on it and by continuously thrusting for some period of months you could slowly, slowly, slowly alter the velocity by a fraction of a centimeter per second and we could measure that from the Earth so we could verify that it's worked and then we say, well, what can we learn from this?

Well, remember that this is not really a planetary protection system, but it's a first attempt to learn more about the mechanics of asteroid deflection because like I said, a lot of technical complications and unknowns about asteroids themselves, their structure, what they're made of, but the way to make progress I think is to build, fly and test.

You need to go there to find out the questions that you don't even know yet. And besides the benefit of actually being able to demonstrate that you can do this there's a lot of interesting scientific questions you can answer at the same time. Again, the best way to learn about asteroids is to go there.

So how does this fit into NASA's New Exploration Initiative?

Well, in the near term, we think this mission would be an ideal way to flight test the nuclear propulsion systems already under development as part of "Project Prometheus." It could also serve as a precursor to a crewed mission, meaning with people on board to go visit an asteroid.

These missions have been proposed as an intermediate step to test your spacecraft systems for eventual longer term missions to Mars. I would personally love to go on one of those missions.

In the longer term, the ability to land on and manipulate asteroids is an enabling technology for extending human and robotic presence throughout the solar system.

If we're to truly open up the solar system, this mission we feel is a good way to start. It's likely that someday we're going to use asteroids for fuel, building materials or simply space habitats, mining, people are going to earn money off this. And the B612 Mission would mark a fundamental change in spacecraft in that it would actually alter in a measurable way an astronomical object rather than simply observing it.

We can become active participants in the cosmos versus just being interested observers. Human beings need to eventually take charge of our own destiny in this manner or we will some day go the way of the dinosaurs when the next great asteroid impact occurs. Thank you.

[The prepared statement of Dr. Lu follows:]

PREPARED STATEMENT OF DR. EDWARD LU, NASA ASTRONAUT AND PRESIDENT, B612 FOUNDATION

Thank you for the opportunity today to discuss a bold new proposal to demonstrate altering the orbit of an asteroid. I represent the B612 foundation, a group of astronomers, engineers, and astronauts, concerned about the issue of asteroid impacts. Recent developments have now given us the potential to defend the Earth against these natural disasters. To develop this capability we have proposed a spacecraft mission to *significantly alter the orbit of an asteroid in a controlled manner by 2015.*

Why move an asteroid? There is a 10 percent chance that during our lifetimes there will be a 60 meter asteroid that impacts Earth with energy 10 megatons (roughly equivalent to 700 simultaneous Hiroshima sized bombs). There is even a very remote one in 50,000 chance that you and I and everyone we know, along with most of humanity and human civilization, will perish together with the impact of a much larger kilometer or more sized asteroid. We now have the potential to change these odds.

There are many unknowns surrounding how to go about deflecting an asteroid, but the surest way to learn about both asteroids themselves as well as the mechanics of moving them is to actually try a demonstration mission. The first attempt to deflect an asteroid should not be when it counts for real, because there are no doubt many surprises in store as we learn how to manipulate asteroids.

Why by 2015? The time to test, learn, and experiment is now. A number of recent developments in space nuclear power and high efficiency propulsion have made this goal feasible. The goal of 2015 is challenging, but doable, and will serve to focus the development efforts.

How big of an asteroid are we proposing to move? The demonstration asteroid should be large enough to represent a real risk, and the technology used should be scaleable in the future to larger asteroids. We are suggesting picking an asteroid of about 200 meters. A 200 meter asteroid is capable of penetrating the atmosphere and striking the ground with an energy of 600 megatons. Should it land in the ocean (as is likely), it will create an enormous tsunami that could destroy coastal cities. Asteroids of about 150 meters and larger are thought to be comprised of loose conglomerations of pieces, or rubble piles, while smaller asteroids are often single large rocks. The techniques we test on a 200 meter asteroid should therefore also be applicable to larger asteroids.

What does "significantly alter the orbit" mean? If proposed asteroid searches are enacted, we expect to have decades or more of warning before an impact. Given this amount of warning, to prevent an impact only requires that the orbital velocity of an asteroid be altered by a small amount, less than of order 1 cm/sec, or about .02 MPH. This is a tiny velocity increment, considering that the orbital speeds of asteroids are of order 70,000 MPH. However, this is still a very difficult task since the mass of a 200 meter asteroid is of order 10 million tons.

Why does the asteroid need to be moved in a "controlled manner"? If the asteroid is not deflected in a controlled manner, we risk simply making the problem worse. Nuclear explosives for example risk breaking up the asteroid into pieces, thus turning a speeding bullet into a shotgun blast of smaller but still possibly deadly fragments. Explosions also have the drawback that we cannot accurately predict the resultant velocity of the asteroid—not a good situation when trying to avert a catastrophe. Conversely, moving an asteroid in a controlled fashion also opens up the possibility of using the same technology to manipulate other asteroids for the purposes of resource utilization.

How can this be accomplished? This mission is well beyond the capability of conventional chemically powered spacecraft. We are proposing a nuclear powered spacecraft using high efficiency propulsion (ion or plasma engines). Such propulsion packages are currently already under development at NASA as part of the Prometheus Project. In fact, the power and thrust requirements are very similar to the Jupiter Icy Moons Orbiter spacecraft, currently planned for launch around 2012. The B612 spacecraft would fly to, rendezvous with, and attach to a suitably chosen target asteroid (there are many candidate asteroids which are known to be nowhere near a collision course with Earth). By continuously thrusting, the spacecraft would slowly alter the velocity of the asteroid by a fraction of a cm/sec—enough to be clearly measurable from Earth.

What will we learn from this? It is important to remember that this mission is merely a first attempt to learn more about the mechanics of asteroid deflection. There are a number of technical complications, as well as many unknowns about the structure and composition of asteroids. However, the way to make progress is to build, fly, and test. Much of what we will learn is generic to many proposed asteroid deflection schemes, with the added benefit of being able to answer important scientific questions about asteroids themselves. The best way to learn about asteroids is to go there.

How does this fit into the new Exploration Initiative at NASA? In the near term, this mission would be an ideal way to flight test the nuclear propulsion systems under development as part of the Prometheus Project. It could also serve as a precursor to a crewed mission to visit an asteroid. Such missions have been proposed as intermediate steps to test spacecraft systems for eventual longer term crewed missions to Mars.

In the longer term, the ability to land on and manipulate asteroids is an enabling technology for extending human and robotic presence throughout the solar system. If we are to truly open up the solar system, this mission is a good way to start. It is likely that someday we will utilize asteroids for fuel, building materials, or simply as space habitats. The B612 mission would mark a fundamental change in spacecraft in that it would actually alter in a measurable way an astronomical object, rather than simply observing it. Human beings must eventually take charge of their own destiny in this manner, or we will someday go the way of the dinosaurs when the next great asteroid impact occurs.

Senator BROWNBACK. Thank you, Dr. Lu. Mr. Schweickart. I guess both of you having traveled to space that's—thank you for being here.

STATEMENT OF DR. RUSSELL L. SCHWEICKART, CHAIRMAN OF THE BOARD, B612 FOUNDATION

Dr. SCHWEICKART. Thank you for holding hearings, sir. I'll deal a bit more with some of the policy issues implied in what's been said today in previous testimony. I think it is extremely important and reflected to a certain extent by the questions you've been asking yourself for people to get a picture of what it is that we're talking about. And so in addition to repeating, you know, that Near Earth Asteroids in the hundreds of thousands pose an occasional but substantial threat to life. Let me give you a couple of specific examples.

As Ed said a moment ago, we're all talking about the same elephant and giving you a different snapshot of it. It's all basically the same statistical data, but we're trying to give a realistic picture. So let me try it this way.

Last night something on the order of hundreds of thousands to a million bits and pieces of asteroids and comets hit the Earth. The people that looked up and saw them called them, "shooting stars." That's what you and I would call them if we happened to be looking up on a clear night as well. They don't do any damage as you know because the atmosphere protects us.

But getting a little bit bigger and of course a little fewer of them, a little less frequent with the impacts. If we took a Near Earth Asteroid the size of this room, one of those is going to hit us about once every 2 to 3 years and that would in fact also not do much damage but that would in fact result in something on the order of a 10 to 15 kiloton, about a Hiroshima size explosion in the upper atmosphere. That is something the size of this room every 2 to 3 years.

Now, getting a bit bigger and where it starts getting dangerous, step outside and picture something the size of the U.S. Capitol Building. Now, have that come flying at the Earth at about 20 times the speed of a rifle bullet, if you will. That's going to happen on the order of every few hundred years to a thousand years, and in that case, we're going to have an explosion the size of the largest nuclear weapon in the U.S. arsenal, something on the order of 10 to 15 megatons of energy.

That again compares with the Tunguska Event of 1908 that we heard about earlier or a little bit larger if something like that happened over—if the U.S. Capitol flew at the U.S. Capitol it would destroy the Washington Metropolitan area totally. It wouldn't hit the surface. It would actually explode something 10 to 20,000 feet above the Capitol, but it would decimate everything underneath it for the whole metropolitan area.

Now, that particular size that I just related is the smallest thing that we have all been talking about detecting ahead of time. That is something down in the vicinity of 100 meters in diameter, so that gives you an idea. That's the smallest thing that we're all up here proposing that the Congress direct that NASA, NSF, whoever take under their wing to get early warning and intelligence on this threat to public safety.

Protection of the public—so I'll go on from those examples. Protection of the public from this hazard, and as I say there's something around 200,000 of these things to be discovered yet that circle around the sun right now. And the protection from this hazard depends entirely on increasing the capability of our current asteroid detection and tracking program.

This is a known hazard for which public safety is critically dependent on timely information gathering, as is the case in all intelligence about threats to public safety.

The hazards posed by Near Earth Asteroids will become widely know by the general public as the detection and tracking programs shift their focus to the far more numerous, but very dangerous smaller NEOs of—and when I say "smaller NEOs," I'm talking about the size of the U.S. Capitol Building.

Close calls with NEOs in the future will trigger a growing public concern and commensurate expectation that the government is doing something about this. The government is doing something to protect them. At the moment, that is not the case at all. The government is doing nothing to actually protect people from any NEOs which are coming our way to hit us. We are detecting them, but we're not yet providing actual or active protection.

Unlike other natural disasters, this hazard that we're talking about here is both predictable and preventable, using technologies that are being developed by NASA today in its Prometheus Program.

What is missing today is the goal to explore these Near Earth Asteroids to gather the critical understanding necessary to ultimately protect the public from this threat.

Near Earth Asteroids—well, let me just say happily Near Earth Asteroids are not only a threat. Near Earth Asteroids are also a rich exploratory—exploration target, excuse me, for both scientific and economic benefit. Asteroids are easily accessible gold mines of information about the origins of the solar system.

They also, and perhaps more importantly, contain a wealth of resources for utilization in space which are far more accessible than resources on the moon. In fact, as in the case with the moon, the Near Earth Asteroids can serve as stepping stones to Mars.

It is not and probably should not be NASA's job to protect the Earth from asteroid impacts, but it is NASA's job to develop space technologies and capability to serve humanity. Since Near Earth Asteroids represent both an opportunity for and a threat to humanity and NASA is currently seeking mission opportunities for its

Prometheus Program, it is entirely appropriate that a portion of its efforts be directed to this end.

Therefore, B612 Foundation of which both Ed and I are representing here, call today on the Congress to task NASA first with increasing the capability of the current Space Guard Survey consistent with the recommendations of the recent NASA NEO Science Definition Team Report which you've heard reported on. In other words, we need, absolutely need better intelligence to protect the public.

Second, we call on Congress to direct NASA to incorporate the B612 Mission Goal to demonstrate the capability to land on, explore and deflect an asteroid as part of it Prometheus Program.

And third, we call on Congress to request that OSTP initiate a high level study to develop a U.S. Government Policy for both national and international response to deflection of Near Earth Asteroids. This is not, as you're well aware, a domestic problem only. This is a global problem and we need to be coordinating around this planet with means to protect life in the future.

I'd like to emphasize in closing something that Ed alluded to and that is for the first time in the history of humanity, we have developed the technology which will enable us, provided we focus on it, to protect the future of life on this planet. Up until this time, we've been lucky in this shooting gallery. The dinosaurs were not lucky. We now have a chance. What we've got to do is focus on it and take responsibility for the future of life on this planet and today we have that possibility. Thank you very much, sir, and we'd be happy to answer any questions.

[The prepared statement of Dr. Schweickart follows:]

PREPARED STATEMENT OF RUSSELL L. SCHWEICKART, CHAIRMAN, B612 FOUNDATION

Chairman Brownback, Senator Breaux, members of the Committee:

Introduction

First I'd like to thank you for the invitation to speak with you today about this emerging public policy issue of near Earth objects (NEOs) threatening life on Earth. One might have thought, just a few years ago, that the subject of asteroids was one for space wonks and wanna-be astronauts and astronomers. But today the realization is rapidly dawning on the media and the general public that asteroids are a subject of more than passing interest! More and more people are coming to know that some few of these asteroids do not silently pass the Earth, but indeed crash in, largely unannounced. On the rare occasions when this happens they can wreak havoc of a magnitude unprecedented in human history. At the upper limit impacts by large asteroids have caused global destruction leading to the virtually instantaneous extinction of life for most of the species living at the time. The dinosaurs were momentary witnesses to a billion megaton event of this kind 65 million years ago. At the lower limit of concern, but occurring much more frequently, we are dealing with events with an explosive force of 10–15 megatons. It is worth pointing out, however, that these small, most frequent events are more powerful than the blast from the most powerful nuclear weapon in the current U.S. nuclear arsenal.

Given the extremely low frequency of these natural events in combination with the extremely grave consequences when they occur, we find ourselves challenged to properly place this subject in our normal list of priorities. Inattention to infrequent events, regardless of their impact, is the "default" solution of choice given the crowd of issues continually burning around our feet.

Therefore the Committee is to be congratulated for its foresight and exemplary public service in realizing the importance of dealing with this issue now.

History

Perhaps the best logic path to bring the Committee to appreciate our recommendations for action is to briefly outline the key realities the founders of the

B612 Foundation faced when we first came together back in October 2001. We are primarily a group of technical experts familiar with or working within the fields of space exploration and planetary science. We are astronauts, astronomers, engineers and a few others who are knowledgeable about the subject of comets and asteroids and their history of impacts with the Earth and other solar system bodies. We came together out of a deep concern that the threat to life implied in our knowledge of near Earth asteroids (NEAs) was not resulting in any organized effort to take action to protect the public from this hazard. We came together to explore whether or not something could be done, and if so, whether we could trigger a program to protect the public.

In summary, we faced the following facts:

(1) Asteroid impacts with Earth have, do, and will continue to occur with devastating consequences to life.

(2) Our detection program (the Spaceguard Survey) has produced a good statistical characterization of the overall threat and actual knowledge that at least 60 percent of the asteroids larger than 1 kilometer in diameter will not strike the Earth in the next 100 years.

(3) Many impacts by asteroids less than 1 km in diameter, however, which occur hundreds of times more frequently than those over 1 kilometer, will cause unacceptable devastation at both local and regional levels.

(4) The increasing capability of our detection programs in the next several years will result in a dramatic increase in the discovery rate of these smaller but very dangerous asteroids.

(5) The media and the general public will become ever more aware of this threat and concerned that something should be done about it.

(6) A known threat that can potentially destroy millions of lives AND can be predicted to occur ahead of time, AND prevented, cannot responsibly go unaddressed.

This inexorable logic led us to decide to take action and examine whether preventive measures could be taken to mitigate this threat, and if so, what specific course of action we would recommend.

The Challenge

It became immediately clear to us that the combination of advanced propulsion technologies and small space qualified nuclear reactors, both operating in prototype form already, would be powerful enough, with reasonable future development, to deflect most threatening asteroids away from a collision with the Earth, given a decade or more of advance warning.

Nevertheless we saw two immediate problems.

First we lack the specific knowledge of the characteristics of NEAs necessary to design anything approaching a reliable operational system. We could readily show that the technology would exist within a few years to get to and land on an asteroid. We also determined that after arriving at the asteroid we would have enough propulsive energy available to successfully deflect the asteroid from an Earth impact a decade or so later. What was missing however was knowledge about the structure and characteristics of asteroids detailed enough to enable successful and secure attachment to it.

Second we recognized that before we would be able to gather such detailed information about NEAs there would likely be many public announcements about near misses and possible future impacts with asteroids which would alarm the general public and generate a growing demand for action. We felt strongly that there needed to be some legitimate answer to the inevitable question which will be put to public officials and decision makers, "and what are you doing about this?"

These two considerations led us to the conclusion that the most responsible course of action would be to mount a demonstration mission to a NEA (one of our choosing) which would accomplish two essential tasks: (1) gather critical information on the nature of asteroid structure and surface characteristics, and (2) while there, push on the asteroid enough to slightly change its orbit thereby clearly demonstrating to the public that humanity now has the technology to protect the Earth from this hazard in the future.

We furthermore determined that this demonstration mission could be done with currently emerging capabilities within 10–12 years.

We therefore adopted the goal of *"altering the orbit of an asteroid, in a controlled manner, by 2015"*.

Reflecting the work that we have done to bring this goal to realization, a number of us wrote a descriptive article for *Scientific American* magazine entitled, "The Asteroid Tugboat." *Scientific American* published it in the November 2003 issue of the magazine. I have provided reprints of this article to the Committee and I would like to submit a copy with this testimony and ask that it be incorporated in the record.

Implementation

A key to implementing this mission is NASA's Prometheus Program. Shortly after B612 Foundation began work on outlining a mission to explore and deflect an asteroid NASA announced the formation of its Prometheus Program to develop and demonstrate technologies to permit routine human and robotic activity in space "beyond low Earth orbit".

The key technologies which NASA recognized would enable this capability are identical with what we had determined were necessary to demonstrate the capability to land on and deflect a near Earth asteroid, *i.e.,* high performance electric propulsion systems and the space nuclear electric power systems to power them. Shortly after announcing the Prometheus Program NASA announced the Jupiter Icy Moons Orbiter (JIMO) mission complete with schematic representations of the spacecraft. Integral to the design of this mission were the very high performance engines and space nuclear power system which would be necessary to enable our B612 mission. We therefore adopted, as an explicit element of our design, the JIMO/Prometheus capabilities, recognizing that this was the most likely path to meeting the demonstration goal that we had set.

Mounting a mission to assure the public that when we discover an asteroid "with our name on it" we can deflect it from a life threatening impact on Earth does not require the development of additional new technologies. The key capabilities required are already "in the pipeline" of the existing Prometheus Program. No new NASA money is required, nor is a change in NASA's mission called for. What is required is that the B612 mission be incorporated within the Prometheus Program . . . a matter of policy.

Indeed, if one examines the technical requirements associated with the B612 mission, one sees not only a mission ideally suited to demonstrating the Prometheus technology, but a mission notably less demanding than the currently planned JIMO mission. One could then quite easily consider the B612 mission as either a follow-on or a precursor to the JIMO mission, depending on NASA's technical judgment as to where it fits most logically in their mission model.

The B612 mission also fits well into the President's Space Exploration Initiative. This mission both utilizes and graphically demonstrates the key enabling technologies for routine future operations "beyond low Earth orbit". It is an ideal way to demonstrate the technology and the greatly enhanced propulsive capability implicit in the Prometheus exploration program. In executing such a mission humankind will, for the first time in its history, have altered the trajectory of a cosmic body, a demonstration of evolving capability in space technology and exploration if there ever was one!

Additional Perspective

A few final comments are perhaps appropriate.

Near Earth asteroids are a reality which is here to stay. In fact they will become far more prominent in the public mind as time goes on and our detection of them continues to improve. It is therefore appropriate that we take a more circumspect look at these sometimes unruly, but ever-present, neighbors. Near Earth asteroids are, in fact, both a threat and an opportunity.

Certainly we need to learn more about our capability to protect life here on Earth, and the sooner the better.

Visiting asteroids can also teach us a great deal about the origins of the solar system, and perhaps even the origins of life. Unlike the material of the Earth, which has been melted and processed through extensive geologic activity, the materials of small asteroids have not been so extensively reprocessed. They are fossil building blocks left over from the formation of the planets and as such can teach us a great deal about the original material from which the planets formed.

Perhaps even more important, asteroids, and especially the near Earth asteroids, are also the most readily accessible and rich reservoir of non-terrestrial resources available to us. The new space initiative has emphasized our determination to return to the Moon and then extend our capability outward to Mars and beyond. One of the purposes advocated for returning to the Moon is to explore and potentially develop the capability to utilize the resources there for human benefit. The possibility of extracting oxygen, water and perhaps other materials from lunar soils has long been advocated as a potential capability for reducing the cost of future space operations.

Yet these same resources, and others in rich abundance, characterize the makeup of asteroids. Unlike lunar materials, which are largely depleted of heavy minerals, the asteroids are quite rich in metallic elements, as well as those minerals which may provide water and oxygen. Furthermore it is significantly less expensive to fly to and from selected near Earth asteroids than to and from the Moon due to the virtual absence of gravitational forces associated with these bodies.

When commercial, entrepreneurial activity emerges into deep space it will undoubtedly include the development and exploitation of in-situ resources and services. Given the critical importance of benefit/cost analysis in any commercial venture it would be surprising if utilization of asteroidal resources, especially water, is not one of the first deep space initiatives attracting private capital.

Given then the infrequency of actually having to deflect an asteroid in order to avoid an Earth impact it is unlikely that humanity will ever need to develop a stand-alone planetary defense system. However, given the commercial, as well as the scientific value implicit in near Earth asteroids it is highly likely that operations to and from the asteroids will become a routine part of human space operations. One can readily imagine a time when visiting, using and even moving near Earth asteroids becomes a routine human capability. Simply calling on the "Ace Asteroid Mining and Moving Company" to nudge asteroid 2018 FA322 gently out of the way may then be all that is required to prevent an otherwise devastating event.

While the above scenario is somewhat fanciful, it is, given time, only slightly so. In the meanwhile, in the immediate future, we will be discovering an increasing number of potentially life threatening NEAs and the public will become justifiably concerned. Without a legitimate answer to this concern for their safety this concern could morph into alarm.

While many lives are lost every year in natural disasters of one kind or another, there are few natural disasters that can reliably be predicted, much less prevented. Throughout human experience we have been faced with comforting and compensating the devastated after the disaster is over. With near Earth asteroid impacts, however, we are confronted with a massive natural disaster that can be both predicted AND prevented, and the public will come to understand that this is the case.

Given the justifiable public expectation of being protected from both natural and manmade disasters it is incumbent on us to address this known threat responsibly. We therefore make the following specific recommendations:

(1) We call on the Congress to task NASA with increasing the capability of the current Spaceguard Survey consistent with the recommendations of the recent NASA Near-Earth Object Science Definition Team report.[1]

(2) We call on Congress to direct NASA to incorporate the B612 mission goal of demonstrating the capability of landing on, exploring, and deflecting an asteroid as part of its Prometheus Program.

(3) We call on Congress to request that OSTP initiate a high level study to develop a U.S. Government policy for both national and international response to the deflection of near Earth asteroids.

[1] 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, August 22, 2003.

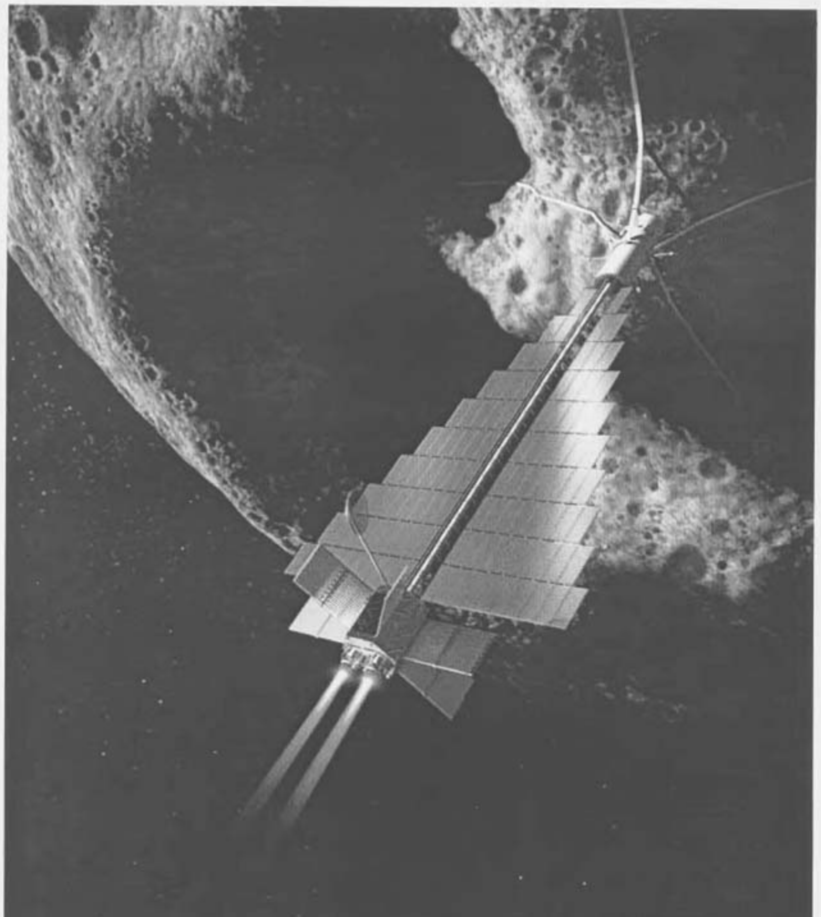
ATTACHMENT

To prevent
an asteroid from
hitting Earth,
a space tug
equipped with
plasma engines
could give it a push

The Asteroid Tugboat

By Russell L. Schweickart, Edward T. Lu, Piet Hut and Clark R. Chapman

On an average night, more than 100 million pieces of interplanetary debris enter Earth's atmosphere. Luckily, most of these bits of asteroids and comets are no bigger than small pebbles; the total weight of the 100 million objects is only a few tons. And our planet's atmosphere is thick enough to vaporize the vast majority of these intruders. So the debris usually streaks harmlessly overhead, leaving the bright trails popularly known as shooting stars.



SPACE TUG is shown pushing an asteroid in this artist's highly speculative rendering of a deflection mission. The tug could use plasma engines to steadily thrust the asteroid in the desired direction. An array of radiator panels would dissipate the heat from the craft's nuclear reactor, located in the section closest to the asteroid's surface. The segmented arms on the surface attach the tug to the asteroid and stabilize the craft.

When bigger objects slam into the atmosphere, however, they explode rather than vaporize. In January 2000, for example, a rock about two to three meters wide exploded over Canada's Yukon Territory with a force equivalent to four or five kilotons of TNT. This kind of event occurs once a year, on average. Less frequently, larger rocks produce even more powerful explosions. In June 1908 a huge fireball was seen descending over the Tunguska region of Siberia. It was followed by an enormous blast that flattened more than 2,000 square kilometers of forest. The consensus among scientists today is that a rocky asteroid about 60 meters in diameter exploded some six kilometers above the ground with a force of about 10 megatons of TNT. The blast wave devastated an area approximately the size of metropolitan New York City.

Recent observations of near-Earth objects—asteroids and comets whose paths could intersect Earth's orbit—suggest that the chance of a similar event happening in this century is about 10 percent. Asteroids 100 meters across and larger pose an even more ominous threat because they will penetrate deeper into the atmosphere or hit the surface. Such an impact, which has a 2 percent chance of occurring before 2100, would cause an explosion equivalent to 100 megatons or more of TNT. If a large asteroid crashes into the ocean, which happens in about 70 percent of impacts, it could create a tsunami that might kill millions of people by inundating coastal cities. Events of this kind happen once every 40,000 years or so. And an asteroid with a diameter bigger than one kilometer would strike Earth with the energy equivalent of 100,000 megatons of TNT, far greater than the combined energy of all the nuclear weapons in existence. Impacts of this size and larger have the potential to wipe out human civilization, and there is a chance of perhaps one in 5,000 that such a strike will occur in this century.

Rather than giving an asteroid a brief, powerful shove, the tug would deliver gentle pressure.

Can humanity prevent these catastrophes? Over the past decade scientists and engineers have proposed a variety of schemes to deflect an asteroid that is heading toward Earth [*see box on page 58*]. Several researchers have advocated detonating a nuclear weapon on or near the asteroid to either break it up or change its course, but the effects of a nuclear blast are difficult to predict, and that uncertainty has led many experts to view this option as a last resort at best. Recently interest has focused on more controlled options for shifting an asteroid's trajectory. For the past two years we have been studying the concept of an unmanned space tug that would rendezvous with an incoming asteroid, attach to its surface and slowly push the body so that it misses Earth. (Because of the unique characteristics of comets, we do not address them in this proposal. New studies indicate that comets constitute only about 1 percent of the overall impact threat to Earth.) To push the asteroid, the space tug would use nuclear-powered engines that expel jets of plasma, a high-temperature mix of ions and electrons. We believe that a mission to

demonstrate the asteroid-tug concept could be accomplished by 2015.

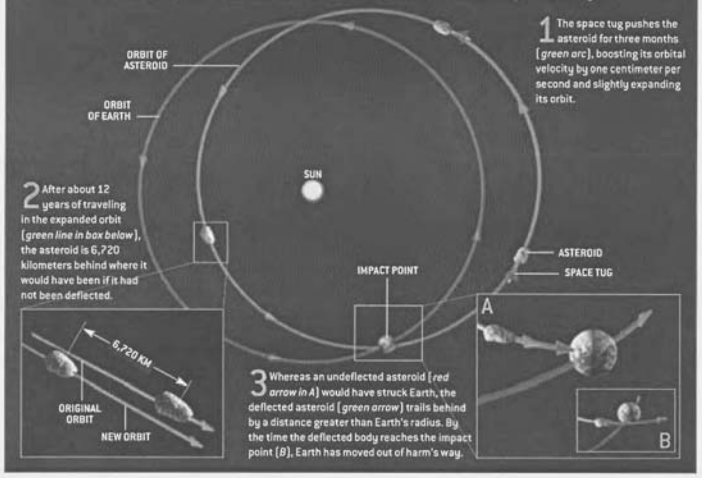
Why develop such a spacecraft now, before astronomers have identified any asteroids on a collision course with Earth? Because the system should be tested before it is urgently needed. By attempting to deflect an asteroid that is not on, or even close to, a collision trajectory, researchers will acquire the experience necessary to build a reliable defense. Potentially hazardous asteroids have not yet been studied in any detail; because we do not know much about their interior makeup, surface characteristics or structural integrity, we cannot know what will happen when a space tug nudges one. The best way to learn about these crucial aspects is to land a spacecraft on an asteroid and then try to move it. As a bonus, the mission would add to our understanding of asteroids, pioneer the way to asteroid mining, and demonstrate critical technologies for future exploration of the solar system.

What is more, NASA is already working on the key technologies needed for the asteroid tug. As part of the Prometheus Project, the space agency is trying to design nuclear reactors that could power ion-propulsion systems for interplanetary

PAT RAWLINGS/SAIC (*preceding pages*)

Overview/*Nudging an Asteroid*

- Near-Earth asteroids pose a threat to humanity. A direct hit by a 100-meter-wide asteroid would destroy a large city, and a one-kilometer-wide object could wipe out our civilization.
- Previous proposals for deflecting Earth-bound asteroids, such as nuclear explosions or kinetic-impact schemes, are unreliable. But a space tug equipped with plasma engines could provide a gentle push that would cause the asteroid to miss its rendezvous with Earth (assuming sufficient warning time).
- A mission to demonstrate the asteroid-tug concept could be accomplished by 2015. NASA is already developing nuclear reactors and propulsion systems that could be used by the space tug.



AVERTING A COLLISION

A SPACE TUG can alter an asteroid's orbit by pushing in the direction of its orbital motion. This diagram assumes that the tug begins pushing 12 years before the projected impact and that the asteroid has an orbital period of 1.15 years.

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spacecraft. NASA plans to integrate these systems into the Jupiter Icy Moons Orbiter (JIMO), a spacecraft that is expected to visit the Jovian moons of Ganymede, Callisto and Europa in the next decade. The same technologies could be applied to the greatest public safety project in history: warding off the doomsday rock that will sooner or later threaten humanity.

The B612 Mission

THE PROBLEM OF DEFLECTING an asteroid resolves into a timing issue. First, astronomers must detect the asteroid at least a decade before impact to provide time for the actions to take effect. Fortunately, with continued improvement in ongoing asteroid-detection programs, this is a reasonable expectation. To prevent the rock from hitting Earth, the most efficient plan is to either speed up the body by pushing it in the direction of its orbital motion or slow it down by pushing in the opposite direction. Changing the asteroid's velocity alters its orbital period—the time it takes to go around the sun. Because Earth moves along its orbit at an average speed of 29.8 kilometers per second and its diameter is 12,800 kilometers, our planet takes 215 seconds to move half its diameter. If an asteroid were headed for a bull's-eye collision with Earth, the challenge would be to change the asteroid's orbital period so that it arrives at the rendezvous site at least 215 seconds before or after Earth does, allowing the body to whiz safely by our planet [*see illustration above*].

Applying a soft but prolonged push on the asteroid about 10 years before it is expected to hit Earth, the tug would need to boost the asteroid's velocity by only about one centimeter per second. This change would slightly expand the asteroid's orbit and lengthen the time it takes to travel around the sun. For example, for an asteroid with an orbital period of two years, a one-centimeter-per-second velocity change would increase its period by 45 seconds and create a delay of 225 seconds over 10 years—enough for the asteroid to miss Earth by a small margin. Alternatively, the space tug could slow down the asteroid, shrinking its orbit and reducing the period by 45 seconds; after 10 years, the asteroid would arrive at the rendezvous site 225 seconds before Earth does. Of course, if the space tug reaches the asteroid when it is closer to striking Earth, it would need to give the body a bigger push. This fact underscores the importance of early and accurate detection of all near-Earth asteroids [*see box on page 60*].

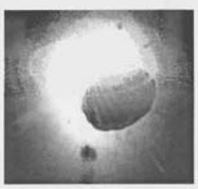
To demonstrate this concept and the technologies involved, we have proposed the development of a space tug that could deflect a 200-meter-wide asteroid, which would cause regional devastation if it hit Earth. We have dubbed this test project the B612 mission (B612 is the name of the asteroid in *The Little Prince*, the well-known children's book by Antoine de St. Exupéry). A rocky 200-meter asteroid has a mass of about 10 billion kilograms. Rather than giving the asteroid a brief, powerful shove—which might shatter the body instead of altering its course—the B612 tug would deliver gentle pressure. The force would be only about 2.5 newtons, approximately equivalent to the force required to hold up a glass of milk. But if this light nudge were applied for just over three months, it would be enough to change the asteroid's velocity by 0.2 centimeter per second. Should we be faced with an actual threat by a 200-meter asteroid, our small demonstration mission would either have to be scaled up by a factor of five or more to prevent the body from smashing into Earth, or else we would have to act at least 50 years before impact.

Because the force must be provided continuously for an extended period, the space tug's engines would require a significant amount of fuel. An additional large supply of propellant would be needed to get the tug to rendezvous with the asteroid. The average velocity change to get from our planet to a typical near-Earth asteroid is about 15 kilometers per second—one third more than the velocity change required to escape Earth's gravity. The standard chemical rocket engines, which mix fuel with oxidizer in a combustion chamber, would be hard-pressed to propel a substantial spacecraft (and all the fuel needed to push the asteroid) to these speeds. Such a vehicle would require so much propellant to per-

Asteroid Roundup

THE VARIOUS PLANS for deflecting an Earth-bound asteroid fall into two categories: those that rely on brief but intense applications of force and those that involve gently pushing or pulling the body over a long time. The most frequently mentioned concepts are described below.

NUCLEAR EXPLOSIONS have been proposed in two schemes. The obvious one is to destroy the asteroid by blasting it to smithereens. The less obvious approach would be to detonate a nuclear device off to one side of the asteroid, which would intensely heat the surface facing the explosion. The vaporization of surface rocks on that side of the asteroid would accelerate it slightly in the opposite direction. The advantage of these options is that the technology already exists and could be rapidly deployed. Theoretically, a powerful nuclear explosion could deflect a large asteroid that is just months from hitting Earth, a capability beyond that of any other technique. The problem, however, is that the results are neither predictable nor controllable. The explosion could split the asteroid into several large pieces, which might compound the problem rather than solve it.



NUCLEAR EXPLOSION might split an asteroid instead of changing its course

KINETIC IMPACT plans also take advantage of existing technology. Simply launch the largest spacecraft available and smash it into the threatening asteroid at as high a velocity as can be mustered. Given the extremely high relative velocities necessary to deflect a substantial asteroid, a major challenge would be guiding the spacecraft so that all its impact energy goes into moving the asteroid off course and not spinning the body or knocking off a small chip. And as with nuclear explosions, splitting the asteroid is also a concern.

A MASS DRIVER is a device built on the surface of the asteroid that would repetitively hurl rocks into space, causing the asteroid to accelerate slowly in the opposite direction. Throwing enough rocks in the right direction would change the velocity of the asteroid enough to avoid a collision with our planet. The advantage of the mass driver is that it ejects materials from the asteroid itself, obviating the need to carry propellant from Earth. Throwing rocks, however, still requires a substantial energy source. The design of such a machine and its robotic installation on the asteroid's surface would be daunting tasks.

ABLATION is similar in concept to the standoff nuclear explosion but much slower. A small area on one side of the asteroid would be heated by a powerful laser flying near the asteroid or by sunlight reflected from a very large space mirror. Vaporized surface material would propel the asteroid in the desired direction. The attractive aspect of this option is that the asteroid's rotation is of no concern. But the laser or mirror must be able to maintain its position accurately to the side of the asteroid for a long period and therefore would require a substantial fuel supply. The optical elements of such concepts would also be vulnerable to coating by the ablating material from the asteroid.

SOLAR PRESSURE is another possible mechanism. A spacecraft would coat the asteroid's surface with highly reflective paint, which would change the radiation pressure caused by solar heating and very gradually alter the asteroid's course. But it is difficult to see this technique as a workable option given the massive amount of paint required and the difficulty of applying it to the surface.

LAND AND PUSH, the concept behind the asteroid tug, is very straightforward. The propulsion system required to get to the asteroid, which would also have to be developed for the other alternatives, is used to deflect the rock as well. The greatest advantage of this option is that it is fully controllable. The challenge lies in maneuvering the spacecraft and attaching it to the asteroid.

PAT RAWLINGS/SAIC

form the B612 mission that it could not be launched by a single rocket; dozens of heavy-lift rockets would be needed to boost all the components into low Earth orbit. Then the spacecraft would have to be assembled in orbit, which would drastically raise the mission's cost and delay the journey to the asteroid.

Our goal is to design a space tug that could be launched on a single heavy-lift rocket, such as a Proton, Ariane 5 or Titan 4. Because the tug must have a total mass less than about 20 tons, it needs extremely fuel-efficient engines. The primary measure of rocket efficiency is specific impulse, which is the thrust generated for each unit of fuel consumed per second. The most efficient chemical rockets have a specific impulse of up to 425 seconds when operating in the vacuum of space. (The units of specific impulse are seconds.) But the engines of our asteroid tug must have a specific impulse of 10,000 seconds.

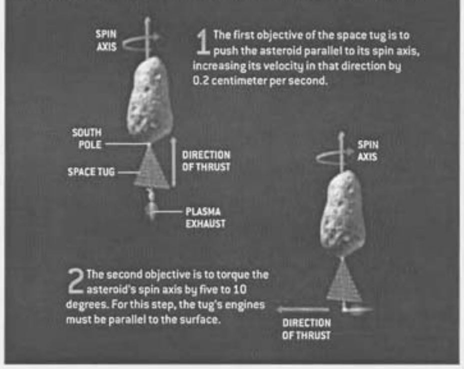
This performance is not feasible for standard chemical rockets but is comfortably within the range of electric engines, which use electrical or magnetic fields to accelerate ions out the exhaust nozzle of the rocket. In this way, the engines can achieve much higher exhaust velocities than chemical rockets, which simply burn fuel and allow the expanding hot gases to escape out the nozzle. Ion engines with a specific impulse of 3,000 seconds have successfully flown in space. A promising new engine known as the VASIMR (Variable Specific Impulse Magnetoplasma Rocket) uses radio waves to ionize a gas and accelerate the plasma to even higher exhaust velocities [see "The VASIMR Rocket," by Franklin R. Chang Díaz; SCIENTIFIC AMERICAN, November 2000]. Rather than using a conventional nozzle, the VASIMR employs magnetic fields to direct the expanding stream of ions out of the rocket at specific impulses between 3,000 and 30,000 seconds.

Of course, there is a price to be paid for such high performance. Although plasma and ion engines are more efficient than chemical rockets, their thrust is much lower (because the high-temperature exhaust is so tenuous). Several ion engines now under development could achieve specific impulses approaching the target of 10,000 seconds, but with the exception of the VASIMR, most electric engines generate less than 0.1 newton of force. Thus, many such engines would have to be ganged together to reach the desired thrust level of 2.5 newtons. Even when combined, the engines must push on the asteroid for a very long time to alter its orbit. Long-term operation has already been demonstrated, however: the ion engine on the Deep Space 1 spacecraft, launched in October 1998, accumulated 677 days of operating time.

To provide the required thrust, the plasma engines would need about 250 kilowatts of electrical power (assuming an engine efficiency of 50 percent). This amount of power is considerably beyond the capability of the solar arrays typically used for small spacecraft. Even the enormous solar arrays of the International Space Station, when completed, will produce less than half this amount (and they will weigh more than 65 tons). Clearly, such an array is infeasible for a spacecraft that must weigh less than 20 tons in total. The only current technology that can steadily supply this much power for several years in a package that weighs just a few tons is nuclear fission.

THE B612 MISSION

THE GOAL of the B612 mission is to significantly alter an asteroid's orbit in a controlled manner by 2015. The space tug would need to rendezvous with a target asteroid, attach itself to the surface and show its ability to maneuver the object.



ALFRED T. KAMAJIAN

THE AUTHORS

In October 2002 *RUSSELL L. SCHWEICKART, EDWARD T. LU, PIET HUT* and *CLARK R. CHAPMAN* formed the B612 Foundation, a nonprofit group dedicated to developing and demonstrating the capability to deflect asteroids from Earth. Schweickart, chair of the foundation's board, is a former NASA astronaut who piloted Apollo 9's lunar module in 1969 and served as the backup commander for the first Skylab mission in 1973. Lu, the foundation's president, is a current astronaut who e-mailed his contributions to this article while onboard the International Space Station. Hut is a professor at the Institute for Advanced Study in Princeton, N.J., whose main research interests are computational astrophysics and the study of dense stellar systems. Chapman, a scientist at the Southwest Research Institute in Boulder, Colo., is a member of the science team for the upcoming MESSENGER mission to Mercury.

The asteroid tug needs a simple, small and safe nuclear reactor. Fortunately, NASA has already proposed some new designs for spacecraft reactors, and one has undergone preliminary testing. An important safety feature in these new designs is that the nuclear fuel is minimally radioactive until the reactor has produced power for a significant amount of time. Because the reactor would be launched cold—that is, inactive—even a catastrophic launch accident would pose little environmental danger. If the entire uranium core of the SAFE-1000, an advanced space reactor being developed at Los Alamos National Laboratory, were dispersed in a launch explosion, the radiation released into the environment would be only six to 10 curies—less than the total radiation contained in the walls of New York City's Grand Central Station. Ground controllers would send the command to activate the reactor only after it was safely in space.

The Problem of Spin

A MAJOR CHALLENGE for the B612 mission will be maneuvering around the target asteroid, landing on the body and attaching to its surface. In 2000 the NEAR Shoemaker spacecraft successfully maneuvered into orbit around Eros, the second largest of the known near-Earth asteroids, and even managed an impromptu landing on the 34-kilometer-long body. Japan's Hayabusa spacecraft (formerly Muses-C) is now on its way to near-Earth asteroid 1998 SF36 using ion propulsion. Once there it will lightly touch the asteroid's surface several times to pick up samples that will be returned to Earth. But the asteroid tug would be far larger than either of these spacecraft, and it would have to attach itself firmly to the asteroid because the gravitational attraction at the surface of such a body is only a hundred-thousandth of the gravity on Earth. Researchers are considering several concepts for a mechanism to hold the tug to the asteroid's surface, but the final design will most likely depend on the results of upcoming missions that will study the composition and structure of small asteroids.

To speed up or slow down the asteroid, the space tug must keep the direction of thrust parallel to the body's orbital motion. Small asteroids, though, often spin at rates of 10 rotations or more a day. One way to solve this problem would be to stop the rotation before pushing the asteroid. The tug would land on the asteroid's equator (the ring midway between the two poles of the axis of rotation), point its engines horizontally along the equator and fire them until the thrust brought the rotation to a halt.

This method could be risky, however, because most rocky asteroids appear to be porous, low-density "rubble piles," collections of many large and small boul-

Scouring the Sky

ON MARCH 18, 2002, newspapers and TV news shows around the world reported that Earth had just survived a near miss with a newly discovered asteroid named 2002 EM7. Astronomers observed the 70-meter-long rock four days after it passed within 461,000 kilometers of our planet, about 1.2 times the distance between Earth and the moon. Although it received quite a bit of attention, 2002 EM7 is just one of hundreds of thousands of asteroids that have come close to or crossed Earth's orbit. The international effort to detect and track these potentially threatening objects is called the Spaceguard Survey.

In 1998 NASA, at the urging of Congress, adopted the goal of detecting 90 percent of the 1,100 or so near-Earth objects (NEOs) larger than one kilometer in diameter. Halfway into the 10-year program, astronomers have found more than 660 NEOs of this size and more than 1,800 smaller bodies. Many of the asteroids currently being tracked were first seen as they were leaving Earth's vicinity, just as 2002 EM7 was. Fortunately, any asteroid destined to smash into Earth will most likely pass within a few lunar distances of our planet thousands of times before finally striking it. If researchers identify an object headed toward us, destined for an Earth impact, they will probably spot it decades or even centuries before it actually hits. The short-warning scenario, as dramatized in the 1998 movies *Armageddon* and *Deep Impact*, is exceedingly improbable.

SPACEGUARD SURVEY uses telescopes like this one at the White Sands Missile Range in New Mexico.

Every time Spaceguard detects a new NEO, scientists make projections based on its orbit to determine if it might strike Earth in the next 100 years or so. The vast majority of the objects discovered so far (more than 99 percent) do not seem to pose a threat. On rare occasions Spaceguard finds a NEO that is predicted to swing close by Earth in several decades. Because the procedure for determining future orbits, like all predictions, has only limited precision, one of these objects might actually be on a collision course. So Spaceguard monitors these few NEOs very carefully, gradually improving the accuracy of the predictions of their trajectories.

An asteroid with a diameter of 200 meters would not wreak the planetwide devastation that a one-kilometer-long rock could, but with an explosive force of 600 megatons or so it would still completely obliterate a city should it make even a nearby hit. Although Spaceguard has found many asteroids of this size, larger telescopes will be required to efficiently detect all the 100,000 smaller but still dangerous asteroids that cross Earth's orbit. Scientists have made a number of proposals to extend the asteroid search down to objects of about 200 meters, but no commitment yet exists. At best, such an augmented survey will not be complete until 15 to 20 years from now.

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ders, interspersed with pebbles and smaller grains loosely held together by the body's weak gravity. Although this type of structure could withstand a force of several newtons distributed over two to five square meters of its surface, the same cannot be said for the internal stresses created by slowing down and stopping the body's rotation. It seems highly likely that altering the finely balanced gravitational and centripetal forces associated with asteroid rotation would cause significant and possibly destructive rearrangements—in other words, asteroid quakes.

For this reason, a better alternative might be to allow the asteroid to continue rotating but to torque the spin axis gradually until it is parallel with the body's orbital motion and keep it there. With the axis properly aligned, the tug would push the spinning asteroid along its orbit like a pinwheel. For the B612 demonstration mission, we plan to choose an asteroid spinning at about four rotations a day (typical of asteroids this size) and torque its spin axis by five to 10 degrees [*see illustration on page 59*]. Using 2.5 newtons of thrust applied at either the asteroid's north or south pole, the task would require a couple months of steady torquing. Although this result would clearly demonstrate the capability to maneuver an asteroid, an actual deflection would require many months, and perhaps even years, to properly orient the asteroid and accelerate it in the desired direction.

Another important challenge would be to deflect the asteroid in such a manner that it does not simply return again several years later on a new collision path. Bodies passing close to Earth are often gravitationally deflected into resonance orbits that have periods that are proportional to Earth's period; as a result, the bodies may periodically return to our planet's vicinity. We must therefore precisely deflect the asteroid onto a trajectory that ensures it will not end up in a resonance orbit. This requirement for precision is one of the best arguments for the asteroid-tug concept. The tug provides a carefully controlled maneuver, whereas most of the other deflection schemes yield an approximate, uncontrolled velocity change at best, thereby risking a boomerang scenario.

Protecting Our Planet

THE MISSION we are proposing would cost about $1 billion—a bit more than half of 1 percent of NASA's expected spending over the next 10 years—provided that off-the-shelf power and propulsion systems are used and a single existing launch vehicle can lift the spacecraft. Is this project worth the expense? Although the actual use of an asteroid deflection system would be rare—never in our lifetimes, we hope—its value would be beyond measure. An asteroid collision with Earth would be so potentially devastating that preventing it would be worth almost any cost. By practicing an asteroid deflection, the B612 mission would show whether the asteroid-tug concept is feasible and, if so, how it should be refined in the event of a real impact threat.

> Although the use of an asteroid deflection system would be rare, its value would be beyond measure.

The scientific benefits of the demonstration mission would also be significant. Asteroids are remnants of the early solar system and have much to tell us about the formation of the planets and perhaps even the origins of life. Researchers have already learned a great deal by studying meteorites, the pieces of asteroid debris that survive the fiery plunge through Earth's atmosphere, but a much greater payoff would come from visiting the source of these fragments.

In addition, asteroids are believed to contain large amounts of metals, minerals and water ice. Experts on space exploration claim that taking advantage of these resources could dramatically reduce the cost of future interplanetary flights [see "Tapping the Waters of Space," by John S. Lewis; SCIENTIFIC

AMERICAN PRESENTS, Spring 1999]. The B612 mission would vividly show that spacecraft could access these materials; using the same maneuvering and docking techniques developed for the asteroid tug, other vehicles could land on asteroids and begin mining operations. And these efforts may eventually pave the way for a manned mission to a near-Earth asteroid. Indeed, many experts contend that sending astronauts to an asteroid would be quicker, less costly and more worthwhile than a human mission to Mars.

Most important, the B612 demonstration would fulfill NASA's stated mission, "To protect our home planet ... as only NASA can." A better match could hardly be found. ■

MORE TO EXPLORE

Rain of Iron and Ice: The Very Real Threat of Comet and Asteroid Bombardment. John S. Lewis. Perseus, 1997.

Cosmic Pinball: The Science of Comets, Meteors, and Asteroids. Carolyn Sumners and Carlton Allen. McGraw-Hill Trade, 1999.

Report of the Workshop on Scientific Requirements for Mitigation of Hazardous Comets and Asteroids. Michael J. S. Belton. National Optical Astronomy Observatory, March 2003. Available online at **www.noao.edu/meetings/mitigation/report.html**

More information about the B612 mission can be found at **www.b612foundation.org**

New reports on near-Earth objects are available at **neo.jpl.nasa.gov/neo/report.html**, **impact.arc.nasa.gov/** and **neo.jpl.nasa.gov/neo/pha.html**

Senator BROWNBACK. Mr. Griffin—Dr. Griffin, how many times has the Earth been struck by a substantial sized asteroid? By this, I mean something a 100 meters or greater that we know about or that we have a pretty good idea it took place. You've cited a couple, but how many times? Do we know?

Dr. GRIFFIN. I would have to defer to someone with greater expertise on that than myself, but in fact I don't think the answer is known. We have catalogued around the globe several dozen, many dozen known impact events by the scars that they leave behind.

Senator BROWNBACK. Known impact events that had a substantial impact on the Earth in that particular area?

Dr. GRIFFIN. Right. Like the meteor crater in Arizona or larger. OK. Many dozen of those are known. Some of them ancient. Some of them relatively new in geologic terms. But the Earth heals itself quite rapidly. The Earth is not a good witness plate for such events. I'll look at the moon and it probably offers a better estimate of what really happens to a celestial body over the course of time.

Senator BROWNBACK. And it's actually even a smaller target to hit than the Earth so——

Dr. GRIFFIN. That's correct. Senator, just by chance I happen to have been asked to provide a lecture somewhat along those very lines so I can tell you that the answer is greater than hundreds of thousands of times the Earth being hit in its history by objects a hundred meters and greater in size.

Now, we don't have much evidence of that in the form of scars. We do see scars from only about 200 impacts that we're aware of at this time, but again looking at the moon, you can take each crater there and multiply by about 20 to 30 and know that that's hit the Earth—that we have been hit—the Earth that many times.

Senator BROWNBACK. Is that where you come up with that number as you look at the moon and then multiply out the number of craters?

Dr. GRIFFIN. What I would refer you to as the most authoritative thing, sir, would be in fact the report sitting in front of Grant Stokes here that he co-chaired in terms of the development. And there is within that report a graph which give you the best knowledge that we have, statistical knowledge of the frequency of asteroids in near Earth space and you can simply utilize that graph at any size asteroid you want and get the number and the size and power of any of these asteroids. So I refer you to that excellent report.

Senator BROWNBACK. Dr. Stokes. Do you know the answer to that question?

Dr. STOKES. What we've done to come up with the best estimate of impact actually looks at a number of things. One looks a lunar cratering rate to get an estimate.

One can also get an independent estimate looking at the performance of the search systems that have been ongoing which have been making a lot of progress recently. And in fact, you can take all the search volume that they've done, and all the detections and all the re-detections, use that to estimate an impact rate. And in fact, it's getting to the point where all of those numbers are beginning to come together and be consistent and so we're very happy with the about 1,100 larger than a kilometer size. We believe that's a good estimate.

Once you have that estimate and then work some extrapolations from there which can be tied down at various sizes from the moon and also the experience of very small events, things hitting LDEF for instance, micrograins, you can put those all into a continuum and the story sticks together very well.

On that basis, we can then estimate the rate of impacts as a function of size, which is where we came up with the numbers that I previously had quoted.

Senator BROWNBACK. Well, how many times this last century has the Earth been struck by a substantial asteroid that caused at least significant localized damage?

Dr. GRIFFIN. I think we know of two specific instances. One in Siberia in 1908. One again in Russia in 1947, both of which caused substantial damage on the ground. We know of a number of other events that range down to an asteroid hitting a car in the Eastern seaboard a few years ago and——

Senator BROWNBACK. That would be a real unlucky day, wouldn't it? I mean, you're just sitting here in your car and——

Dr. GRIFFIN. Actually, it hit a car in a garage and I think it vastly increased the price of that car that day.

Senator BROWNBACK. That's not so unlucky.

Dr. GRIFFIN. There certainly have been many other events where things get down to the ground many of which land in the water. Many of which land in unpopulated areas and are not seen. Another way to get data is to look at the military satellites that look down for events in the atmosphere. They routinely detect, you know, modest size objects, but kiloton and larger events in the upper atmosphere, so there are statistics coming from those as well.

Senator BROWNBACK. What's the chance of getting international cooperation at the operational or funding level to get at least the catalogue of these objects?

Dr. GRIFFIN. Let's see. I think to some extent there is a loosely coordinated international effort ongoing now. Most of the large surveys are operated in the United States based largely on NASA funding, and I think there's a view in the—at least Europe and the rest of the world that if NASA's doing that maybe we should just let them do that and contribute where we can.

Another place that work has to be done is in following up objects. The large surveys where we go out and find a large number of these objects, initially finding them is only part of the process.

We also need a continuing stream of observations to develop a good orbit and keep track of them. Many of those are provided by international sources. Many of them are provided by amateurs that are very interested in doing this. Many of them Japanese. Eastern Europe in fact has some very active professionals that do this.

And all of that data is sent to a place called, The Minor Planet Center in the Harvard Smithsonian in Cambridge, Massachusetts where all that data comes together and is used to maintain a catalogue of all of the objects. So that is chartered by the International Astronomical Union. It is an international body that gives discovery credit and monitors naming rights and things like that.

So there is a very international flavor on these after discovery and that works actually very well.

Dr. SCHWEICKART. Yes, just a minor additional comment. There is an excellent report that was chartered by the Parliament of the United Kingdom several years ago and I also recommend that Task Force Report to you. It made excellent recommendations in terms of the U.K. jumping in to provide resources for this very vital task. Unfortunately, there has been no action taken on the excellent recommendations of that report. As recently as a couple of months ago in Parliament specific recommendations were considered and the bottom line is nothing in fact happened.

Another action has been taken by the OECD. OECD has begun to hold several discussions on the issue of mitigation of asteroid and comet impacts and what might be done in terms of disaster preparedness. There was a meeting a year ago, January in Frascati, Italy, but again, there was no expenditure of funds.

What was done there which I would strongly urge, Senator Brownback, is that all nations participating in the OECD hearing were recommended that they identify a particular governmental institutional person to monitor this issue of asteroid impacts and their consequences.

Ironically, while NASA is today tasked with conducting certain surveys, there is no identification within the U.S. Government of direct responsibility for monitoring this as a public safety issue. And that would be—that is in fact a recommendation by a number of organizations and I would encourage that that be looked at by this committee.

Senator BROWNBACK. I think that's one of the proposals in the Rohrabacher bill from the House side.

Dr. GRIFFIN. Yes, it is.

Senator BROWNBACK. That we're looking at here from this side. I understand that maybe some of you already have commented on this and I haven't picked it up. But the American Institute of Aeronautics and Astronautics held a conference on protecting the Earth recently and were any of the recommendations that you've put forward recommended by that conference or does anybody——

Dr. GRIFFIN. Yes, sir, I can address that. In fact, I talked yesterday by phone with the General Chairman of the AIAA Conference on protecting the Earth from asteroid and cometary impacts. There is a final report from the conference itself and I can, or better yet AIAA, American Institute of Aeronautics and Astronautics, can make that conference report available to you.

It has also been compressed and presented or is being presented to the AIAA per se as a policy document. They will shortly vote on that and there will be an official AIAA recommendation, but that has not yet been issued. I can read you one final paragraph to give you a flavor of the AIAA position. They say: "Future impacts by comets and asteroids are a certainty. Such impacts could have severe consequences even ending civilization and humanity s existence. Life on Earth has evolved to the point where we can mount a defense against these threats. It is time to take deliberate steps to assure a successful defensive effort should the need arise."

So the AIAA I believe will take a fairly strong position on this proposal.

Mr. RICHARDSON. I would echo that. I'm the President-Elect of AIAA for the coming year and a member of the Board of Directors and I have followed this and feel quite certain that the organization—or the directors will vote affirmatively as Rusty has suggested.

Senator BROWNBACK. Is this a high priority for that organization?

Mr. RICHARDSON. Yes, it is, again, in support of the overall conclusions of the study that has been referenced here several times and of the President's exploration initiative because we believe that it is all tied together.

Senator BROWNBACK. That this should be a key part of the President's overall exploration initiative?

Mr. RICHARDSON. I believe that's correct.

Senator BROWNBACK. It seems to me that it ties in with it as well and that there's an additional—this huge safety factor and issue here for the area that might get hit or all of civilization even in the most catastrophic——

Mr. RICHARDSON. That's correct. The safety issue is a little difficult for many people to get their arms around because if you take other threats for example, you can calculate quite well the odds that any individual has of being struck by lightning and we know that, but most individuals will not ever be struck by lightning.

However, we know that in any given year the odds are quite small that the Earth will be struck by a major asteroid. But we know that sooner or later that will occur and when it occurs everyone will die. Unlike most other catastrophic hazards to life and property which affect only a small subset of the human race, it is inevitable that an asteroid will strike the Earth and that it will have the capability to essentially take out the whole plant and that's what's different about this particular hazard.

Dr. GRIFFIN. Senator Brownback, if I could try a slightly different perspective to the question that we're discussing right now. If you think about the asteroids as a mixed bag, that is there's good news and bad news. The bad news we've been focusing on here today, but there's good news there in terms of resources as well as scientific knowledge.

But if I just deal with resources, let me say that the whole President's new initiative in space to enable routine operations of human kind beyond low Earth orbit will ultimately depend upon accessing resources that are already in space and utilizing them.

Asteroids are the ideal source of that because you don't have to lift them off the moon number one because it has such low gravity. They're right there with no gravity around them and they're actually richer than the lunar soils. So in terms of commercial private enterprise activity in space, I think there's no question but that private investment, once there is a buyer of the products and services, private investment will find it profitable to mine and produce—to mine minerals or whatever, oxygen, water, you name it, and provide services associated with the Near Earth Asteroids.

Now, when that commercial operation gets going, the once every three or four hundred years that you will need to deflect an asteroid because we find one heading our way, will be a simple matter of contracting with the Ace Mining and Moving Company to push that one a bit you know in what they're doing and get it out of the way.

So I think that you're looking at routine operations developing around asteroids and almost as a natural byproduct of that, the capability to protect the Earth will emerge. So I think there is a great deal of correlation between the overall capability that we're looking for and the long-term development of the space environment beyond low Earth orbit as in the President's initiative.

Senator BROWNBACK. Well, gentlemen, thank you very much for joining me today. We'll keep the record open for the requisite amount of time if you would care to add to your comments that were put forward here today.

I did submit a series of questions and I don't—I think some of them were to you gentlemen from Mr. Nelson and so those will be submitted to you. And if you could respond to those, I know Senator Nelson would certainly appreciate that as well.

Very interesting. Very illuminating and as usual a resource issue. And resources is always about a competing set of interests in it and hopefully we can get more resources to this for both the protection and for the opportunity that they represent.

God speed to you. It's a very interesting field that each of you are involved in and quite important for the future of society, future of humanity.

Thank you for coming. The hearing is adjourned.

[Whereupon, at 4:19 p.m., the hearing was adjourned.]

A P P E N D I X

PREPARED STATEMENT OF CONGRESSMAN DANA ROHRABACHER (R–CA)

I want to thank Senator Brownback for his leadership in holding today's hearing on the threat posed by near Earth objects (NEOs). As Chairman of the Space and Aeronautics Subcommittee, I've made addressing this threat one of my top priorities. Our hearings have revealed that monitoring and tracking NEOs such as comets and asteroids is not only vitally important to the advancement of the field of astronomy, but also critical in identifying NEOs that threaten the Earth. Recent press accounts of asteroids passing close to the Earth have raised public awareness of the possibility that these objects could one day hit the Earth with potentially catastrophic consequences. Given the vast number of asteroids and comets that inhabit Earth's neighborhood, greater efforts for tracking and monitoring these objects are critical.

This is why I introduced H.R. 912 the "Charles 'Pete' Conrad Astronomy Awards Act," which passed the House last month, and H.R. 3813 the "George E. Brown, Jr. Near-Earth Objects Survey Act." It is vital that we use all available public and private sector resources for tracking and monitoring NEOs.

H.R. 912 authorizes the NASA Administrator to give one award each year to the amateur astronomer or to the group of amateur astronomers that discovered the intrinsically brightest near-Earth asteroid among the near-Earth asteroids discovered during the preceding year by amateur astronomers, and another award to the amateur astronomer or group of amateur astronomers that made the greatest contribution during the preceding year to the Minor Planet Center's catalogue of known asteroids. The recipients of the awards, in the amount of $3,000, are limited to U.S. citizens and permanent residents.

This bill is a tribute to Pete Conrad for his tremendous contributions to the aerospace community over the last four decades. Pete Conrad was a pilot/explorer/entrepreneur of the highest caliber. He commanded Apollo XII, and during that mission became the third man to walk on the Moon. I find no better way to honor Pete Conrad than to establish an annual astronomer's award for future asteroid discovers in his name. He always wanted people to be looking up with a positive "can-do" American spirit—exemplified by his historic description of landing on the Moon.

H.R. 3813 authorizes the NASA Administrator to plan, develop, and implement a near Earth objects survey program for the purpose of detecting, tracking, cataloguing, and characterizing physical characteristics of near-Earth asteroids and comets 100 meters or greater in diameter. The bill also amends the NASA Act of 1958 by directing the agency to use its resources and the expertise of its workforce to carry out the NEO survey program—so as to provide warning and mitigation of the potential hazards of NEOs that threaten impact with the Earth. The bill authorizes appropriations in the amount of $20 million for Fiscal Years 2005 and 2006 to enable NASA's efforts in this area.

In his agency vision statement, NASA Administrator Sean O'Keefe talked about the planet's environment. I believe protecting our planet from impacting asteroids should also be one of NASA's major concerns. A few years ago, NASA initiated the "Spaceguard" plan, which is intended to catalog at least 90 percent of them by 2010. Presently, the Spaceguard program appears to be on track, but its focus is on surveying asteroids large enough to destroy all life on Earth. Surveys of smaller asteroids with the potential to destroy cities, countries, and to bring about changes in global climate should also be vigorously pursued.

Of course, the threat of an asteroid hitting the world is a serious matter. The idea of a catastrophic asteroid or comet impacting on the Earth has garnered much attention in the media and popular culture. It's vital for all of us to realize, however, that this is not science fiction. We all know that the Earth's moon and many other planetary bodies in the solar system are covered with impact craters. Most people have heard of the "dinosaur extinction" theory or perhaps seen pictures of the meteor crater in Arizona. However remote the possibility of NEOs striking the Earth and causing worldwide calamity in our lifetime, it has happened and it will happen again unless mankind is able to detect and possibly avert a catastrophe.

While the asteroid that killed the dinosaurs is estimated to occur once every 100 million years, smaller, yet still very hazardous asteroids impact the Earth much more frequently. For example, the destructive force of the 1908 Tunguska event in Siberia was roughly equal to a 10-megaton blast of TNT caused by an asteroid estimated to be about 200 feet Greenland involving an asteroid, which had a destructive force measuring 100 kilotons of TNT.

Ironically, if you look at asteroids from the perspective of our national goals in space, they also offer us unique opportunities. In terms of pure science, asteroids are geological time capsules from the era when our solar system was formed. Even better, they are orbiting mines of metals, minerals, and other resources we can use to possibly build large structures in space without carrying everything up from the Earth. So far, NASA has surveyed 600 asteroids, but this is a small fraction of the projected total. What needs to be done now is to fully survey the NEO population.

In closing, it is my hope that H.R. 3813 will bring greater attention to the NEO issue by focusing NASA more closely on this critical area of study, because NEOs have given the topic of planetary defense a serious tone within the scientific community. The first step is a thorough tracking of all sizeable NEOs, and H.R. 912 and H.R. 3813 are modest steps toward this goal. Thank you, Mr. Chairman.

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