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Statement of
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before the

Subcommittee on Space and Aeronautics
Committee on Science and Technology
U.S. House of Representatives

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear today to review the findings and recommendations of NASA's report to Congress in response to the NASA Authorization Act of 2005 (P.L. 109-155). Below, I have addressed the questions posed by this Subcommittee in your invitation to testify.

Question #1: What were the principal findings and recommendations of NASA's *Near-Earth Object Survey and Deflection Analysis of Alternatives: Report to Congress*, March 2007, and what was the basis for those findings and recommendations?

The principal findings were the result of a study team, led by NASA's Office of Program Analysis and Evaluation (PA&E) that conducted an analysis of alternatives with inputs from several other U.S. government agencies, international organizations, and representatives of private organizations. The team developed a range of possible options from public and private sources and then analyzed their capabilities and levels of performance including costs, development schedules, and technical risks. In order to meet the congressional goal of completing the survey by 2020, the study team assumed primary project elements would have started their development by October 1, 2007.

NASA recommended that the existing "Spaceguard Survey" program continue as currently planned, and that NASA would also take advantage of opportunities using potential dual-use telescopes[1] and spacecraft—and partner with other agencies as feasible—to make progress toward achieving the legislative goal of discovering 90 percent of all potentially hazardous objects 140 meters in mean diameter and greater. However, due to budget constraints, NASA cannot initiate a new program beyond the Spaceguard Survey program at this time.

NASA would be pleased to implement a more aggressive NEO program if so directed by the President and Congress. However, given the constrained resources and strategic objectives the Agency has already

[1]The proposed Large Synoptic Survey Telescope (LSST) and Panoramic Survey Telescope And the Rapid Response System (Pan-STARRS) present possible future opportunities, if they are funded by other agencies. Another possible opportunity would be the Lowell Discovery Channel Telescope (DCT), but its contribution would be less than LSST or Pan-STARRS.

been tasked with, NASA cannot place a new NEO program above current scientific and exploration missions.

For ease of following the findings and recommendations, simplified definitions are as follows:

- “Detection” is the act of finding the objects;
- “Tracking” is the act of determining their orbits;
- “Characterization” is the act of determining their physical properties;
- “Cataloging” is the act of maintaining a data base of the orbits and physical properties of known objects and predicting potential impacts with the Earth; and
- “Mitigation” is the act of deflecting, destroying, or reducing the impact consequences of a specific object that is predicted to strike the Earth.

Key Findings for the Survey Program

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

- The Agency could achieve the specified goal of surveying for 90 percent of the potentially hazardous NEOs by the end of 2020 by partnering with other government agencies on potential future optical ground-based observatories and building a dedicated NE0 survey asset, assuming the partners’ potential ground assets come online by 2010 and 2014, and a dedicated asset by 2015.

- Together, the two observatories potentially to be developed by other government agencies could complete 83 percent of the survey by 2020 if observing time at these observatories is shared with NASA’s NE0 Survey Program.

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

- Radar systems cannot contribute to the search for potentially hazardous objects, but may be used to rapidly refine tracking and to determine object sizes for a few NEOs of potentially high interest.

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

Key Findings for Diverting a Potentially Hazardous Object (PHO)
The study team assessed a series of approaches that could be used to divert a NEO potentially on a collision course with Earth. Nuclear explosives, as well as non-nuclear options, were assessed.

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

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

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

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

Question #2: How were the cost estimates and technical options contained in the report arrived at, and was any independent assessment of the cost estimates and technical options conducted?

Technical Options
The technical options contained in the report were developed through a systematic exploration of the trade space for feasible alternatives, followed by a conceptual design of selected options. Concepts were selected to represent the available range of cost, performance, and acceptable technical risk to complete the detection, tracking, cataloguing, and characterization missions. Concepts were based on historical and existing projects and on white papers presented at a NASA-sponsored workshop of national experts.

Trade trees were developed to describe the technical options. The detection and tracking trade tree consisted of existing and new ground- and space-based observatories operating in the visible and infrared spectra; ground based radars were considered for tracking. The characterization trade tree contained existing, proposed, and new remote and in-situ observing assets. Cataloguing considered a range of operations and data management options based on historical, proposed, and new information systems.

Cost Estimates
Life cycle costs were calculated as the total architecture cost in fiscal year 2006 billions of dollars including development, production, deployment, and operation of the alternatives. Life cycle costs for the detection, tracking, and data management options were calculated both for a fixed period (through 2020) and until the objective of cataloguing 90 percent of specified threats was complete. For some options that rely on existing systems or available technology, operational costs were much higher than the development costs over the 15-20 year life cycle. In order to meet the Congressional goal of completing the survey by 2020, the study team assumed primary project elements would have started their development by October 1, 2007.

For space-based systems, the total life cycle costs included estimated costs for program management, systems engineering, mission assurance, launch vehicle, spacecraft, scientific instruments, mission specific ground data systems, mission operations, and data analysis. Ground-based systems included the cost of development, production, and operations. Operations costs were calculated over either the survey period for detection, tracking, and cataloguing missions or the predicted duration of characterization missions.

The cost estimates for the space vehicles relied on multiple methods including historical analogies and prior cost-estimating experience. Cost-risk analyses were performed using these data as inputs and assumed that every cost element could be represented by statistical characteristics such as mean, standard deviation, and mode. A cumulative probability distribution of total cost was generated for this analysis by combining cost distributions from the different cost elements, and costs were estimated at the 65 percent cost confidence level when applicable. Programmatic costs were based on historical actual costs and applied as a percentage of the space vehicle costs. Launch vehicle costs were based on recent, publicly released estimates for commercial launch vehicles.

Ground-based observatory costs were based on reported expenses for currently operating systems or based on estimates for systems currently in development. For several ground based options, concepts of operations postulated utilizing (sharing) data that would be collected on existing or planned systems without materially affecting the primary mission of these systems. For these systems, it was assumed that the NEO program would fund only a small portion (or none) of the development costs, but that an equitable portion of the annual operations costs would be funded by NASA. In cases where the ground based systems were expected to be copies of systems that are currently in development, only the production and operation costs of the NASA-acquired systems were considered -- substantially reducing their development costs and cost-risk.

Although multiple cost-estimating methodologies, databases, and organizations were used, truly independent cost estimates were not generated as these are typically not within the scope of a conceptual, architecture-level study. Likewise, assessments of the technical options were carried out using an experienced team of personnel from several organizations, but fully separate evaluations of the concepts were not performed.

Question #3: What is the *"recommended option and proposed budget to carry out the Survey program pursuant to the recommended option"*, as called for in Sec. 321(d)(2)?

NASA recommended that the existing "Spaceguard Survey" program continue as currently planned, and that NASA would also take advantage of opportunities using potential dual-use telescopes[2] and spacecraft—and partner with other agencies as feasible—to make progress toward achieving the legislative goal of discovering 90 percent of all potentially hazardous objects 140 meters and greater.

The goal of finding 90 percent of potentially hazardous objects 140 meters and larger is 1-2 orders of magnitude more technically challenging than the Spaceguard mission. To reach this goal within 10-15 years requires at least one new dedicated ground or space observatory.

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Cataloging the number of total number of objects—approximately 100,000 —at the rate they would be discovered, which is between 30 and 50 per day, requires a new tracking and data management infrastructure whose ongoing operations may constitute a sizeable portion of total costs.

A delay (e.g. 5-10 years) in achieving the legislative goal carries little additional risk when the impact interval for 140 m objects is about once every 5000 years. This rate of impacts also indicates that the system may need to operate (searching and tracking) for an extended period before identifying a credible threat. There are three epochs to the problem of detection and tracking:

- Now: We know where few 140 m objects are and when/if they will impact.

- Initial 10-20 years of the survey: Average warning time will rise, unwarned impact risk gradually decline. Decades of warning become likely.

- Steady-state: After 10-20 years of the survey, unwarned impacts of 140 m objects would be highly unlikely. Centuries of warning become possible.

Currently, NASA carries out the "Spaceguard Survey" to find NEOs greater than 1 kilometer in diameter, and this program is currently budgeted at $4.1 million per year for FY 2006 through FY 2012. We also have benefited from knowledge gained in our Discovery space mission series, such as the Near Earth Asteroid Rendezvous (NEAR), Deep Impact, and Stardust missions that have expanded our knowledge of near-Earth asteroids and comets. Participation by NASA in international collaborations such as Japan's Hayabusa mission to the NEO "Itokawa" also greatly benefited our understanding of these objects. NASA's Dawn mission, launched on September 27, 2007, will increase our understanding of the two largest known main belt asteroids, Ceres and Vesta, between the planets Mars and Jupiter. NASA conducts survey programs on many celestial objects — the existing Spaceguard program for NEOs, surveys for Kuiper Belt Objects, the search for extra-solar planets, and other objects of interest such as black holes to understand the origins of our universe. The science community could propose such a NEO survey mission under the competitively-selected Discovery program.

NASA also identified an exemplar NEO Survey Program and estimates for its architectural costs that, if funded, could have achieved the specified goal of surveying 90 percent of the PHOs by the end of 2020 by constructing or funding a dedicated survey asset combined with NASA partnerships with other government agencies on potential future optical ground-based observatories: the Panoramic Survey Telescope and Rapid Response System (PanSTARRS-4 or PS4) and the Large Synoptic Survey Telescope (LSST) . Details of the exemplar program were provided in NASA's report. Note that budget estimates in the report are rough "architecture costs" and would require more rigorous analysis before a program could be assessed for implementation.

<u>Question #4: Will NASA's current NEO program satisfy the requirement established in Sec. 321(d)(1) of the NASA Authorization Act of 2005, and if not, what is NASA's plan for satisfying that requirement?</u>

The current NASA NEO "Spaceguard Survey" program, without any augmentation, would not be able to satisfy the requirements outlined in section 321(d)(1) of the NASA Authorization Act for 2005. The requirements for the Spaceguard Survey program are to find only NEOs greater than 1 kilometer in diameter, and its funding is currently budgeted at $4.1 million per year. NASA estimates that the current program, if continued without major augmentation, would detect 14 percent of the 140 meters or larger potentially hazardous objects by the end of 2020. However, NASA is initiating plans to use other survey systems to increase the survey's detection sensitivity and rates. For example, NASA has begun providing funds to the Air Force Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) project so that it will be capable of providing data on NEO detections after it starts operations on its first telescope in the next year. If the Air Force continues to fund this project to its intended four telescope configuration by 2010, this system alone could discover over 70 percent of the potentially hazardous objects larger than 140 meters by 2020.

NASA recommended that the existing "Spaceguard Survey" program continue as currently planned, and that NASA would also take advantage of opportunities using potential dual-use telescopes and spacecraft—and partner with other agencies as feasible—to make progress toward achieving the legislative goal of discovering 90 percent of all potentially hazardous objects 140 meters and greater.

NASA would be pleased to implement a more aggressive NEO program, if so directed by the President and Congress. However, given the constrained resources and strategic objectives the Agency has already been tasked with, NASA cannot place a new NEO program above current scientific and exploration missions.

Question #5: How is progress on meeting the requirements of Section 321 being measured and monitored?

Survey performance is tracked continuously by the NEO Program Office at JPL, and reported monthly on NASA's NEO Program website at http://neo.jpl.nasa.gov/stats . This database shows the performance of each survey team and reports the number of NEOs, including Earth approaching comets, found each month by orbit and size (larger or smaller than one kilometer) class. It also breaks out the objects which are potentially hazardous by size class. Specific orbit and estimated size information for each discovered NEO can also been found on the website, as well as probability of impact statistics for Potentially Hazardous Objects.

The discovery statistics information is rolled up each year and reported by the Science Mission Directorate as part of our Government Performance Reporting Act (GPRA) submittal.

In closing, NASA recommends that the existing "Safeguard Survey" program continue, as planned, and that the Agency take advantage of opportunities using potential dual-use telescopes and spacecraft, as well as partner with other agencies, to make progress toward achieving the legislative goal.

Mr. Chairman, I would be pleased to respond to any questions you or the other Members of the Subcommittee may have.