NATIONAL NEAR-EARTH OBJECT PREPAREDNESS STRATEGY

PRODUCT OF THE

INTERAGENCY WORKING GROUP FOR DETECTING AND MITIGATING THE IMPACT OF EARTH-BOUND NEAR-EARTH OBJECTS (NEOS) (DAMIEN)

OF THE NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

DECEMBER 2016

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About the DAMIEN IWG

The DAMIEN IWG was convened in January 2016 to consider options to mitigate impacts from NEOs, including detection, characterization, trajectory determination, impact analysis; senior U.S. decision making, international cooperation and communications; long-term and short-term mitigation options, as well as quantification of success and risks from different mitigation options; public outreach, and disaster planning, operations, and recovery. The IWG's primary goal was to provide focused input, via this National Strategy, into the National Planning Framework called for by the Presidential Policy Directive 8 (PPD-8): National Preparedness (2011).

About this Document

This document was developed by the Interagency Working Group (IWG) for Detecting and Mitigating the Impact of Earth-bound Near-Earth Objects (NEOs) (DAMIEN). The Strategy seeks to improve our Nation's preparedness to address the hazard of near-Earth object (NEO) impacts by enhancing the integration of existing national and international assets and adding important capabilities that are currently lacking. The Strategy builds on efforts at the National Aeronautics and Space Administration (NASA) to better detect and characterize the NEO population as well as recent efforts at the Department of Homeland Security (DHS) to prepare for and respond to a NEO impact. The document was published by OSTP.

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Executive Summary

The *National Near-Earth Object Preparedness Strategy* (Strategy) and the forthcoming *National Near-Earth Object Preparedness Action Plan* (Action Plan) together seek to improve our Nation's preparedness to address the hazard of near-Earth object (NEO) impacts by enhancing the integration of existing national and international assets and adding important capabilities that are currently lacking. The Strategy and Action Plan build on efforts at the National Aeronautics and Space Administration (NASA) to better detect and characterize the NEO population as well as recent efforts at the Department of Homeland Security (DHS) to prepare for and respond to a NEO impact. Together, they aim to foster a collaborative effort in which the Nation can better understand, prevent, and prepare for the effects of a NEO impact. The Nation must continue to leverage existing networks of expertise and capabilities, both public and private, and pursue targeted enhancements to improve the ability to manage the risks associated with NEOs.

Seven strategic goals underpin the effort to enhance the Nation's preparedness to NEO impacts:

1. **Enhance NEO Detection, Tracking, and Characterization Capabilities.** Objectives include: developing a capability roadmap to inform a strategy for investing in both U.S. and foreign abilities for detection, tracking, and characterization; improving observation capabilities for more complete and rapid observation of the entire population of NEOs; and updating existing observatories with capabilities to improve characterization assessments.
2. **Develop Methods for NEO Deflection and Disruption.** Objectives include: developing capabilities for fast-response focused reconnaissance and characterization; researching deflection and disruption capabilities for NEOs of varying size, mass, composition, and impact warning times; and researching technologies required for deflection and disruption concepts.
3. **Improve Modeling, Predictions, and Information Integration.** Objectives include: ensuring that adequate modeling capabilities are developed for each topical need, especially for modeling NEO trajectories to reduce orbit uncertainties and predicted impact effects; determining what outputs are required by whom; and establishing an organizational construct to coordinate the development and dissemination of modeling results.
4. **Develop Emergency Procedures for NEO Impact Scenarios.** Objectives include: promoting a collaborative national approach to defend against, mitigate, respond to, and recover from a NEO impact event; and developing coherent national and international communication strategies to facilitate NEO impact preparations.
5. **Establish NEO Impact Response and Recovery Procedures.** Objectives include: establishing national and international protocols to efficiently respond to a NEO impact, whether in deep ocean, coastal regions, or on land; and facilitating international cooperation and planning to recover from a NEO impact in a timely manner with minimal disruption.
6. **Leverage and Support International Cooperation.** Objectives include: building international support and policies for acknowledging and addressing the potential Earth impact of a NEO as a global challenge; fostering consultation, coordination, and cooperation channels and efforts for the planning for, impact emergency preparedness before, and response to a NEO impact; increasing engagement with the international community on observation infrastructure, data sharing, numerical modeling, and scientific research; strengthening international coordination and cooperation on NEO data and

analyses; and promoting a collaborative international approach to preparedness for NEO events.

7. **Establish Coordination and Communications Protocols and Thresholds for Taking Action.** Objectives include: coordinating the communication of detected impact threats within the U.S. Government, as well as with other governments, media, and the public; developing a set of thresholds to aid U.S. decisions in whether to implement deflection or disruption missions; developing decision flowcharts for NEO hazard scenarios incorporating benchmarks and decision thresholds; and developing protocols for international interactions regarding NEO impacts outside of U.S. territory.

Introduction

Near-Earth Objects (NEOs) are asteroids or comets with heliocentric orbits that come near or intersect Earth's orbit.[1] They range in size from small "meteoroids" of only a few meters in size, to much larger bodies several kilometers wide. Figure 1 shows the current known near-Earth asteroid (NEA)[2] population (green bars), the current estimate of total NEA population (red line), the completeness percentage of survey efforts (blue line), and the estimated damage from a NEA impact (background), all as a function of the estimated size of the NEA.[3]

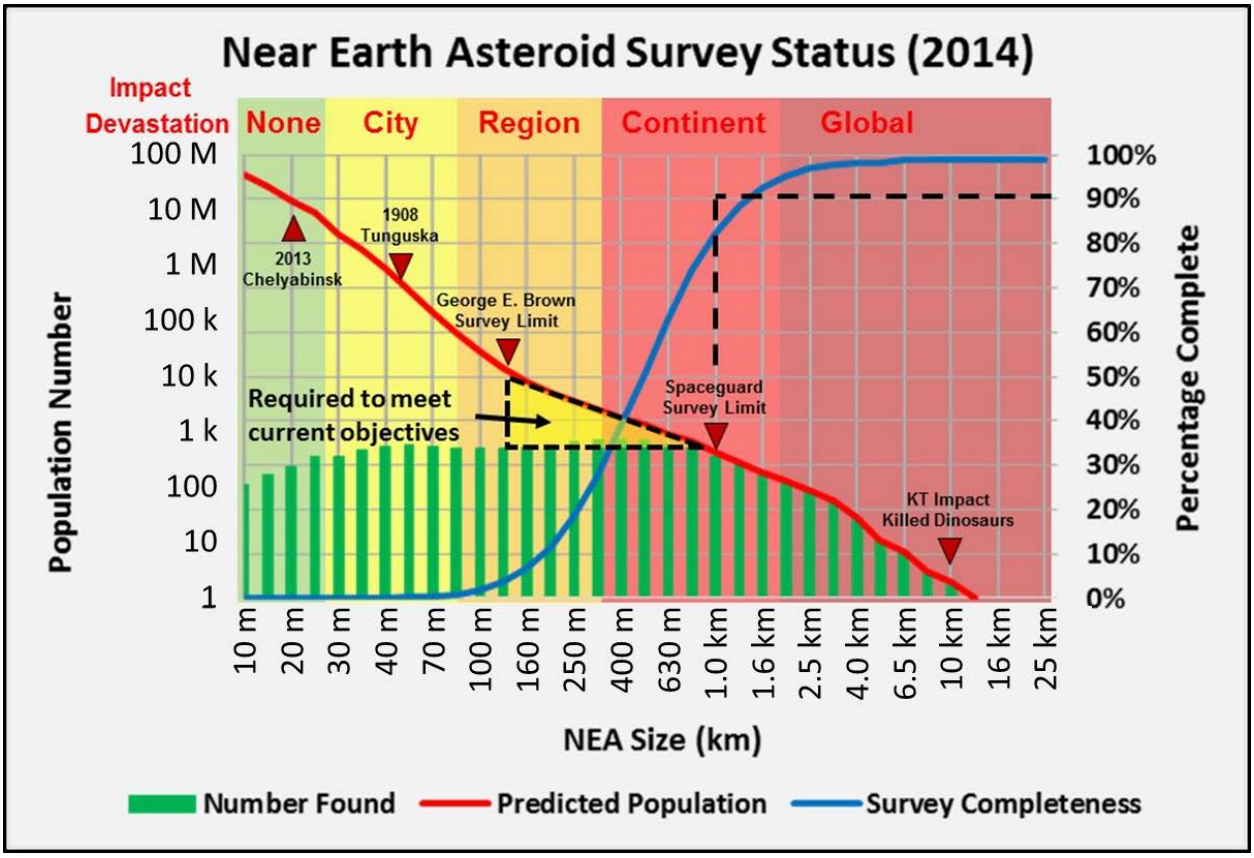

Figure 1: NEAs of various sizes: number detected to date and estimated total number.

Smaller asteroids fly by or enter Earth's atmosphere frequently. The greatest number are small enough to burn up in the atmosphere, and most go completely undetected. Recently released U.S. Department of Defense data show that between 1994 and 2013, 556 bolide (see Glossary) events were observed in the atmosphere; these correspond to asteroids ranging from 1 meter to 20 meters in size entering Earth's

[1] See the Glossary for definitions of key terms used in this document.

[2] This survey status does not include comets, hence the distinction between NEOs and NEAs in Figure 1. However, Earth approaching comets represent less than 1% of the NEO population, and their enhanced signature from expelled dust make them much easier to detect once they cross inside the orbit of Mars.

[3] Harris, Alan, and Asteroid Grand Challenge. "NEA Populations and Impact Frequency." *Population*, 10 (2014): 6.

atmosphere.

Even small NEOs can have significant destructive effects (see the background shading in Figure 1). For example, the airburst near Chelyabinsk, Russia on February 15, 2013 was caused by a small asteroid approximately 20 meters wide that had an energy equivalent of almost 500 kilotons of trinitrotoluene (TNT), or roughly 20-30 times greater than the energy released from the first atomic bombs. Current estimates of the NEO population predict that almost 10 million objects with a diameter greater than 20 meters exist but have not yet been detected.

Similarly, an object estimated to be approximately 40 meters wide exploded over Tunguska, Russia in 1908 with the equivalent of 5-10 megatons of TNT and leveled over 2,000 square kilometers of trees. If a similar airburst event were to occur over a major metropolitan area, millions of injuries and casualties could result. Current estimates of the NEO population predict that over 300,000 objects greater than 40 meters in size could be an impact hazard to the Earth and have not yet been detected.

The most recent Congressionally-directed asteroid survey requires that NASA find 90% of objects that are 140 meters in size or greater (see References). Such objects would strike Earth with a minimum energy equivalent of over 60 megatons of TNT, which is more energy than yielded by the most powerful nuclear weapon ever tested. After almost two decades of search, about 28% of the estimated population of asteroids 140 meters in size or larger have been discovered. The highlighted triangle in Figure 1, “Required to meet current objectives”, illustrates estimates of the predicted population of objects >140m that are yet to be discovered.

Larger NEOs (>140 m), representing the potential to inflict serious damage to entire cities or regions, are also easier to detect and track, therefore more is known about this population than what is known about smaller objects. As Figure 1 shows, there are far fewer larger objects than smaller objects, so the probability of impact of a larger object is much lower compared to the probability of impact of a smaller object.

The exact effects from a NEO impact depend on, among other things, its composition, size, shape, porosity, and impact velocity. Small, rocky NEOs are likely to explode before hitting the ground, resulting in an airburst that could cause a wider radius of moderate damage compared to a similarly sized NEO composed of mostly metal that would strike the ground and cause localized devastation. However, larger, denser NEOs would require more energy to deflect, and have more kinetic energy overall upon impact. As more NEOs are detected, and the total population of NEOs is better characterized, assessing the overall hazard of a NEO impact will become more achievable.

Unlike other natural disasters (*e.g.*, hurricanes) and space weather events (*e.g.*, solar flares), NEO impacts are predictable many years in advance and, most importantly, potentially preventable when a survey of the population is complete. NEO impacts are a global hazard and could have major environmental, economic, and geopolitical consequences detrimental to the United States, even if the impact is beyond U.S. territory. Although currently a global leader in detecting and tracking NEOs, the United States will depend (in part) on international cooperation and coordination to help develop capabilities for characterization and future capabilities related to the development and implementation of deflection and disruption capabilities for NEOs.

When a NEO that is on course to impact Earth is identified, it is a global threat that requires the leadership of the United States to establish a coordinated global approach for detection, tracking, and characterization as well as for deflection and disruption operations, if necessary, and preparedness in the event of an impact. If prevention proves technically infeasible or is attempted and fails, the United States may also need to take a leadership role in helping the international community reduce the negative consequences of a NEO impact.

While it is highly unlikely that there will be a civilization-ending NEO impact over the next two centuries, the risk of smaller but still catastrophic NEO impacts is real, and there is currently no whole-of-government or international strategy to respond to such an event throughout all phases of a NEO impact scenario timeline (Figure 2). The *National Near-Earth Object Preparedness Strategy* (Strategy) and the forthcoming *National Near-Earth Object Preparedness Action Plan* (Action Plan) identify goals and activities to enhance the understanding of risk from, and national preparedness for, NEO impacts.

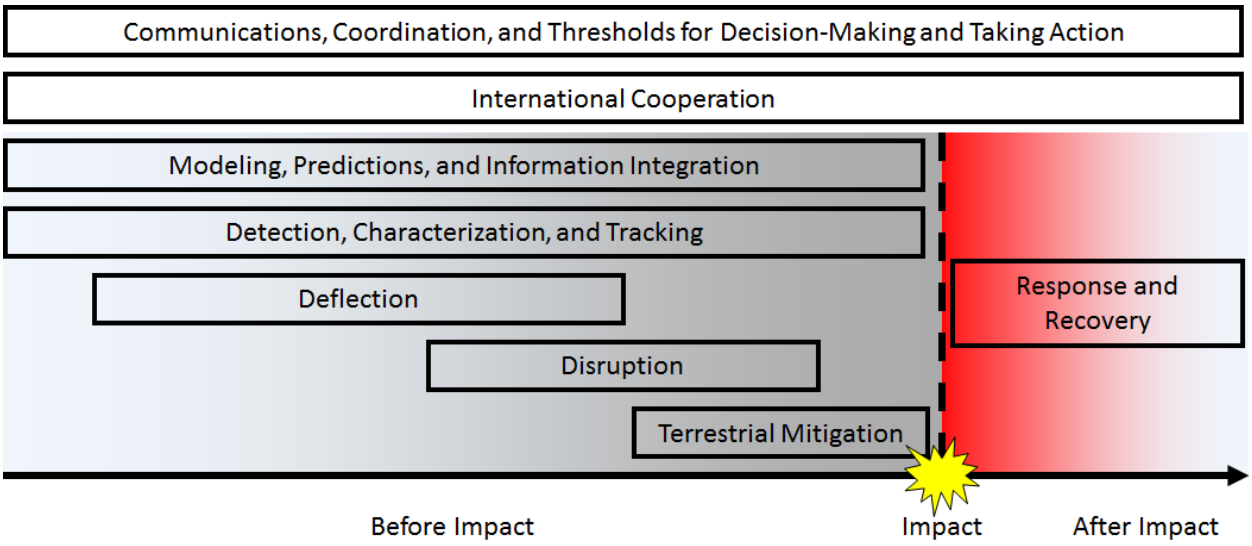

Figure 2: Illustrative timeline of the phases of operations in a NEO preparedness strategy.

This Strategy outlines objectives for enhancing the Nation's NEO preparedness in three key areas: hazard and threat assessment, decision-making, and response. Some Federal departments and agencies have already taken significant steps in these key areas. The goals outlined in this Strategy will leverage these efforts and existing policies, while promoting enhanced coordination and cooperation across the public and private sectors in the United States and abroad.

Authority for Creation of the National Near-Earth Object Preparedness Strategy

To address the mandates and challenges above, an Interagency Working Group (IWG) for Detecting and Mitigating the Impact of Earth-bound Near-Earth Objects (DAMIEN) was established in 2016 by action of the Committee on Homeland and National Security within the National Science and Technology Council (NSTC). The DAMIEN-IWG developed this Strategy and will develop the forthcoming Action Plan to enhance preparedness for the hazard of NEO impacts.

This Strategy will work to ensure that NEO impact preparedness is fully integrated with and builds upon several governmental frameworks already in place. These include: Presidential Policy Directive (PPD)-4, "National Space Policy" (June 28, 2010); PPD-8, "National Preparedness" (March 30, 2011); and PPD-21, "Critical Infrastructure Security and Resilience" (February 12, 2013); Section 321 of the NASA Authorization Act of 2005 and Section 804 of the NASA Authorization Act of 2008; and the Office of Science and Technology Policy's (OSTP) 2010 response to Congress (See References for the complete citations).

PPD-4 instructs NASA to "pursue capabilities, in cooperation with other departments, agencies, and commercial partners, to detect, track, catalog, and characterize NEOs to reduce the risk of harm to

humans from an unexpected NEO impact on our planet and to identify potentially resource-rich planetary objects."

PPD-8 calls for an integrated, all-of-Nation, capabilities-based approach to preparedness for all hazards. It also calls for the creation of a series of National Planning Frameworks. Accordingly, the Department of Homeland Security (DHS) coordinated the development of the Strategic National Risk Assessment (SNRA). As of now, the SNRA does not include preparedness for the hazard of NEO impacts.

PPD-21 identifies three strategic imperatives to drive the Federal approach to strengthening critical infrastructure security and resilience at the core of this Strategy. The Directive identifies energy and communications systems as vital due to the enabling functions they provide across all critical infrastructure sectors. The Directive also instructs the Federal Government to engage with industry and international partners to strengthen the security and resilience of domestic and international critical infrastructures on which the Nation depends.

Section 321 of the NASA Authorization Act of 2005, labeled the George E. Brown, Jr. Near-Earth Object Survey Act, directs NASA to detect, track, and characterize 90% of all NEOs with a size of 140 meters or greater, to be completed by 2020 (see Figure 1 (yellow triangle) for an estimation of how many such objects remain to be discovered). This survey will take much longer to complete without significant upgrades to capabilities that aid in detecting and tracking NEOs.

Subsequently, Section 804 of the NASA Authorization Act of 2008 requires that the Director of OSTP: (1) develop a policy for notifying Federal agencies and relevant emergency response institutions of an impending NEO threat if near-term public safety is at risk; and (2) recommend a Federal agency or agencies to be responsible for: (A) protecting the United States from a NEO that is expected to impact Earth; and (B) implementing a deflection campaign in consultation with international bodies, should one be necessary. In October 2010, OSTP responded to Congress and laid out Administration plans to meet the requirements in the NASA authorization.

Implementation of the National Near-Earth Object Preparedness Strategy

The Action Plan, to be released subsequent to this Strategy, details the Federal activities that will be undertaken to implement this Strategy and achieve the seven high-level goals, and includes deliverables, timelines, and metrics to measure progress and success. This Strategy acknowledges the challenges associated with planning and preparing for events with low probability of occurrence but potential for catastrophic consequences, as well as high uncertainty on the correct course of action when a threat materializes. As a result, the activities identified herein should be prioritized accordingly. The Executive Office of the President will coordinate the development and execution of the Action Plan and will reevaluate and update the Strategy and Action Plan within three years of the date of publication respectively, or as needed.

Full implementation of this Strategy will require the action of a global network of governments, U.S. Government agencies, intergovernmental organizations, and non-governmental organizations including academia, the media, nonprofit organizations, and industry. Strong collaborations must be established among the Federal Government, other nations, industry, and academia to enhance NEO observing networks, conduct research, improve prediction models, plan and execute deflection and disruption missions, and supply the services necessary to protect life and property. These partnerships between the United States and the international community, industry, and academia will form the backbone of preparations for any threat of a NEO impact event.

Strategic Goals

This Strategy defines seven strategic goals to prepare the Nation for a variety of NEO impact scenarios. These goals aim to improve the Nation's warning of, options for preventing, planning for, recovery from, and international collaboration responding to, NEO impacts. These strategic goals address the entire range of possible NEO impact scenarios, from decades of warning to no warning at all. Various possible phases, as well as capabilities that encompass the entire timeline of how to respond to potential NEO impacts, are shown in Figure 2.

The seven high-level goals for Federal research, development, deployment, operations, coordination, and engagement are:

1. Enhance NEO Detection, Tracking, and Characterization Capabilities
2. Develop Methods for NEO Deflection and Disruption
3. Improve Modeling, Predictions, and Information Integration
4. Develop Emergency Procedures for NEO Impact Scenarios
5. Establish NEO Impact Response and Recovery Procedures
6. Leverage and Support International Cooperation
7. Establish Coordination and Communications Protocols and Thresholds for Taking Action

Enhance NEO Detection, Tracking, and Characterization Capabilities

Finding NEOs as early as possible is the first priority for planetary defense, in order to give adequate time to make decisions and implement courses of action. This fact must be stressed: the earlier a NEO threat is detected, the better the emergency response to the threat will be. However, accurately predicting their orbits and understanding their structure and composition are equally critical to assessing the NEO impact hazard and how to best respond to a NEO impact threat.

NASA is the global leader for ground- and space-based observations to detect, track, and characterize near-Earth asteroids and comets. Part of characterization is identifying and interpreting spectral signatures of near-earth objects, and the U.S. Geological Survey develops and maintains the spectral libraries necessary for this work. NASA and the Department of State collaborated with the United Nations to foster the International Asteroid Warning Network (IAWN), a voluntary organization of astronomers to encourage rapid reporting of asteroid observation data from observatories worldwide. NASA funds the Minor Planet Center (MPC), a clearinghouse for worldwide asteroid observations that identifies objects in potentially hazardous orbits, currently hosted by the Smithsonian Astrophysical Observatory. These, and other partnerships, have increased the global detection rate substantially over the last 10 years. Furthermore, attention to tracking smaller objects has increased with improved awareness of the negative consequences of impacts by smaller but far more populous NEOs. This has resulted in increased detection rates of these objects even though they are much harder to detect. Careful stewardship has enabled expansion of U.S. NEO observations through small investments in new technologies and analytic capabilities that have increased the fidelity and breadth of those observations. However, efforts to comply with congressional directives to complete the search for objects as small as 140 meters in size are several years behind schedule.

The following objectives would improve detection, tracking, and characterization capabilities:

- **Develop a capability roadmap to inform a strategy for both U.S. and foreign capabilities for detection, tracking, and characterization.** Development of a capability roadmap to inform

investments by contributing nations will enable improvements to the overall global network. A roadmap will incorporate innovations in optical and infrared detection capabilities, improvements in ground-based radar capabilities, and improvements in automating and improving accuracy of analytical software. More costly, but just as important, is the development of improvements in on-board data processing and downlink for space-based observatories.

- **Improve observation capabilities for more complete and rapid observation of the entire population of NEOs.** To cite one example, several study reports have found that a space-based observatory, working in concert with observations from ground-based telescopes, may be the best approach to detecting, tracking, and characterizing the NEO population. This combination would more rapidly complete the survey of objects larger than 140 meters while greatly improving our understanding of the hazard from the 50-140 meter NEO population, and provide a voluminous dataset for both science and planetary defense.
- **Update existing observatories with capabilities to improve characterization assessments.** Efforts to deflect or disrupt a NEO could be made more effective if a basic understanding of the object's mass, composition, and structure is first obtained. For example, improvements in spectroscopy will enable faster estimates of gross composition. Ease of access to larger aperture telescopes when critical data are needed should be coordinated. Additionally, better planetary radar capabilities, such as increased power, radar frequency, or time available at major radio telescopes, are also critical to improving orbit determination, measuring size and understanding rotation states, and obtaining essential information about the object's surface structure. These data, when combined with advanced spectroscopic observations, can provide critical information to inform development of space-based technologies to prevent a NEO impact.

Develop Methods for NEO Deflection and Disruption

Several studies over the last two decades have pointed out that technologies exist that may be capable of preventing a NEO impact, and that true preparedness may need to include the ability to deflect (turn away) or disrupt (break into small pieces) a NEO headed towards Earth. The NEO population is quite diverse, a fact which presents significant unknowns when considering how to develop technologies capable of deflecting or disrupting the object. Observations, including optical and planetary radar (when objects are accessible for observation), over many years may improve our understanding of the composition, mass, and behavior of any particular object (see Goal 1, above), which in turn could improve design of deflection technologies. Disruption of the NEO may be required if there is little warning time or if the object is very large. Technologies to deflect the NEO away from Earth can be used, but to either disrupt or deflect a very large object, research and development of high-energy solutions is required.[4]

The following objectives would improve deflection and disruption capabilities:

- **Develop capabilities for fast-response focused reconnaissance and characterization.** The objective of Goal 1 is to provide timely, high-certainty, actionable warning that a NEO threat exists, but because of the diversity of NEOs an effective deflection or disruption mission may need more detailed information on the specific threat. One candidate concept for this objective would be a capability to rapidly launch, intercept, and conduct reconnaissance on a NEO, to

[4] Challenges associated with the transfer of space-related data, technologies, and equipment required for asteroid deflection and disruption, or other purposes discussed in this Strategy, would only be approved if consistent with U.S. export control laws and regulations as well as international obligations and commitments.

provide up-close imagery, composition, and mass measurements (*e.g.*, passive (visible, thermal, multi/hyperspectral) and active (radar, LIDAR, *etc*.) imaging techniques) in order to determine ways to enhance the effectiveness of any subsequent deflection or disruption missions.

- **Research deflection and disruption capabilities for NEOs of varying size, mass, composition, and impact warning times.** With enough warning time, a NEO impact can be prevented. To address most impact scenarios, prevention capabilities should include the ability to achieve timely effects and feedback, for example: to launch a deflector or disruptor that can rapidly reach the object; conduct rendezvous and proximity operations when needed; and deploy kinetic impactors or other technologies. Additionally, deploying an instrumented means to measure the deflection over time can provide assurance of mission success. Where practical, real world demonstration of the deflection or disruption technique to test effectiveness and reduce uncertainties should be pursued, particularly when this can be done as a part of a mission to an asteroid or comet with broader science and exploration objectives. An assessment of the technical, policy, and legal issues with regard to delivering and triggering a high-energy device to deflect or disrupt NEO impact threat objects will be required.
- **Research technologies required for deflection and disruption concepts.** Given the potential short time between first detection and potential NEO impact, precursor reconnaissance of the object may not be possible. To improve mission success, some key technologies to be developed include:
  - Rapid assessment capabilities for ground-based, orbital, and deep-space systems.
  - Fast orbit transfers to maximize momentum transfer for kinetic impactors or maximize distance from Earth at point of intercept for deflection missions. High-acceleration maneuvering, near the point of intercept, is critical for optimized intercept locations and course corrections immediately before intercept.
  - Algorithms and on-board artificial intelligence for short-notice disruption missions to self-assess the optimal time and location for interception or disruption.

Improve Modeling, Predictions, and Information Integration

The NEO population is diverse, and the effects of impact with Earth are not well understood. Additionally, efforts to catalog and track NEOs, and to model NEO impact effects, are a very recent undertaking. A successful national strategy for NEO preparedness will depend, in part, upon quantitative modeling and analysis capabilities to more accurately predict a NEO's orbital trajectory, including non-gravitational perturbations, to determine what effects different deflection and disruption techniques may have on the orbital trajectory. Furthermore, it will be necessary to estimate the potential damage from a NEO impact, including secondary effects like local environmental and climate disturbances and economic consequences, and communicate how these models and analyses integrate across a range of activities. Given the relative immaturity of our understanding of these objects, it is understood that rapid advances could be made with modest investments that leverage existing analytical capabilities.

Numerical modeling and leveraging state-of-the-art computational facilities and advanced simulation codes are of central importance in understanding prevention options and their consequences, predicting impact effects, and estimating uncertainties. Examples of modeling include the estimation of impact probabilities (or locations) of detected NEOs, evaluation of deflection and disruption technologies and techniques and how NEOs of varying sizes and compositions respond, and analysis of the risk to life and infrastructure by NEO impact effects in air, land, and water. The resultant information will be utilized throughout all phases of a response, including evaluation of the efficacy and risks of prevention, planning

for emergency preparation and response, and estimation of casualty and property losses—essential information for decision-makers. The quality and sufficiency of modeling and analysis capabilities underpin all other efforts, permitting decision-makers to understand what could happen and to plan and act accordingly. Modeling also can be used to study alternative courses of action, advise training and preparation exercises, and inform cost-benefit decisions, among other roles.

The following objectives would enhance modeling and prediction capabilities and their integration across the Nation's effort:

- **Ensure that adequate modeling capabilities are developed for each topical need, especially for modeling NEO trajectories to reduce orbit uncertainties and impact effects.** In light of the core role of modeling and analysis, a comprehensive review should be conducted of modeling and analysis needs for planetary defense purposes to inform an assessment of current capabilities, including identifying strengths and gaps. A plan should be formed to establish capabilities where none exist or where the current capability is inadequate, as well as to maintain and improve existing capabilities, including identification of appropriate resources to support the activities.
- **Determine what outputs are required by whom.** When a potential NEO impact threat is detected, it will be important that all parties involved have, well in advance, a clear understanding of who requires what information, in order to reduce delays or confusion. Various agencies each have their own needs, while some information is required across the entire response effort. In addition to an *a priori* list of what each organization will need, training and preparation exercises provide an excellent means to uncover unexpected requests and interdependencies, and should be employed to search for omissions.
- **Establish an organizational construct to coordinate the development and dissemination of modeling results.** A national planetary defense response capability will need to rely on an as-yet-to-be-developed organization spread across a range of governmental and non-governmental organizations. In the case of a real event, many independent sources of information and analysis are expected to emerge, both foreign and domestic. A capability or process will be needed to rapidly sort through the many sources of data and determine which are most valid and useful to decision-makers. It is important to ensure rapid assessment and timely delivery of valid information among U.S. Government agencies, as well as to international and intergovernmental organizations and foreign capitals through diplomatic, scientific, and emergency management channels, and provide verified information, notifications, and warnings in order to manage public awareness.

Develop Emergency Procedures for NEO Impact Scenarios

In an ideal situation, an Earth-bound NEO can be deflected or disrupted well before it reaches Earth. Scenarios may occur in which a NEO impact cannot be prevented because there is not enough time between detection and impact to deflect or disrupt it. In the event that a NEO impact can be predicted, but cannot be prevented, a plan must be in place to prepare for the impact to avoid loss of life and mitigate damage to critical infrastructure as much as possible. The recently established NASA/FEMA-led Planetary Impact Emergency Response Working Group (PIERWG) has been coordinating efforts to integrate ways to address the risks and dangers of potential NEO impacts into national disaster response protocols to ensure the establishment of operational response capabilities unique to NEO impacts.

Adding NEO impacts to the Strategic National Risk Assessment (SNRA) will have the additional benefit of including the problem of this scenario in the national lists of priorities. No study has been conducted to determine whether NEO emergencies meet the statistical criteria for inclusion in the SNRA; however,

while NEO events are rare, the consequences for failure to prepare or respond to a NEO event are extremely high. Inclusion in the SNRA will provide policy makers with the opportunity and motivation to include funding for future NEO emergency efforts. Under this structure, FEMA will have the requirement to at least consider preparing emergency response plans for these events. It is expected that existing plans for other hazards such as earthquakes or volcano eruptions, for which the U.S. Geological Survey has monitoring and warning responsibility, can be leveraged for a NEO-impact response plan. Coordination and training will be required to inform local, state, tribal, territorial, and regional emergency planners.

The following objectives would benefit establishment of effective national preparedness procedures:

- **Promote a collaborative national approach to defend against, mitigate, respond to, and recover from NEO impact events.** Response to a predicted NEO-impact event would require an approach that would be facilitated by multiple agencies, with potential participation by other governments and industry. Such an approach should also include:
    - Facilitating the exchange of information and best practices with national and international emergency management stakeholders to strengthen global capacity to mitigate, respond to, and recover from NEO impacts.
    - Assessing the potential implications of a NEO impact event on critical infrastructure and supply chain dependencies, both foreign and domestic.
    - Coordinating international partnership activities to support the objectives of preparedness and response exercises.
- **Develop coherent national and international communications strategies to facilitate NEO impact preparations.** Such communications strategies should include:
    - Developing and disseminating training materials to assist Federal, state, and local governments as well as foreign governments in understanding the threat, and to assist in preparedness and recovery planning.
    - Using national emergency alert and warning protocols currently in place (*i.e.*, orbital debris impact warnings) as much as possible while modifying existing protocols for other natural disasters where necessary.
    - Assisting in coordinating worldwide forecasts, alerts, and warnings using consistent nomenclature and non-technical terminology whenever possible.
    - Continuing to coordinate with the United Nations International Asteroid Warning Network to develop standard public awareness protocols and possible warning formats.

Establish NEO Impact Response and Recovery Procedures

The Department of Homeland Security, through its operational component FEMA, has coordinated the development of emergency response plans for all hazards via the Federal Interagency Operations Plans (FIOP) and Annexes. The FIOPs are the Federal Government's concept-of-operations documents that provide detailed explanations of how Federal agencies work together in crisis situations. The FIOPs are "all-hazards" documents and have separate annexes to cover specific hazards. This strategic goal seeks to identify all of the unique aspects of a NEO impact and ensure that our emergency responders and citizens are prepared to respond and provide the capability for national resilience in such an unusual scenario. While it is expected that a NEO impact emergency response could be similar to a hurricane response plan (including evacuations and other preparations in the event that there is warning before impact) or an earthquake response plan (in the event that there is no warning), NEO impact modeling and simulation

will inform specific details. Whether a NEO impact occurs with or without warning, a NEO impact Annex to the FIOP should be in place to inform decision-makers of possible first steps and to provide the basis of planning for local emergency responders. The remediation of damage to critical infrastructure should be prioritized to expedite recovery across all sectors.

The following objectives would help to establish effective response and recovery procedures:

- **Establish national and international protocols to efficiently respond to a NEO impact, whether in deep ocean, coastal regions, or on land.** Different types of NEO impact scenarios have different national and international considerations, especially regarding the environmental consequences. Earthquakes and tsunamis could result from larger NEO impacts, creating consequences that spread far beyond the impact site, and the mechanisms for timely notifications and warnings should be developed and exercised as necessary to ensure proper public understanding and response to the emergency.
- **Facilitate international cooperation and planning to promote recovery from a NEO impact in a timely manner with minimal disruption to the status quo.** This includes assessments of critical infrastructure damage to effectively deliver foreign aid and recovery equipment to governments as needed.

Leverage and Support International Cooperation

The risk of a NEO impact is a global hazard best addressed well in advance of detecting the first potential impact through consultations, coordination, and cooperation with the international community directed towards improving detection, deflection, disruption, mitigation, and disaster relief. The United States' role would be to foster global collaboration and take advantage of mutual interests and international capabilities to improve preparedness for potential NEO impacts. If deflection or disruption proves technically infeasible, the United States may be best postured to take a leadership role in helping to reduce the severity of, and facilitate recovery from, the aftereffects of a NEO impact, even if the impact is outside U.S. territory.

The United States and other nations are sharing observations and research, disseminating data products and services, and collaborating on real-time predictions which could be used to avoid or reduce potential damage to critical technology and infrastructure. For example, the NASA Planetary Defense Coordination Office works with the International Asteroid Warning Network (IAWN), sponsored by the U.N Committee on the Peaceful Uses of Outer Space (UNCOPUOS). The Network is a voluntary collaboration among governments, institutions, observatories, and individuals that enables coordination among astronomers and enables a free and open data exchange. IAWN members, and other observatories, voluntarily submit data to the Smithsonian Astrophysical Observatory's Minor Planet Center, a NASA-funded clearinghouse for NEO detection data. It is expected that more nations will join the effort to work together to foster greater global collaboration, taking advantage of mutual interests and international capabilities to improve situational awareness, predictions, and preparedness for NEO events. However, addressing the challenges associated with asteroid deflection and disruption through the transfer of space-related data, technologies, and equipment, or other purposes discussed in this Strategy, would only be approved if consistent with U.S. export control laws and regulations as well as international obligations and commitments.

The following objectives would enhance leveraging and support of international cooperation:

- **Build international support for acknowledging and addressing the potential Earth impact of a large NEO as a global challenge.** While detection rates are increasing, it is estimated that less than 30% of NEOs large enough to cause regional damage have been identified. A prerequisite

to enhanced international cooperation and high-level support for appropriate policies and coordination mechanisms among partner countries is increased awareness of the risks and dangers of NEOs to the entire planet.

- **Foster consultation, coordination, and cooperation channels and efforts for the planning for, mitigation of, and response to NEO impacts.** The United States should take a leadership role in consulting, coordinating, and cooperating through multilateral channels including, but not limited to, the U.N. General Assembly, the U.N. Security Council, UNCOPUOS, and intergovernmental organizations, as well as in bilateral channels. In particular, the United States should continue its leadership in IAWN and the U.N.-mandated Space Mission Planning Advisory Group (SMPAG). The United States should also explore the necessity for additional consultative and coordination mechanisms at the bilateral government-to-government and intergovernmental level to discuss and share information related to detection, tracking, and characterization, prevention planning and options, as well as mitigation and recovery plans in order to supplement/complement existing mechanisms.
- **Increase engagement and cooperation with the international community on observation infrastructure, data sharing, numerical modeling, and scientific research.** The Federal Government should explore opportunities to work with the international community to enhance research, observations, models, and forecasting tools that will improve NEO detection, characterization, and trajectory forecasting. This will be done in compliance with U.S. export control laws and regulations as well as international obligations and commitments.
- **Strengthen international coordination and cooperation on NEO data and analyses.** Providing high-quality NEO data products and analyses worldwide requires international consensus and cooperation. Toward this end, the United States should:
    - Seek international agreement on common terminology, measurements, and scales of magnitude.
    - Continue to promote and coordinate sharing and dissemination of NEO observations, model outputs, and forecasts.
    - Establish coordination procedures across NEO research, forecasting, and detection centers (*e.g.*, Minor Planet Center and the Jet Propulsion Laboratory's Center for NEO Studies).
- **Promote a collaborative international approach to preparedness for NEO events.** A NEO impact can have global consequences regardless of impact location. Towards this end, the United States should:
    - Foster the development of international standards for NEO events requiring potential prevention, mitigation, emergency response, and recovery efforts to aid in decision-making.
    - Foster the development of international communication standards to ensure NEO events are effectively and responsibly communicated to the international community across diverse cultures via diplomatic, scientific, and media channels.
    - Conduct tabletop and physical exercises with global partners regarding preparedness for prevention, mitigation, response, and recovery efforts.

Establish Coordination and Communications Protocols and Thresholds for Taking Action

Developing the process and procedures, including protocols and thresholds, to be used in decision-making and communications—especially during a crisis with inherently high uncertainty—is necessary for timely

and effective implementation of prevention and mitigation measures. It is possible that there may be little to no warning of an impending NEO impact, therefore pre-planning and conducting simulations and exercises of emergency decision-making and communication across all—but especially time-critical and stressful—NEO impact scenarios are critical to prevention, mitigation, emergency response, and recovery. Coordination across all areas of government is necessary.

The following objectives would assist creation of a comprehensive framework for determining the proper course of action across every phase of a NEO impact threat scenario:

- **Coordinate communication within the U.S. Government, as well as with other governments, the media, and the public regarding NEO threats.** Governments, scientists, observatories, and institutions will have the shared responsibility to make announcements using only verified and validated data if a potentially hazardous object is detected. The combination of public access to data, and its rigorous analysis by the worldwide network, will help to minimize the promulgation of false predictions.
    - NASA, per direction from the National Space Policy (PPD-4), has the responsibility to assess and report threats as they are detected. The NASA Planetary Defense Coordination Office (PDCO) was specifically created to confirm data and analysis on potential impact threats are properly verified and validated and to ensure credible, rapid, and concise information transmission to the Executive Office of the President and other Federal agencies. PIERWG, co-chaired by NASA and FEMA, was created to ensure coordinated Federal response for terrestrial preparedness to the announcement. The PDCO also has the responsibility to draft announcements for providing information to the media and the public. FEMA will have a responsibility of communicating emergency response plans and notifications to the public. It is expected that a significant amount of basic education about this particular type of hazard will need to be provided, in addition to developing means of communicating uncertainties regarding the risks of a NEO impact and its aftereffects.
    - NASA should develop plans for notifying the U.S. Congress as appropriate for the magnitude of a projected NEO impact threat. Interagency teams should provide briefings to the appropriate Committees and Subcommittees prior to, or concurrent with, diplomatic notifications.
    - The Department of State, in coordination with other U.S. departments and agencies, should develop plans for notifying foreign governments and international and intergovernmental organizations as appropriate for the magnitude of the projected NEO Earth impact threat. The Department of State, after receiving the information from NASA, and in coordination with other government agencies, will notify leadership of nations across the world of the impending risk and danger of an Earth-impacting NEO in an appropriate timeframe. As an example, the notification should include known characterization of the NEO, the date of its expected impact with Earth and projected impact location, plans (if any) for deflection or disruption, and preparedness plans including those for mitigation, emergency response, and recovery, including offers of U.S. assistance.
- **Develop a set of thresholds to aid U.S. decisions for whether to implement deflection or disruption missions for projected NEO Earth impacts on U.S. territory and outside of U.S. territory.** UNCOPUOS has endorsed the establishment of SMPAG for space agencies to lay the groundwork for an international response to a predicted NEO impact. Once technologies are developed and the capability exists to deflect or disrupt an incoming NEO, thresholds will aid the United States, in consultation and coordination with its global partners, in determining whether

an impact can be, or should be, prevented. The United States must nevertheless retain the decision-making authority and ability to act by itself to defend its national interests from NEO threats, especially when time is limited or the international consensus is lacking or not attainable.

- **Develop decision flowcharts for NEO threat scenarios incorporating benchmarks and decision thresholds.** Prior to any NEO crisis, flowcharts should be created which integrate decision-making thresholds to help guide non-expert decision-makers to make the best decisions under uncertainty. These flowcharts should cover a wide range of variables to a NEO impact scenario such as size, composition, impact probability or location, and time before impact. These flowcharts will also help identify additional research and development gaps.
- **Develop protocols for international interactions regarding NEO impacts outside of U.S. territory.** Prior to any NEO crisis, decision-making and communications protocols should be created to guide the transmission of notifications and warnings through multilateral and bilateral diplomatic, scientific, and emergency management channels, as well as through the media. Through consultations, coordination, and cooperation the United States would work closely with the international community to address the risks and dangers of any potential NEO threats.

Conclusion

As with other low-probability, high-consequence hazards, potential NEO impacts pose a significant and complex challenge. This Strategy is a step in addressing the myriad challenges of managing and reducing the risks posed by both large and small NEOs. The seven high-level goals and associated objectives outlined in this Strategy support a collaborative and Federally-coordinated approach to developing effective policies, practices, and procedures for decreasing the Nation's vulnerabilities associated with the NEO impact hazard.

Glossary

Bolide: one type of NEO impact where a relatively small NEO creates a bright flash in the atmosphere. Bolides release most of their kinetic energy by interaction with the atmosphere, though small pieces (meteorites) can still reach the surface of the Earth.

Characterization: actions that are taken to learn more about detected NEOs—garnering data such as orbital ephemeris, shape, size, composition, structure—to determine which deflection or disruption techniques will be best-suited to prevent or reduce the severity of an impact.

Deflection: actions that are taken to move the asteroid away from a predicted collision point with Earth, usually by changing its orbital speed, such as by pushing or tugging with or against the velocity vector instantaneously or over an extended time, and thereby changing the time it crosses Earth's orbital path.

Detection: actions that are taken to find previously unknown NEOs, usually by telescopes operating in visible or infrared bands but also could include other methods.

Disruption: actions that are taken to hit or break apart the asteroid, especially as a last resort. Disruption may reduce the overall damage caused by the asteroid, but may not prevent the asteroid or parts of it from hitting Earth.

Hazard: the risk and consequences of a potential impact with any of the population of NEOs. This is in contrast to a "threat," which is a specific NEO that has been identified to be on a course that could impact Earth.

Impact: when a NEO collides with Earth, either by passing through and mostly burning up in the atmosphere (*e.g.*, bolides or airbursts), or by striking the surface (*e.g.*, meteorites that create craters)

Intercept: when a NEO is met by a spacecraft before it has a chance to impact Earth. Intercept could refer to a rendezvous (*e.g.*, a scout mission to study a NEO in more detail), a deflection (*e.g.*, a kinetic impactor), or a disruption (*e.g.*, a high-energy device that interacts with the surface or subsurface of a NEO).

Kinetic Impactor: one specific example of a deflection mission that alters the trajectory of a NEO by colliding with the NEO to change its momentum. This should not be confused in this document with the term "impact," which refers to when a NEO strikes the Earth.

Mitigation: actions that are taken to prevent loss of life or property and infrastructure damage. "Terrestrial mitigation" specifically refers to these actions that are taken on the ground, which include evacuations, communications, ground operations, and anything done before the impact event to prepare for the recovery, including logistics and planning. In a broader context, mitigation can also include actions in space (*e.g.*, deflection, disruption) to prevent or reduce the severity of the NEO impact. The definition of "terrestrial mitigation" is similar to the PPD-8 term "National Preparedness" but focused specifically on terrestrial activities.

Near-Earth Object (NEO): an asteroid, meteoroid, or comet that has an orbit that brings it within 1.3 astronomical units (AU), approximately 125 million miles, of the Sun and therefore near the Earth's orbit. They may also be referred to as either a Near-Earth Asteroid (NEA) or an Earth-Approaching Comet (EAC) as appropriate.

Planetary Defense: actions that are taken to detect, track, and characterize NEOs and prevent them from impacting Earth. The term is typically applied less broadly than the term "preparedness" is being used in this document; here, "preparedness" included planetary defense, terrestrial preparedness, and response and recovery.

Preparedness: actions taken to plan, organize, equip, train, and exercise to build and sustain the capabilities necessary to prevent, protect against, mitigate the effects of, respond to, and recover from those threats that pose the greatest risk to the security of the Nation.

Prevention: actions that are taken that would cause an asteroid that is or might be on a collision course with Earth to (a) miss Earth entirely (b) impact in a different, safer location, or (c) be broken into smaller pieces that would do less damage than an intact NEO. Deflection and disruption are the two ways a NEO impact can be prevented. This

definition differs from PPD-8 since "prevention" in that document refers only to actions taken to "stop a threatened or actual act of terrorism."

Recovery: refers to those capabilities necessary to assist communities affected by an incident to recover effectively, including, but not limited to, rebuilding infrastructure systems; providing adequate interim and long-term housing for survivors; restoring health, social, and community services; promoting economic development; and restoring natural and cultural resources.[5]

Response: refers to those capabilities necessary to save lives, protect property and the environment, and meet basic human needs after an incident has occurred.

Threat: a specific NEO that has been identified that could potentially hit Earth. This is in contrast to a "hazard," which is the probability of an impact of some NEO over time, but no specific NEO on an impact trajectory has yet been identified.

Tracking: actions that are taken to observe a NEO over time, predict its path, and reduce its orbital error ellipse.

[5] "Response" and "recovery" definitions are aligned with PPD-8 definitions.

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Presidential Policy Directive 4 (PPD-4): the National Space Policy, signed June 29, 2010.

Presidential Policy Directive 8 (PPD-8): National Preparedness, signed March 30, 2011.

Presidential Policy Directive 21 (PPD-21): Critical Infrastructure Security and Resilience, signed February 12, 2013.

Abbreviations

DAMIEN	Detecting and Mitigating the Impact of Earth-bound Near-Earth Objects
DHS	Department of Homeland Security
FEMA	Federal Emergency Management Agency
FIOP	Federal Interagency Operations Plans
IAWN	International Asteroid Warning
IWG	Interagency Working Group
LIDAR	Light Detection and Ranging
MPC	Minor Planet Center
NASA	National Aeronautics and Space Administration
NEA	near-Earth asteroid
NEO	near-Earth object
NSTC	National Science and Technology Council
OSTP	Office of Science and Technology Policy
PDCO	Planetary Defense Coordination Office
PIERWG	Planetary Impact Emergency Response Working Group
PPD	Presidential Policy Directive
SMPAG	Space Mission Planning Advisory Group
SNRA	Strategic National Risk Assessment
TNT	trinitrotoluene
UNCOPUOS	U.N. Committee on the Peaceful Uses of Outer Space