National Near-Earth Object Preparedness Strategy and Action Plan

A Report by the

INTERAGENCY WORKING GROUP FOR DETECTING AND MITIGATING THE IMPACT OF EARTH-BOUND NEAR-EARTH OBJECTS

of the

NATIONAL SCIENCE & TECHNOLOGY COUNCIL

JUNE 2018

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The Detecting and Mitigating the Impact of Earth-bound Near-Earth Objects (DAMIEN) Interagency Working Group (IWG) of the Committee on Homeland and National Security, NSTC was convened in January 2016 to define, coordinate, and oversee goals and programmatic priorities of Federal science and technology activities related to potentially hazardous near-Earth objects (NEOs). The IWG's primary goal was to develop a National NEO Preparedness Strategy and Action Plan to improve capabilities for prediction (detection, characterization, and monitoring) and National preparedness (protection, mitigation, response, and recovery).

About this Document

This document was developed through the extensive discussions and interchange of representatives from the U.S. government agencies involved in the DAMIEN IWG. This Strategy and Action Plan will improve our Nation's preparedness to address the hazard of NEO impacts by leveraging and enhancing existing national and international assets and adding important capabilities across government. The Strategy and Action Plan builds on efforts at NASA to better detect and characterize the NEO population as well as recent efforts at DHS and DOE to prepare for and respond to a NEO impact.

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Acronyms

DHS	Department of Homeland Security
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
State	Department of State
FEMA	Federal Emergency Management Agency
NASA	National Aeronautics and Space Administration
NNSA	National Nuclear Security Administration
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
ODNI	Office of the Director of National Intelligence
OSTP	Office of Science and Technology Policy
OMB	Office of Management and Budget
PDCO	Planetary Defense Coordination Office
USAF	United States Air Force
USGS	United States Geological Survey

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Executive Summary

The *National Near-Earth Object Preparedness Strategy and Action Plan* (Strategy and Action Plan) will improve our Nation's preparedness to address the hazard of near-Earth object (NEO) impacts over the next 10 years. Its primary role is to help organize and coordinate NEO-related efforts within Federal Departments and Agencies (agencies), with a particular focus on efforts that are already existing and resourced. It seeks to leverage and enhance existing assets and capabilities—National and international, public and private—to effectively manage the risks associated with NEOs. The Strategy and Action Plan builds on efforts by the National Aeronautics and Space Administration (NASA), Department of Homeland Security (DHS), and Department of Energy (DOE) to detect and characterize the NEO population and to prevent and respond to NEO impacts on Earth.

Five strategic goals, each supported by a set of strategic objectives and specific associated actions, underpin the effort to enhance the Nation's preparedness for potential NEO impacts:

Goal 1: Enhance NEO Detection, Tracking, and Characterization Capabilities: NASA will lead the development of a roadmap for improving national capabilities for NEO detection, tracking, and characterization. Supporting actions will reduce current levels of uncertainty and aid in more accurate modeling and more effective decision-making.

Goal 2: Improve NEO Modeling, Prediction, and Information Integration: Agencies will coordinate the development of validated modeling tools and simulation capabilities that aid in characterizing and mitigating NEO impact risks while streamlining data flows to support effective decision-making.

Goal 3: Develop Technologies for NEO Deflection and Disruption Missions: NASA will lead development of technologies for fast-response NEO reconnaissance missions and timely missions to deflect or disrupt hazardous NEOs. Developing these technologies before an imminent threat arises will strengthen our ability to prevent NEO impact disasters.

Goal 4: Increase International Cooperation on NEO Preparation: Agencies will work to inform and develop international support for addressing global NEO impact risks. International engagement and cooperation will help the Nation to prepare more effectively for a potential NEO impact.

Goal 5: Strengthen and Routinely Exercise NEO Impact Emergency Procedures and Action Protocols: The United States will strengthen and exercise procedures and protocols for assessing NEO threats, communication regarding threats, and response and recovery activities. Coordinated communications and notifications within the U.S. Government and with foreign governments will improve impact emergency preparedness and reduce the physical and economic harm to the Nation.

The Strategy and Action Plan should inform the policy development process. Any commitment of Federal resources to support the activities outlined in this document will be determined through the budget process.

Introduction

NEO Impact Hazard

Near-Earth Objects (NEOs) are asteroids and comets that come close to or pass across Earth's orbit around the Sun.[1] They range in size from small "meteoroids" only a few meters across, to much larger bodies several kilometers wide. When NEO orbits bring them into Earth's atmosphere, smaller objects harmlessly fragment and disintegrate, while larger objects can cause local damage or even global devastation. The shaded background of Figure 1 shows roughly how impact damage varies with asteroid size.[2] Figure 1 also shows the known population of near-Earth asteroids, or NEAs[3] (green bars), the current estimate of the total NEA population (red line), and the estimated completeness of survey efforts (blue line).

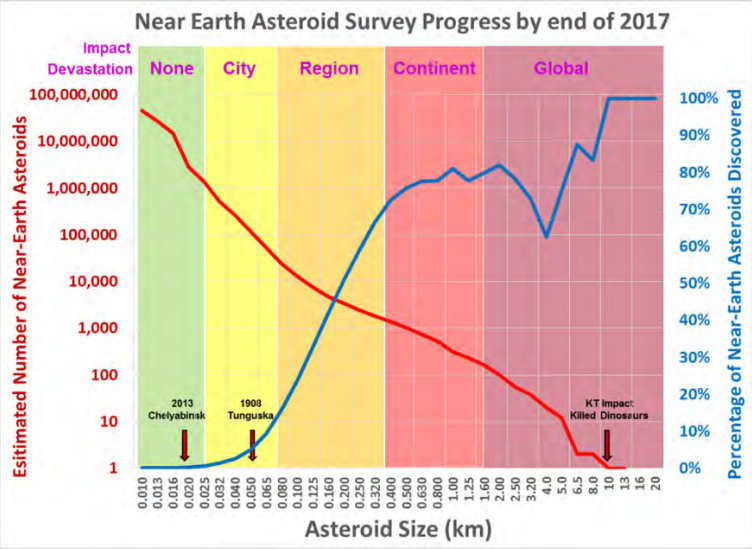

Figure 1: NEAs of various sizes: number detected to date and estimated total number.[4]

NEO impacts of varying size could have major environmental, economic, and geopolitical consequences detrimental to the United States, even if the impact is outside U.S. territory. The direct effects from a NEO impact depend on its size, composition, and impact speed. Small, rocky NEOs are likely to explode before hitting the ground, resulting in an airburst that could produce a wider area of moderate damage compared with a similarly sized metallic object that would strike the ground and cause heavier, more localized devastation.

Even small NEOs can have significant destructive effects. For example, on February 15, 2013, an asteroid approximately 20 meters in size created an airburst near Chelyabinsk, Russia, with roughly 20-30 times more energy than that released by the first atomic bombs. It damaged thousands of buildings and

[1] Defined as an asteroid or comet whose orbit brings it within a distance from the Sun of 1.3 times the Earth's average distance from the Sun. This includes Near-Earth Asteroids (NEAs) and Earth-approaching comets.
[2] In this document, references to a NEO's size denote a representative distance across the object. This would equal the diameter of a spherical asteroid, or an average span for an irregularly-shaped object.
[3] NEOs include comets as well as asteroids, but the survey status in Figure 1 shows only asteroids. However, near-Earth comets (NECs) represent less than 1 percent of the NEO population, and once comets cross into the orbit of Jupiter they are much easier to detect. 107 NECs have been catalogued to date.
[4] Source: NASA Planetary Defense Coordination Office

injured over a thousand people, mostly due to glass broken by the shock wave (Figure 2). According to current estimates, there are almost 10 million NEOs larger than 20 meters, but they are extremely difficult to detect prior to entering Earth's atmosphere.

Figure 2: (Left) A meteor that created an airburst over Chelyabinsk, Russia in 2013.[5] *(Right) Broken glass in a building caused by the shockwave from the airburst.*[6]

Another object approximately 40-60 meters in size exploded over Tunguska, Russia in 1908, with the equivalent of 5-10 megatons of TNT (hundreds of times greater than the first atomic bombs), leveling over 2,000 square kilometers of forest. If a similar event occurred over a major metropolitan area, it could cause millions of casualties (Figure 3). NASA estimates there are over 300,000 objects larger than 40 meters that could pose an impact hazard and would be very challenging to detect more than a few days in advance.

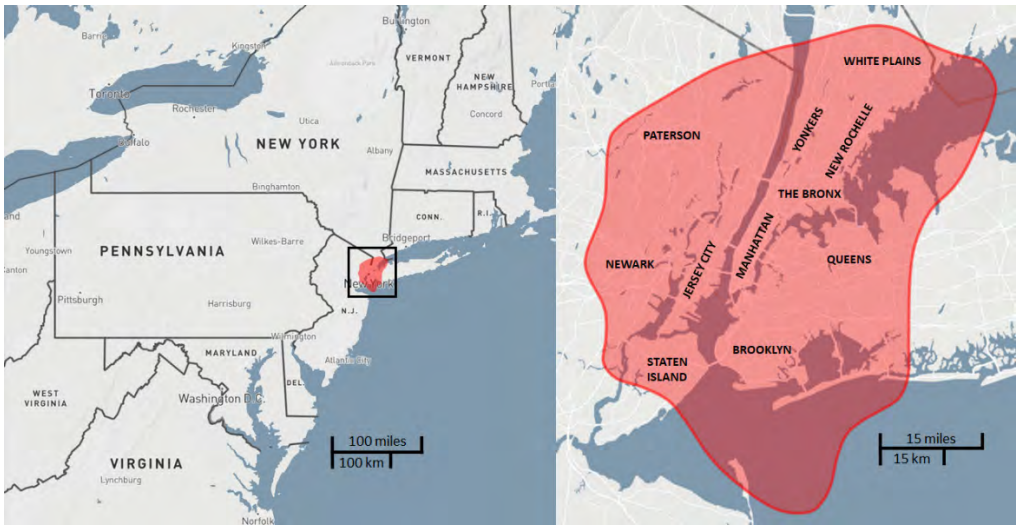

Figure 3: Equivalent area of destruction for a Tunguska-sized asteroid over New York City.[7]

Larger NEOs greater than 140 meters have the potential to inflict severe damage to entire regions or continents. Such objects would strike Earth with a minimum energy of over 60 megatons of TNT, which is more than the most powerful nuclear device ever tested. Fortunately, these are far less common and

[5] Source: Aleksandr Ivanov, https://www.youtube.com/watch?v=iCawTYPtehk. Licensed under CC BY 3.0.
[6] Source: Nikita Plekhanov, http://gallery.ru/watch?ph=z6Q-ewl8A. Licensed under CC BY-SA 3.0.
[7] Background map imagery from Mapbox; Damage pattern from Boyarkina, A. P., D. V. Demin, I. T. Zotkin, and W. G. Fast. 1964. "Estimation of the blast wave of the Tunguska meteorite from the forest destruction." Meteoritika 24:112-128 (in Russian).

are easier to detect and track than smaller NEOs. After almost two decades of search, NASA and its partners have catalogued about one third of the estimated 25,000 NEAs that are at least 140 meters.

Objects close to and larger than 1 kilometer can cause damage on a global scale. They can trigger earthquakes, tsunamis, and other secondary effects that extend far beyond the immediate impact area. An asteroid as large as 10 kilometers across is thought to have caused the extinction of the dinosaurs when it struck the Yucatan peninsula some 65 million years ago. NASA is confident that it has discovered and cataloged all near-Earth asteroids large enough to cause significant global damage and determined that they are not on collision courses with Earth, but there is still some chance that large comets from the outer solar system could appear and impact the Earth with warning times as short as a few months.

Our ability to assess the overall risks of a NEO impact improves with more detection and better characterization of the total NEO population. In 2005, Congress directed NASA to find at least 90 percent of NEOs that are at least 140 meters by 2020.[8] Since 2005, the number of NEOs catalogued in this range has almost tripled, while the total number of catalogued NEOs has increased by almost five times (Figure 4). Nevertheless, according to a 2017 report from NASA's NEO Science Definition Team, current observational capabilities are suited to only finding less than half of all 140 meter objects by 2033, and planned improvements will still fall short of the timeline that Congress directed.[9]

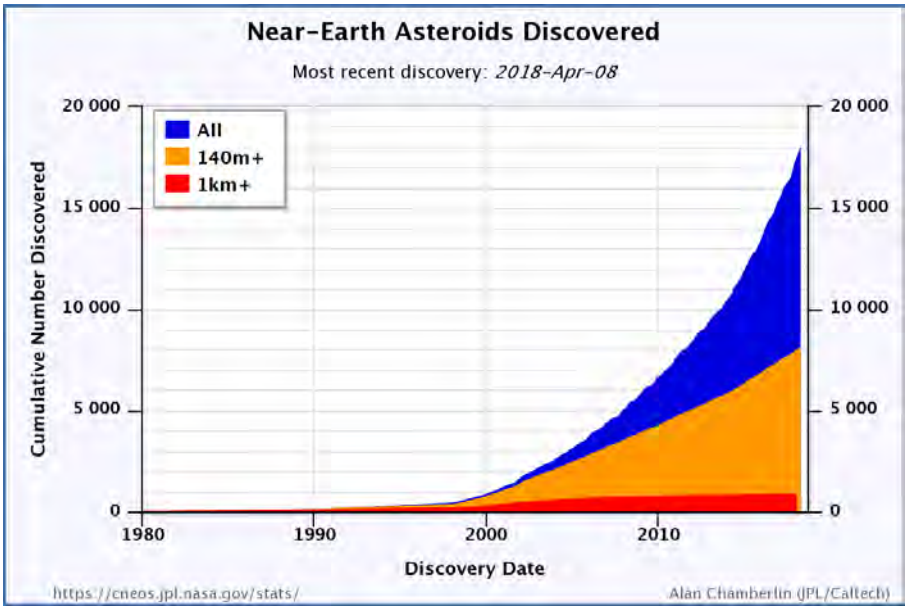

Figure 4: Cumulative number of near-Earth asteroids discovered by year since 1980.[10]

Managing the NEO Impact Hazard

Unlike other natural disasters (*e.g.*, hurricanes), once a NEO is detected and tracked we can typically predict many years in advance whether it will cause a devastating impact, and, most importantly, we can potentially prevent impacts when detected with sufficient warning time. A NEO may be deflected via spacecraft systems designed to alter the NEO's orbit such that it misses the Earth. When deflection

[8] National Aeronautics and Space Administration Authorization Act of 2005, Section 321 the George E. Brown, Jr. Near-Earth Object Survey.

[9] National Aeronautics and Space Administration. 2017. *Update to Determine the Feasibility of Enhancing the Search and Characterization of NEOs.* https://cneos.jpl.nasa.gov/doc/2017_neo_sdt_final_e-version.pdf

[10] Source: https://cneos.jpl.nasa.gov/stats/totals.html

is not practical or advisable, a NEO may be disrupted via spacecraft systems designed to fragment the NEO into smaller pieces that are more likely to miss the Earth or burn up in the atmosphere. The United States must also prepare to manage the consequences of NEO impacts where impact prevention is not feasible, preferable, or successful. Effective emergency procedures can save lives and mitigate damage to critical infrastructure.

The Trump Administration's 2018 National Strategy for Space[11] recognizes the NEO hazard, and directs agencies to undertake multilateral efforts that promote U.S. scientific, economic, and security interests, including mitigation of space environmental hazards such as near-Earth objects. National Space Policy[12] directs the NASA Administrator to "pursue capabilities, in cooperation with other departments, agencies, and commercial partners, to detect, track, catalog, and characterize near-Earth objects to reduce the risk of harm to humans from an unexpected impact on our planet."

The United States should lead in establishing a coordinated global approach for tracking and characterizing NEO impact threats, preparing to prevent damaging impacts where possible, and responding to and recovering from NEO impacts. While international cooperation is the most effective way to manage NEO impact risks, the United States should also be prepared to act independently through all phases that may occur during an impact scenario (Figure 5) to protect and preserve America's interests.

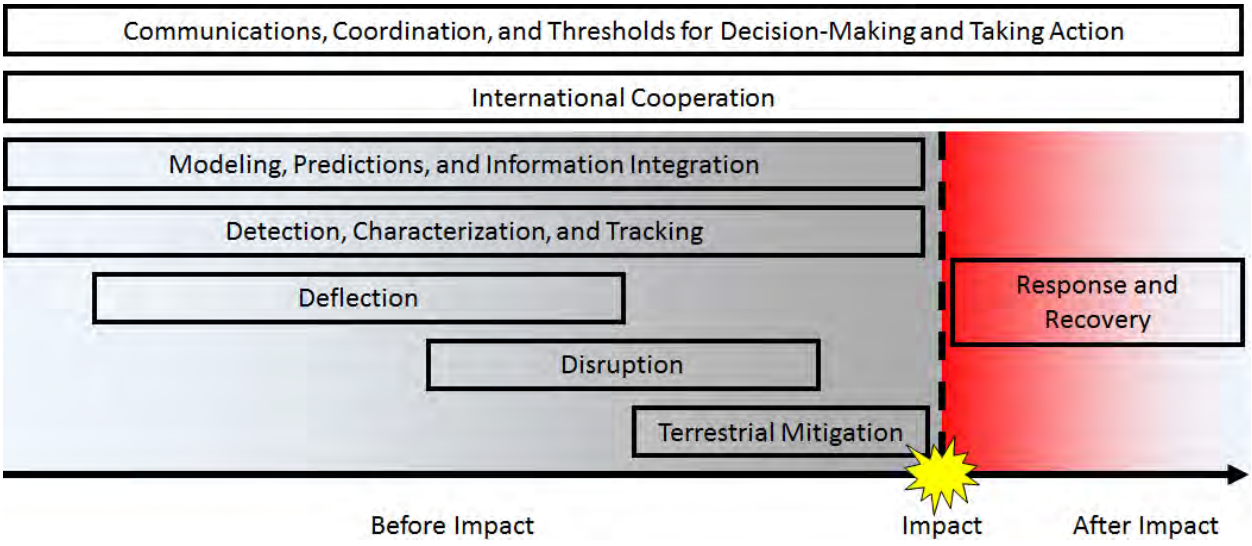

Figure 5: Illustrative timeline of the potential phases of operations in a NEO threat scenario.

Recognizing the lack of a whole-of-government or international strategy for addressing NEO hazards, the Committee on Homeland and National Security within the National Science and Technology Council (NSTC) established an Interagency Working Group (IWG) for Detecting and Mitigating the Impact of Earth-bound Near-Earth Objects (DAMIEN). The DAMIEN-IWG developed this Strategy and Action Plan to enhance national preparedness over the next decade for the hazard of NEO impacts. Its primary role is to help organize and coordinate NEO-related efforts within agencies, with a particular focus on efforts that are already existing and resourced.

[11] https://www.whitehouse.gov/briefings-statements/president-donald-j-trump-unveiling-america-first-national-space-strategy/

[12] Presidential Policy Directive 4 (PPD-4): National Space Policy of the United States of America, signed June 28th, 2010.

The *National Near-Earth Objective Preparedness Strategy and Action Plan* establishes five overarching strategic goals to mitigate the risk of NEO impacts through improved understanding, forecasting, prevention, and emergency preparedness:

Goal 1: Enhance NEO Detection, Tracking, and Characterization Capabilities

Goal 2: Improve NEO Modeling, Predictions, and Information Integration

Goal 3: Develop Technologies for NEO Deflection and Disruption Missions

Goal 4: Increase International Cooperation on NEO Preparation

Goal 5: Strengthen and Routinely Exercise NEO Impact Emergency Procedures and Action Protocols

A set of strategic objectives supports each goal and will enhance NEO threat preparedness in three key areas: threat and risk assessment, decision-making, and response and recovery. Some Federal agencies have already taken steps in these areas. This Strategy and Action Plan will leverage existing efforts and policies while promoting enhanced coordination and cooperation across the public and private sectors in the United States and abroad.

One or more specific actions supports each objective. Each action includes a desired timeline for completion. The timeline is described as **Short term** for less than two years, **Medium term** for two to five years, **Long term** for five to ten years, and **Ongoing** if expected to be repeated within the ten-year horizon of this Action Plan. Each Action includes a list of relevant agencies, with the recommended lead agency listed first, but does not prescribe a specific approach. These lists of relevant agencies are not meant to be exhaustive or limiting. Participation by additional agencies not listed will benefit many actions.

The *National NEO Preparedness Strategy and Action Plan* is formulated to inform the policy development process. Any commitment of Federal resources to support the activities outlined in this document will be determined through the budget processes. Most actions should not require allocation of additional resources. Actions requiring additional resources could come from redirection from lower priority Federal Agency activities and/or from State, local, or other resources. Recognizing the challenges of planning for events such as NEO impacts that are low probability but threaten very high consequences, agencies should prioritize accordingly and consistent with existing authorities.

Goal 1: Enhance NEO Detection, Tracking, and Characterization Capabilities

Early detection and characterization of hazardous NEOs increases the time available to make decisions and take effective mitigating action, and it is the first priority for planetary defense. Accurately predicting NEO orbits and understanding their physical structure and composition are both critical to assessing impact risk and determining how to best respond to NEO impact threats.

NASA is the global leader for ground- and space-based observations to detect, track, and characterize near-Earth asteroids and comets. NASA has been conducting a NEO survey program since 1998, starting with objects 1-kilometer in size and larger. For many years, NASA has funded the Minor Planet Center, currently hosted by the Smithsonian Astrophysical Observatory, as a clearinghouse for worldwide asteroid observations and identification of objects in potentially hazardous orbits. In 2013, the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) established, with collaboration and endorsement from NASA and the Department of State (State), the International Asteroid Warning Network (IAWN), a voluntary organization of astronomers that fosters collection and rapid reporting of asteroid observation data from observatories worldwide. These and other partnerships have substantially increased the global NEO detection rate over the last 10 years. In the near future, a partnership with the Large Synoptic Survey Telescope—funded by NSF and currently under construction in Chile—is expected to provide a significant contribution to the detection of NEOs after it becomes operational in 2023.

Attention to tracking smaller NEOs has increased with improved awareness of the damage these far more numerous objects can cause. Careful stewardship has enabled expansion and increased fidelity of U.S. NEO observations through small investments in new technologies and analytic capabilities. However, efforts to comply with statutory directives to achieve at least 90 percent completion in the search for objects down to 140 meters in size are many years behind the schedule established in 2005.

Once a NEO is detected and catalogued, its characterization relies heavily on measuring and analyzing different frequencies of light (its spectral signature), supplemented with radar data when possible. NASA, the U.S. Geological Survey, and various investigators maintain spectral libraries that provide reference samples to aid researchers in determining NEO composition. Academia largely conducts these analyses, relying on an informal collaboration network across institutes. This process has provided excellent scientific results, but its reliability has not been demonstrated in a crisis situation.

There is one strategic objective for this goal: improve national capabilities for NEO detection, tracking, and remote characterization.

Improve national capabilities for NEO detection, tracking, and remote characterization

Developing and pursuing roadmaps for enhancing detection, tracking, and remote characterization capabilities will enable faster completion of the survey of larger NEOs and provide critical improvements to our understanding of the 50-140 meter NEO population. The 2017 Report of the Near-Earth Object Science Definition Team,[13] which NASA sponsored, provides a source for critically examining existing and proposed ground and space telescope programs, how anticipated upgrades to existing telescopes will assist in completing the required NEO catalog, and how each option or combination of options for adding new telescopes could improve our understanding of the NEO impact hazard. The Science Definition Team report provides findings for how to effectively complete the survey of larger NEOs (140 meters in size and larger). Due to the devastation smaller objects can cause, it also

[13] https://www.nasa.gov/planetarydefense/supporting_documents

recommends that the search program and capabilities should be extended to detecting and cataloguing objects as small as 50 meters in size. If a NEO impact threat is detected, characterizing the NEO is critical to developing an informed mitigation strategy. Multiple data types and sources, including a mix of ground-and space-based assets, are needed to provide the necessary level of detail. The following actions support this strategic objective:

1.1 **Identify opportunities in existing and planned telescope programs to improve detection and tracking by enhancing the volume and quality of current data streams, including from optical, infrared, and radar facilities.** Existing and planned space situational assets, including commercial systems, might also contribute to NEO detection and tracking. Where possible, a cost/benefit analysis should characterize these opportunities in terms of how they would reduce overall uncertainty in NEO impact risks. [Short term; NASA, National Science Foundation (NSF), United States Air Force (USAF)]

1.2 **Identify technology and data processing capabilities and opportunities in existing and new telescope programs to enhance characterization of NEO composition and dynamical and physical properties.** This analysis should include opportunities in automation and analytical software, deployed sensor systems, data processing capabilities, and an investigation into any existing national capabilities that could aid in asteroid characterization. Improving these capabilities will inform NEO impact threat assessments and enhance decision-making by aiding estimation of size, shape, rotation period, pole orientation, mass, mineralogical composition, hydration state, internal structure, and other properties. [Short term; NASA, NSF, United States Geological Survey (USGS)]

1.3 **Use the roadmaps developed in Actions 1.1 and 1.2 to inform investments in telescope programs and technology improvements to improve completeness and speed of NEO detection, tracking, and characterization**. [Long term; NSF, NASA, U.S. Air Force Space Command]

1.4 **Establish and exercise a process for rapid characterization of a potentially hazardous NEO.** Developing and exercising a plan for rapid characterization of a NEO will inform development of the capability roadmap and will further aid in meeting Goals 2 and 3. Periodic exercises should serve to identify and correct any issues with the timeliness, quality, and quantity of information provided to the modeling group and decision makers. [Short term and Ongoing; NASA, NSF, USGS]

Goal 2: Improve NEO Modeling, Predictions, and Information Integration

National NEO preparedness will depend upon quantitative modeling and analysis capabilities to inform decision makers about: 1) predicted Earth impact probabilities, 2) impact timing and location, 3) impact effects and consequences, and 4) options for impact prevention. Achieving this goal will require establishing and continually improving a capability and framework for generating, disseminating, and utilizing modeling results.

The strategic objectives to improve NEO modeling, predictions, and information integration are:

- Establish an interagency NEO impact modeling group
- Establish an integrated suite of computational tools for modeling NEO impact risks and mitigation techniques
- Exercise, evaluate, and continually improve modeling and analysis capabilities

Establish an interagency NEO impact modeling group

The impact modeling group will coordinate the development and validation of modeling results for dissemination to decision-makers and the public, and utilize exercises to assess, improve, and prepare for potential NEO impact events. The working group should include subject matter experts and convene at least annually (perhaps more frequently in the first year or two) to remain cognizant of relevant modeling and prediction activities and to track effective implementation of the actions supporting this strategic goal.

A credible national planetary defense response capability will depend on integrated support from this working group. In the event of an impending NEO impact, many independent foreign and domestic sources of information and analysis will emerge. Ensuring rapid assessment and timely delivery of verified information to U.S. Government agencies, and to international and intergovernmental organizations, will be essential to enable decision making and to manage public awareness.

2.1 **Establish an interagency working group for coordination and enabling dissemination of the results of NEO threat modeling and analysis**. This group will develop a plan for the management of modeling and analysis efforts, including a list of all contributing and affected organizations, and will help manage the tasking and flow of modeling and analysis results to relevant officials and organizations. [Short term; NASA, DHS Science and Technology Directorate, DHS National Protection and Programs Directorate, in collaboration with providers of modeling and analysis results]

Establish an integrated suite of computational tools for modeling NEO impact risks and mitigation techniques

A national, coordinated modeling effort will require developing a range of validated tools and integrating them into a single framework. Agencies will leverage existing capabilities wherever possible.

2.2 **Ascertain what information each participating organization requires on what timeframe, identify gaps, and develop recommendations for modeling improvements**. This includes an assessment of the adequacy of current modeling capabilities. [Short term; NASA, Federal Emergency Management Agency (FEMA)]

2.3 **Develop and validate a suite of computer simulation tools for assessing the outcome of deflection or disruption techniques applied to a NEO**. [Medium term; DOE, NASA]

2.4 **Establish a suite of computer simulation tools for assessing the local, regional, and global risks associated with an impact scenario**. Probabilistic Earth impact consequence models should link to existing infrastructure mapping capabilities to achieve a suite of simulation tools that predicts impact damage and can provide, for a detected NEO on a potential impact trajectory, a list of at-risk infrastructure and associated probability of damage. [Medium term; Department of Defense (DoD) Defense Threat Reduction Agency (DTRA), Nuclear Regulatory Commission (NRC), NASA, National Nuclear Security Administration (NNSA) National Laboratories, National Oceanic and Atmospheric Administration (NOAA), USGS]

2.5 **Assess the sensitivities of these models to uncertainties in NEO dynamical and physical properties.** This analysis includes but is not limited to understanding how variations in NEO properties affect the effectiveness of a deflection or disruption technique; the damage caused by an airburst or impact; and the largest deflection a NEO can tolerate (especially so-called "rubble pile" NEOs with little intrinsic strength) before beginning to disrupt. [Medium term; NASA, NNSA, FEMA]

Exercise, evaluate, and continually improve modeling and analysis capabilities

Exercising scenarios on a regular basis, and including key agency personnel every two to three years, will be important to evaluate the ability of end-to-end impact modeling capabilities to meet the needs of decision makers. Exercises also provide opportunities to add, integrate, and evaluate new and improved capabilities into the modeling framework.

2.6 **Continually assess the adequacy and validity of modeling and analysis through annual exercises, test problems, comparison to experiments, and peer review activities**. Structure exercises to identify gaps, formulate needed improvements, test connections within the national framework, and improve operational readiness. This action should include an annual lessons learned document and plan for increasing operational readiness to be shared among interested parties. [Ongoing; FEMA National Exercise Division, NASA, NNSA, USGS, in collaboration with providers of modeling and analysis results]

Goal 3: Develop Technologies for NEO Deflection and Disruption Missions

Preparing to respond effectively to a NEO impact threat scenario includes developing capabilities for both deflection and disruption. There is much that is not known about the orbits, size, and material composition of many NEOs, and it is essential to account for these uncertainties when developing and utilizing technologies for impact prevention. For example, multiple technologies may be suitable for preventing NEO impacts that are predicted well in advance, while disruption via nuclear explosive device may be the only feasible option for NEOs that are very large or come with short warning time. Observing NEOs over many years (as outlined in Goal 1) will improve the understanding of their orbits and future trajectories, and should also improve our understanding of their size and composition, which would assist in planning for deflection or disruption space mission campaigns.

The strategic objectives to develop technologies for NEO deflection and disruption missions are:

- Develop technologies and designs for rapid-response NEO reconnaissance missions
- Develop technologies and designs for NEO deflection and disruption missions

Develop technologies and designs for rapid-response NEO reconnaissance missions

An effective deflection or disruption mission will most likely require more detailed and accurate information about the incoming NEO than existing and planned remote observational capabilities can provide. A capability to rapidly launch a spacecraft to rendezvous with or fly by the NEO and perform reconnaissance is the only clear way to meet this need. A rapid reconnaissance mission would ideally provide up-close imagery, compositional information, and mass measurements.

3.1 **Assess technologies and concepts for rapid-response NEO reconnaissance missions.** This assessment should include dedicated reconnaissance via spacecraft flyby or rendezvous, as well as mission concepts in which the reconnaissance spacecraft could also carry out deflection or disruption. The assessment should consider both commercial-off-the-shelf parts and new hardware development. [Short term; NASA]

3.2 **Evaluate the capabilities of current and projected domestic and international launch vehicle infrastructure to support planetary defense missions.** This analysis includes considering both rapid-response reconnaissance and deflection/disruption missions, accounting for integration and testing processes, and recommending processes for accomplishing rapid response planetary defense space-lift. [Short term; NASA/LSP, Air Force Space Command]

3.3 **Create plans for the development, testing, and implementation of NEO reconnaissance mission systems**. These plans should lead to establishment of operational NEO reconnaissance capabilities, including rapid-response. Planning could include developing a system to automatically calculate possible trajectories for planetary defense spacecraft to reach potentially hazardous NEOs. [Short term; NASA]

Develop technologies and designs for NEO deflection and disruption missions

The United States should develop and validate technologies and techniques for deflecting and disrupting NEOs of varying physical properties before the need arises to deploy them in an actual threat scenario. For most NEO threat scenarios, Earth impact prevention capabilities should include the ability to rapidly reach the NEO, conduct necessary rendezvous and proximity operations, and deploy

deflection/disruption technologies. Additionally, deploying an instrumented means of measuring the deflection over time can provide valuable assurance of mission success and critical post-mission situational awareness. Where practical, we should establish confidence through a real world demonstration—consistent with all U.S. treaty obligations and international commitments—of the deflection or disruption technique, potentially as a part of a mission or program with broader scientific and exploration objectives.

3.4 **Identify, assess the readiness of, estimate in the costs of, and propose development paths for key technologies required by NEO impact prevention concepts.** This assessment should include the most mature in-space concepts—kinetic impactors,[14] nuclear devices, and gravity tractors[15] for deflection, and nuclear devices for disruption[16]—as well as less mature NEO impact prevention methods. Technology assessments should consider contemporary work, including potential synergies with relevant private industry interests (*e.g.*, asteroid mining). They should also consider NEO impact scenarios that may have received insufficient attention thus far (e.g., binary asteroids, high-speed comets). [Short term; NASA, NNSA, DoD]

3.5 **Perform a risk analysis on planetary defense mission success under varying assumptions and circumstances.** This effort will address current deficiencies in understanding how rapidly the United States can deploy planetary defense missions while maintaining acceptable reliability and mission success probability, and with sufficient redundancy. [Medium term; NASA]

3.6 **Develop preliminary mission designs for NEO deflection mission campaigns.** This action includes preliminary designs for a gravity tractor NEO deflection mission campaign, and for a kinetic impactor mission campaign in which the spacecraft is capable of either functioning as a kinetic impactor or delivering a nuclear explosive device. For the latter case, the spacecraft would contain all systems necessary to carry and safely employ a nuclear explosive device, but would carry a mass simulator with appropriate interfaces in place of an actual nuclear device. Designs should include reconnaissance spacecraft and methods to measure the achieved deflection. [Medium term; NASA, NNSA]

3.7 **Conduct a series of flight demonstrations to validate NEO deflection and disruption system concepts.** These flight demonstrations would focus on harmless NEOs to test and validate deflection/disruption system concepts and identify design issues for correction. Any flight demonstrations relevant to nuclear explosive techniques would not incorporate an actual nuclear device, or involve any nuclear explosive testing. Results would inform decision-making processes during an actual NEO threat scenario. Thorough flight testing of a deflection/disruption system prior to an actual planetary defense mission would substantially decrease the risk of mission failure. [Long term; NASA]

[14] A kinetic impactor is a spacecraft that collides with a NEO to change its orbit.

[15] A gravity tractor is a spacecraft positioned near a NEO that uses the spacecraft's own gravity over a long period of time to slowly change the NEO's orbit.

[16] These techniques were recommended in a 2010 report published by the National Research Council (National Research Council. 2010. *Defending Planet Earth: Near-Earth-Object Surveys and Hazard Mitigation Strategies*. Washington, DC: The National Academies Press. https://doi.org/10.17226/12842).

Goal 4: Increase International Cooperation on NEO Preparation

The risk of a NEO impact is a worldwide hazard, and international cooperation is the best way to improve both warning and response. The United States should assume a leadership role in fostering global collaboration and leveraging international capabilities to improve NEO preparedness and response.

The United States and other nations already share observations and research, and are considering options for coordinated responses. The NASA PDCO works with the IAWN and the Space Mission Planning Advisory Group (SMPAG), whose establishment was recommended by the UNCOPUOS. These expert bodies promote coordination among astronomers, scientists, and policy makers seeking to detect, characterize, and respond to potential NEO impacts. Further increasing international participation in these efforts will improve our collective situational awareness, predictions, and overall preparedness for NEO events.

The strategic objectives to increase international cooperation on NEO awareness and preparation are:

- Build international awareness of potential NEO impacts as a global challenge
- Increase international engagement and cooperation on observation infrastructure, numerical modeling, and scientific research
- Foster consultation and coordination on NEO impact planning, mitigation, and response

Build international awareness of potential NEO impacts as a global challenge

Greater international awareness of NEO dangers is a critical step towards effective cooperation and high-level support.

4.1 **Inform foreign governments of the need for a comprehensive and coordinated approach to preparing for a NEO event.** Underscore U.S. positions in relevant international NEO impact initiatives and promote awareness in other international organizations and meetings. This action could include an annual U.S. Statement under the NEOs agenda item of the Scientific and Technical Subcommittee of the UNCOPUOS; special technical presentations on NEOs at UNCOPUOS and other relevant international bodies; developing and implementing a plan for outreach and education to assist countries in understanding NEO impact effects for use by relevant international disaster management bodies to aid in decision-making; and adding NEOs as an agenda item in bilateral consultations, including existing space policy dialogues with key spacefaring nations. [Ongoing; State, NASA]

4.2 **Continue to demonstrate U.S. leadership in technical international NEO organizations, and increase awareness among all countries, in particular space agency officials, of the need to address NEO issues in major international bodies**. This action should include making NEO issues an agenda item at scientific and technical meetings as appropriate. It should also include adding NEO issues and the need to address them to agendas at major international conferences. [Ongoing; NASA, State]

Increase international engagement and cooperation on observation infrastructure, numerical modeling, and scientific research

The United States provides a significant majority of the global observational infrastructure and scientific research related to NEOs. Others countries and institutions are beginning to expand their work in this field, but we should do more to leverage the resources of the global community.

4.3 **Improve international collaboration on observation infrastructure and data sharing, as well as numerical modeling and scientific research**. This action should be accomplished by involving more countries in the work of IAWN, consistent with law, so that it can serve as an effective body for international collaboration on observation infrastructure, data sharing, numerical modeling, and scientific research. [Ongoing; NASA, NSF]

4.4 **Lead development of a plan for improving NEO monitoring through enhanced coordination (and potential expansion) of U.S. and key country ground-based telescopes.** This plan should focus on existing telescopes, but could look at coordinating new and planned hardware to optimize the range of capabilities. This action could include holding an international workshop on the use of ground-based telescopes to improve global NEO monitoring in conjunction with the 70th International Astronautical Congress in Washington, DC. [Short term; NSF, NASA]

4.5 **Encourage countries to initiate and continue programs to develop space- and ground-based telescopes to detect, track, and characterize NEOs and coordinate via the IAWN**. This could include sponsoring sessions at international astronomical conferences on how to initiate and conduct programs for NEO observation, addressing both existing capabilities and needs. [Ongoing; NASA, NSF]

Foster consultation and coordination on NEO impact planning, mitigation, and response

International efforts to address scientific and technical issues work best when there are effective forums available to deal with a given issue. Focusing resources on identifying and improving existing international institutions can begin the process of planning for, mitigating, and responding to NEO impacts.

4.6 **Strengthen the IAWN and SMPAG as the primary international technical bodies for addressing NEO planning and mitigation.** Provide continued support and engagement to make both international bodies more effective and to increase the number of actively participating nations. This action should include developing and implementing a plan to broaden and enhance U.S. interagency participation in these forums, and a list of actions to encourage other nations to join the activities, consistent with law. [Medium term; State, NASA]

4.7 **Encourage participation in tabletop and physical exercises with global partners regarding preparedness, prevention, response, and recovery efforts**. Include realistic modeling data from the integrated suite of computational tools developed in Goal 2 and the scenarios developed in Action 5.1 to ensure high fidelity in the exercise. This action could include sponsoring a workshop for global and international disaster management organizations on NEO preparedness, response, and recovery. [Ongoing; State, DHS]

Goal 5: Strengthen and Routinely Exercise NEO Impact Emergency Procedures and Action Protocols

Developing and exercising procedures and action protocols to support decision-making and communications will enable timely and effective implementation of NEO impact response and mitigation measures. Communication and coordination are necessary across all areas of government and span the entire impact scenario timeline, as shown in Figure 5 on page 5.

Since NEO impact emergencies are extremely rare, it is important to leverage procedures and practices used for other disasters wherever practical. At the same time, due to the unique nature of the NEO threat (including the rarity of damaging events, the scale of potential consequences, and the legal and policy implications of potential mitigation measures), most scenarios will involve direct Presidential decision making. Response and mitigation actions cannot be made routine to the same degree that they are for other natural disasters such as hurricanes. Rather, establishing and exercising thresholds and protocols will aid agencies in preparing options and recommending courses of action.

NASA and FEMA have established notification processes for potential NEO impacts, and also established in August 2015 the Planetary Impact Emergency Response Working Group (PIERWG) to develop guidance for NEO impact preparation. PIERWG will continue to perform its coordination responsibilities under FEMA direction. FEMA will maintain the statutory responsibility to manage emergency planning and response and will leverage existing coordination and communications mechanisms wherever appropriate. FEMA and NASA will jointly develop public communication protocols.

FEMA coordinates development of emergency response plans for all hazards via the Federal Interagency Operations Plans (FIOP) and Annexes. Under current authorities, the FEMA Administrator will ensure that procedures and response plans are in place to respond to the unique aspects of a NEO impact.

The strategic objectives to establish NEO impact emergency procedures and action protocols are:

- Strengthen protocols for conducting a threat-assessment, upon detection of a potential NEO impact, to inform subsequent communication and decision making
- Strengthen protocols for coordinated communications and notifications regarding NEO threats
- Establish protocols for recommending space-based reconnaissance and mitigation missions
- Establish procedures and protocols for recommending and executing NEO impact emergency preparedness, response, and recovery

Strengthen protocols for conducting a threat-assessment, upon detection of a potential NEO impact, to inform subsequent communication and decision making

Following identification of any potential NEO impact, the Federal government will assess the nature of the threat and prepare key information to inform subsequent communications and decisions regarding defense and other forms of consequence mitigation. NASA has already developed a disciplined approach to initial assessment of NEO impact threats. The existing process, overseen by NASA's PCDO, includes receipt and analysis of observations by the Minor Planet Center, transmission of potential impact analysis results by the JPL Center for NEO Studies, and formal notification to the Office of Science and Technology Policy (OSTP). This approach provides a sound basis upon which to build. Additional action will ensure that the content, format, and timeline of NASA's notification to OSTP and any others effectively support subsequent communications and decision-making.

5.1 **Develop a set of real-world scenarios based on credible impact threats with observable parameters to inform planning and procedure development.** This action should lead to materials made widely available, such as on NASA websites and ready.gov, and that can provide the basis for planning and exercises at the Federal, State, and local levels. It should also include providing after-action reports from previous exercises for DHS National Protection and Programs Directorate, FEMA Exercise Division, and FEMA National Preparedness Assessments Division, along with names of subject matter experts who can answer questions from government officials [Short term; FEMA, DHS, NASA]

5.2 **Establish a procedure and timeline for conducting a threat assessment upon detection of a potential NEO impact, and for updating the threat assessment based on improved data**. Standardize the threat assessment content to provide suitable inputs for subsequent decisions regarding notification, mitigation, response, and recovery. It should include specified thresholds for time to impact (*e.g.*, hours, days, months, years, decades); probability of impact (*e.g.*, greater than 0.1%, 1%, 10%, 50%); expected level of damage (*e.g.*, local, regional, global); and whether a deflection/disruption mission is feasible for mitigation. This action should culminate in a NEO Preparedness Threat Assessment format and protocol, including key points of contact from relevant agencies, delivered to OSTP, NASA, DHS/FEMA, and other agencies. [Short term, with updates as needed; NASA PDCO, OSTP, NASA, FEMA]

Strengthen protocols for coordinated communications and notifications regarding NEO threats

Developing decision-threshold-based protocols for communications and notifications regarding NEO impact threats will enable an integrated federal response that is also coordinated with State, Local, and foreign governments. The initial threat assessment referenced in Action 5.2 must be structured in part to support these communications. Decision thresholds for notifications and other communications will likely depend on probability of impact, predicted impact location, and expected level of damage, though notification thresholds may not depend on the time until impact.

5.3 **Revisit and validate the current notification protocol chain-of-command.** Adjust accordingly the protocols for notifying and communicating within the Federal government regarding NEO threats. This action should culminate in an action flowchart and updated or revalidated memo for NASA PDCO and FEMA. [Short term; OSTP, NASA, FEMA]

5.4 **Develop protocols for notifying The White House and Congress (including briefing appropriate subcommittees), State and Local governments, the public, foreign governments, and other international organizations, regarding NEO threats**. Adopt or modify existing NASA PDCO and IAWN plans for exchange of information among national emergency response stakeholders. Develop appropriate modifications from existing emergency alerts based on specific NEO impact factors. Use tabletop exercises to determine effectiveness with emergency managers at local, state, and national levels. This action should include developing an action flowchart for NASA PDCO. It should also include developing warnings and text for emergency alerts. [Medium term; OSTP, NASA, FEMA, State]

5.5 **Develop informational material for different audiences providing basic education, information on uncertainties, and emergency response plans**. This action should include developing an integrated information and education package with social media, internet, and traditional press release formats for relevant information. [Short term; NASA, FEMA, OSTP]

Establish protocols for recommending space-based reconnaissance and mitigation missions

When a threat assessment concludes that a NEO poses a real impact threat and that space-based mitigation is feasible, that assessment should initiate a process to develop recommendations for the President regarding space-based reconnaissance and mitigation missions. This process includes an analysis of mitigation alternatives to examine the risks, benefits, and uncertainties associated with various approaches, leading to recommendations on how to proceed. Decision flowcharts will likely incorporate decision thresholds based on time to impact, probability of impact, expected level of damage, and impact location.

5.6 **Establish a procedure and timeline for conducting a risk/benefit analysis for space-based mitigation mission options following a NEO threat assessment**. [Short term; NASA, OSTP, DOE, DOD]

5.7 **Develop benchmarks for determining when to recommend NEO reconnaissance, deflection, and disruption missions**. This action should culminate in a threshold-based flowchart for agencies. [Short term; NASA, DOE, DOD, OSTP]

Establish procedures and protocols for recommending and executing NEO impact emergency preparedness, response, and recovery

When an impact threat assessment concludes that a NEO poses a real threat, that assessment should initiate a process to recommend and implement emergency preparedness, response, and recovery protocols. Decision flowcharts will likely incorporate thresholds based on time to impact, probability of impact, expected level of damage, and impact location. Protocols for other emergencies apply to some aspects of NEO impact response, reducing the need to develop additional resources; however, responding effectively to a NEO threat may also require some NEO-specific protocols.

5.8 **Incorporate NEO impacts into All-Hazards Response and Recovery Plans**. The FEMA Administrator will, under current authorities granted by the Stafford Act, Post Katrina Emergency Management Reform Act, and other applicable statues, implement response and recovery actions necessary to save lives, mitigate suffering, and limit property damage. [Short term; FEMA, NASA PDCO, OSTP, EPA]

Conclusion

NEO impacts pose a significant and complex risk to both human life and critical infrastructure, and have the potential to cause substantial and possibly even unparalleled economic and environmental harm. This Strategy and Action Plan provides a road map for a collaborative and federally coordinated approach to developing effective technologies, policies, practices, and procedures for decreasing U.S. and global vulnerability to NEO impacts. When implemented, the activities outlined herein will improve detection, research, mission planning, emergency preparedness and response, and domestic and international engagement. Implementing the NEO Action Plan will increase the United States' ability and readiness, together with domestic and international partners, to mitigate the impact hazard posed by NEOs.