Space Mission Planning Advisory Group

SMPAG 5.5 – Planetary Defense Action Plan

October 2018

Executive Summary

This Planetary Defense Action Plan (PDAP) for the Space Mission Planning Advisory Group (SMPAG) was developed to address Action Item 5.5 "A Plan for SMPAG Action in Case of a Credible Threat." Depending on the warning time of an impact threat, specifically the time between confirmation that an asteroid or comet is on an impact trajectory with the Earth to the time of the actual impact, there are multiple methods to deflect or disrupt an impactor. These methods include a variety of nuclear options (i.e., standoff, surface, and subsurface), kinetic impactors, conventional explosive methods, gravity tractor approaches, laser ablation, focused solar ablation, and mass drivers. The objective of this plan is to define how SMPAG members will work together to understand the nature of the potential impact threat, develop the basic goals of a deflection or disruption campaign, and develop an agreed upon course of action in response. The plan considers approaches for two basic scenarios: a short-warning impact threat (approximately one to a few years), where a response must be mounted quickly and demands the use of existing payloads and launch vehicles, and a longer-range threat (many years-decades) where a more measured response can be developed and a detailed campaign to address the threat can be implemented.

Timelines for a short-warning impact and longer-range threat are discussed in Section 3. A short-warning impact threat will require rapid authorization and funding approval and will need mission design efforts to begin immediately after confirmation of the impact threat or a sufficient probability of impact is exceeded.

For a short-warning impact, *in-situ* characterization is likely to be impractical, so there will be a greater reliance on remote characterization and the mission design will be required to handle a broader range of impactor uncertainties (e.g., size, composition, spin state, etc.). Hardware and launch vehicle procurement will need to be expedited in order to maximize the time before impact that the deflection/disruption effort can be initiated. It is likely that time to fabricate hardware will be extremely limited and the ability to obtain existing assets will be vital. Additionally, having multiple spacecraft and launch vehicles will be a critical need to increase the probability of mission success, along with contingency plans in the event that planned mitigation efforts are unsuccessful. The short-warning impact threat will drive most aspects of the PDAP. A longer-range threat will allow more detailed remote characterization to facilitate the design and development of reconnaissance spacecraft and more time to refine the mission planning. Ideally, final mission planning and development would be initiated after *in-situ* data is returned and analyzed to inform the mission and spacecraft design. For either scenario, it is highly desirable to deliver a transponder to the vicinity of the target to confirm the modified trajectory resulting from a deflection effort.

	Event	**Duration**
●	PHO detected; precise orbit determined	Months to years
∗	Remote characterization performed	Days to Months
∗	In-situ characterization designed, launched	2-3 Years
∗	In-situ characterization performed	Months to 2 Years
●	Threat threshold exceeded; Deflection action initiated	Indeterminate
●	Mission design	Months to 1 Year
●	Funding Approval	Weeks to Months
●	Hardware Fabrication and Test	1-3 Years
●	Approval of Launch(es)	Weeks to Months
●	Deflection Launch and Transit	Months to years
●	Action Time at PHO	Nearly instantaneous if impulsive; years-decades for slow push/pull techniques
●	Assessment	Nearly instantaneous with transponder
∗	Backup Action Initiated	Indeterminate (see above)

● necessary step ∗ optional but valuable step

Table 1: Approximate timeline for response efforts.

For the purposes of this initial version of the PDAP, we presume a decade prior notification of discovery of a threatening asteroid or comet until its impact with the Earth. Table 1 (above) highlights the likely response efforts and a general range of their durations, including the critical milestones and decision points.

Each step shown in Table 1 requires decision making (i.e., time) spanning across several time zones amongst several centers of expertise from the SMPAG member states. Furthermore, the information available throughout may be ambiguous, non-intuitive, and sometimes contradictory. Additionally, the mission development and funding might need to be approved before it is truly known whether an impact will occur. Finally, the greatest element of schedule uncertainty may likely be due to societal (and not technical) delays.

The PDAP calls for SMPAG member states to provide identification of launch site, launch vehicle, payload hardware, and other critical resources required for a deflection/disruption campaign that could be provided by their countries, along with the technology readiness level of these systems. Since this is a constantly evolving dataset, it is more manageable and practical for each participating member state to maintain this information and make it available in a timely manner to determine what resources might be used in the campaign. For reference, Table 2 provides a high-level summary of the estimated readiness for currently identified deflection/disruption methods along with an overall description of their respective timeliness to respond to a threat. A more detailed overview of each method is provided in Section 5 of this document.

Mounting a mitigation mission (or missions) assumes that the threshold criteria in SMPAG Action Item 5.1 have been met and that the IAWN has notified the SMPAG chair of a pending threat (see section 6 of this document for further details on threshold criteria). In turn, SMPAG convenes the members to discuss and prepare mission recommendations that can be conveyed to the United Nations COPUOS/OOSA and world nations. Figure 1 provides a simplified depiction of this interaction process. There are a variety of mitigation mission types that can be mapped to various threat scenarios. Currently, reference missions for those various threat scenarios have yet to be matured. However, the kinetic impactor mission concept is considered the most mature method and is has the Double Asteroid Redirection Test (DART) mission currently planned as a demonstration mission and is be used as an example in the PDAP.

It is acknowledged that the SMPAG 5.5 Action Item relies heavily on the other items in the SMPAG workplan from the other space agencies in order to present a more coherent mitigation plan in the event of a confirmed impact threat. The consequences of failing to provide the necessary deflection or disruption to the impactor, along with the turnaround time required to mount a backup mission, make the planning and successful implementation a critical international endeavor, particularly for the short-warning impact threat. Clear, concise, and correct open communication and transparency on the development and execution of the threat response is essential. Establishing relationships and working closely with individuals from the member states on an on-going basis is critical to having a cohesive team in place when needed for an actual impact event. Activities such as the Planetary Defense Conference (PDC) and groups like the International Asteroid Warning Network (IAWN) can assist in fostering these relationships, but an ongoing collaboration through SMPAG can help assure the development of relationships and can be accomplished by the engaging in the various activities described in Section #.#. These activities include conducting periodic exercises (virtual and co-located) to assure that SMPAG is properly prepared. These exercises will facilitate the development of effective mitigation plans. Additionally, they will allow lessons to be learned that can be applied to the mitigation of an actual future threat and minimize any issues that might be detrimental to the time-critical planetary defense efforts necessary in the future.

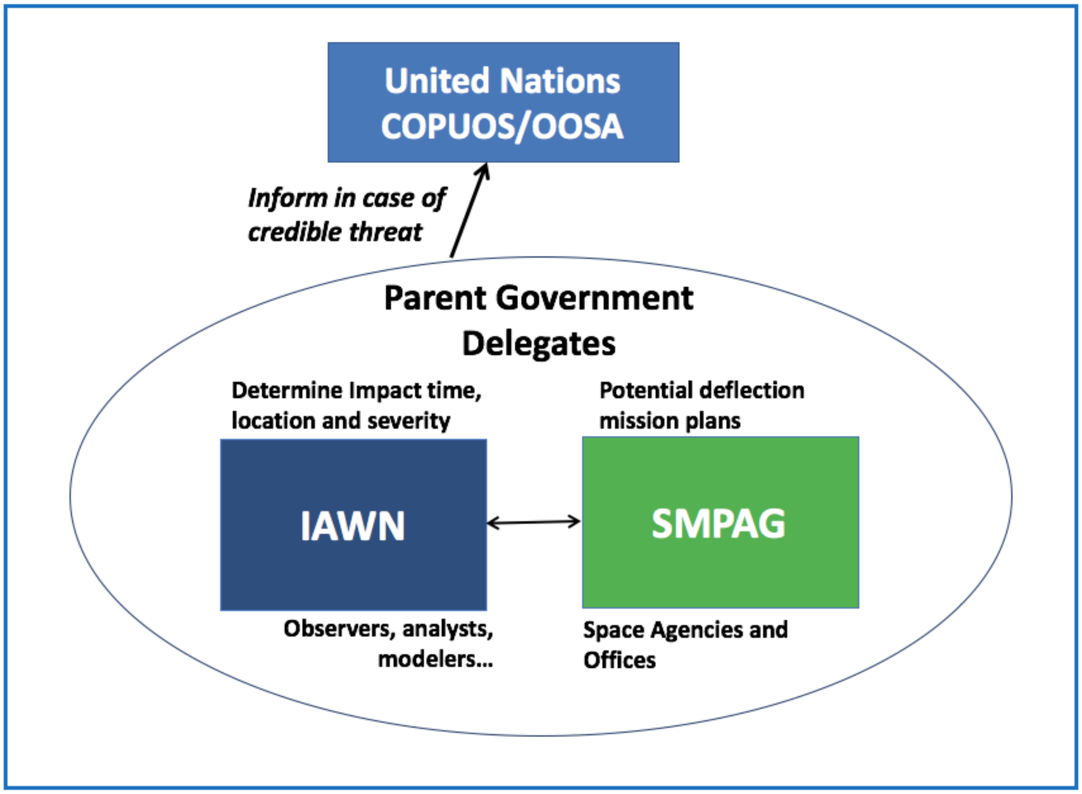


Figure 1: Simplified SMPAG and IAWN functions and information flow for a credible threat.

The final section of the PDAP (Section 7) provides an example impact scenario based on a presumed warning time of up to a decade (10 years) for an impact of a 150 meter object with the Earth. As stated earlier in the executive summary, it utilizes a kinetic impactor deflection method based on NASA's Double Asteroid Redirection Test (DART) demonstration mission. This example represents a scenario that emphasizes many of the stressing aspects of an impact threat and utilizes a high-TRL deflection method that is scalable to a variety of threat sizes and warning times.

1. Introduction

Near-Earth objects (NEOs) are asteroids and comets that come close to or pass across Earth's orbit around the Sun. These leftover remnants of the solar system's formation 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 or regional damage or even global devastation.

NEO impacts of varying size could have major environmental, economic, and geopolitical consequences to the world. 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 more extensive damage over a more localized area.

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 are easier to detect and track than smaller NEOs. After almost two decades of search, approximately one-third of the estimated 25,000 NEAs that are 140 meters in size and larger have been catalogued.

In June of 2018, the United States released its "National Near-Earth Object Preparedness Strategy and Action Plan." The document was developed to improve the capabilities for prediction (detection, characterization, and monitoring) and preparedness (protection, mitigation, response, and recovery) at a U.S. national level. The goals of the plan, in particular Goals 2, 3, and 4, are directly applicable to the SMPAG Planetary Defense Action Plan (PDAP) and can serve as a guide in formulating the SMPAG PDAP.

Goal 2 of the plan, "Improve NEO modeling, predictions, and information integrations," acknowledges that NEO preparedness depends on modeling and analysis capabilities to inform decision makers. The strategic objectives of this goal include:

- 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

Goal 3 of the plan, "Develop technologies for NEO deflection and disruption missions," realizes that in order to prepare and respond effectively to a NEO impact threat scenario includes developing capabilities for both deflection and disruption.

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

Goal 4 of the plan, "Increase International Cooperation on NEO Preparation," identifies the current coordination of NASA's Planetary Defense Coordination Office (PDCO) with IAWN and SMPAG and concludes that "Further increasing international participation in these efforts will improve our collective situational awareness, predictions, and overall preparedness for NEO events." The strategic objectives of this goal include:

- 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

This document focuses on a plan for action in the event of a credible threat posed to the Earth to include suggested response effort timeline(s), resources, deflection and disruption options, coordination, and finishes with an example scenario.

2. Response Effort Time Line

A. Overview of Events & Durations

A Potentially Hazardous Object (PHO) is a dynamical subset of NEOs which can make an extraordinarily close approach to the Earth and is large enough to impart significant regional damage in the event of an impact. The moment a PHO is detected, it may take several months to years to precisely determine its orbit and whether or not it will impact the Earth. Remote characterization from the Earth (i.e., astrometry, spectroscopy, radar, etc.) and/or space-based assets (i.e., telescopes in Earth orbit or at Sun-Earth Lagrange points) may take days to months.

Under ideal conditions, if deemed warranted, efforts to conduct an *in situ* characterization space mission would commence. Currently, the design, implementation, and launch of such a mission would likely take two to three years. Upon arrival, the in-depth/up-close *in situ* characterization begins. This may last several months to two years, with data confirming its basic properties (size, mass, etc.) coming shortly after the reconnaissance spacecraft's arrival, and with more time required to collect more detailed information (composition, topography, structure, etc.). The intent of such a mission is to examine the surface and subsurface for a later planetary defense mission, or missions, to be able to effectively deflect or disrupt the PHO in time to avert an impact with Earth.

Assuming ideal conditions (i.e., favorable geometry, funding approvals, procurement of the spacecraft and launch, services, optimal mission design(s), logical/executable timelines, etc.), the actual planetary defense mission(s) to the PHO will likely take several years. Additionally, the action time at the PHO and the additional time needed for the momentum transfer to alter the PHO's orbit enough to miss the Earth both need to be considered. Figure 2 provides a broad overview of the applicability of short-term vs. long-range warning planetary defense responses as a function of the impactor's size. For this initial version of the PDAP, only the kinetic impactor option is considered. This represents a method that is relatively mature from a technology standpoint with an action time at the PHO that would be nearly instantaneous.

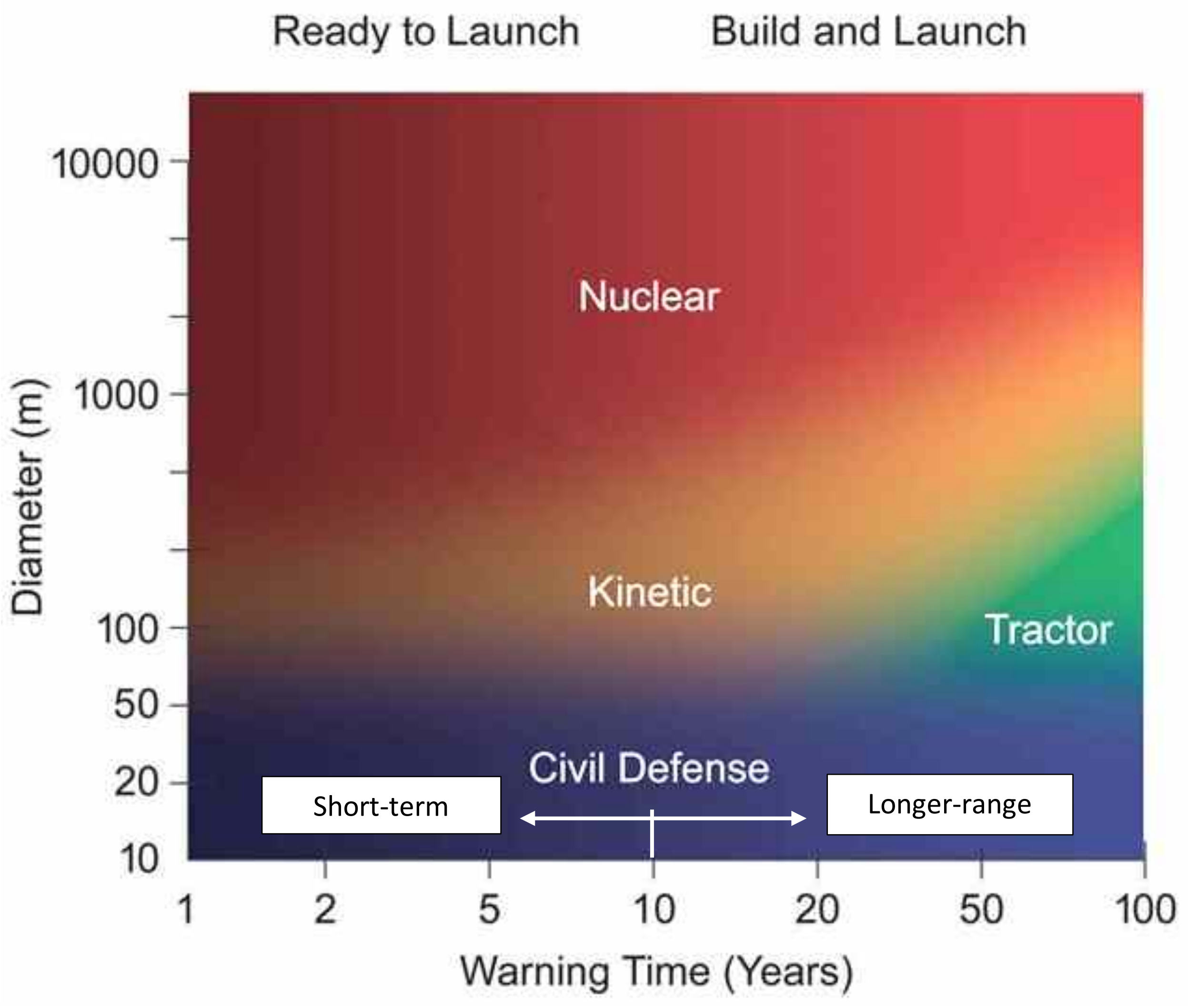


Figure 2: For a ~10 year warning time, short-term actions (depending on the size of the object) would likely include kinetic impactors. For warning times of a few decades, a gravity tractor method may be a more appropriate consideration.

An assessment of the effectiveness of a deflection effort to alter the trajectory of an impactor could be nearly instantaneous if a transponder is placed on the PHO. Depending on the operational lifetime of the reconnaissance spacecraft, it is possible that it could provide information about the PHO after the planetary defense mission is completed. Furthermore, if the viewing geometry is favorable, ground-based planetary radar could also verify the new orbital elements of the PHO. A disruption effort would likely be more difficult to assess and confirm that no portion of the impactor is a threat.

Figure 3 (below) is intended to complement Table 1 (above, in the Executive Summary). The modeling and understanding is layered onto the decision making; which, in turn, cross feeds into the international cooperation as well as coordinating the communications effort.

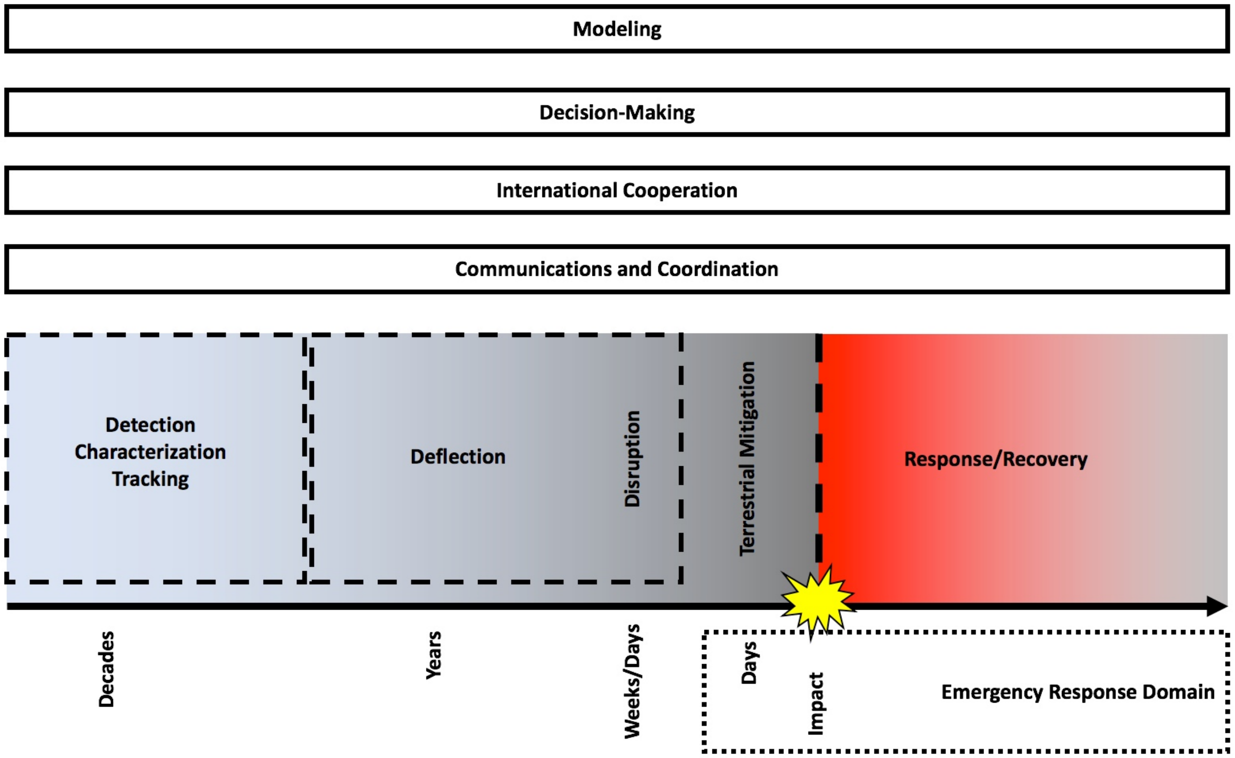


Figure 3: An approximate timeline for the response effort(s). The first step is the discovery/detection of the NEO and next several [and often concurrent] steps will be crucial follow-up observations – all of which feed into the modeling and, in turn, decision-making and international coordination and communications (from the U.S. National NEO Preparedness Strategy).

B. Short-Warning Impact Response

A short-warning impact response is assumed to be a decade or less in which a planetary defense mission (or, possibly missions) could be launched in an attempt to avert an impact event with the Earth. A short-warning time impact threat will require a rapid response and will likely have to leverage as many existing capabilities and assets as possible. Many technical factors, including technology maturity and launch vehicle availability, will influence the success of the response, as well as international follow-up efforts. These efforts include both coordinated post-impact observational efforts via IAWN to determine the orbit and may also necessitate a follow-up mitigation mission.

If the warning time is extremely short (i.e., weeks to months), depending on the size and nature of the impactor, it is more likely that communications warning of the impact, as detailed in SMPAG Action Item 5.6, and civil defense measures would be the only mitigation actions taken.

C. Long-Range Impact Response

A long-range impact response is assumed to be on the order of a decade and longer, possibly several decades. The additional warning time would afford the opportunity to be much more measured and may likely enable the opportunity for a reconnaissance mission followed up by several kinetic impactors. In so doing, SMPAG members would be able to develop a procedure and [long-range] timeline for conducting a risk/benefit analysis for space-based mitigation mission options following a NEO threat assessment. Development of these benchmarks will, in turn, allow a more logical set of protocols to recommend NEO reconnaissance efforts as well as the ability to select one or more planetary defense methods to be used against the impact threat. Again, it should be emphasized that very massive PHOs will require substantial force and/or action time order to sufficiently deflect the impactor.

Whether it is a short-term or long-range response, time is the key consideration. Time is needed to impart sufficient momentum transfer and allow it to integrate over time and result in a successful deflection. For scenarios in which the warning time is limited such that the mitigation effort (impactor) cannot be applied in the few years or months prior to impact to the Earth, the required magnitude for the deflection will be too large to be practical. Delay and uncertainty can significantly diminish the practicality of the kinetic impactor.

4. Response Effort Resources

An accurate, up-to-date inventory of the resources available for the timely implementation of a successful planetary defense effort is extremely valuable. The available warning time will directly influence the selection of everything from the deflection or disruption technique used to the launch vehicles required to deliver the payload to the target, and a compilation of the available resources can allow options to be properly evaluated and timely decisions to be made. A significant effort is required to develop and maintain such as inventory, which is constantly evolving and requires periodic updates to make it useful for planning purposes and ultimately for supporting implementation.

The SMAG PDAP identifies launch site, launch vehicle, payload hardware (spacecraft systems, subsystems, devices, etc.), and other critical resources (e.g., ground- and space-based infrastructure) as information that needs to be provided by the SMPAG member states to support a deflection/disruption campaign and associated planning prior to a confirmed impact threat. Additionally, the technology readiness level (TRL) and availability of each resources needs to be identified. A low-TRL system would not be a viable option for an impact threat scenario with very little warning, nor would a launch vehicle that is still in development. The following is an initial example list of launch vehicle parameters that would need to be provided:

- Launch Vehicle
- Nation
- Manufacturer
- Launch Site
- Payload Mass to 500 km Low-Earth Orbit (kg)
- Payload Mass to C3=0 (kg)
- Payload Mass to C3=25 (kg)
- Payload Mass to C3=50 (kg)
- Payload Mass to C3=75 (kg)
- Payload Mass to C3=100 (kg)
- Payload Fairing Diameter (m)
- Payload Fairing Length (m)
- Adapter Diameter (m)
- Adapter Length (m)
- Max. Launch Rate (launches/year)
- Approx. Cost/Launch ($2018)
- Initial Operational Capability (IOC) Year
- % of Successful Launches after IOC
- Website
- Notes

Since this resource inventory is constantly evolving, it is likely more manageable and practical for each participating member state to maintain this information and make it available in a timely manner to determine what resources that could be used in the campaign. The PDAP recommends that a SMPAG working group is formed to determine what data parameters should be included in the inventory, along with the best method for capturing and maintaining the information. This resource inventory could be included as part of any periodic SMPAG-sponsored scenario exercises to facilitate the development of effective mitigation plans as described in Section #.#. As a second example, the following is an initial list of spacecraft parameters that would need to be provided:

- Spacecraft
- Nation
- Manufacturer
- Total Mass (kg)
- Total Power (kW)
- Total Volume (m^3)
- Propulsion System
- Thrust (N)
- Size (m)
- Approx. Unit Cost ($2018)

- Reliability
- Initial Operational Capability (IOC) Year
- Min. Design Life (years)
- Max. Design Life (years)
- Website
- Notes

In addition to the actual vehicles and systems that will ultimately be needed for deflecting or disrupting an impactor, the availability of analytical tools is also critical to be able to credibly inform decision makers in developing a mitigation strategy. The tools for modeling the physical and orbital parameters of the NEO, performing end-to-end mission analyses, determining the effectiveness of mitigation techniques, and assessing impact effects and consequences also need to be part of the resource inventory or part of a separate complimentary inventory. The development of this proposed resource inventory would be extremely beneficial to successfully conducting SMPAG-sponsored scenario exercises and could be developed prior to or in conjunction with the initial exercise and improved based on the content of the scenario and inputs from the participants.

5. Identified Deflection/Disruptions and Characterization Options

Developing the capabilities to deflect or disrupt a NEO is critical for successfully preparing for and responding to an impact threat. Due to uncertain nature of these objects (orbits, size, composition, structure, etc.) and the large range of possible warning times, a variety of options can envisioned for planetary defense. Additionally, the ability to provide rapid, in-situ reconnaissance (i.e., NEO flyby or rendezvous) is extremely valuable for characterizing a particular threat beyond what remote observational capabilities, either ground- or space-based, can provide. However, this may not be possible given a particular NEO and associated warning time, and any planetary defense strategy must be robust to the situation.

Table 2 provides a high-level summary of the estimated readiness for currently identified deflection/disruption methods, along with an overall qualitative description of their respective timeliness to respond to a threat as indicated by the amount of momentum transfer that can be imparted to the target. Since the desire for a deflection mission is to impart a sufficient incremental velocity (ΔV) for a deflection technique, the approaches that provide a significant amount of momentum transfer are viable for short warning time threat scenarios. For scenarios with significant warning time (e.g., decades), a lower momentum transfer may be sufficient, but high-TRL systems may be needed to support in-situ reconnaissance of the target to assist in the development of the actual planetary defense approach. As would be expected, the slow push/pull techniques would require more time prior to impact than the impulsive techniques to be effective in altering the NEO's trajectory sufficiently to avert an Earth impact.

Planetary Defense Method	Technology Readiness	Momentum Transfer
Impulsive Techniques		
Kinetic Impact	High	High
Nuclear standoff	High	Very high
Nuclear surface	High	Very high
Nuclear subsurface	Medium	High
Slow Push/Pull Techniques		
Gravity Tractor	Medium	Low
Enhanced Gravity Tractor	Low	Medium
Ion Beam Deflection	Medium	Medium
Focused Solar Ablation	Low	Medium
Pulsed Laser Ablation	Low	Medium
Mass Driver	Low	Medium
Direct Push ("Space Tug")	Low	Medium
Enhanced Yarkovsky Effect	Very Low	Very Low

Table 2: Overview summary of estimated general TRLs for various mission techniques and the timeliness of momentum exchange to the NEO.

The impulsive techniques involve either the use of a hypervelocity kinetic impact or the use of a nuclear explosive device (NED). These impulsive techniques are also the primary approaches for any attempt to disrupt an impacting asteroid or comet, with a NED being the most effective, since the rapid momentum transfer can also substantially alter the integrity of the NEO's structure. The slow push/pull techniques include approaches that apply a more controlled technique, but provide much lower momentum transfer than the impulsive techniques. Since these options would require more warning time, it is likely that addition development and testing could be possible. That being said, for impact scenarios with warning times on the order of several years or a decade these techniques would also greatly benefit from higher TRLs than currently exist.

Kinetic impactors are currently considered the most mature of the planetary defense options. While not a planetary defense demonstration mission, in 2005, a small kinetic impactor was successfully demonstrated during the *Deep Impact* mission which delivered a 372-kg instrumented impactor to Comet 9P/Tempel 1 (~6 km nucleus) with a relative velocity of 10.2 km/s. However, the vast majority of potential NEO threats are much smaller and more difficult to target. Further, *Deep Impact* was science-driven mission and not intended to make a measurable change in Comet Tempel 1's orbit.

NASA is currently developing the Double Asteroid Redirection Test (DART) mission, which is planned to impact the approximately 150-meter moonlet of near-Earth asteroid (65803) Didymos in early October 2022. The DART spacecraft has a mass of approximately 500 kg and will impact at a speed of approximately 6 km/s. Both of these missions deliver small masses to the target, but demonstrate the basic sensors, software, and operations needed to perform this planetary technique. For this reason, the kinetic impactor is the primary focus of the example scenario discussed in Section 7 and it is recommended that it should also be the focus of any of the initial scenario exercises described in Section #.#. Kinetic impactor missions are also capable of delivering NEDs and there may be momentum exchange advantages for the NED to come in close contact with the surface before detonation or provide emplacement of the NED to attempt a disruption of the NEO. Demonstration missions capable of successfully delivering a NED would contain all of the necessary systems and interfaces, but would only carry a simulated payload rather an actual nuclear device.

As shown in Table 2, there are a number of viable techniques besides kinetic impactors and NEDs which generally have very low to medium TRL levels associated with them. This highlights the need to advance the technologies and capabilities associated with these techniques and successfully conduct demonstration missions that can elevate their TRL levels to an operational state.

Finally, both deflection or disruption missions can greatly benefit from detailed and accurate information about the impacting NEO, both before the technique is applied, as well as after. A rapid reconnaissance capability to rendezvous with or fly by the NEO are currently the only approaches envisioned to improving the knowledge about the impactor beyond what existing and planned remote observational capabilities can provide. A rendezvous spacecraft can also accurately measure the achieved deflection or provide valuable information about the final state of the NEO after disruption (e.g., imagery, updated mass estimate, etc.). For short warning time scenarios, a hybrid approach that provides rapid, detailed planning info via a flyby, but delivers a small, less capable rendezvous spacecraft could provide a viable approach to gathering the required in-situ data. The flyby spacecraft could also serve as a communications relay for the rendezvous spacecraft with low data rate. Each planetary defense method should include mission designs that include reconnaissance spacecraft to provide these kinds of important information if the method cannot inherently do so.

6. Response Effort Coordination

A coordinated response effort will be complicated and will require good organizational communication on a global scale. It is recognized that each nation will have it its respective emergency notification plans. Still, utilizing the infrastructure within the United Nations Office of Outer Space Affairs (UNOOSA) for parallel communications with member states can provide a venue for planning a coordinated international response.

A. Pre-impact Preparation & Exercises

Working with respective space agencies around the world, it is essential that IAWN and SMPAG continue to assist in developing a set of real-world scenarios based on credible impact threats with observable parameters to inform planning and procedure development. Currently, an aspect of this occurs on a semi-annual basis. The International Academy of Astronautics' (IAA)

Planetary Defense Conference (PDC) is an excellent venue in which to demonstrate the engagement of the world's space agencies, governments, the United Nations as well as the utility of IAWN and SMPAG. The threat scenarios that are conducted during PDC are valuable introductions to the complexities associated with planetary defense efforts, but additional coordinated exercises could increase the ability to successfully respond to an actual threat.

B. Impact Identification and Notification

The criteria and thresholds for action for a potential NEO impact threat stem directly from SMPAG action item 5.1 and are re-stated here. Following identification of a potentially hazardous NEO on an impact trajectory towards the Earth, IAWN shall:

1) Warn of predicted **impacts exceeding a probability of 1%** for all objects characterized to be **greater than 10 meters in size**, or roughly equivalent to **absolute magnitude of 28** if only brightness data can be collected.

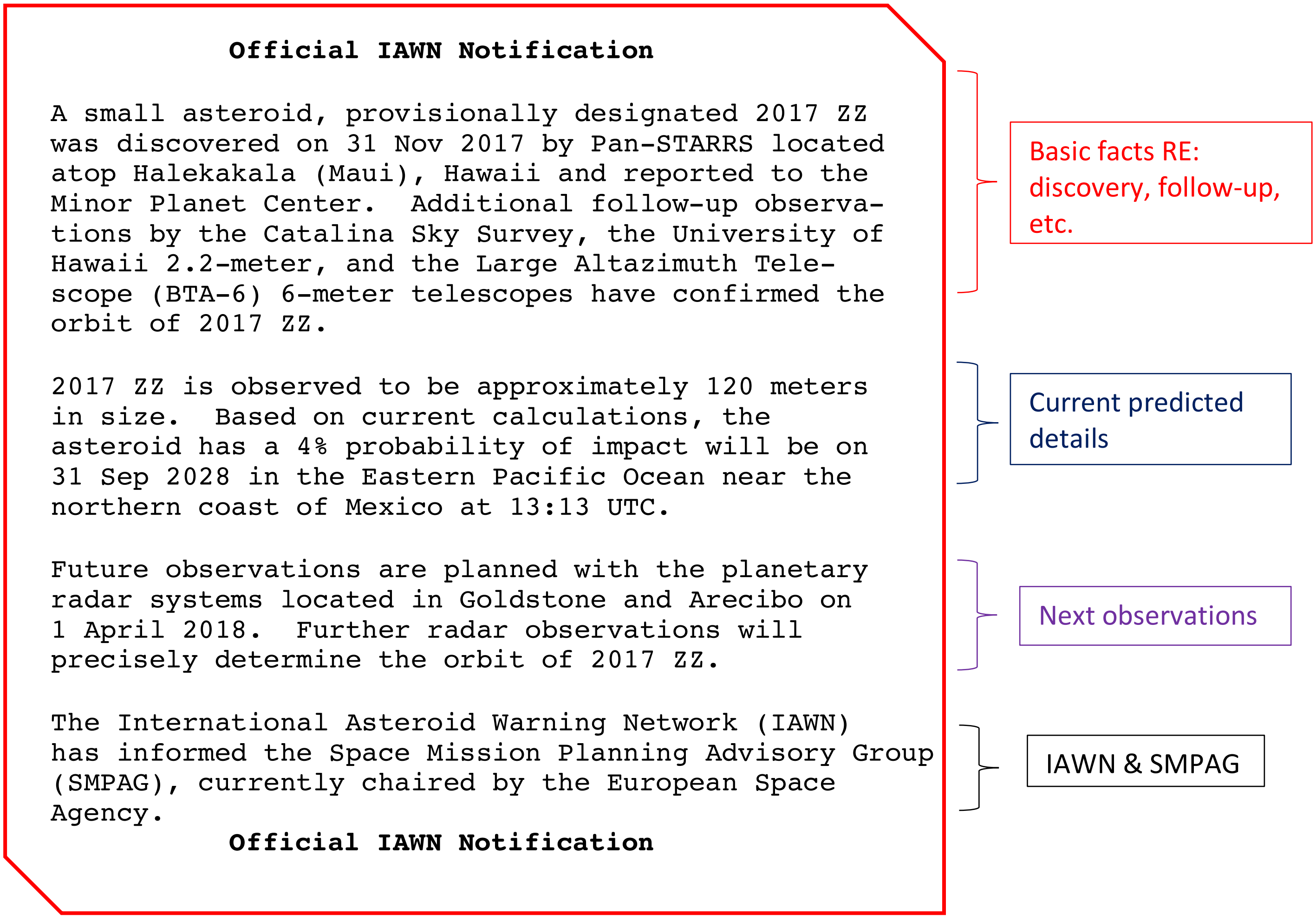
2) Terrestrial preparedness planning should begin when warned of a possible impact:

    - Predicted to be **within 20 years**,
    - Probability of impact is assessed to be **greater than 10%,** and
    - Object is characterized to be **greater than 20 meters in size**, or roughly equivalent to **absolute magnitude of 27** if only brightness data can be collected.

3) SMPAG should start mission option(s) planning when warned of a possible impact:

    - Predicted to be **within 50 years**,
    - Probability is assessed to be **greater than 1%,** and
    - Object is characterized to be **greater than 50 meters in size**, or roughly equivalent to **absolute magnitude of 26** if only brightness data can be collected.

Prior to transmitting a notification, IAWN membership shall include the asteroid name/designation (to include characteristics; i.e., size, composition, brightness/albedo, etc.); observational history (discovery information, follow-up observations); prediction of the asteroid trajectory including closest distance to the surface of the Earth as well as date and time of close approach. Further, this notification statement should include a colloquial (non-statistical) qualifier of impact risk(s); note the hazard to space assets; and the plan for future observations. This is the very essence of SMPAG action item 5.6. Figure 4 below, is an example notification sheet.



Official IAWN Notification

A small asteroid, provisionally designated 2017 ZZ was discovered on 31 Nov 2017 by Pan-STARRS located atop Halekakala (Maui), Hawaii and reported to the Minor Planet Center. Additional follow-up observations by the Catalina Sky Survey, the University of Hawaii 2.2-meter, and the Large Altazimuth Telescope (BTA-6) 6-meter telescopes have confirmed the orbit of 2017 ZZ.

2017 ZZ is observed to be approximately 120 meters in size. Based on current calculations, the asteroid has a 4% probability of impact will be on 31 Sep 2028 in the Eastern Pacific Ocean near the northern coast of Mexico at 13:13 UTC.

Future observations are planned with the planetary radar systems located in Goldstone and Arecibo on 1 April 2018. Further radar observations will precisely determine the orbit of 2017 ZZ.

The International Asteroid Warning Network (IAWN) has informed the Space Mission Planning Advisory Group (SMPAG), currently chaired by the European Space Agency.

Official IAWN Notification

Basic facts RE: discovery, follow-up, etc.

Current predicted details

Next observations

IAWN & SMPAG

Figure 4: Example IAWN Notification of a potentially hazardous asteroid on a possible impact trajectory to the Earth. SMPAG Action Item 5.1 describes the threshold criterion; Action Item 5.6 describes the notification details IAWN provides to SMPAG.

Upon notification of the probable/possible impact hazard or threat, SMPAG members will convene to assess the nature of the threat and prepare key information to inform subsequent communications and decisions regarding planetary defense and other forms of consequence mitigation techniques.

The results of the SMPAG recommendations are then briefed to the United Nations member states. If the member states concur and agree to support the SMPAG recommendations, the member states inform the United Nations of the action(s) to be taken.

C. Contact Information

NASA has developed a process outlined in a high level in Figure 5 below. Starting at the upper left in this flow chart, survey systems detect the small objects moving across the field of background stars and report their observations to the Minor Planet Center (MPC). At the MPC, all world-wide observations are collected and then either correlated with known objects or determined to be a new discovery and an initial approximate orbit is determined. With the initial orbit, it is determined whether it is a potentially hazardous object (PHO) or just another common small body of the solar system. If it is a PHO, a rough estimate is made by the MPC of whether it poses a threat of impacting the Earth. Most PHOs do not pose a threat and are, in turn, routinely processed and cataloged.

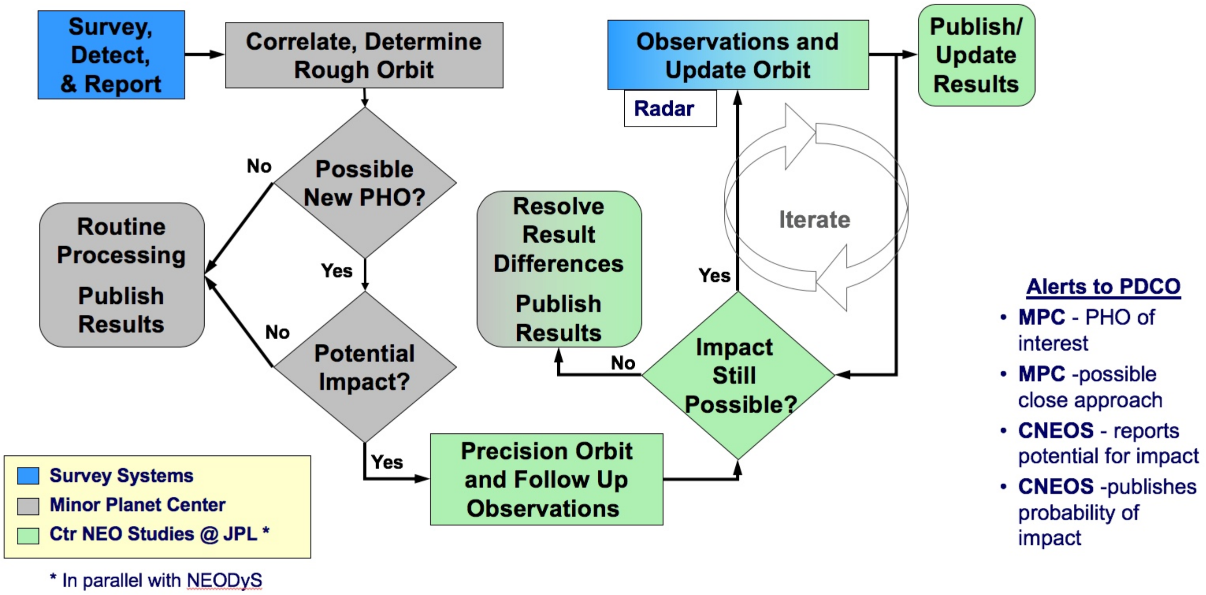


Figure 5: This flow charts shows the process that NASA employs to assess and predict whether a newly discovered object is an impact hazard. It includes several survey systems (and follow-up observations by observatories world-wide). In the event of a PHO on an impact trajectory, NEODyS also provides high-precision orbit determination.

However, if a PHO is identified as a potential impactor, CNEOS is alerted to perform more precise orbit determination and the network is requested to provide follow-up observations. If a potential impact is determined to be real by the precision orbit determination, the PDCO is alerted at NASA Headquarters and the maximum number of possible observations are requested of the survey and follow-up network. The object is also assessed for possible observation by planetary radar, which would provide the most precise parameters if the object is observable by those systems. The orbit is iterated on as quickly as new data becomes available, and the CNEOS compares its predictions with those from the NEO Dynamic Site (NEODyS) of the University of Pisa, Italy, providing a valuable verification and validation of the resulting information. All information collected on the object and its orbit is published by both the MPC, CNEOS, and NEODyS on their respective websites. Figure 6 below suggests a notional communications work flow in the event of a credible threat that follows the NASA notification process outlined in Figure 5 (above). Figure 6 (below) is the notional flow to/from IAWN and SMPAG and relevant UN entities.

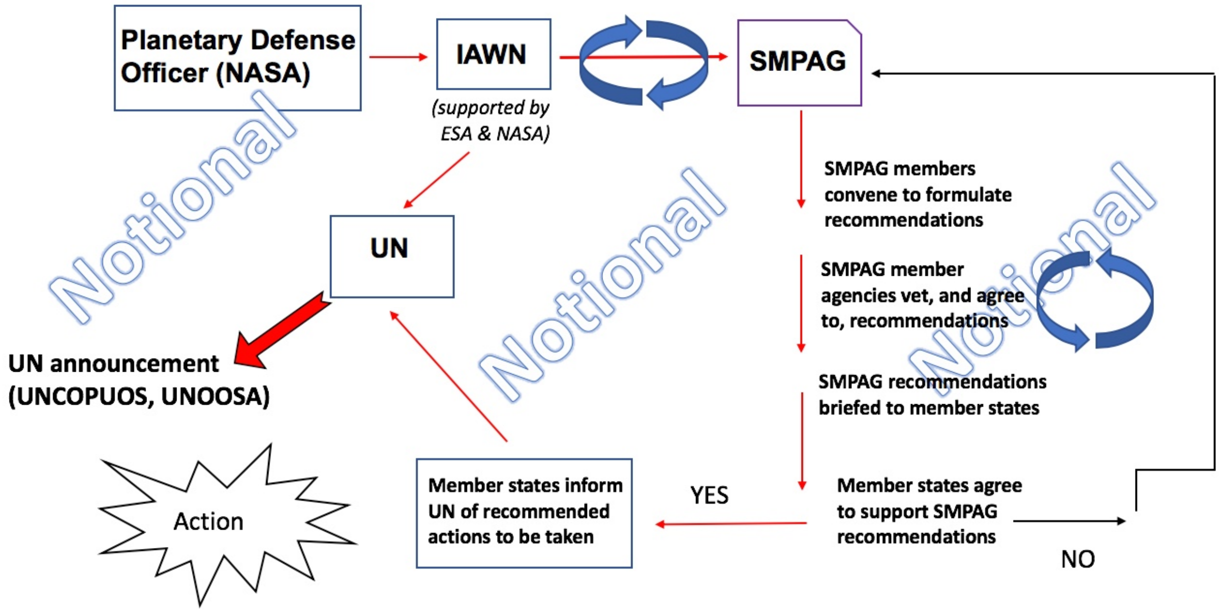


Figure 6: This [notional] flow chart follows the information process from the previous figure, showing the moment IAWN alerts SMPAG and, in turn, SMPAG convenes to vet and concur up a recommended course of action.

D. Planning of a Coordinated Response

The United Nations (UN) does not authorize nations nor their respective space agencies to establish a procedure and timeline for conducting a threat assessment upon detection of a potential NEO impact. However, updating the threat assessment based on improved data, communicating the current status of mitigation missions, etc. utilizing UNCOPUOS as a forum to improve coordination as well as the organizational communication of these activities is encouraged. Standardization of the threat assessment content is important to provide suitable inputs for subsequent decisions regarding notification, mitigation, response, and recovery. The assessment 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 entities.

IAWN has developed a disciplined an approach for the initial assessment of NEO impact threats. SMPAG Action Item 5.1 describes the criteria and thresholds to initiate the organizational communications process of informing member states of the impending hazardous threat.

E. Open Communication and Transparency

The ability to plan and execute a timely and effective international response effort to an impact threat requires open communication and transparency between the member states. The most effective way to foster this critical aspect of a planetary defense effort is to establish solid working relationships between the personnel involved in a future response before that response is required. Regular meetings of SMPAG and participation on working groups will help develop those connections and provide the foundation of an effective core team. This core team will be able to facilitate the addition of new individuals or replacements, either prior to an actual threat or during the increased membership that would occur during an actual threat. Developing these relationships beforehand will allow working relationships to established well in advance of the threat. This is valuable to be able achieving critical milestones during the campaign, which is enabled by the team making well-informed decisions based on the open exchange of information.

Despite the best intentions, communications and transparency issues can develop. It is recommended that SMPAG develop a standard agreement between member states identifying types of information that will be shared and any associated restrictions, along with a pledge to operate in an open and transparent manner on the development and execution of the threat response. It is important to have this in place between member states as soon as possible to ensure that there is a clear understanding of the agreement/pledge. It is critical that trust established between any member states is not broken or even perceived to be compromised. Any breach of trust could affect other aspects of SMPAG cooperation, which would impede cooperative activity, possibly at the most inopportune time. It is also recommended that a process be developed that would permit members states to openly vet any concerns and allow discussion and resolution of any issues. This process could be a two-tiered approach, with the first level being a process within SMPAG and the second level (if needed) overseen by the Working Group on Near-Earth Objects (NEOs) of the Scientific and Technical Subcommittee of the UN COPUOS.

F. Possible Impediments to Action and Potential Remedies

There are many possible impediments to acting on a credible threat, beginning with establishing the probability of whether an impact will actually occur to the successful implementation of a deflection/disruption effort. The follow is a list of the likely impediments identified, major and minor, and possible remedies to avoid the impediment from occurring:

- Lack of precise orbit determination (major) – more measurements with sufficient resolution and more capable radar observations (e.g., bistatic operations between global installations).

- Insufficient physical characterization (major) – improved remote capabilities (spectroscopy, radar) and telescope priority when needed; rapid-response robotic reconnaissance spacecraft.
- Launch failures (major) – multiple launch vehicle options at different launch sites.
- Spacecraft failures (major) – redundant systems and subsystems on spacecraft; redundant suppliers; redundant deflection/disruption methods.
- Failure to be open and transparent, actual or perceived (major) – strong cooperative working relationships; agreements/pledges in place prior to identification of a credible threat (see "Open Communication and Transparency" discussion in this section)
- Political pressures (minor or major) – isolate, to the greatest extent possible, any political pressures from SMPAG to allow participants to remain objective and focused on planetary defense campaign.
- Unit conversion errors (minor, but important) – globally adopt the International System of Units (SI) as the standard for all planetary defense efforts (e.g., analyses, data collection, reporting, communications, etc.).
- Impact of different time zones on cooperative efforts (minor) – identify a common time period to conduct live telecons/meetings that is acceptable SMPAG personnel; work asynchronously to the greatest extent possible; and establish times of day for data to be provided by next working team. During an the actual execution of the threat response, this impediment would like require flexibility on everyone to accommodate differing time zones.

7. Example Scenario

The SMPAG PDAP recommends that a kinetic impactor-based scenario be developed as part of the initial SMPAG scenario exercise, based on a presumed warning time of 5 years prior notification of confirmation of an impact of a 150 meter object with the Earth. This hypothetical scenario is challenging, but solvable and emphasizes many of the stressing aspects of an impact threat and can provide insight into what can be accomplished in relatively short period of time. The scenario utilizes a high-TRL deflection method that is scalable to a variety of threat sizes and warning times. It is also consistent with what the warning time that could be expected for this size object currently or in the near future and parallels the hypothetical impact exercise that was conducted during the 2015 Planetary Defense Conference (PDC) in Frascati, Italy. In this scenario with approximately 7 years of warning time, an approximately 300-m asteroid was fragmented during a kinetic impactor deflection mission and the airburst of an 80-m fragment over Dhaka, Bangladesh in the summer of 2022.

The scenario would baseline the used a kinetic impactor deflection design based on NASA's Double Asteroid Redirection Test (DART) demonstration mission. DART uses an uncommon mission opportunity to deliver a low-mass spacecraft (~500 kg) to impact the moonlet of the Didymos binary system that makes a close approach with the Earth to impart a measurable deflection. DART was approved to begin the preliminary design phase in the middle of 2017 and the impact date is planned in October 2022 – just over 5 years. In order to provide sufficient velocity change in the hypothetical scenario the mass of the DART would be need to be a scaled up and the rapid development, launch, and simultaneous operation of multiple kinetic impactors would be required.

The modified DART spacecraft would have its impact mass increased by an order of magnitude or more in order to provide sufficient momentum transfer with a reasonable number of spacecraft. The propulsion, power, thermal, and communications systems would also need to be increased to accommodate the larger impact mass and more distant range to Earth. Changes to the avionics, sensors, flight software, and guidance, navigation and control (GN&C) would likely not be needed. The scenario would allow the deflection performance to be characterized and would allow the applicability of a DART-derived spacecraft to be assessed.

The specific details of the scenario would be planned in coordination with Paul Chodas (NASA CNEOS at JPL), who has developed the scenarios for past PDC impact exercises.

8. Conclusion

While a low-probability event, impacts due to asteroids or comets are also of high consequence to human life, civilization, and extraordinary impact on the environment. This Planetary Defense Action Plan is intended to provide an initial set of guidelines for a collaborative and internationally coordinated approach to developing effective technologies, policies, practices, and procedures for decreasing Earth's vulnerability to NEO impacts.

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Appendices (TBD)

(acronym list; example tables of capabilities, launch sites, etc.;)