Conference Summary and Recommendations

OVERVIEW

The 2019 International Academy of Astronautics (IAA) Planetary Defense Conference was held on April 29-May 3, 2019 in The Hotel at the University of Maryland located in College Park, Maryland. This was the eighth in a series of conferences that began in 2004 in Anaheim, California, with subsequent conferences in Washington, D.C. in 2007, Granada, Spain in 2009, Bucharest, Romania in 2011, Flagstaff, Arizona in 2013, Frascati, Italy in 2015, and Tokyo, Japan in 2017. The conference became associated with the IAA in 2009. Summary reports from conferences beginning in 2009 are available at http://pdc.iaaweb.org.

Individuals from five space agencies, government agencies, universities, several nonprofits, and commercial companies served on the Organizing Committee for the 2019 conference, and several members also served on the Local Organizing Committee. Members of both groups are noted in ATTACHMENT 1. The Organizing Committee met monthly via telecon and developed the details of the conference. Several also served as chairs of sessions, where they selected papers for presentation, invited key speakers, and ran their sessions during the conference. The Local Organizing Committee selected the conference venue, managed day-to-day details of the conference infrastructure, and managed registration. Sponsoring organizations (see ATTACHMENT 2) provided funds to help keep the registration costs low and make scholarships available for students and invited experts.

The conference was attended by 281 individuals, which included 22 students and 33 members of the press. ATTACHMENT 3 provides a list of attendees; Fig. 1 is a group photo.

Figure 1. Conference Attendees (image credit: JHUAPL).

As the Program given in ATTACHMENT 4 shows, the 5-day conference followed a single-track format, meaning that all presentations were sequential, and all were presented in a plenary session. The goal was that all attendees would receive the latest information on all aspects of planetary defense, including: what we know about asteroids and comets; how a threatening object might be deflected or otherwise mitigated; designs of deflection missions and campaigns; and consequences if an asteroid were to strike our planet and how a disaster might be managed. Sessions concluded with discussions of how the public should be notified of a threat and kept informed as the threat evolved, and also considered political and policy issues that might affect the decision to take timely action. A total of 100 authors gave presentations on their work, and there were 94 poster presentations, as well. Papers, detailed abstracts and presentation materials are available at the conference website, http://pdc.iaaweb.org.

As with the 2013, 2015, and 2017 conferences, the 2019 conference included a tabletop exercise where conference participants were presented with a hypothetical asteroid threat and asked to consider and recommend specific actions that should be taken as the threat evolved. Goals of the exercises are to illustrate how an actual threat of impact by an asteroid or comet might look and might evolve and help understand:

- Reactions and responses of the public, leadership, disaster responders
- How information should be presented and made understandable to the public and leadership
- Threat timelines and decisions leaders must be prepared to make as a threat evolves (e.g., commit resources for missions to assess and respond to the threat, disaster preparedness, and possible disaster response)
- “Hot buttons” that might affect timely decision making
- Opportunities for international coordination and collaboration on threat mitigation.

The 2019 exercise included a pre-conference “press release” giving details of what was known about a fictional object and the threat it posed when the conference began (there was a 1/100 chance the object might impact Earth in eight years). The press release was posted on the conference webpage before the conference to provide the opportunity for advance work by analysts, and background information and details on the threat were presented to all conference attendees the afternoon of the first day. The subject object of the exercise was an asteroid, but a separate threat posed by a fictional comet was also introduced but not discussed as part of the exercise.

On the second day, the threat was updated based on new tracking data that showed the probability of impact of the asteroid had increased to 10%. After presentation of information behind the new prediction, attendees participated in discussions of what should be done given this information. Their recommendations were passed to the decision maker for that day, who agreed that a mission should be launched for a fast flyby of the oncoming object to collect information on its size, shape, and other information to would refine the risk and inform a deflection mission should that be necessary. From that point, the probability of impact of impact rose to 100%, and a deflection campaign using kinetic impactors was launched. On the final day of the conference, participants discussed the outcome of the exercise. Details on the threat and the exercise are presented in ATTACHMENT 5.

Conference highlights included the keynote address presented by The Honorable James Bridenstine, the Administrator of the National Aeronautics and Space Administration (NASA), who emphasized the importance of preparing for the eventually of an asteroid threat. A video of Administrator Bridenstine’s presentation, and a videos of each speaker, is available at the conference website.

At the conclusion of the conference, prizes were awarded for what were judged to be the best papers submitted by students. These were:

First Prize: Joe DeMartini, "Using a Discrete Element Method to Investigate Seismic Response and Spin Change of 99942 Apophis During its 2029 Tidal Encounter with Earth"

Second Prize: Esther Drolshagen and Theresa Ott for their paper "NEMO: A Global Near Real-time Fireball Monitoring System"

Third Prize: Yaeji Kim, "Assessment of Resurfacing Process on Apophis During the 2029 Earth Flyby"

Honorable Mention: Mr. Artash Nath, a 7th-grade student from Canada, for his paper "Using Machine Learning to Predict Risk Index of Asteroid Collision"

NEXT CONFERENCE: The United Nations Office of Outer Space Affairs (UNOOSA) will host the next conference, which will be held on April 26-30, 2021 in Vienna, Austria.

SESSION HIGHLIGHTS:

As noted, the conference was a single-track conference, meaning that all presentations were given in a plenary session.

Session 1: Key Developments

Speakers in Session 1 provided information on current activities and planned missions that relate to planetary defense. Presenters described activities at the United Nations, the European Space Agency (ESA), The U.S. National Aeronautics and Space Administration (NASA), and the Israel Space Agency (ISA). Highlights were presentations on:

- Recent United Nations activities that included a 2013 resolution that led to establishment of two UN-endorsed organizations that will inform the United Nations of credible threats:
    - International Asteroid Warning Network (IAWN) (http://www.iawn.net) is a virtual network linking together the institutions performing functions such as discovering, monitoring and physically characterizing the potentially hazardous NEO population. Its work includes search-and-characterization of NEOs, providing input to emergency management organizations, and communications with the media and general public. IAWN aims to serve the global community as the authoritative source of accurate and up-to-date information on NEOs and NEO impact risks – information that is available to all countries.
    - Space Mission Planning Advisory Group (SMPAG) (http://www.smpag.net) is laying out the framework, timeline and options for initiating and executing space mission response activities and promoting opportunities for international collaboration on research and techniques for NEO deflection. Membership in SMPAG is open to all national space agencies or governmental or inter-governmental entities that coordinate and fund space activities and are capable of contribution to or carrying out a space-based NEO mitigation campaign.
- Recent accomplishments of IAWN and SMPAG include:
    - A recommendation by SMPAG supporting asteroid orbit deflection demonstration missions (such as the DART mission discussed later)
    - Criteria and thresholds for action. Specifically:

        - IAWN shall 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.
        - Terrestrial preparedness planning is recommended to begin when warned of a possible impact: Predicted to be within 20 years; Probability of impact is assessed to be greater than 10 %; and the threatening 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.
        - 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 (this magnitude threshold would presume an albedo of approximately 3 %; i.e., a possible dark object).
    - SMPAG established an Ad Hoc Working Group on legal issues to review and assess legal issues relevant to the execution of NEO deflection missions, both for test purposes and in an emergency, and associated aspects of planetary defense.
    - A roadmap for future work on planetary defense
- UN General Assembly resolution 71/90 grants UNOOSA role as the secretariat to SMPAG and declared 30 June International Asteroid Day to raise awareness globally about the NEOs, their potential harmful impacts, and efforts in planetary defense.
- SMPAG and IAWN participate in the sessions of the Scientific and Technical Subcommittee of COPUOS and report annually to the Subcommittee on the progress of their work on planetary defense.
- European Space Agency (ESA) plans to
    - Finish installation of Flyeye Telescope #01 and start its operation
    - Start full operations of Test-Bed Telescopes, install #02 in La Silla and begin its operation
    - Enhance cooperation with existing telescopes
    - Build a fireball camera for a hosted payload
    - Continue establishing international protocols for impact threat warning and response
    - Implement Hera asteroid mission to validate NASA’s DART kinetic impactor test.
- The planetary defense program of the United States, which includes;
    - Establishment of the Planetary Defense Coordination Office (PDCO) in 2016 to manage planetary defense related activities across NASA and coordinate with both U.S. interagency and international efforts to study and plan response to the asteroid impact hazard.
    - PDCO’s mission is to lead national and international efforts to detect any potential for significant impact of planet Earth by natural objects, appraise the range of potential effects by any possible impact, and develop strategies to mitigate impact effects on human welfare.
    - Release of new White House “National Near-Earth Object Preparedness Strategy and Action Plan” in June 2018.
    - Plans for the launch of the Double Asteroid Redirection Test (DART) mission, which will be launched in July 2021 and impact the moon of asteroid 65803 Didymos in September 2022 (more information on DART was included in session presentations).
- The Israel Space Agency has joined SMPAG and IAWN, and a representative presented a summary of its activities supporting planetary defense and related missions.

Session 2: Advances in NEO Discovery and Characterization:

Authors presented 29 presentations in this session, which highlighted the latest information on what's being done to discover and characterize potentially threatening asteroids and comets. Key topics included:

- Migration of the NEO Dynamic Site (NEODyS) to ESA's NEO Coordination Centre. NEODyS computes the impact probability for NEOs just discovered or with recently updated astrometric data and includes impact risk data for the next 100 years.
- NEMO, a system that collects data from multiple sources on objects that regularly impact the Earth's atmosphere, are too small to be detected by NEO surveys, and cause bright fireballs.
- A new impact monitoring system built by the Institute of Applied Astronomy of the Russian Academy of Sciences.
- Estimates that approximately 95% of Near Earth Asteroids larger that 1 km have been discovered (and do not pose an impact threat in this century) and that the last few large NEAs are "mostly hiding behind the sun in resonant orbits, thus will not 'strike out of the blue', but instead will move into discoverable regions of sky long before a close approach or impact with the Earth."
- About 70% of objects greater than 140 m in size remain undetected.
- Tunguska-sized impacts occur about once in three quarters of a millennium.
- New discovery and follow-up capabilities of: Catalina Sky Survey; the Asteroid Terrestrial-impact Last-alert System (ATLAS); Pan-STARRS; NEOWISE; the 4.1-m Southern Astrophysical Research (SOAR) Telescope; NASA's 3.0-m Infrared Telescope (IRTF) facility; the 4.3-m Discovery Channel Telescope; Las Cumbres Observatory's global telescope network; the UH-2.2m telescope; the 1-meter telescope at Pic du Midi, France; two smaller telescopes in Romania; and the coming Large Synoptic Survey Telescope (LSST) and NEOCam systems (see below).
- Arecibo radar observations of PHAs.
- The role and planned upgrades of the Minor Planet Center.
- Estimates that there are 6100 bolide events that result in meteorite falls, with 1800 of these falls over land. Estimates are that ¼ of the falls over land result in damage. There is no clear indication of an excess in the distribution of falling meteorites and fireballs with date or solar longitude.
- Manx (nearly tailless) comets will approach the inner solar system at high velocities. They appear to be made of rocky material like asteroids and have higher densities than long-period comets. Manx comets would likely have short warning times and would impact hard.
- Using the boulders on the surface of asteroids Ryugu and Bennu as clues to the formation of top-shaped morphologies.
- The proposed Near-Earth Object Camera (NEOCam), which would be placed in a Sun-Earth L1 orbit. NEOCam is optimized to find and characterize the risks posed by potentially hazardous objects (PHOs), both as individual objects and as populations and thousands of short- and long-period comets. NEOCam is expected to see hundreds of thousands of NEOs smaller than 140 meters. (At the end of the conference, participants approved a resolution supporting the development and launch of the NEOCam mission)

Session 3: Apophis

This session was added to begin special focus on what might be learned during the coming very close approach to Earth by asteroid 99942 Apophis on Friday, April 13, 2029—less than 10 years away. Apophis has a mean diameter of 340+/-40 meters, will pass within the geosynchronous ring where many television relay and weather satellites reside, but will not impact Earth during this pass or pass through a keyhole that will place it on a resonant return trajectory. Highlights from this session include:

- The unknown size of the Yarkovsky acceleration on Apophis is the largest source of uncertainty in the distance of the 2029 close approach to Earth. Attempts are being made to directly measure the Yarkovsky acceleration of Apophis from an extensive set of astrometric data to provide a better constraint on the size of the acceleration and ascertain whether Apophis remains an impact threat in 2068.
- The close approach will provide an opportunity to estimate of Apophis' moments of inertia and center of mass, providing insight on interior structure.
- Possible structural changes on Apophis due to the gravitational pull Earth produces may be measurable.
- An Apophis rendezvous mission is conceivable
- There are many possible encounter missions that include possible flybys, orbit and possible placement of landing of small devices, possibly including a seismometer to detect and measure tidal interactions with Earth and the Sun.
- Goldstone and Arecibo delay-Doppler radar images obtained before and after the flyby in 2029 should reveal changes to the asteroid's spin state and might reveal subtle changes on the surface.
- The best Goldstone images will have range resolution as fine as 1.875 m. Arecibo will use their 7.5 meter imaging capability.

It was noted in this session that in addition to the Apophis flyby, there are six very close flybys by other potentially hazardous objects in the late 2020s. The largest of these is by 2001 WN5 on June 26, 2028. That object will pass Earth at 0.65 Lunar Distances and has a size of 0.93 km.

Session 4: Deflection and Disruption Models and Tests

This session focused on how a threatening object might be deflected or disrupted and recent testing of mitigation approaches. Highlights were:

- Detailed impact modelling in preparation for the Double Asteroid Redirection Test (DART). DART impact, scheduled for 2022, is the first direct test of an asteroid deflection technique and provides critical information to understand what we can do to protect our planet.
- The DART mission will measure the momentum transferred by the impact of DART on the moon of Didymos, Didymos-B, via its effect on the orbit of Didymos-B around Didymos.
- Impact modelling shows that Impact angle, controlled both by local topography and broader asteroid shape, makes a major contribution to the measurable delta-v imparted to Didymos-B by the DART impact and to Beta (β is momentum transferred to the object by the spacecraft's impact divided by momentum of the impacting vehicle; the momentum transfer can be enhanced by ejecta leaving the impact area).
- Porosity, strength, and composition effects on the delta-v may be small compared with impact geometry effects.
- A more diffuse spacecraft with voids will probably be less effective as a penetrator, altering the results and most likely reducing ejecta and β.
- Models including realistic spacecraft shapes and internal density profiles result in different predicted craters and β than simplified projectiles.
- The type of porosity in the target affects the momentum transferred and resultant velocity change following impact. Impacts into matrix/regolith may cause local disruption of boulders, adding to ejecta and momentum enhancement.

- ESA's Hera mission would arrive at Didymos-B several years after the DART impact and would perform detailed measurements that would enable validation of numerical predictions. Hera would collect data on the morphology and size of the DART crater, make bulk density measurements, conduct an asteroid surface survey, and the returned data would help derive a surface cohesion estimate. (Given the critical nature of the measurements and the unique opportunity created by DART, conference attendees approved a resolution strongly supporting the Hera mission)

Session 5: Mitigation Campaign Design

Presentations in this session discussed design of mitigation missions, campaigns that would deliver deflection techniques to an approaching body, and missions that would position asteroid detection resources in orbital positions that would enable detection and characterization of objects approaching Earth from the direction of the sun.

- Adapting flight-proven Mobile Asteroid Surface Scout(s) (MASCOTs) for fast flyby missions as well as landing on the surface and characterizing potentially threatening asteroids.
- Designing a mission to move fictitious asteroid 2019 PDC using a modestly-sized nuclear explosive device.
- Concepts for using a 6-U CubeSat for the Hera mission, which would characterize the effects of the DART impact on Didymos-B and collect the first detailed investigation of a binary asteroid.
- A renderer and camera emulator for NASA's DART mission.
- Detailed overview and challenges of the DART mission.
- The design of the Near-Earth Object Camera (NEOCam), an instrument optimized for detecting moving objects that has no moving parts save for the aperture cover. NEOCam, a space-based telescope with infrared NEO detection capabilities would greatly accelerate completion of the search for as-yet undiscovered potentially hazardous objects and also provide enhanced remote characterization of those objects.
- A concept where two low-cost satellites would orbit L1, which would enable detecting Near Earth Asteroids (NEAs) coming from the Sun up to one day before possible collision with the Earth and provide warning time of 4 to 10 hours.

Session 6: Impact Consequences and Disaster Response

Presenters in this session discussed modelling of airbursts and impact effects and potential consequences of large object entries and of resources that detect entries of large meteors. UN Office of Outer Space Affairs support of planetary defense and related disaster management planning was also described.

- Overview of atmospheric injection of materials following impacts of kilometer-sized asteroids and suggestions for future work to characterize these effects.
- Ongoing work to characterize how asteroid properties affect breakup, resulting energy deposition, and potential damage on the ground.
- Comparing output from semi-analytic asteroid airburst models to hydrocode predictions, with conclusions that individual models have several uncertain parameters that are poorly defined and make a noticeable difference on the outcomes. Initial testing shows that the initial mass loss is faster in hydrocodes than semi-analytical models and that the spreading ratio is far smaller.
- Good agreement with Tunguska observations is achievable using a semi-analytical model.
- There is no single effective Height of Burst (HoB) for an asteroid entry. A superposition of multiple HoB's based on full energy deposition curve would be a more accurate heuristic. An

approximation that uses static burst at altitude at peak energy deposition (or 50% energy loss) may overestimate damage in some cases and underestimate it in others. It is recommended that a probabilistic asteroid impact risk model should be recalculated to account for this effect to determine if it makes significant difference in the bottom-line risk assessment.

- Evaluation of detections by the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) International Monitoring System (IMS), which fuses and screens infrasound measurements collected from worldwide sensors, found that only 12% of all JPL fireballs for E>0.08 kT (roughly meter-sized) are recorded by CTBTO in the Reviewed Event Bulletin (REB); 40% of all JPL fireballs for E>1 kT (~2-m sizes) are recorded in REB; and more than 90% of all 1-kT fireballs are detectable by the current network.
- An analysis of a glass-strewn field in Chile indicate that a Super-Tunguska fireball(s) over Chile ~12,500-13,000 years ago generated widespread glasses and strong winds. The object was likely a rubble pile, with trapped grains indicative of a primitive body consistent with a volatile-rich carbonaceous or comet. Humans likely witnessed the event.
- Advantages of using parallel Graphics Processing Units (GPU) for computationally intensive applications, such as modelling hypersonic flow around an asteroid.
- Given a predicted asteroid entry, parameterizations may enable fast predictions of energy release in the atmosphere, overpressures on the ground, wind speeds, radiation, and cratering. Where parameterizations are not accurate enough, shock physics code results can cover the range of the input space. The authors suggest that accuracy of this approach be tested against observed meteors.
- Using initial baseline values, the disintegration altitudes of stony and iron asteroids for the 2019 PDC asteroid entry scenario are 42.3 km and 12.3 km, respectively, and the airburst altitudes are 5 km and 0 km, respectively. Uncertainty of input parameters will have a large influence on the initial disintegration altitude, airburst altitude, etc., which will affect the range of ground damage to a great degree. The most influential input parameters include asteroid diameter, entry angle, cloud mass fraction, and luminosity coefficient. The study concluded that the damage radius of 4-psia overpressure for Earth impact by the asteroid 2019 PDC is from 30 to 84 km, while the damage radius of third-degree burns is from 6 to 135 km. The study notes that input parameters are uncertain, and airburst is regarded as a point explosion at the altitude of maximum energy disposition.
- An overview of the United Nations Platform for Space-Based Information for Disaster Management and Emergency Response (UN-SPIDER) and how the UN Office of Outer Space Affairs supports planetary defense and related disaster management planning.

Session 7: Issues Affecting the Decision to Act

Presenters discussed legal issues associated with planetary defense, the importance of developing a decision process before a real threat is discovered, and elements of a mandate for States that might undertake planetary defense actions.

- Several international law rules are applicable to the conduct of planetary defense missions. Some additional steps could be taken to:
    - Ensure that planetary defense missions are carried out in conformity with international law and
    - Enhance legal certainty, diminish political concerns, and increase international acceptance for proposed planetary defense measures.
- In the case of a NEO impact threat emergency situation, there will be limited time to make decisions and take action, and instruments for potential future planetary defense missions could

be developed in advance to address important points that should be considered before action is taken to mitigate a NEO impact threat.

- Elements of a mandate for State(s) carrying out the planetary defense mission should include:
  - A draft agreement by the potentially affected State(s) and the State(s) capable and willing to conduct the mission
  - Modalities for the cooperation among States participating in the mission as well as common procedures to undertake the mission
  - Modalities for the dissemination of information regarding NEO impact threats
  - Generally agreed criteria for the selection of planetary defense methods
  - Parameters for the authorization for certain planetary defense technologies, most importantly nuclear explosive devices (NEDs).
  - Safety standards for the conduct of planetary defense missions

Session 8: Communications to the Public

Communications to the public will be critical in the event an actual threat is discovered. Presenters summarized recent developments:

- The International Asteroid Warning Network (IAWN) is an UN-endorsed partnership of scientific institutions, observatories, space agencies and other interested parties that perform observations, orbit computation, modeling and other scientific research related to the impact potential and effects of asteroids and comets.
  - IAWN endeavors to foster a shared understanding of the NEO hazard and optimize the scientific return on these small celestial bodies.
  - IAWN is specifically tasked with developing a strategy using well-defined communication plans and protocols to assist Governments in the analysis of asteroid impact consequences (and in the planning of mitigation responses).
  - IAWN has prepared a guideline template in the event of a pending, credible real-world impact event. The rationale for these communications guidelines is to provide correct, clear, and concise information on the nature of an impact hazard. The product provides a "playbook template" that IAWN (and SMPAG) can quickly reference, including the thresholds and criteria already outlined in Session 1.
  - An IAWN website has been created (http://www.iawn.net).
- A recent IAWN communications workshop recommends
  - Establishment of a 5-year plan and midterm actions for becoming the global trusted and credible source of NEO information, notification and warning
  - Employment of a full-time communications officer to oversee the development of the 5-year plan.
  - Define more concrete cooperation between UNOOSA and IAWN in areas of communication with the general public, dissemination of NEO-related information (early warning) to Member States, and capacity-building activities (through the UN-SPIDER network).
  - Recommendation to establish IAWN ad-hoc working group on communications.
- Asteroid search campaigns and naming campaigns provide opportunities to educate the public.
- The PDC threat exercise could be used to bring students in all age brackets, from multiple disciplines and even from multiple universities together to collect data to determine whether and how age and cultural behavior differences might affect how decisions are made.

  - Academic material could be developed for all age brackets based on existing resources, including JPL's NEO Deflection app, Planetary Society educational videos, and from those online who have been conducting similar activities.
  - Over the long term, a coordinated effort on Asteroid Day (June 30th) 2020 (and/or in parallel to the 2021 PDC) involving the public in schools in the US and around the world could use this material for citizen science exercises.
- Pertinent information about detecting, characterizing and mitigating NEO threats is dispersed throughout different organizations. Scattered and unorganized information can have a significant impact at the time of crisis, resulting in inefficient processes and decisions made on incomplete data. A Planetary Defense Mitigation Gateway has been developed to provide a framework to better integrate the dispersed, diverse pieces of information residing at different organizations across the world. The gateway includes:
  - A state-of-the-art smart search discovery engine based on PD knowledge base, information mining, and reasoning;
  - A document archiving and understanding mechanism for managing and utilizing the results produced by the PD science community
  - An evolving PD knowledge base accumulated from existing literature, using natural language processing and machine learning
  - A 3D visualization tool that allows viewers to analyze Near-Earth approaches in a three-dimensional environment.

Media Panel Session

Discussion by a panel of invited journalists provided the following specific thoughts and recommendations:

- Reporters can live with uncertainty; don't fudge on what you don't know for sure—it's OK to say you don't know.
- Reporters expect patience from sources and a willingness to provide background in terms understandable to laymen.
- A good perspective is "Something you should know is..."
- NASA's Planetary Defense Coordination Office could produce a 10-minute video on planetary defense for broadcast meteorologists in smaller towns nationwide as a way to make the general public aware of what's being done.
- Experts should be careful with graphics (e.g., the risk corridor and its meaning).
- Representatives of the media work hard to get it right, and "would much rather be corrected during interviews than have to correct after publication."
- The media are particularly interested in breaking news, fundamental breakthroughs, and "wondrous things."
- Experts should "get over" seemingly sensational headlines. The media won't use scientific language that's not understandable to the general public.
- We should consider using a bulletized format in "press releases" for our tabletop exercises and possibly for real events. And possibly three levels of announcements for: 1) national/general media, 2) emergency managers, 3) full-blown scientific information for experts.
- The media prefers talking directly with experts in a timely fashion, noting that PR folks often get in the way.
- Technical experts should avoid speaking in too much technical jargon, but if they use technical terms, they should translate. For example, explain what a risk corridor is/means and why a member of the public should care.

- A teleconference could be a good way to get a consistent message out for a big event.

RESOLUTIONS AND RECOMMENDATIONS

Resolutions

At the end of the conference, participants voted to accept and strongly support three items:

1. **Develop Plans for the Apophis Close Approach**: The PDC 2019 recognizes the April 13, 2029 close encounter (inside the distance of geosynchronous satellites) by the potentially hazardous asteroid (99942) Apophis is a once-per-thousand-year natural event that will provide a unique opportunity for advancing small body knowledge for both science and planetary defense. PDC 2019 encourages the community to continue to evaluate the opportunities that the flyby provides, including prospects for advancing public outreach and education.
2. **Support Development and Launch of ESA's Hera Mission:** PDC recognizes the criticality of testing the kinetic impactor, as it is currently the most technologically mature planetary defense technique. With the DART mission now in development and on track for a July 2021 launch and September 2022 encounter with Didymos-B, Hera will maximize the collection of data on the deflection test such as determining the momentum transfer efficiency via precise measurement of the mass of Didymos-B. The community gathered at the PDC 2019 conference encourages all ESA Member States to fully support ESA's Hera mission for full implementation at the upcoming Space19+ conference. This action will help understand the effectiveness of and gain confidence in kinetic impactors as a means to deflect a threatening object and advance worldwide planetary defense capabilities.
3. **Support NEOCam Development and Launch:** The PDC2019 conference participants are excited to see the progress of the NEOCam team in developing their design. Multiple studies now support the finding that the NEOCam space-based telescope, with its infrared NEO detection capabilities, will greatly accelerate completion of the search for as-yet undiscovered potentially hazardous objects. At the same time, NEOCam will also provide enhanced remote characterization of those objects. Early detection and cataloging of those objects provide us with our best chance of successfully defending ourselves against future Earth impacts. Additionally, the data collected by NEOCam will expand our opportunities for future exploration, solar system science, and resource utilization. Therefore, the planetary defense community gathered at the PDC conference encourages the full funding of the NEOCam mission for flight development at the earliest opportunity.

Recommendations from the Exercise

Legal aspects of planetary defense

- More study of the legal aspects of planetary defense and incorporation of legal provisions into planetary defense planning and preparation is warranted (e.g., during the hypothetical asteroid threat exercise, a good-faith attempt to deflect the incoming asteroid did deflect the majority of the asteroid's original mass from the original impact location (Denver, Colorado, USA) but still left a fragment of damaging size on course to impact New York. This example raises questions about the associated liabilities, legalities, etc., both domestically and internationally).

Deflection uncertainties

- The uncertainties associated with the deflection imparted to a NEO via a nuclear device need to be studied (similar to the way that "beta" is studied for kinetic impactors).

- Uncertainty in how much applied deflection "Delta-V" (change-in-velocity) an NEO can absorb without accidental fragmentation continues to cause difficulties in designing and sizing NEO deflection missions; e.g., When is the Delta-V too high? Will dividing the Delta-V into smaller applications via multiple spacecraft avoid accidental NEO fragmentation? How many spacecraft/launches are needed?) These considerations can dramatically affect the required size, cost, complexity, and development timeline for mitigation missions and need to be understood well enough for effective planning and implementation of missions in a real scenario.

Public Information

- Develop improved designs for documentation, imagery, etc., intended for public communications (e.g., improved ways to communicate scenario status with uncertainty, the concept of the "risk corridor," etc.).
- The planetary defense community should assess and enhance the capabilities of web-based services likely to see large increases in traffic during a real scenario.
- The community should develop proactive approaches to counteract conflicting information from unreliable sources.

Mitigation

- Nuclear device deflection modeling capabilities should be incorporated into the CNEOS NEO Deflection App.
- While an 8-year warning time is long enough to offer a wide range of space mission options to mitigate the impact of a ~200 m asteroid, similar thresholds should be developed for shorter warning times.
- Solar Electric Propulsion (SEP) is an important enabling technology for missions to characterize and mitigate the threat: it widens the envelope of possible space missions, especially for rendezvous. Other advanced propulsion techniques (e.g., nuclear thermal propulsion) could enable faster response times.
- An early, fast-response characterization mission is highly recommended, and may be key to a successful deflection campaign.
- Great progress has been made in modeling impact effects; more work seems warranted in modeling the physics of asteroid deflection (e.g., deflection vs. fragmentation vs. total disruption).
- Use of nuclear explosive devices for asteroid deflection continues to face legal and political concerns, but progress is being made in understanding the issues.
- It’s important to maintain an accessible and searchable archive of past sky images. Such “precovery” observations could be critical for enhancing orbit and risk predictions in short-warning scenarios.

Participants also provided their thoughts and suggestions of items that should be considered by organizers of the 2021 conference (will be held in the United Nations Facility in Vienna, Austria). These are summarized in ATTACHMENT 6.

ATTACHMENT 1: ORGANIZING COMMITTEE

NAME	AFFILIATION	
William Ailor	The Aerospace Corporation	Co-Chair
Brent Barbee*	NASA Goddard Space Flight Center	Co-Chair
Gerbs Bauer*	University of Maryland	
Bruce Betts	The Planetary Society	
Mark Boslough	University of New Mexico	
Marina Brozovic	JPL	
Jual Cano	Deimos Space	
Ian Carnelli	European Space Agency (ESA)	
Nancy Chabot*	APL	
Clark Chapman	Southwest Research Institute	
Andy Cheng*	APL	
Paul Chodas	NASA Jet Propulsion Laboratory	
Jean-Michel Contant	International Academy of Astronautics (IAA)	
Fabrice Dennemont	International Academy of Astronautics (IAA)	
Gerhard Drolshagen	Carl von Ossietzky University Oldenburg, Germany	Co-Chair
Victoria Friedensen	NASA Headquarters	
Mariella Graziano	GMV Aerospace	
Alan Harris (DLR)	German Space Agency (DLR)	
Alan Harris (US)	More Data!	
Curtis Iwata	The Aerospace Corporation	
Barbara Jennings	Sandia National Laboratories	
Lindley Johnson	NASA Planetary Defense Officer	
Tom Jones	Association of Space Explorers	
Alex Karl	Space Generation Advisory Council	
Romana Kofler	United Nations Office of Outer Space Affairs	
Detlef Koschny	European Space Agency, ESA/ESTEC	
Rob Landis	NASA Headquarters	
L.A. Lewis	Federal Emergency Management Agency (FEMA)	
Ed Lu	LeoLabs	
Amy Mainzer	NASA Jet Propulsion Laboratory	
Nahum Melamed	The Aerospace Corporation	
Patrick Michel	Côte d'Azur Observatory	
David Morrison	NASA Lunar Science Institute	
Jan Osburg	RAND Corporation	
Marius-Ioan Piso	Romanian Space Agency (ROSA)	
Gisela Poesges	Ries Crater Museum	
Andy Rivkin*	APL	
Margaret Simon*	APL	
Michael Simpson	Secure World Foundation	
Angela Stickle*	APL	
Megan Syal	Lawrence Livermore National Laboratory	
Marco Tantardini	ARM Study, Keck Institute for Space Studies	
Giovanni Valscchi	IAPS, INAF	
Karel van der Hucht	International Astronomical Union (IAU)	
Makoto Yoshikawa	Japan Aerospace Exploration Agency (JAXA)	

*Member of Local Organizing Committee

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United Nations Office of Outer Space Affairs (UNOOSA)

ATTACHMENT 3: ATTENDEES

First Name	Last Name	Company
Paul	**Abell**	NASA Johnson Space Center
Elena	Adams	JHUAPL
Michael	Aftosmis	NASA
Harrison	Agrusa	University of Maryland
William	Ailor	The Aerospace Corporation
Rudolf	Albrecht	Austrian Space Forum
Alice	Anderson	Feature Story News
Victoria	Andrews	NASA
Steve	Arnold	JHU Applied Physics Laboratory
Jacques	Arnould	Centre national d'etudes spatiales
David	Aswad	
Justin	Atchison	The Johns Hopkins Applied Physics Lab
Myra	Bambacus	NASA
Flavio	Bandini	Thales Alenia Space
Brent	Barbee	NASA/GSFC
Meghan	Bartels	Space.com
James Gerbs	Bauer	University of Maryland
Seth	Baum	Global Catastrophic Risk Institute
Jacques	Bedel	Saint-Thomas Productions
Jim	Bell	Arizona State University
Harel	Ben-Ami	Israel Space Agency (ISA)
Lance	Benner	JPL/Caltech
George	Berkheimer	The Business Monthly
Fabrizio	Bernardi	Space Dynamics Services
Bruce	Betts	The Planetary Society
Linda	Billings	NIA
Richard	Binzel	MIT
Mirel	Birlan	Paris Observatory
Petr	Bohacek	Charles University
Aaron	Boley	The University of British Columbia
Mark	Boslough	Los Alamos National Lab
Peter	Brown	Dept of Physics and Astronomy, Western University
William	Brown	Colorado State University Pueblo
Jared	Brown	Future of Life Institute
Marina	Brozovic	Jet Propulsion Laboratory
Megan	Bruck Syal	Lawrence Livermore National Laboratory
Alexandria	Bruner	FEMA
Juan Sebastian	Bruzzone	Catholic University of America
Michael	Buckley	Johns Hopkins Applied Physics Lab
Adriano	Campo Bagatin	Universidad de Alicante
Juan	Cano	ESA / ESRIN
Sean	Carey	IPAC/Caltech
John	Carrico	
Nancy	Chabot	JHU/APL
Clark	Chapman	Southwest Research Inst. (retired)
Serge	Chastel	Institute for Astronomy - University of Hawai`i
Andrew	Cheng	JHU Applied Physics Lab
Bin	Cheng	Tsinghua University
Steve	Chesley	JPL
Paul	Chodas	Jet Propulsion Lab
Eric	Christensen	The University of Arizona
Alberto	Conti	Ball Aerospace
William	Cooke	NASA-MSFC
Ben	Corbin	IDA Science and Technology Policy Institute
Ivan	Couronne	Agence France-Presse
Roc	Cutri	Caltech/IPAC

Terik	Daly	JHU/APL
Doris	Daou	NASA
Andrey	Degtyarev	Voice of America
Jakob	Deller	MPI for Solar System Research
Joseph	DeMartini	University of Maryland, College Park
Larry	Denneau	University of Hawaii
Joshi Yogeshkumar	Dileepkumar	International Astronomical Search Collaboration (IASC) / Poornima University, Jaipur
Jessie	Dotson	NASA Ames Research Center
Casey	Dreier	The Planetary Society
Gerhard	Drolshagen	University of Oldenburg
Esther	Drolshagen	University of Oldenburg
David	Dunham	KinetX Aerospace, Inc.
John	Dyster	Northrop Grumman Innovation Systems
Alissa	Earle	MIT
Michael	Egan	NGA
Siegfried	Eggl	University of Washington / LSST
Jacob	Elliott	Purdue University
Martin	Elvis	Center for Astrophysics | Harvard & Smithsonian
Carolyn	Ernst	JHU/APL
Souheil	Ezzedine	LLNL
Laura	Faggioli	ESA NEO Coordination Centre
Eugene	Fahnestock	Jet Propulsion Laboratory
Albert	Falke	Airbus
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Jeff	Foust	SpaceNews
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Deborah	Gembara	Reuters Television
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Tommy	Grav	Planetary Science Institute
Bill	Gray	Project Pluto
Mariella	Graziano	GMV A&D
Kevin	Greenaugh	DOE/NNSA
Nell	Greenfieldboyce	National Public Radio
Phil	Groves	Apophis Pictures LLC
Jan Thimo	Grundmann	DLR German Aerospace Center Institute of Space Systems
Alissa	Haddaji	Harvard Business School
Alan	Harris	MoreData!
Christine	Hartzell	University of Maryland
George	Helou	Caltech/IPAC
Alain	Herique	UGA / IPAG / CNRS
Daniel	Hestroffer	IMCCE/Paris Observatory - CNRS
Masatoshi	Hirabayashi	Auburn
Catherine	Hofacker	Aerospace America
Matthew	Holman	Center for Astrophysics, Harvard & Smithsonian
Carrie	Holt	University of Maryland College Park
Harry	Horton	Feature Story News
Kirsten	Howley	Lawrence Livermore National Laboratory
Nikolay	Ivanovich	SRIAM
Venkataramaiah	Jagannatha	Jan University, Bengaluru
Scott	Janzwood	University of Waterloo
Nastassia	Jaumen	Voice of America
Robert	Jedicke	University of Hawaii
Ruediger	Jehn	ESA

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Lynne	Jones	
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Mathew	Kaplan	The Planetary Society
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Alex	Karl	IAF TC NEOs
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Yaeji	Kim	Auburn University
Patrick	King	University of Virginia/Lawrence Livermore National Laboratory
Thagoon	Kirdkao	Learning Center for Earth Science and Astronomy
Valarie	Klavens	Motivf Corporation
Matthew	Knight	University of Maryland
Romana	Kofler	United Nations Office for Outer Space Affairs
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Emily	Kramer	JPL/Caltech
Steven	Krein	Northrop Grumman Innovation Systems
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Burt	Lamborn	Space Dynamics Laboratory
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Jeffrey	Larsen	University of Arizona
Chatchai	Leaorsrisuk	Learning Center for Earth Science and Astronomy
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Ruthan	Lewis	NASA Goddard Space Flight Center
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Eva	Lilly	Planetary Science Institute
Tyler	Linder	Astronomical Research Institute
Tim	Lister	Las Cumbres Observatory
Xiang	Liu	IPAC/Caltech
Sen	Liu	Hypervelocity Institute, CARDC
Randolph	Longenbaugh	NASA Ames Research Center
Wayne	Loschen	Johns Hopkins University Applied Physics Laboratory
Bertrand	Loyer	ST THOMAS PRODUCTIONS
Edward	Lu	Asteroid Institute
Robert	Luther	Museum für Naturkunde / Freie Universität Berlin
Mark	Lysek	Jet Propulsion Laboratory
Joshua	Lyzhoft	NASA - Goddard Space Flight Center
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Abigail	Nastan	Jet Propulsion Laboratory
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Zeeve	Rogoszinski	University of Maryland
Clemens	Rumpf	NASA Ames Research Center & USRA
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Nikola	Schmidt	Charles University
Peter	Schultz	Brown University
Robert	Seaman	University of Arizona
Ishan	Shams	George Mason University
Michael	Shao	Jet Prop Lab
Fazle	Siddique	Applied Physics Lab
Margaret	Simon	Applied Physics Lab
Joshua	Sloane	
Sarah	Sonnett	Planetary Science Institute

Kya	Sorli	Lawrence Livermore National Laboratory
Timothy	Spahr	NEO Sciences, LLC
Robert	Spencer	Department of Energy/NNSA
Thomas	Statler	NASA Headquarters
Bringfried	Stecklum	Thuringian State Observatory
Duncan	Steel	Centre for Space Science Technology
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Justyna	Surowiec	Johns Hopkins University Applied Physics Laboratory
Martin	Svec	Charles University
Tim	Swindle	University of Arizona
Erik	Syrstad	Space Dynamics Laboratory
Gonzalo	Tancredi	Depto. Astronomia, UdelaR
Marco	Tantardini	Presidency of the Council of Ministers
Patrick	Taylor	Lunar and Planetary Institute
Stacy	Teng	Institute for Defense Analyses
Robert	Terry	Dr. Robert E. Terry, Independent Research Professional, LLC
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Bruno	Victorino Sarli	NASA - Goddard Space Flight Center
Anne	Virkki	Arecibo Observatory/Univ. of Central Florida
Paul	Voosen	Science
Richard	Wainscoat	University of Hawaii, Institute for Astronomy
James	Walker	Southwest Research Institute
Maya	Wei-Haas	National Geographic
Robert	Weryk	University of Hawaii
Thomas	Whalen	University of Maryland
Lorien	Wheeler	NASA Ames, RedLine Performance Solutions
Bailey	Williamson	College of Charleston
Jason	Witry	George Washington University
Nancy C.	Wolfson	DC Media Tech Studies
Lisa	Wood	Ball Aerospace
Chaowei	Yang	George Mason University
Donald	Yeomans	JPL
Yang	Yu	Beihang University
Anatoliy	Zaremba	The Aerospace Corporation
Dongyue	Zhao	Beijing Institute of Technology
Alan	Zucksworth	Miami Valley Astronomical Society

ATTACHMENT 4: PROGRAM

DAY 1		Monday 29 April 2019	
0800		REGISTRATION	
0850		OPENING REMARKS: Conference Organizers	
0900		WELCOME: Jason Kalirai, Civil Space Mission Area Executive, JHUAPL	
0905		WELCOME: Welcome - GSFC	
0910		KEYNOTE: The Honorable James Bridenstine, NASA Administrator	
0940		BREAK	
		SESSION 1: KEY DEVELOPMENTS SESSION ORGANIZERS: Detlef Koschny, Lindley Johnson	
1000	IAA-PDC-19-01-01	The United Nations And Planetary Defence: Key Developments Following UNISPACE+50 In 2018	Kofler, OOSA
1012	IAA-PDC-19-01-02	Planetary Defence India: Capability, future requirements, and Deflection Strategy for 2019 PDC	Singh, ISRO
1024	IAA-PDC-19-01-03	Planetary defence activities at the European Space Agency	Jehn, ESA
1036	IAA-PDC-19-01-04	Planetary Defense Program of the United States	Johnson, NASA
1048	IAA-PDC-19-01-05	Israel Space Agency & Planetary Defense	Harel Ben-Ami, ISA
		SESSION 2: ADVANCEMENTS IN NEO DISCOVERY & CHARACTERIZATION SESSION ORGANIZERS: Alan Harris (US), James (Gerbs) Bauer, Giovanni Valsecchi, Amy Mainzer	
1100	IAA-PDC-19-02-01	Recent Evolutions In ESA's NEO Coordination Centre System	Cano, Italy
1112	IAA-PDC-19-02-02	NEODyS services migration to ESA's NEO Coordination Centre: the effort and the improvements	Bernardi, Italy
1124	IAA-PDC-19-02-03	Building the Reference Small Body Population Model	Spahr, USA
1136	IAA-PDC-19-02-04	NEMO - a global near real-time fireball monitoring system	Drolshagen & Ott, Germany
1148	IAA-PDC-19-02-05	Observational Activities At ESA's NEO Coordination Centre	Micheli, Italy
1200	IAA-PDC-19-02-06	Impact Monitoring System of the Institute of Applied Astronomy of the Russian Academy of Sciences	Vavilov, Russia
1212	IAA-PDC-19-02-07	Update Of NEA Population And Current Survey Status	Harris, USA
1224	IAA-PDC-19-02-08	Catalina Sky Survey's Increased Discovery and Follow-up Capability	Christensen, USA
1236		LUNCH	
		SESSION 2 (CONTINUED)	
1400	IAA-PDC-19-02-10	Detection Of Small Impacting Asteroids With The ATLAS Telescope System	Denneau, USA
1412	IAA-PDC-19-02-11	The PAN-STARRS Data Archive — An Invaluable Resource Of Faint Near Earth Object Detections	Wainscoat, USA
1424	IAA-PDC-19-02-12	The Minor Planet Center Data Processing System	Holman, USA
1436	IAA-PDC-19-02-13	The Digest2 – NEO classification code	Veres, USA

1448	IAA-PDC-19-02-14	Is There A Prefered Date For A Possible Impact?	Tancredi Uruguay
1452	IAA-PDC-19-02-15	The Contribution Of Intermediate- And Long-Period Asteroids To The Overall Large-Body Impact Hazard	Steel, New Zealand
1504	IAA-PDC-19-02-16	The Earth-Impact Risk From Manx Comets	Ramanjooloo, USA
1516	BREAK		
1546	IAA-PDC-19-02-17	The Impact of Small Near-Earth Asteroid 2018 LA	Farnocchia, USA
1558	IAA-PDC-19-02-18	Identifying Short-Term Impactors With LSST	Naidu, USA
1610	IAA-PDC-19-02-19	Recent Results In Characterization Of Near-Earth Objects By The Neowise Mission	Masiero, USA
1622	IAA-PDC-19-02-20	Rapid Response Characterization of Potential NEO Impactors	Moskovitz, USA
1634	IAA-PDC-19-02-21	Arecibo Radar Observations Of Potentially Hazardous Asteroids	Taylor, USA
1646	IAA-PDC-19-02-22	The LCO Follow-up Network for NEOs	Lister, USA
1658		INJECT: PRESS RELEASE #1	
1730		ADJOURN DAY 1	
		WELCOME RECEPTION (18:00 to 20:00, accompanying persons invited)	

DAY 2		Tuesday 30 April 2019	
0820		INTRODUCTORY REMARKS	
		Session 2: Continued	
0830	IAA-PDC-19-02-23	The boulders on asteroid Ryugu: clues to the formation history of the top-shaped morphology	Cheng, China
0842	IAA-PDC-19-02-24	Faint NEO Observations Using The UH-2.2m Telescope	Fohring, USA
0854	IAA-PDC-19-02-25	Discovering and Studying Near Earth Objects with The Large Synoptic Survey Telescope (LSST)	Jones, USA
0906	IAA-PDC-19-02-26	The Near-Earth Object Camera: Overview	Mainzer, USA
0918	IAA-PDC-19-02-27	NEOCam Survey Cadence and Simulation	Grav, USA
0930	IAA-PDC-19-02-28	The NEOCam Science Data System	Cutri, USA
0942	IAA-PDC-19-02-29	Near-Earth Asteroids Monitoring for Hazard Assessments	Birlan, France
0954	IAA-PDC-19-02-30	Find_Orb: Orbit Determination and Analysis Software	Gray, USA
1006		BREAK	
		SESSION 3: APOPHIS SESSION ORGANIZERS: Marina Brozovic, Davide Farnocchia	
1036	IAA-PDC-19-03-01	Apophis 2029: Planetary Defense Opportunity Of The Decade	Binzel, USA
1048	IAA-PDC-19-03-02	Yarkovsky Acceleration Of (99942) Apophis	Tholen, USA

1100	IAA-PDC-19-03-03	Abrupt Alteration of Apophis' Spin State Redux	Scheeres, USA
1112	IAA-PDC-19-03-04	Using a Discrete Element Method to Investigate Seismic Response and Spin Change of 99942 Apophis During its 2029 Tidal Encounter with Earth	DeMartini, USA
1124	IAA-PDC-19-03-05	Trajectory Concepts For An Apophis Rendezvous Mission	Siddique, USA
1136	IAA-PDC-19-03-06	Asteroid Probe Experiment: Mission To Apophis	Plescia, USA
1148	IAA-PDC-19-03-07	AI3: The Asteroid In-Situ Investigation – 3 Ways to measure the interior of asteroid Apophis	Deller, Germany
1200	IAA-PDC-19-03-08	A Cubesat Mission to Asteroid Apophis Based on M-ARGO?	Koschny, Germany
1212	IAA-PDC-19-03-09	Science and Planetary Defense Priorities for Spacecraft Encounter Mission Concepts at (99942) Apophis During its 2029 Close Encounter with Earth	Bell, USA
1224	IAA-PDC-19-03-10	Six Very Close Potentially Hazardous Asteroid Flybys in the Late 2020s	Benner, USA
1236	**LUNCH & SPEAKER - Mr Dennis Andrucyk, Deputy Associate Administrator, NASA**		
1400	IAA-PDC-19-03-11	Lessons From The 2012 TC4 Campaign: First Global Planetary Defense Exercise	Reddy, USA
1415		**INJECT #2**	
1500		**EXERCISE GROUPS DEVELOP RECOMMENDATIONS**	
1600		**BREAK**	
1630		**GROUPS FEEDBACK RECOMMENDATIONS**	
1700		**DECISION MAKER RESPONSES**	
1730		**ADJOURN DAY 2**	
1730		***POSTER RECEPTION (5:30 to 7:30 PM)***	

DAY 3		**Wednesday 1 May 2019**	
0820		**INTRODUCTORY REMARKS**	
		SESSION 4: DEFLECTION & DISRUPTION MODELS & TESTS **SESSION ORGANIZERS: Patrick Michel, Tom Jones, Andy Cheng**	
0830	IAA-PDC-19-04-01	Simulation Of The Dart Impact: Effects Of Impact Conditions And Target Properties	Bruck-Syal, USA
0848	IAA-PDC-19-04-02	Progress At Los Alamos National Laboratory (LANL) On The Inter-Agency Agreement On Planetary Defense	Plesko, USA
0906	IAA-PDC-19-04-03	Modeling the DART kinetic impactor and crater formation using realistic spacecraft shapes	Owen, USA
0924	IAA-PDC-19-04-04	Exploring Effects of Spacecraft Geometry and Target Structure on the DART Impact	Stickle, USA
0942	IAA-PDC-19-04-05	Understanding the Effect of Rubble Pile Structures on Asteroid Deflection	Graninger, USA
1000	IAA-PDC-19-04-06	Applications Of Dart Impact Simulation Results	Rainey, USA
1018	IAA-PDC-19-04-08	**BREAK (30 minutes)**	

1048	IAA-PDC-19-04-09	Numerical modelling of the DART impact and the importance of the Hera mission	Raducan, UK
1106	IAA-PDC-19-04-10	Impact simulations of the Double Asteroid Redirection Test (DART) - Results from the HERA Impact Simulation Group	Luther, Germany
1124	IAA-PDC-19-04-11	Deflection Of A Small Object Using A Kinetic Impactor	Remington, USA
1142	IAA-PDC-19-04-12	Size Scaling of Momentum Enhancement during Hypervelocity Impact of Porous and Consolidated Rock	Walker, USA
1200		**LUNCH**	
		SESSION 5: MITIGATION CAMPAIGN DESIGN **SESSION ORGANIZERS: Nahum Melamed, Ian Carnelli, Marco Tantardini**	
1330	IAA-PDC-19-05-01	Double Asteroid Redirection Test	Reed, USA
1342	IAA-PDC-19-05-02	Observations of Didymos in Support of AIDA/DART	Thomas, USA
1354	IAA-PDC-19-05-03	Proximity Observations by the Didymos Reconnaissance and Asteroid Camera for OpNav (DRACO)	Ernst, USA
1406	IAA-PDC-19-05-04	Double Asteroid Redirection Test: Technology and Engineering Challenges	Adams, Usa
1418	IAA-PDC-19-05-05	Renderer and Camera Emulator (RCE) for NASA'S Double Asteroid Redirection Test (DART)	Mehta, USA
1430	IAA-PDC-19-05-06	HERA: European component of the Asteroid Impact & Deflection Assessment (AIDA) mission to the binary asteroid Didymos	Michel, France
1442	IAA-PDC-19-05-07	Hera planned mission and payload operations at close proximity of the Didymos binary asteroid system after DART impact	Karatekin, Belgium
1454	IAA-PDC-19-05-08	Autonomous GNC and data fusion for the HERA mission	Graziano, Spain
1506	IAA-PDC-19-05-09	Asteroid Prospection Explorer (APEX) CubeSat for Hera mission	Kohout, Finland
1518	IAA-PDC-19-05-10	A Method for Defending Against Long-Period Comets	Eismont, Russia
1530		**BREAK**	
1600	IAA-PDC-19-05-11	Spacecraft Mission Design For The Mitigation Of The 2019 PDC Hypothetical Asteroid Threat	Barbee, USA
1612	IAA-PDC-19-05-12	Characterization and deflection missions of the fictitious asteroid 2019 PDC	Roa, USA
1624	IAA-PDC-19-05-13	See a New World in 17 Hours – First Results, Design and Mission of the Mobile Asteroid Surface Scout (Mascot) on Ryugu	Ho, Germany
1636	IAA-PDC-19-05-14	More Than One For All – The Synergy of Modularity and Re-Use in Nanolander Development in the Continuation of the Design of Mobile Asteroid Surface Scouts (MASCOT)	Lange, Germany
1648	IAA-PDC-19-05-15	NEOCAM Instrument Design and Performance Model	Trangsrud, USA
1700	IAA-PDC-19-05-16	System of Observation of Daytime Asteroids: trajectory and orbit design	Kovalenko, Russia
1712	IAA-PDC-19-05-17	BIRDY – Potential use of SmallSat for NEO reconnaissance and exploration	Hestroffer, France
1724		**INJECT: PRESS RELEASE #3**	
1800		**ADJOURN DAY 3**	
		PUBLIC EVENT	

DAY 4		**Thursday 2 May 2019**	
0820		**INTRODUCTORY REMARKS**	
		SESSION 6: IMPACT CONSEQUENCES & DISASTER RESPONSE **SESSION ORGANIZERS: David Morrison, Mark Boslough. L.A. Lewis**	
0830	IAA-PDC-19-06-01	Atmospheric Injections from Impacts of Kilometer Scale Asteroids	Robertson, USA
0842	IAA-PDC-19-06-02	Strength and Breakup Factors in Impact Scenario Risk Assessment	Wheeler, USA
0854	IAA-PDC-19-06-03	Next Steps in Impact Risk Assessment	Mathias, USA
0906	IAA-PDC-19-06-04	Asteroid to Airburst; Comparing Semi-analytical Airburst Models to Hydrocodes	McMullan, UK
0918	IAA-PDC-19-06-05	Modeling Thermal Radiation from Asteroid Airbursts	Stern, USA
0930	IAA-PDC-19-06-06	"Effective Height Of Burst" Revisted	Boslough, USA
0942	IAA-PDC-19-06-07	Airburst Detection Capability of the Infrasound Segment of the CTBTO International Monitoring System	Brown, Canada
0954	IAA-PDC-19-06-08	Recent Glass Strewn Field From Fireball Over Chile	Schultz, USA
1006	IAA-PDC-19-06-09	GPU Parallel Algorithm for Hypersonic Flow Around Asteroid	Bai, China
1018	IAA-PDC-19-06-10	The Impact Effects Knowledgebase: Fast Prediction of the Consequences of NEO Collisions with Earth	Luther, Germany
1030		**BREAK**	
1100	IAA-PDC-19-06-11	Simulation of PDC 2019 Asteroid Land and Ocean Impacts: Consequences on US Major Cities for Disaster Response and Management	Ezzedine, USA
1112	IAA-PDC-19-06-12	Hazard Estimate Of 2019 PDC Impact Scenario	Dang, Ghina
1124	IAA-PDC-19-06-13	Coordinated Disaster Preparedness And Response For Near-Earth Object (NEO) Threats – Experiences From The "United Nations Platform For Space-Based Information For Disaster Management And Emergency Response (UN-SPIDER)	Ravan, OOSA/UN-SPIDER
1136	IAA-PDC-19-06-14	Intelligent Surge: Improving Healthcare Preparedness In Times Of Disaster	Loschen, USA
1148	IAA-PDC-19-06-15	Role of Space Technology for Disaster Management: Agenda and Action Plan	Jagannatha, India
1200	**LUNCH & SPEAKERS** • **Dr Aaron Miles, National Security Division, Office of Science and Technology Policy, Executive Office of the President** • **Mr Damon Penn, Assistant Administrator, Emergency Response Directorate, Federal Emergency Management Agency, Department of Homeland Security**		

		SESSION 7: ISSUES AFFECTING DECISION TO ACT **SESSION ORGANIZERS: Mariella Graziano, Victoria Friedensen**	
1330	IAA-PDC-19-07-01	Legality of Planetary Defense Missions and Considerations for International Decision Bodies	Marboe, Austria
1345	IAA-PDC-19-07-02	Sustainability of International Planetary Defense Decision-Making: What Can Go Wrong Even if We Deflect an Asteroid?	Bohacek, Czech Republic
1400	IAA-PDC-19-07-03	International Liability and Responsibility Issues in Planetary Defense	Soucek, The Netherlands
1415	IAA-PDC-19-07-04	Responsibility System on the Defense of Near-Earth Objects	Wang, China
1430	IAA-PDC-19-07-05	The U.S. National Near-Earth Object Preparedness Strategy and Action Plan: Summary of Progress to Date	Friedensen, USA
1445	IAA-PDC-19-07-07	Accounting For Violent Conflict Risk In Planetary Defense Decisions	Baum, USA
1500		**BREAK**	
		SESSION 8: COMMUNICATIONS TO THE PUBLIC **SESSION ORGANIZERS: Alex Karl, Jan Osburg**	
1530	IAA-PDC-19-08-01	A Suggested Communications Standard For Asteroid Impact Alerts	Landis, USA
1545	IAA-PDC-19-08-02	An analysis of IAWN communication audiences and recommendations to increase publicity among the NEO community and the general public	Karl & Wolfson, Belgium
1600	IAA-PDC-19-08-03	Planetary Defense In The Classroom, A Social Science Perspective	Haddaji, USA
1615	IAA-PDC-19-08-04	Planetary Defense Mitigation Gateway: One-Stop Gateway for Pertinent PD- Related Contents	Shams, USA
1630		Poster Presentations	
1645		**INJECT #4**	
1730		**ADJOURN DAY 4**	
		CONFERENCE BANQUET	

DAY 5		Friday 3 May 2019
0850		INTRODUCTORY REMARKS
0900		PANEL SESSION: What journalists want to know about Planetary Defense. MODERATOR: Linda Billings PANELISTS: Dan Vergano, Buzzfeed Melissa Nord, CBS Channel 9 Sarah Kaplan, Washington Post
1000		BREAK
1015		UPDATE #5
1045		GROUP DISCUSSION & RECOMMENDATIONS
1145		DECISION MAKER DISCUSSION & DECISIONS
1230		LUNCH & SPEAKER
1400		DISCUSSION: LESSONS LEARNED AND RECOMMENDATIONS FROM PDC 2019
1500		*CONFERENCE ENDS*

http://pdc.iaaweb.org

POSTER PAPERS PDC 2019

SESSION 1

Bohacek	Czech Republic	IAA-PDC-19-01-P01	International Consequences of Planetary Defense Mission Failure: Parametric Analysis of Scenarios by Mandate and Deflection Method
Schmidt	Czech Republic	IAA-PDC-19-01-P02	The Role of Large Technical Systems in Establishing Global Planetary Defense Regime
Svec	Czech Republic	IAA-PDC-19-01-P03	Near-Earth Object Threat Mitigation in the Context of the Sendai Framework for Disaster Risk Reduction
Svec	Czech Republic	IAA-PDC-19-01-P04	Unilateral Planetary Defense Mission: An International Law Perspective

SESSION 2

Adams	USA	IAA-PDC-19-02-P01	Analysis of Alternatives Study for Near Earth Object Detection, Tracking and Characterization
Batista Negri	Brazil	IAA-PDC-19-02-P02	Analysis of Jupiter's Third-Body Perturbation Effects on Optimal Asteroid Deflection Maneuvers
Bauer	USA	IAA-PDC-19-02-P03	Surveying the Long-Period Comet Hazard
Betts	USA	IAA-PDC-19-02-P04	Shoemaker NEO Grants: Providing Opportunities to Upgrade NEO Observatories
Bolin	USA	IAA-PDC-19-02-P05	Impact Probability Evolution of Virtual Impacting Asteroids Observed by the Large Synoptic Survey Telescope
Carey	USA	IAA-PDC-19-02-P06	Methodology for Photometric Calibration of Infrared Observations of Solar System Objects
Chambers	USA	IAA-PDC-19-02-P07	The Second Pan-STARRS Telescope and Camera and the Performance of the Full Pan-STARRS System

Chastel	USA	IAA-PDC-19-02-P08	The Pan-STARRS Moving Objects Processing System: Six Years of Improvements through Reality Checks
Chesley	USA	IAA-PDC-19-02-P09	The Orbital Properties of Earth Impactors
Desmars	France	IAA-PDC-19-02-P11	DynAstVO: Near-Earth Asteroids Orbits and Close Approaches Databases
Dotson	USA	IAA-PDC-19-02-P12	Bayesian Inference of Physical Properties for Impact Scenarios
Eggl	USA	IAA-PDC-19-02-P13	The Large Synoptic Survey Telescope's Moving Object Processing System
Elvis	USA	IAA-PDC-19-02-P14	Big Telescopes Can Largely Solve the Albedo Question for 2019 PDC
Furfaro	USA	IAA-PDC-19-02-P15	Development of An Intelligent Target Prioritization System for NEOCam Ground-Based Follow-Up
Hartzell	USA	IAA-PDC-19-02-P16	In-Situ Regolith Cohesion Quantification Via Electrostatic Dust Lofting
Ieva	Italy	IAA-PDC-19-02-P17	Physical Characterization of the Carbonaceous NEO Population
Ivantsov	Turkey	IAA-PDC-19-02-P18	Statistics of the Close Encounters Predictions by the World Services
Kim	Korea	IAA-PDC-19-02-P19	Characterization of Earth Close Approaching Phase Using the OWL-Net Telescopes
Knight	USA	IAA-PDC-19-02-P20	What Hazards Lurk in the Soho/Stereo Datasets?
Kramer	USA	IAA-PDC-19-02-P21	Modeling the Photometric Behavior of the Near-Earth Comet Population
Masago Mescolotti	Brazil	IAA-PDC-19-02-P22	Effects of the Errors in the Physical Parameters to Observe the Triple Asteroid 2001SN263
Masci	USA		MODE: a new Moving Object Discovery Engine
Nath	USA	IAA-PDC-19-02-P23	Using Machine Learning to Predict Risk Index of Asteroid Collision
Neff	USA	IAA-PDC-19-02-P24	Near Earth Object Detection using Artificial Intelligence
Nugent	USA	IAA-PDC-19-02-P25	NEAT-R: Near-Earth Asteroid Tracking Reprocessing
Ott	Germany	IAA-PDC-19-02-P26	Infrasound for Global Fireball Monitoring
Shao	USA	IAA-PDC-19-02-P27	Search for NEOs Using a Farm of Small Synthetic Tracking Telescopes
Silva Neto	Brazil	IAA-PDC-19-02-P28	Using the Extended Kalman Filter to Navigate Around a Double Asteroid
Sonnett	USA	IAA-PDC-19-02-P29	The Effects of Binary Asteroids on Hazard Assessment and Mitigation
Spoto	France	IAA-PDC-19-02-P30	The Impact of the Gaia Mission on Asteroid Astrometry
Steel	New Zealand	IAA-PDC-19-02-P31	On the Likelihood of a Neptune-Crossing Object Being Directly Diverted onto a Path with Perihelion In the Inner Solar System
Surace	USA	IAA-PDC-19-02-P32	An Image Simulator for NEOCam

Vavilov	Russia	IAA-PDC-19-02-P33	A Robust Linear Method for Impact Probability Calculation
Virkki	USA	IAA-PDC-19-02-P34	The Capabilities and Future of the Arecibo Planetary Radar System In 2019-2023
Weryk	USA	IAA-PDC-19-02-P35	Near-Earth Objects in the Isolated Tracklet File
Wittholt	Germany	IAA-PDC-19-02-P36	New Impact Risk Scale for Potentially Hazardous Objects (PHO)
Stecklum	Germany	IAA-PDC-19-02-P37	TAUKAM's first look at NEOs

SESSION 3

Barnouin	USA	IAA-PDC-19-03-P01	Exploring Rotational, Surface and Interior Changes of the NEA/PHA Apophis During Its 2029 Close Encounter with the Earth
Boley	Canada	IAA-PDC-19-03-P02	The Beacon Mission
Brozovic	USA	IAA-PDC-19-03-P03	Goldstone and Arecibo Radar Observations of (99942) Apophis in 2021 and 2029
Earle	USA	IAA-PDC-19-03-P04	Apophis Seismology: The 'Smart Marbles' Concept
Gianolio	The Netherlands	IAA-PDC-19-03-P05	Precise Earth Impact Risk Assessment of PHOs via a Multi-Flyby Mission
Schmerr	USA	IAA-PDC-19-03-P06	The Asteroid Probe Experiment (APEX): Seismology At 99942 Apophis
Yaeji	USA	IAA-PDC-19-03-P07	Assessment of Resurfacing Process on Apophis During the 2029 Earth Flyby

SESSION 4

Braroo	USA	IAA-PDC-19-04-P01	Deflection of Potentially Hazardous Asteroids
Chen	China	IAA-PDC-19-04-P02	Research on Asteroid Dynamic Behavior and Deflecting Defense Effect by Space-Based Laser-Driven
Dongyue	China	IAA-PDC-19-04-P03	Terminal Guidance Design and Simulation for Asteroid Guided Collision Missions
Greenstreet	USA	IAA-PDC-19-04-P04	Required Deflection Impulses as a Function of Time Before Impact for Earth-Impacting Asteroids
Howley	USA	IAA-PDC-19-04-P05	The Small Carry-On Impactor from the Hayabusa2 Mission: Models of Jet Formation, Penetration and Crater Creation
King	USA	IAA-PDC-19-04-P06	Gravitational Dynamics of Fragments in Nuclear Disruption Scenarios
Krobka	Russia	IAA-PDC-19-04-P07	Guided Asteroids against Hazardous Asteroids: Innovations from Russia
Managan	USA	IAA-PDC-19-04-P08	Reradiation of Energy Deposited by X-Rays
Melamed	USA	IAA-PDC-19-04-P09	Asteroid Interception at Atmospheric Entry
Sloane	USA	IAA-PDC-19-04-P10	Pulsed Laser Ablation Propulsion of Asteroids: Time-Of-Flight Mass Spectrometry and Direct Force Measurements
Sorli	USA	IAA-PDC-19-04-P11	Hydrodynamic Modeling of the Deep Impact Mission into Comet Tempel 1
Venditti	USA	IAA-PDC-19-04-P12	Potentially Hazardous Asteroid Impact Mitigation Strategy using Tethers
Yang	China	IAA-PDC-19-04-P13	Hybrid Constellation Design for Debris Removal and Asteroid Defense
Zhou	China	IAA-PDC-19-04-P14	Momentum Transfer Measurements of Hypervelocity Impacts Up to 8km/s by using Ballistic Pendulum

SESSION 5

Atchison	USA	IAA-PDC-19-05-P01	NASA's Double Asteroid Redirection Test (DART) Phase C Trajectory Analysis
Cheng	USA	IAA-PDC-19-05-P02	DART: First Test of Asteroid Deflection
Daly	USA	IAA-PDC-19-05-P03	Shape Modeling Testing and Validation for the Double Asteroid Redirection Test (DART)
Eggl	USA	IAA-PDC-19-05-P04	Post Deflection Impact Risk Analysis of the Double Asteroid Redirection Test (DART)
Gordo	Portugal	IAA-PDC-19-05-P05	Helena – Hera Lidar Engineering Model Altimeter Design
Grimm	Germany	IAA-PDC-19-05-P06	Catching a Ride on the Peregrine Falcon – Mascot's Race to Ryugu with Hayabusa2 in 6 Years, 4 Months, and 48 Hours
Grundmann	Germany	IAA-PDC-19-05-P07	Responsive Exploration and Asteroid Characterization Through Integrated Solar Sail and Lander Development Using Small Spacecraft Technologies
Herique	France	IAA-PDC-19-05-P08	Radar Package for a Direct Observation of the Asteroid's Structure from Deep Interior to Regolith: Review of Objectives and Status of the Instruments
Karatekin	Belgium	IAA-PDC-19-05-P09	Hera Planned Mission and Payload Operations at Close Proximity of the Didymos Binary Asteroid System After DART Impact
Krus	Czech Republic	IAA-PDC-19-05-P10	High Power Lasers as a Tool for Meteorite Composition Studies with an Impact on the Asteroid Deflection
Kueppers	Spain	IAA-PDC-19-05-P11	The Hera Mission in the Context of ESA's Proposed Space Safety and Security Program
Melamed	USA	IAA-PDC-19-05-P12	Mitigation of Imminent Comet Impact
Naidu	USA	IAA-PDC-19-05-P13	Physical Characterization of Binary Asteroid 65803 Didymos and Radar Detection of Its Satellite Deflection from the DART Mission Impact In 2022
Seefeldt	Germany	IAA-PDC-19-05-P14	Sailing Towards Unfolding Events – DLR Thin Membrane Deployment Technologies for Solar Sails and Large Space Structures in Responsive Planetary Defense Applications

SESSION 7

Janzwood	Canada	IAA-PDC-19-07-P01	Research Prioritization at the Planetary Defense Coordination Office
Rumpf	USA	IAA-PDC-19-07-P02	Risk Estimation of Threatening Asteroids
Shrivastava	India	IAA-PDC-19-07-P03	Scientific Correlation of Occurrence Tusnami-2004 with Astronomical Movement of Apophis (99942) and Highest Probability of Re-Occurrence of Tsunami In 2029, The Postulates and Disaster Preparedness Planning
Ross	UK	IAA-PDC-19-07-P04	High Impact Low Probability Risk: Risk Management and Risk Governance of Potentially Hazardous Near Earth Objects
Marboe	Austria	IAA-PDC-19-07-P05	Legal Questions Of The PDC2017 Scenario Case Study

SESSION 8

Betts	USA	IAA-PDC-19-08-P01	Planetary Society NEO Public Education from Posters to Stickers to Classes
Marchis	USA	IAA-PDC-19-08-P02	The Contribution of the Unistellar EVSCOPE Network to Planetary Defense
Osburg	USA	IAA-PDC-19-08-P03	Using "Wireless Emergency Alerts" for Planetary Defense Notifications
Prado	France	IAA-PDC-19-08-P04	CHRONOFLASH, A Simple Device for Asteroid Occultations Timing

ATTACHMENT 5: EXERCISE

The PDC 2019 asteroid threat exercise was developed by the following individuals:

JPL/Center for NEO Studies:
Paul Chodas, Javier Roa, Alan Chamberlin, Ryan Park, Marina Brozovic,
Stas Petropoulos, Jon Giorgini, Shigeru Suzuki
NASA Ames/Asteroid Threat Assessment Project:
Lorien Wheeler, Donovan Mathias, Clemens Rumpf,
Jessie Dotson, Michael Aftosmis
NASA Goddard Spaceflight Center:
Brent Barbee, Joshua Lyzhoft, Bruno Sarli
Sandia National Laboratories: Barbara Jennings, Bill Fogleman
Los Alamos National Laboratory: Mark Boslough
NASA/Planetary Defense Coordination Office:
Lindley Johnson, Kelly Fast, Linda Billings, Victoria Andrews
The Aerospace Corporation: Bill Ailor, Nahum Melamed
University of Maryland: Tim Spahr, Gerbs Bauer

The goals of the threat exercises used in this and the three previous conference are to:

- Help us understand the reactions and responses of the public, leadership, and disaster responders to an asteroid threat,
- Assess the best ways to present information to the media, general public, and leaders should an actual threat be discovered and as responses to the threat are developed and executed,
- Understand decisions that leaders must be prepared to make (e.g., disaster preparedness, disaster response, resource allocation),
- Uncover "hot button" topics that might affect timely decision making, and
- Understand how the world community might need to work together to respond to a serious threat.

To assure realism, Dr. Paul Chodas and the exercise development team noted above defined an asteroid threat that is representative of an actual threat and evolved as an actual threat might. For example, as the charts show, for the 2019 conference, the threat begins on April 29, 2019 (the first day of the conference) with discovery of an asteroid of 100 to 300 meters in size that may make a close approach to Earth in about eight years. Shortly after discovery, it is determined that it will, in fact, make a close approach to Earth and has a 1% chance of actually impacting our planet during that passage. At that probability level, the International Asteroid Warning Network (IAWN) issued a notice that a threatening object has been discovered, and information provided by IAWN was used to create the press release given in Fig. 5-1. (It should be noted that one recommendation after the conference was that media professionals should be involved in drafting press releases to assure content is easily and quickly digestible by the media. Another recommendation was that IAWN itself should release this type of information.)

Day 1: Dr. Chodas presented the charts shown in Figs. 5-2 and 5-3 giving background details on information in first press release, which noted that the probability of impact was 1%, meaning that it was much more likely that impact would not occur. The information provided included a line of possible impact points extending from the Pacific Ocean, across the United States, across the Atlantic Ocean and into Africa. Impact could occur at a point on that line should the impact probability increase based on additional data.

Day 2: The IAWN provided an update of the threat representative of what was known on July 29, 2019, showing what would be known given one month of additional observations of the object. Based on that data, the impact probability has increased to 10%. (see Day 2 Press Release and Day 2 charts, Figs. 5-4 through 5-7), and impact, if it were to occur, would be at one point on the same red line as given on Day 1.

Given this information, conference attendees were asked to self-select to participate in one of the first six discussion groups shown below. These groups were representative of groups that decision makers might invite to provide information to help them decide possible actions that should be taken as the threat evolves. Members were assigned to the seventh group, Leadership.

1. **Discovery and Characterization Experts** representing the International Asteroid Warning Network, would provide the best information available on the nature of the approaching object—its size, mass, shape, orbit, and possible impact corridor on Earth. The object's physical and orbit characteristics were essential for the Space Mission Planners and for predicting the consequences of an impact, should one be predicted.
2. **Space Mission Planners** represented the Space Mission Planning Advisory Group, a UN-sanctioned group of representatives of world space agencies who would develop and coordinate defensive actions to observe and if necessary, deflect the threatening object. They would provide their recommended actions, resource requirements, and timelines for launch campaigns to deflect the object.
3. **Disaster Response Planners**, who would need to develop plans for managing evacuations and other activities should the asteroid impact if nothing is done or if any planned mitigation actions fail. These organizations might also help manage public response as the threat evolves and inform space mission planners and leaders of lessons learned from past disasters that might be relevant.
4. **Public Potentially Affected** voice their concerns about potential effects on their homes and communities and express their expectations of what they expect from their local, regional, and national governments as the threat evolves.
5. **Public Not Directly Affected** would provide their perspective on the threat, the potential disaster, and projected short- and long-term consequences should the object impact or should they perceive that mitigation options pose a risk to them or their way of life.
6. **Media.** Providing timely, factual information to the public and to leadership about discovery of the threatening object and as the threat evolves will be essential. This group will provide insights on information the public needs to have and how that information might be presented.
7. **Leadership.** Decisions on actions to be taken were made based on inputs from the six groups above.

Given this information, the exercise teams recommended that a fast flyby mission be authorized to collect more accurate information on the object's orbit, size and other characteristics. Groups also recommended that space agencies begin development of missions to both characterize and, if necessary, deflect the oncoming object.

Day 3: Results of the flyby mission were reported, and it was found that, with high accuracy, the impact would be in the Denver, Colorado area. The Press Release and predicted impact area are shown in Figs. 5-8 and 5-9, and Fig. 5-10 shows the path followed by the flyby observation mission. Fig. 5-11 provides the impact footprint for the impact of the 180-meter object and the economic consequences to the State of Colorado that would result. The impact would require evacuation of about 6500 km^2.

Given the risk level and potential consequences, the exercise groups recommended initiation of campaigns to both rendezvous with the object and deflect the oncoming object. Figure 5-12 provides details of the rendezvous campaign, where two spacecraft would be launched to orbit the asteroid. An option to have each orbiter carry a nuclear explosive device was rejected due to political and legal objections). The deflection campaign would use six kinetic impactors to impart enough Delta-V to move the object's pass away from Earth. Flyby mission selection and timeline are given in Figs. 5-12 through 5-16. Fig. 5-15 shows the timeline of various mission options, key dates shown in Fig. 5-14. While not authorized for use, requirements for a standoff nuclear detonation were developed and are given in Fig. 5-16.

Day 4: The Press Release for Day 4 (Fig. 5-17) reports that the kinetic impactors successfully deflected the main portion of the asteroid away from Earth, but that a single 70-meter fragment remains and will impact somewhere on the line shown in Fig. 5-18—a region with large population centers and significant infrastructure. As Fig. 5-19 shows, the ground area affected is reduced to ~2000 km^2.

A "last-ditch" deflection effort using a nuclear explosive is being considered, and details of that possibility are shown in Figs. 5-20 and 5-21. The analysis concludes that explosion of a 300 KT nuclear device at 50 to 80 meters from the object 60 to 120 days before impact would likely prevent any significant effects on Earth. The device would be carried to the object by a spacecraft using solar electric low-thrust propulsion after launch by a Falcon Heavy launch vehicle. Given the objective to understand the disaster mitigation aspects of a possible impact, the pre-scripted exercise assumed the "last-ditch" deflection attempt was not used.

Day 5: The Press Release for Day 5 (Fig. 5-22) is based on refined estimates of the impact location over a three-month period and recent radar observations, which have narrowed the impact point to the Central Park area in New York City (Fig. 5-23). Discussions on that last day of the conference centered around the need for a plan for such a catastrophe that would include mass evacuation of everyone in the disaster zone--even people who did not want to leave. The plan would include communication to the public of the likely outcome (total destruction of the area) and planning for permanent relocation of a very large number of people. Since the region is a world financial center, plans must be made to move operations and critical data to a safer location. Disaster response managers reported that planning for this eventuality had been ongoing for the eight years preceding the Day 5 release.

EXERCISE ***EXERCISE*** ***EXERCISE***

NOT A REAL-WORLD EVENT *This is part of a hypothetical asteroid threat exercise conducted at the 2019 IAA Planetary Defense Conference*

DAY 1

PRESS RELEASE

NEWLY DISCOVERED ASTEROID POSES SMALL RISK OF EARTH IMPACT

College Park, Maryland, USA – April 29, 2019 – The International Asteroid Warning Network has announced that a recently discovered near-Earth asteroid could pass very close to the Earth 8 years from now, on April 29, 2027, and there is a small chance – 1 in 100 -- that it could impact our planet.

The asteroid, designated 2019 PDC, was discovered on March 26, 2019, by the Pan-STARRS near-Earth object survey project operated by the University of Hawaii for the NASA Planetary Defense Program, and it has been tracked nightly since then by astronomers around the world. Impact monitoring systems at NASA's Center for Near-Earth Object Studies at the Jet Propulsion Laboratory and ESA's NEO Coordination Centre determined from the observations that the chance of impact in 2027 is 1 in 100. That is, chances are 99 out of 100 that the asteroid will safely pass by our planet in 2027.

Astronomers will be able to track 2019 PDC through January 2020 and contribute additional observations to refine the orbit and possibly eliminate the risk of impact in 2027.

Based on the apparent brightness of 2019 PDC, astronomers now estimate that the asteroid is roughly 100 to 300 meters (330 to 1000 feet) in size. The asteroid will approach within 19 million kilometers (12 million miles) of Earth on May 13, but by the end of the year it will no longer be observable by Earth-based telescopes. It will not make another close approach to Earth until 2027.

The International Asteroid Warning Network is disseminating the present information pursuant to United Nations General Assembly resolution 71/90, paragraph 9. The International Asteroid Warning Network (IAWN) is an international network of organizations that detect, track and characterize potentially hazardous asteroids. IAWN will publish weekly updates of impact probability as this asteroid is tracked throughout 2019.

For more information, see https://cneos.jpl.nasa.gov/pd/cs/pdc19/day1.html and www.iawn.net.

Contact: http://iawn.net/misc/contacts.shtml

EXERCISE ***EXERCISE*** ***EXERCISE***

Figure 5- 1.First Inject: Press Release #1.

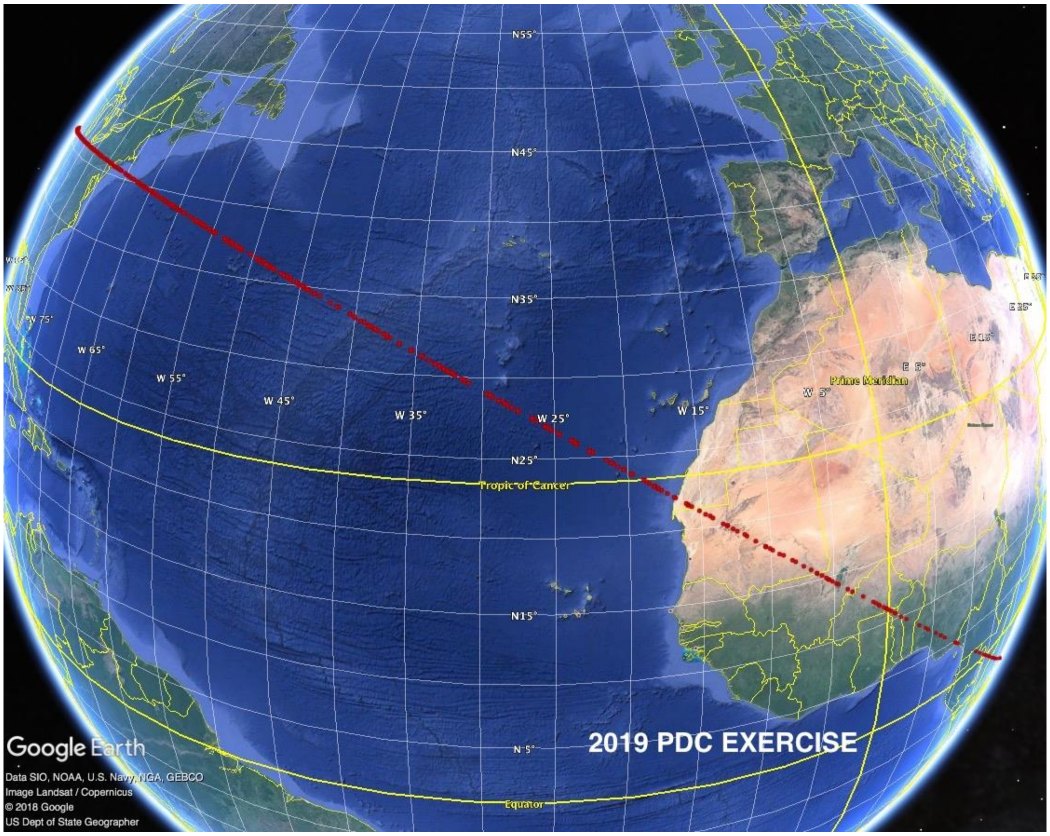


Figure 5- 2. First Inject: Initial threat corridor.

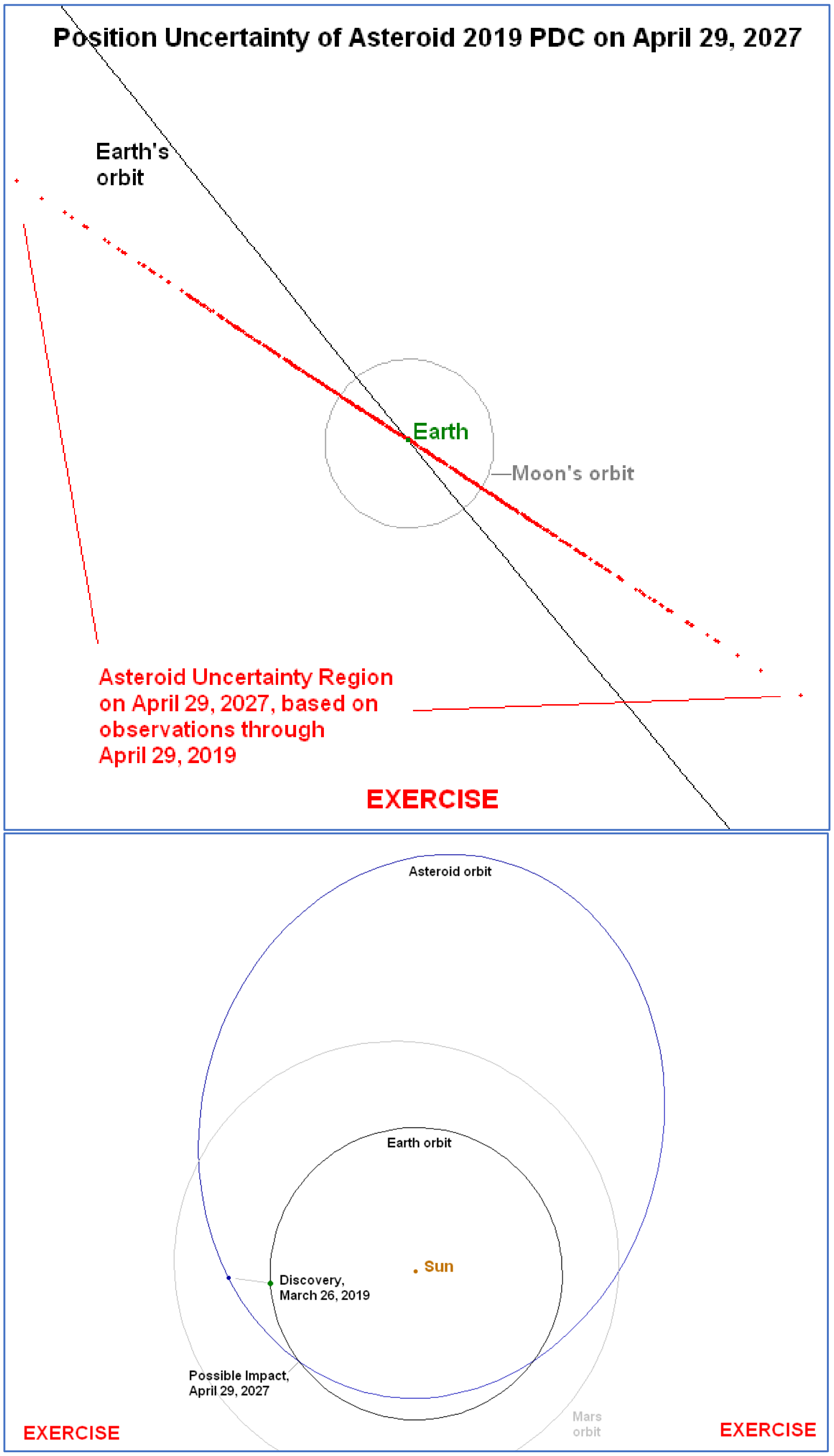


*Figure 5- 3. **First Inject:** Top: Red dots designate line of possible locations of the asteroid when it would cross the vicinity of Earth on date given. Bottom: Orbits of Earth and asteroid at discovery.*

EXERCISE ***EXERCISE*** ***EXERCISE***

NOT A REAL-WORLD EVENT *This is part of a hypothetical asteroid threat exercise conducted at the 2019 IAA Planetary Defense Conference*

DAY 2

PRESS RELEASE

ASTEROID NOW HAS 1 IN 10 CHANCE TO IMPACT EARTH

July 29, 2019 - Based on observations conducted over the last four months, the International Asteroid Warning Network (IAWN) reports that the chance the asteroid designated 2019 PDC could impact Earth on April 29, 2027, is now 1 in 10. This possible impact prediction supersedes the previous prediction of chance of impact that IAWN reported back in April.

Hundreds of observations made by multiple observatories around the world have enabled IAWN experts to improve the understanding of the asteroid's orbital path and update the possible impact predictions made last April. The updated information means that in 9 chances out of 10 the asteroid will pass safely by Earth in 2027. 2019 PDC will remain observable over the next 6 months, and observers around the world will continue to track the asteroid until it moves out of range early next year. These additional observations will enable the experts to further refine their predictions of the asteroids future position and potential for impact in 2027.

The size of asteroid 2019 PDC also still remains uncertain, since the asteroid did not approach close enough to Earth to be directly observed by planetary radar. The best indication of size came from a few space-based infrared observations made by NASA's NEOWISE spacecraft in late April. This allowed astronomers to narrow the estimate of size of 2019 PDC to roughly 140 to 260 meters (460 to 850 feet).

Based on this size estimate, NASA experts supporting IAWN calculate that if this asteroid were to impact Earth it could release in the range of 100 to 800 megatons of equivalent energy, possible producing serious devastation over a large region. IAWN emphasizes, however, that this asteroid is too small to cause globally damaging effects if an impact were to occur.

The international forum for space agencies called the Space Mission Planning Advisory Group (SMPAG) is meeting to consider a coordinated international response to the impact risk posed by 2019 PDC. SMPAG recommends that space-capable nations begin development of a suite of space missions to characterize the asteroid and be prepared to deflect it should it be confirmed it is likely to be on a collision course with Earth

For more information, see: https://cneos.jpl.nasa.gov/pd/cs/pdc19/day2.html. IAWN will publish weekly updates of impact probability as this asteroid is tracked throughout 2019.

Contact: http://iawn.net/misc/contacts.shtml

EXERCISE ***EXERCISE*** ***EXERCISE***

Figure 5- 4. Second Inject: Press Release #2.

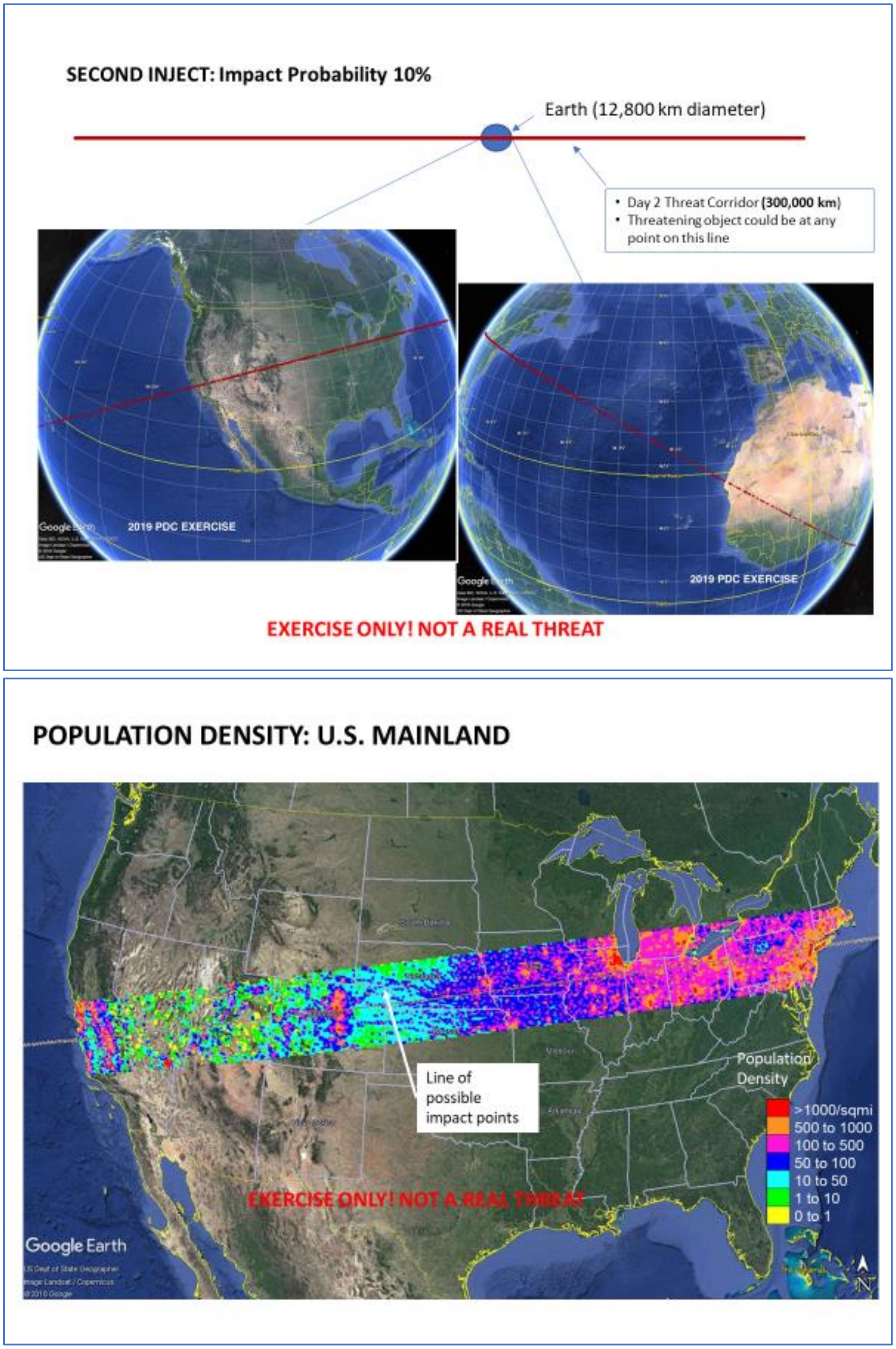


Figure 5- 5. Second Inject: Top: Line of possible impact points at discovery. Bottom: band of population densities along line of possible impacts in continental U.S.

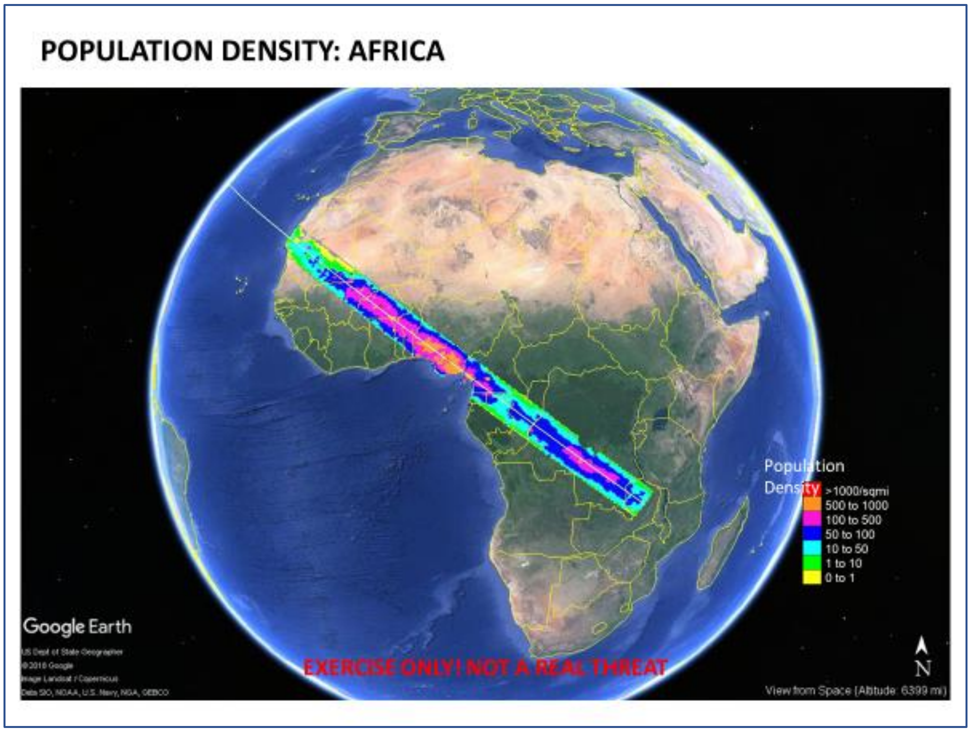


Figure 5- 6. Second Inject: Population densities along possible impact corridor in Africa.

SECOND INJECT

Probability of Impacting

- Earth 10.0% (1/10)
- Pacific Ocean 2.6% (1/38)
- **U.S. Mainland 1.9% (1/50)**
- Atlantic Ocean 2.6% (1/38)
- Africa 2.9% (1/34)

Population Centers at Risk

- **Hawaii**
- **San Francisco and California Coast**
- **Denver, Colorado**
- **Lincoln, Nebraska**
- **Chicago, Illinois**
- **Cleveland, Ohio**
- **New York City and Northeast Coast**
- Western Sahara and Mauritania
- Lagos, Nigeria
- Democratic Republic of the Congo

Risk to a U.S. population center: 1.9%/200 = ~0.01% or 1/1000
Assumed proportion of U.S. ground impact corridor 1/200

EXERCISE ONLY! NOT A REAL THREAT

Figure 5- 7. Second Inject: Population centers at risk and impact probabilities.

EXERCISE ***EXERCISE*** ***EXERCISE***

NOT A REAL-WORLD EVENT *This is part of a hypothetical asteroid threat exercise conducted at the 2019 IAA Planetary Defense Conference*

DAY 3

PRESS RELEASE

ASTEROID PREDICTED TO IMPACT NEAR DENVER, COLORADO ON APRIL 29, 2027: RECONNAISSANCE AND DEFLECTION SPACE MISSION CAMPAIGN UNDER WAY

December 30, 2021 - College Park, MD – A reconnaissance spacecraft that flew by asteroid 2019 PDC yesterday has determined with certainty that the asteroid is on a course to impact near Denver, Colorado on April 29, 2027, the International Asteroid Warning Network reports.

NASA and other space agencies around the world are ramping up work already begun on a fleet of spacecraft that will be launched to the asteroid to deflect it off its impact course with Earth.

Ground-based observations of 2019 PDC conducted from March 2019 through January 2021 enabled experts to determine that impact with Earth is certain on April 29, 2027, unless the asteroid is deflected. The reconnaissance spacecraft that flew by the asteroid yesterday – Recon 1, launched by NASA in 2021 – enabled experts to calculate a more exact impact location, the Denver, Colorado area, and also determine that 2019 PDC is 140 to 220 meters (460 - 720 feet) in size. The asteroid is large enough to cause major damage over a large region around the Denver area.

NASA plans to launch two rendezvous spacecraft, one being repurposed from its originally intended science mission, toward 2019 PDC next spring that will arrive at 2019 PDC in November 2023. They will gather data that will enable experts to more precisely determine the asteroid's mass, density, porosity and structure. These data are vital to the success of any deflection efforts.

Before the two spacecraft are able to arrive at 2019 PDC, 23 months from now, a fleet of six kinetic impactor spacecraft will need to be built and launched by NASA, ESA, JAXA, and the Russian and Chinese space agencies, who all participate with the international Space Mission Planning Advisory Group (SMPAG) that was established for the purpose of collaborative efforts to mitigate an asteroid impact threat. The kinetic impact technique involves hitting the asteroid with a spacecraft to incrementally slow the speed of the asteroid to deflect it off its impact course with Earth.

EXERCISE ***EXERCISE*** ***EXERCISE***

Figure 5- 8. Third Inject: Press Release #3.

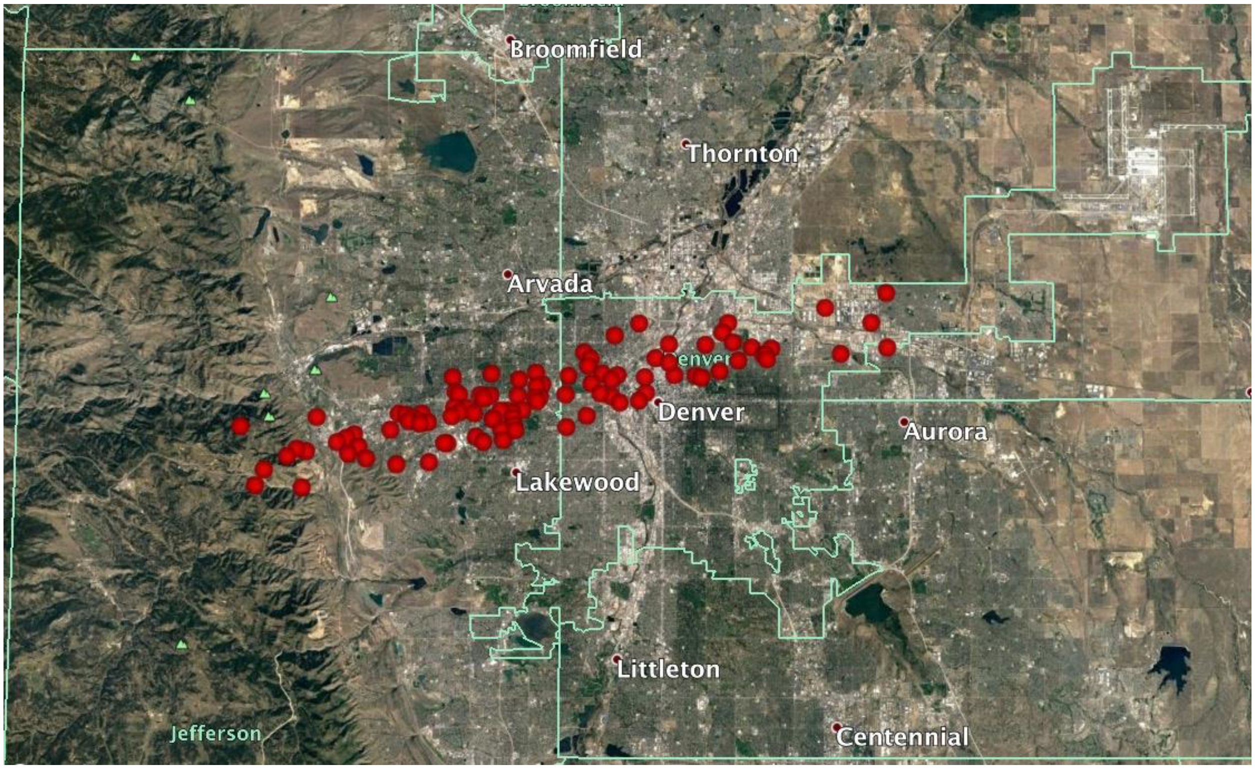


Figure 5- 9. Third Inject: Possible impact point (the Denver, Colorado, area).

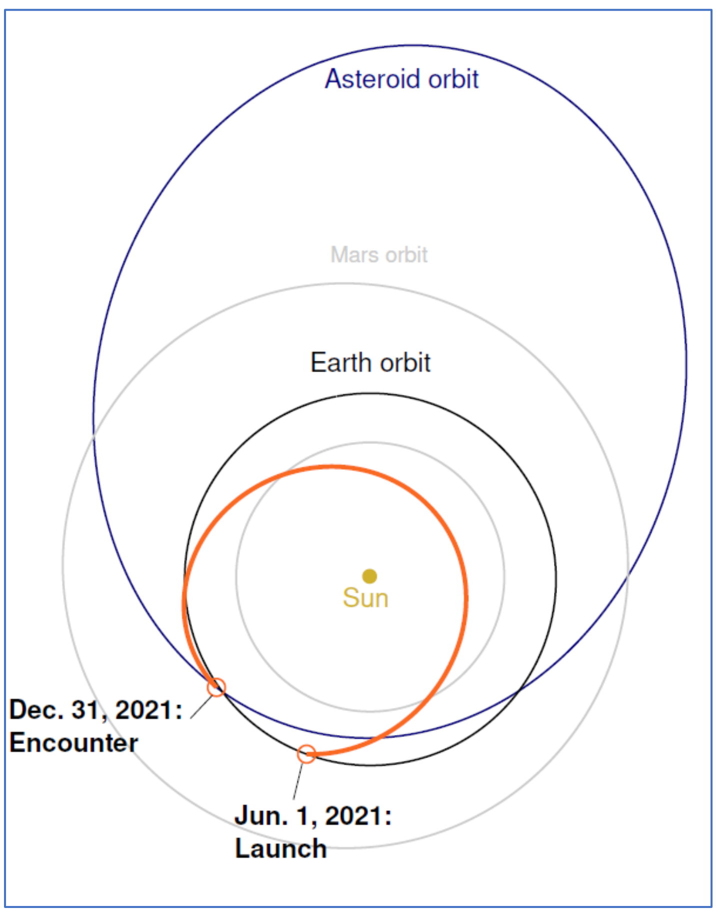
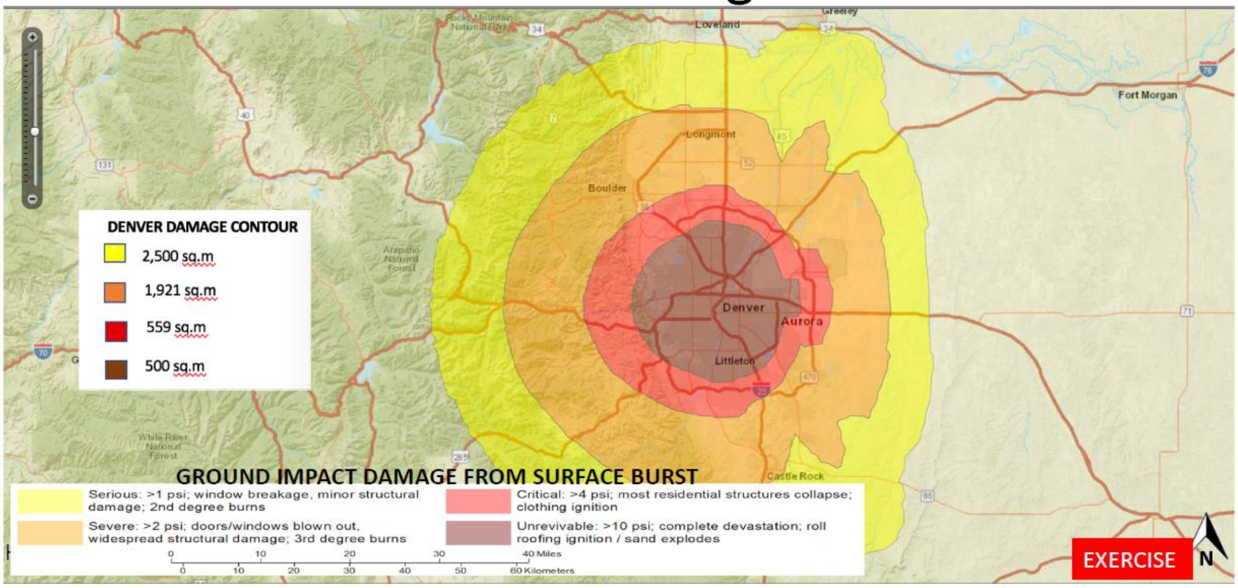


Figure 5- 10. Third Inject. Orbit and encounter of fly-by mission to 2019 PDC.

EXERCISE

Impact Footprint Resulting from "2019 PDC"; 180 meter ~ 511 megaton PHA*

*Mark Boslough, LANL



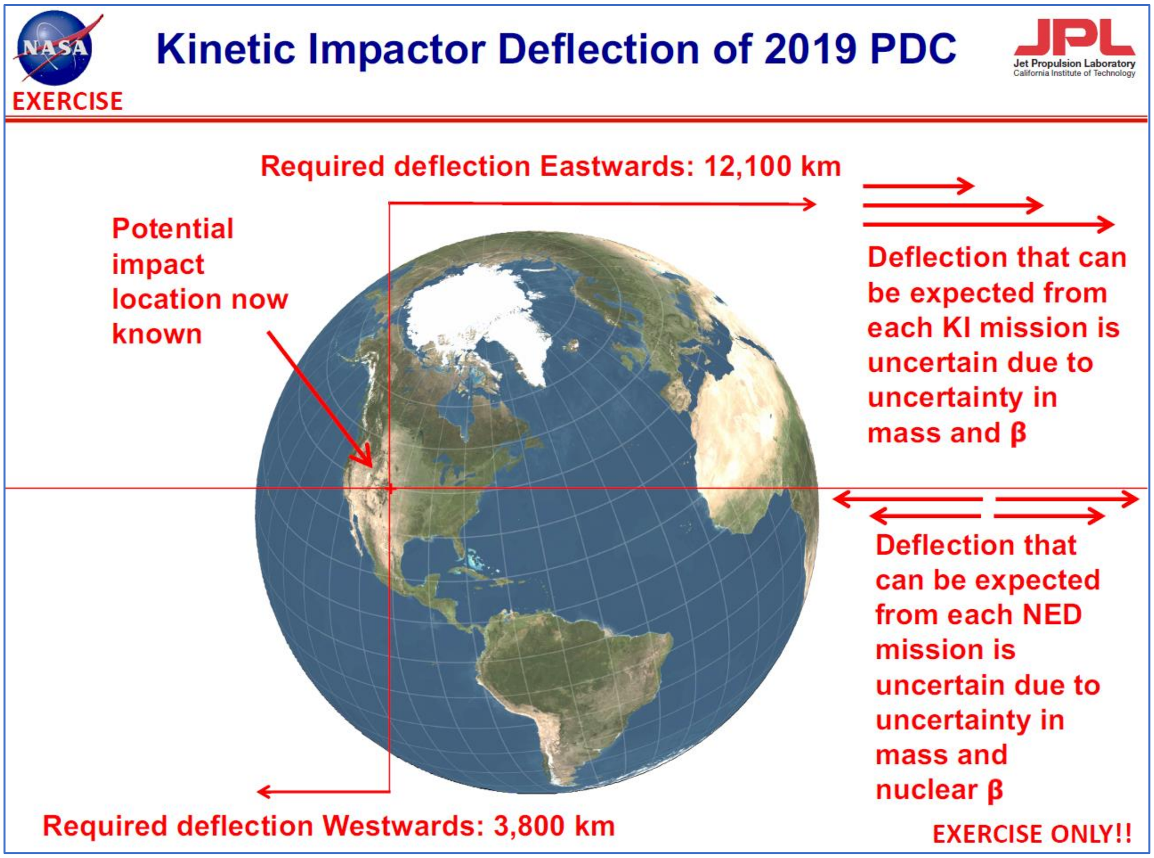
EXERCISE

GDP Economic Impact >100M per Month

State	Direct Impacts ($M)	Indirect Impacts ($M)	Total Impacts ($M)
Colorado	$8,073.2	$12,283.7	$20,356.9

Industry	Total Impacts	Industry	Total Impacts
Accommodation and food services	$652.40	Information	$1,627.60
Administrative and waste management services	$707.20	Management of companies and enterprises	$622.80
Arts, entertainment, and recreation	$218.20	Mining	$893.20
Chemical products	$155.10	Miscellaneous manufacturing	$136.40
Computer and electronic products	$263.00	Other services, except government	$529.90
Construction	$916.80	Professional, scientific, and technical services	$2,436.60
Fabricated metal products	$107.70	Real estate and rental leasing	$2,616.60
Federal Civilian	$1,468.20	Retail trade	$961.90
Finance and insurance	$1,796.90	Transportation and warehousing	$661.80
Food and beverage and tobacco products	$283.70	Utilities	$147.80
Health care and social assistance	$1,216.00	Wholesale trade	$1,359.80

Figure 5- 11. Third Inject. Possible consequences of impact in Denver area.



EXERCISE

Deflection Campaign for 2019 PDC

- The Space Mission Planning and Advisory Group has coordinated an extensive deflection campaign involving multiple space agencies
- A suite of spacecraft of various designs have been under development for the last 2+ years; the updated deflection campaign consists of:
  - 6 Kinetic Impactor (KI) missions to be launched by various space agencies 16 months from now, some launches carrying multiple individual impactors
  - a rendezvous recon spacecraft scheduled to be launched in a few months that is designed to be capable of carrying nuclear explosive devices
  - a previously launched interplanetary science spacecraft is being re-tasked to visit the asteroid, to provide a second rendezvous recon spacecraft
- The KI spacecraft will use intercept trajectories that will move the asteroid's impact point eastwards; the westwards KI missions were not selected as an option due to schedule constraints and ineffectiveness
- The nuclear deflection option has many political and legal implications and faces controversy both nationally and internationally

EXERCISE ONLY!!

Figure 5- 12. Day 3: Details of possible campaign to deflect threatening asteroid.

EXERCISE

Status of Mission Selection and Development

- Decisions from Day 2:
  - Begin build of <u>Flyby Recon 1</u>
    - Multiple versions to be deployed (US, ESA, etc.)
  - Begin build of <u>Rendezvous Recon</u>
    - Designed to be *capable* of carrying NED, but decision to install NED will be made later
      - If the larger version of this spacecraft is built, it could become the "Rendezvous Nuclear Deflection" mission listed in the timeline
  - Begin build of <u>KI Deflection East 2</u> mission fleet
    - Multiple KI spacecraft on multiple launch vehicles from multiple nations
  - Forego KI East 1 (deemed too risky)
  - Forego Flyby Recon 2 (rendezvous recon available during same time frame, and rendezvous is preferred)
  - Forego KI West (not effective enough)

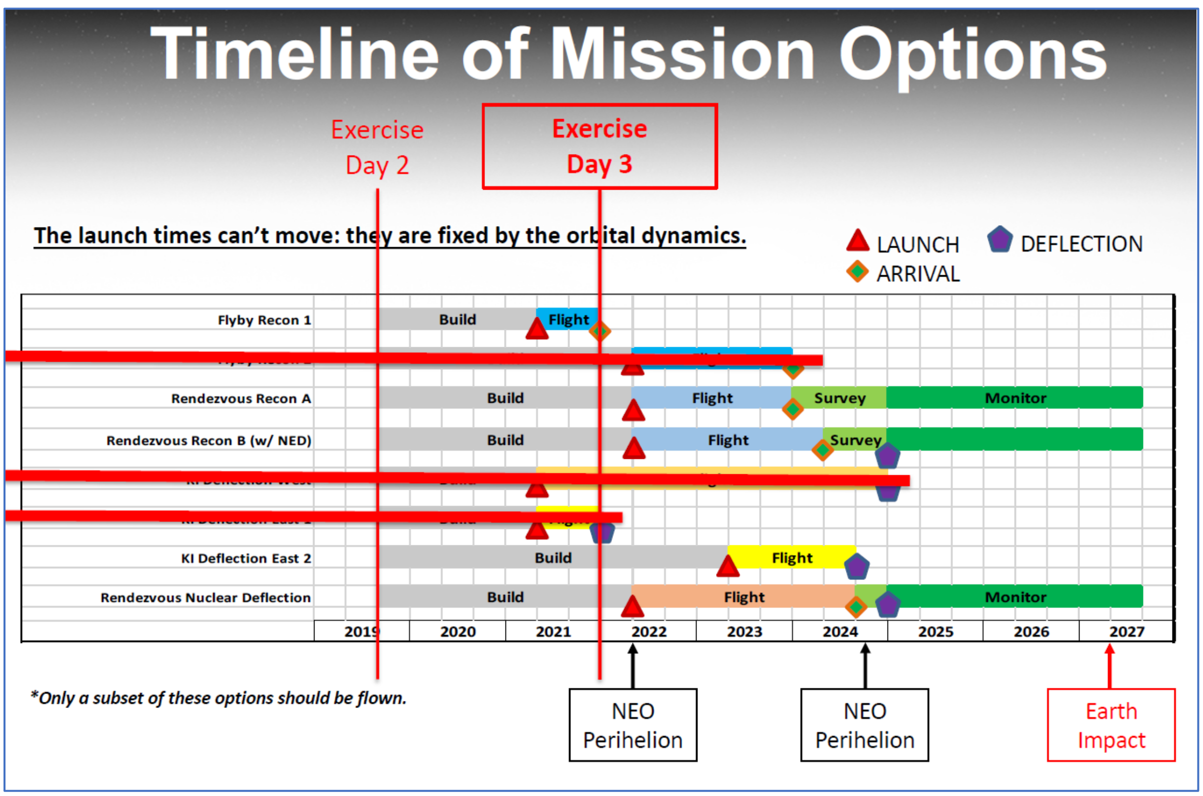
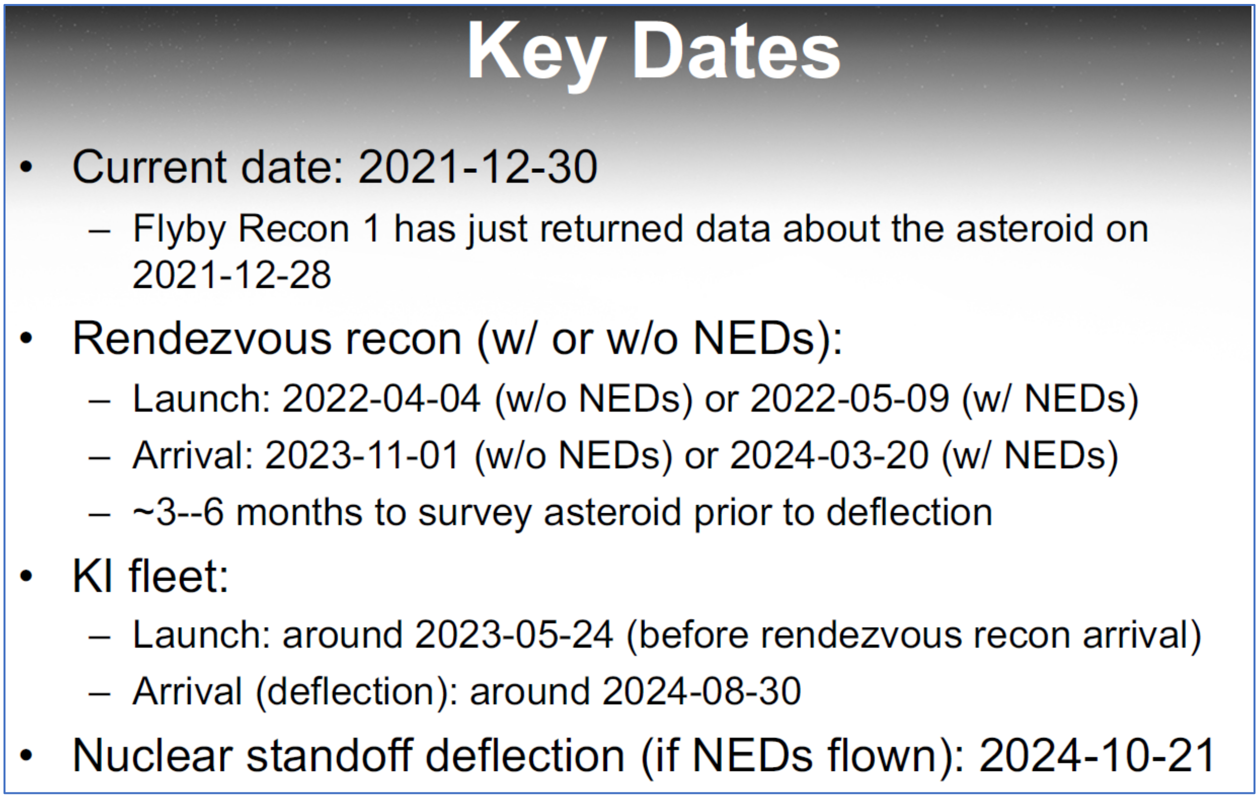


Figure 5- 13. Details of decisions on flyby mission and mission timeline.



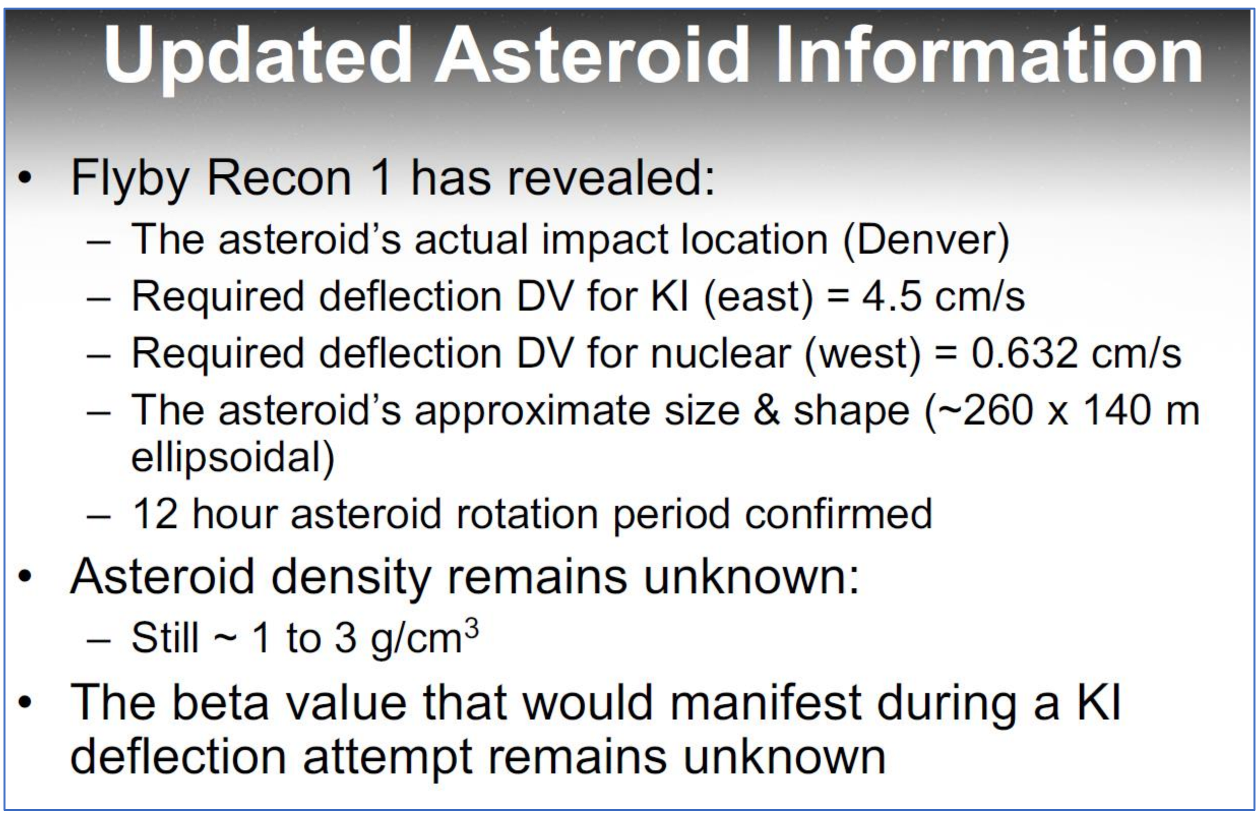
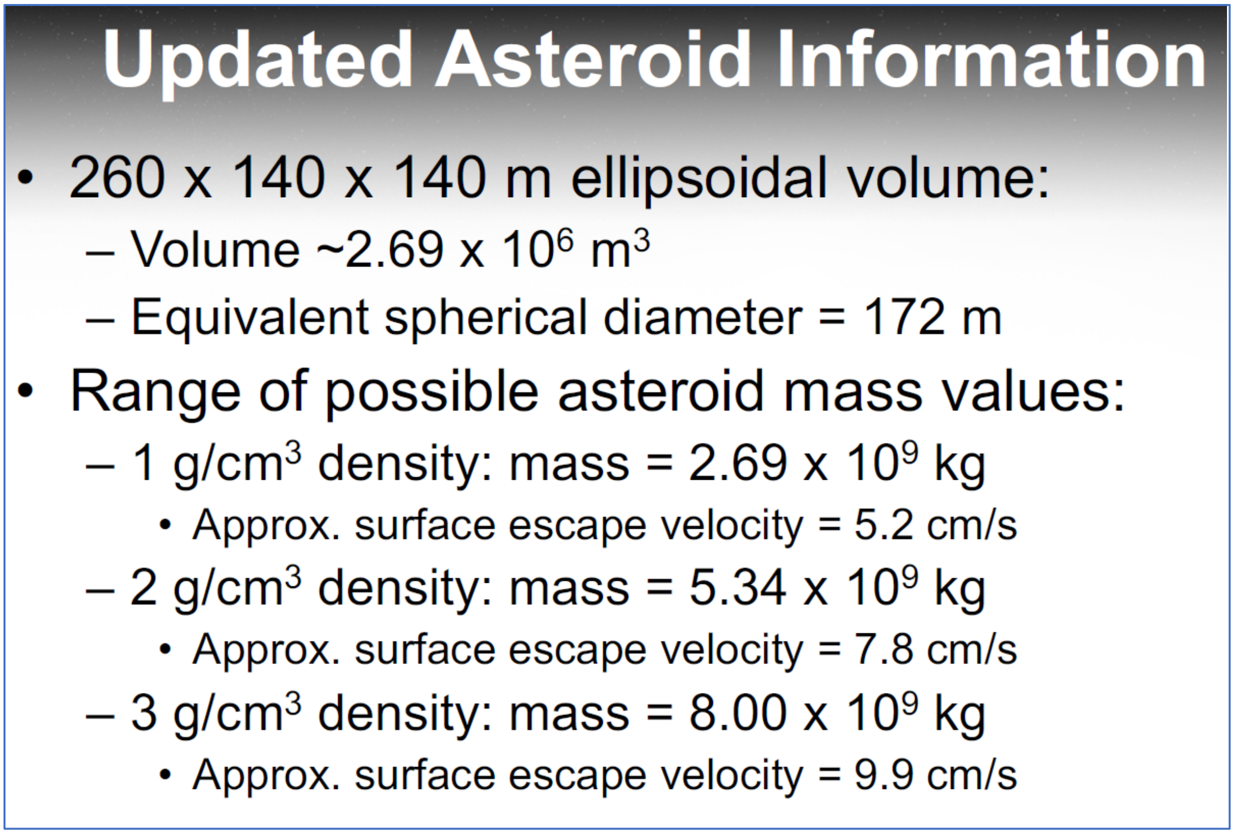


Figure 5- 14. Results of Flyby mission.



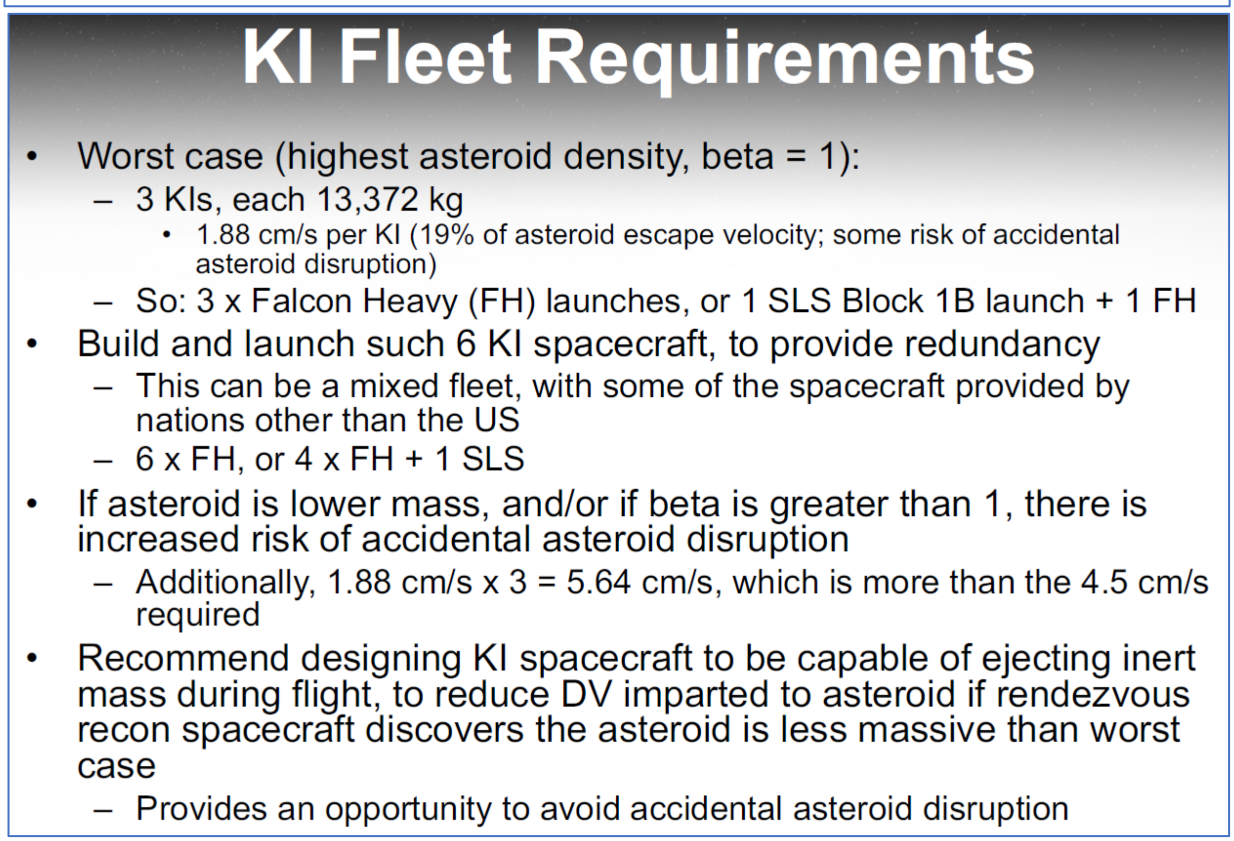


Figure 5- 15. Updated information on asteroid and proposed fleet of vehicles carrying kinetic impactors to deflect asteroid.

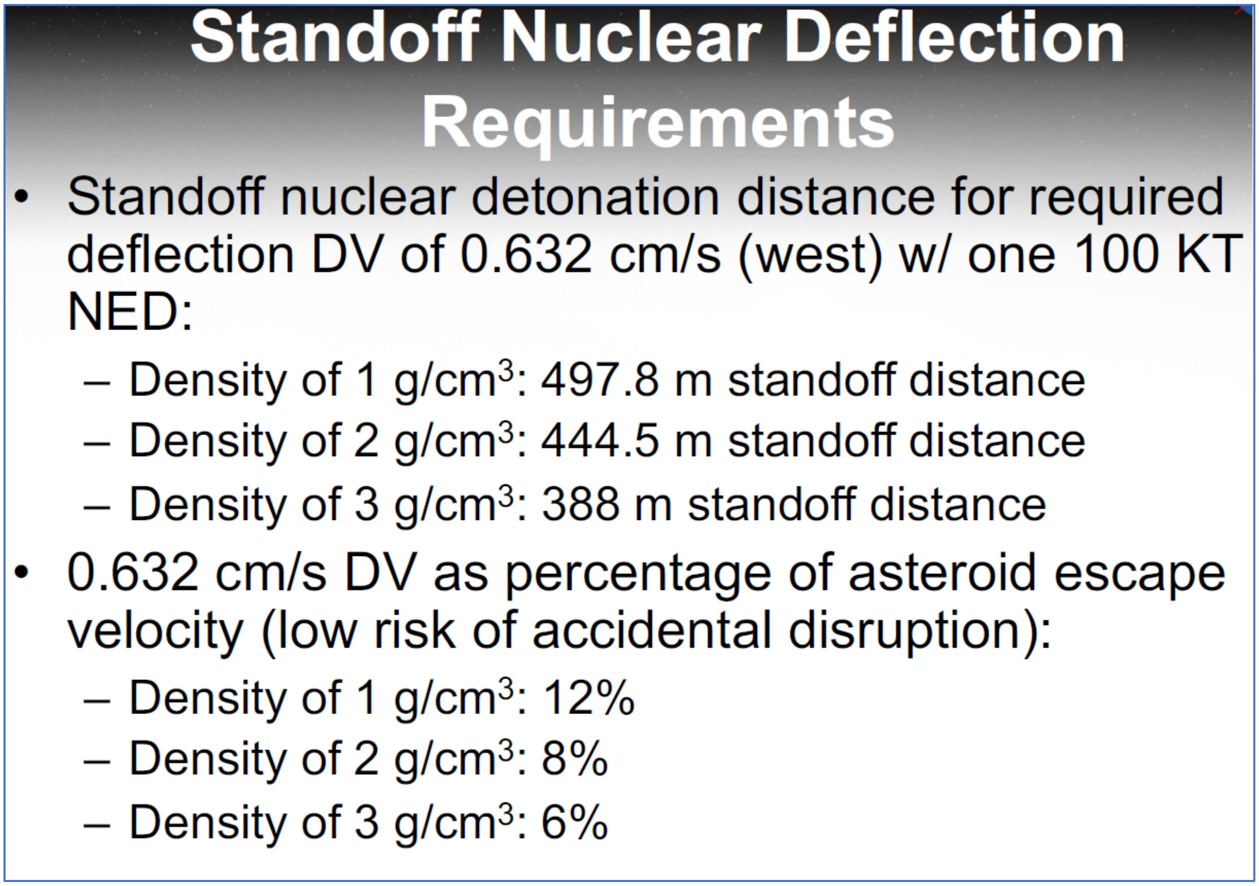


Figure 5- 16. Information on possible use of nuclear explosive device(s) to deflect asteroid.

EXERCISE ***EXERCISE*** ***EXERCISE***

NOT A REAL-WORLD EVENT *This is part of a hypothetical asteroid threat exercise conducted at the 2019 IAA Planetary Defense Conference*

PRESS RELEASE

ASTEROID FRAGMENT REMAINS ON IMPACT TRAJECTORY FOLLOWING DEFLECTION CAMPAIGN: U.S. IMPACT STILL POSSIBLE

September 3, 2024, College Park, MD – Three kinetic impactor missions have successfully deflected asteroid 2019 PDC's main body and it no longer poses an impact threat to Earth, but a large fragment that broke off remains on a certain collision course with Earth on April 29, 2027, the International Asteroid Warning Network reports.

The asteroid fragment is estimated to be 50–80 meters (165–260 feet) in size, and impact with Earth is certain. The exact location for the impact is not yet precisely known, but the Eastern U.S. and the Atlantic Ocean are currently at risk. The International Asteroid Warning Network is organizing a ground-based observing campaign to track the asteroid fragment once it moves away from the Sun's glare into the nighttime sky and becomes visible to large telescopes 2 months from now.

NASA's rendezvous spacecraft, that has been operating in the proximity of asteroid 2019 PDC for the past 10 months, was positioned to observe the kinetic impact campaign. Images sent to Earth of the first deflection by NASA's kinetic impactor showed the large fragment breaking away. Additional images showed successful impacts of the main asteroid body by the JAXA and Russian kinetic impactor spacecraft. Contact was lost with the rendezvous spacecraft soon after the third impact, presumably due to debris from the impacts, according to NASA.

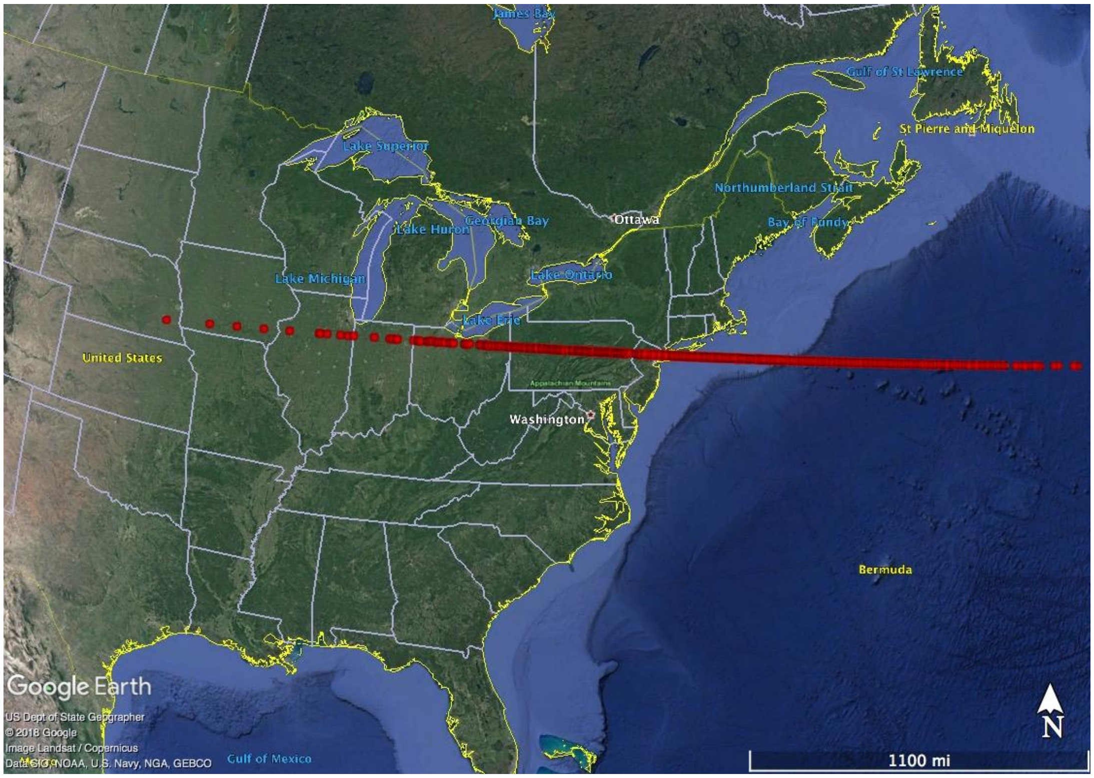
NASA's rendezvous spacecraft was an observer-only spacecraft that was repurposed from a science mission and did not include the nuclear deflection device capability considered soon after 2019 PDC's discovery. The international Space Mission Planning Advisory Group is now studying emergency plans for a space mission to disrupt the fragment still heading for the Earth using a nuclear device. The goal of disruption before impact would be to create smaller fragments that could burn up more completely as they impact the atmosphere and pose a lower risk of damage on the ground. The United Nations and leaders around the world are assessing the political and international treaty ramifications of launching a nuclear device.

The International Asteroid Warning Network (IAWN) is disseminating this information in collaboration with the Space Mission Planning Advisory Group, pursuant to United Nations General Assembly resolution 71/90, paragraph 9. IAWN is an international network of organizations that detect, track and characterize potentially hazardous asteroids. IAWN will publish weekly updates on the status of the observation and mitigation campaigns.

For more information, see https://cneos.jpl.nasa.gov/pd/cs/pdc19/day4.html and www.iawn.net.

Contact: http://iawn.net/misc/contacts.shtml

Figure 5- 17. Forth inject: Press Release #4.



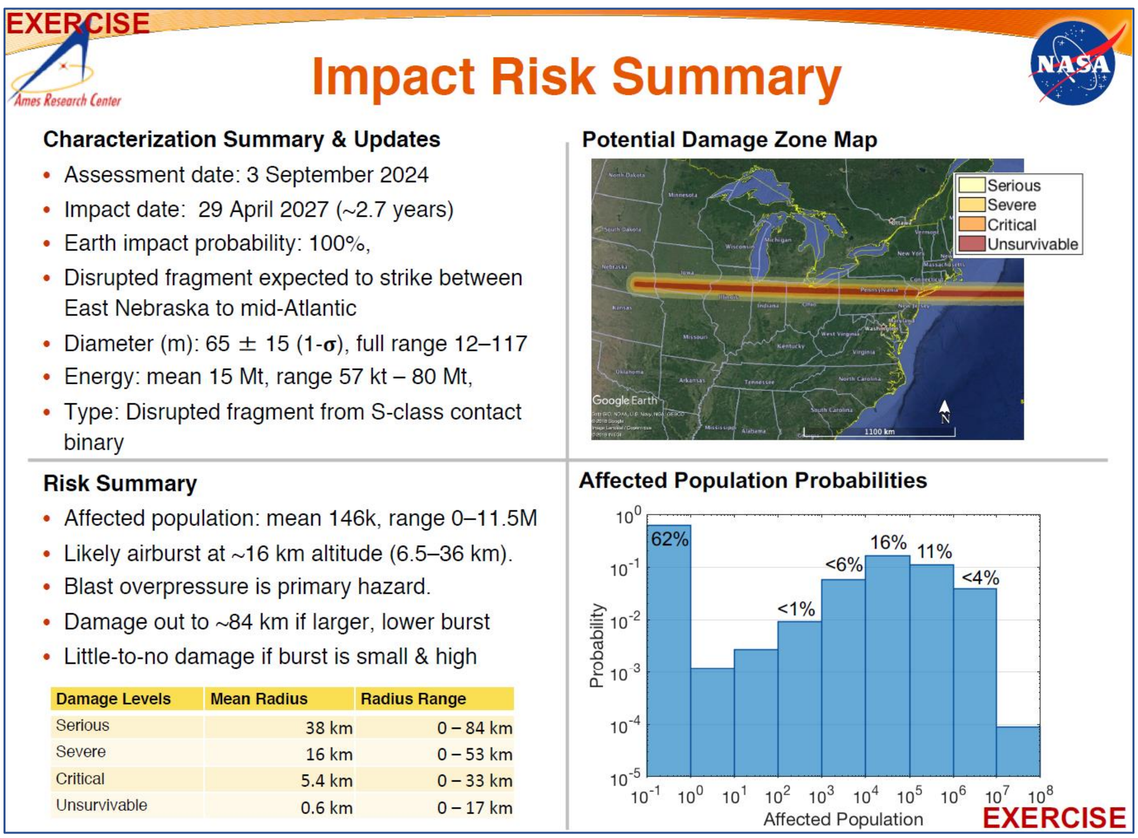
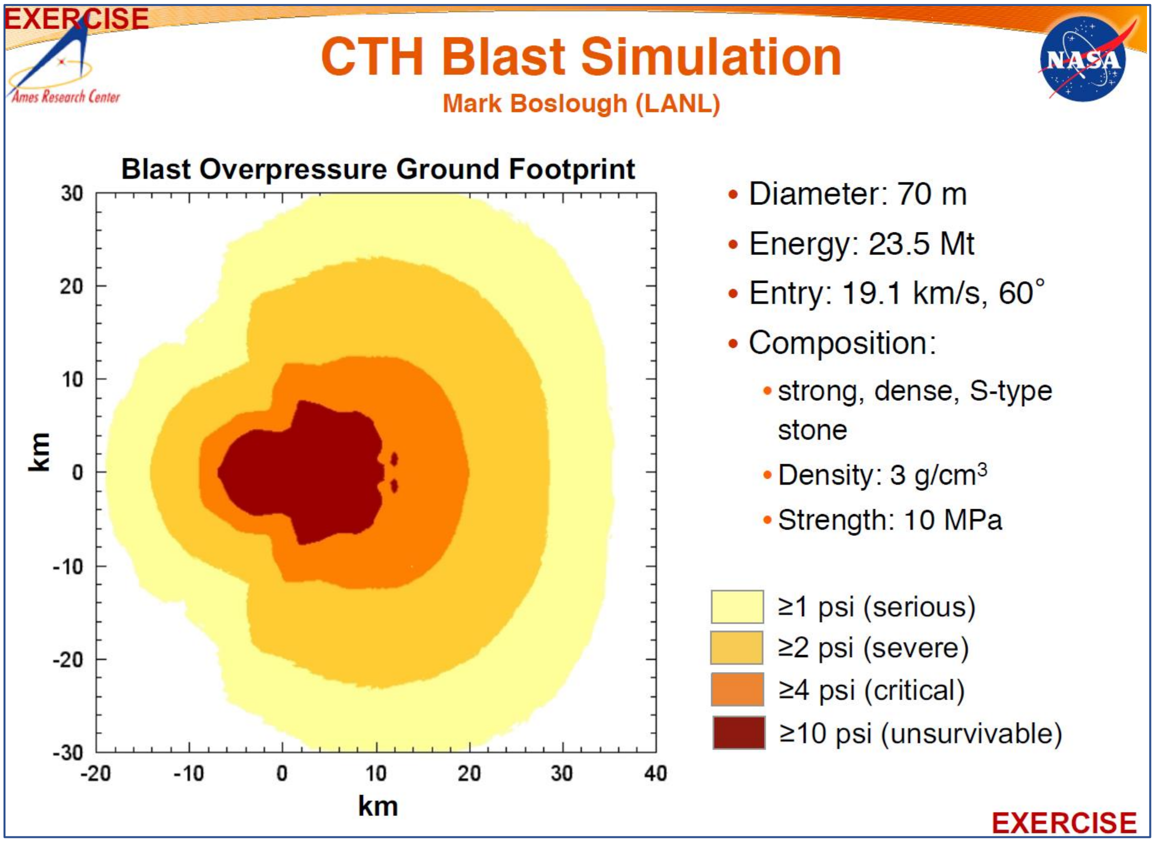


Figure 5- 18. Threat corridor and impact risk summary for Day 4.



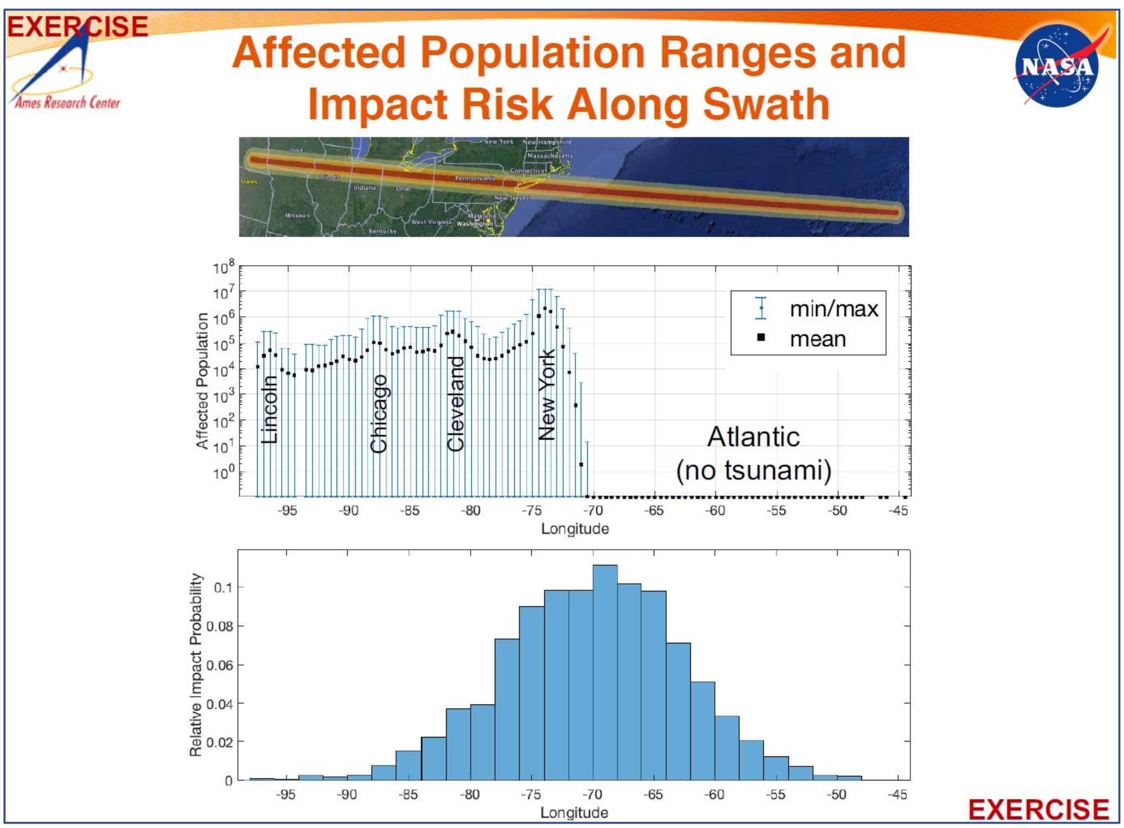


Figure 5- 19. Area and population at risk.

NNSA EXERCISE NASA

Current Status

- Current date: 2024-09-03
- Asteroid was accidentally fragmented by the kinetic impactors
- Nuclear devices were not deployed to the asteroid due to widespread controversy that was not resolved in time
- No active spacecraft remain from the original fleet:
  - All KI spacecraft and rendezvous recon spacecraft were destroyed or disabled
    - 1 KI experienced launch failure
    - 2 KIs experienced system failures before reaching asteroid
    - 3 KIs succeeded in striking the asteroid
    - Purpose-built rendezvous recon spacecraft experienced system failure before reaching asteroid
    - Re-tasked rendezvous observer succeeded in reaching and surveying asteroid, but was disable or destroyed by debris generated by the KI strikes
- Final telemetry from the rendezvous recon spacecraft indicates:
  - First KI (launched by NASA) to strike asteroid unexpectedly fragmented the asteroid
  - A ~50—80 m asteroid fragment remains on an Earth-impacting trajectory; Earth impact location uncertain
  - Fragment density likely to be ~1.5 to 2.5 g/cm^3
- SMPAG has created some emergency plans for last-ditch spacecraft missions to perform a nuclear disruption of the fragment; these plans are outlined herein

Asteroid Disruption vs. Deflection

- As time moves forward and the asteroid fragment comes closer in space and time to Earth impact, the required deflection DV increases
- The asteroid is only ~50—80 m and has a relatively low surface escape velocity
- Thus, the DV that would be required to deflect the asteroid (as a whole) is so large (relative to the fragment's escape velocity) that any deflection attempt would at least weakly disrupt the asteroid (making the situation worse)
- So, we purposely design a robust disruption mission:
  - Deliberately apply a very large DV to the asteroid, at least ~10x the asteroid's escape velocity (a notional heuristic for robust disruption)
  - The objective is to disrupt the asteroid into many pieces that are all (a) small enough to be easily absorbed by Earth's atmosphere, and (b) so widely scattered that very, very few---if any---would go on to hit the Earth anyhow
- During the asteroid's final solar orbit before Earth encounter, the optimal deflection direction becomes increasingly radial and out-of-plane (rather than along-track), as a consequence of orbital physics, and so we position the nuclear device along that direction to help maximize dispersal of the disrupted asteroid material

Figure 5- 20. Current status and possibility of asteroid disruption.

NNSA **EXCERCISE** NASA

Asteroid Disruption Via 300 KT NED

- Asteroid mass: 9.8×10^7 – 6.7×10^8 kg
- Asteroid escape velocity: 1.9 to 4.1 cm/s
- Maximum DV imparted to asteroid by a 300 KT NED: 55 to 251 cm/s
  - 13 to 130 times the escape velocity
  - Notionally sufficient for robust disruption of any combination of the asteroid diameter and density (50—80 m, 1.5—2.5 g/cm^3)
- Standoff detonation distance for maximum imparted DV: 8 to 12 m

Example Emergency Nuclear Disruption Launch Options

- 1 Falcon Heavy (expendable) launch vehicle
- Solar electric low-thrust propulsion: 2 x BPT-4000 (XR5) w/ 90% duty cycle
- Power: 11 kW @ 1 au
- 300 KT NED mass: ~170 kg

Type	Launch	Prep time for launch (days)	C_3 (km^2/s^2)	DLA (deg)	Launch Mass (kg)	Arrival	Arrival (days before Earth encounter)	Arrival Mass (kg)	Arrival Relative Speed (km/s)
Intercept	2025-09-22	336	97.11	22.23	938	2027-02-28	61	600	5
Intercept	2025-04-17	178	37.69	-28.5	1231.5	2027-02-28	61	600	1
Rendezvous	2025-03-22	152	92.85	-22.9	1222	2027-02-28	61	600	0
Intercept	2025-04-11	173	94.34	-21.86	1120.5	2026-12-28	123	600	1
Rendezvous	2025-04-13	175	93.74	-22.54	1160.6	2027-02-06	83	600	0

Figure 5- 21. Asteroid disruption using nuclear explosive and sample launch options.

EXERCISE *EXERCISE* *EXERCISE*

NOT A REAL-WORLD EVENT *This is part of a hypothetical asteroid threat exercise conducted at the 2019 IAA Planetary Defense Conference*

DAY 5

PRESS RELEASE

SMALL ASTEROID TO IMPACT OVER NEW YORK CITY IN 10 DAYS

April 19, 2027, College Park, MD – The 60-meter (200-foot) fragment of asteroid 2019 PDC is predicted to impact over the Central Park area in New York City just after midnight on April 29, 2027, 10 days from now, the International Asteroid Warning Network (IAWN) reports.

The possible impact locations, which had been narrowed down by ground-based observations over the last three months to the New York City metropolitan area, have converged on Central Park following radar ranging measurements by the Arecibo Observatory in Puerto Rico. The small asteroid was not observable by planetary radar until yesterday.

The small asteroid will enter Earth's atmosphere at 19 km/s (43,000 mph) on April 29, producing a very large fireball or "megabolide," and predicted to release the equivalent of 5 to 20 megatons of energy in the airburst. Radar images, which will better determine the size and shape, become possible a few days from now and may help experts better estimate the impact energy.

The U. S. Federal Emergency Management Agency (FEMA) National Response Coordination Center has requested daily updates from IAWN on predicted impact location and damage estimates to finalize their nearly completed evacuation of residents and critical infrastructure, to define a Temporary Flight Restriction zone around the impact area, to coordinate pre-impact access to the area by scientists placing sensors to monitor the impact, and to prepare for any casualties and, ultimately, for recovery.

The International Asteroid Warning Network (IAWN) is disseminating this information in collaboration with the Space Mission Planning Advisory Group, (SMPAG) pursuant to United Nations General Assembly resolution 71/90, paragraph 9. IAWN is an international network of organizations that detect, track and characterize potentially hazardous asteroids. IAWN will publish daily updates for the duration.

For more information, see https://cneos.jpl.nasa.gov/pd/cs/pdc19/day5.html and www.iawn.net.

Contact: http://iawn.net/misc/contacts.shtml

EXERCISE *EXERCISE* *EXERCISE*

Figure 5- 22. Final Press Release (Day 5).

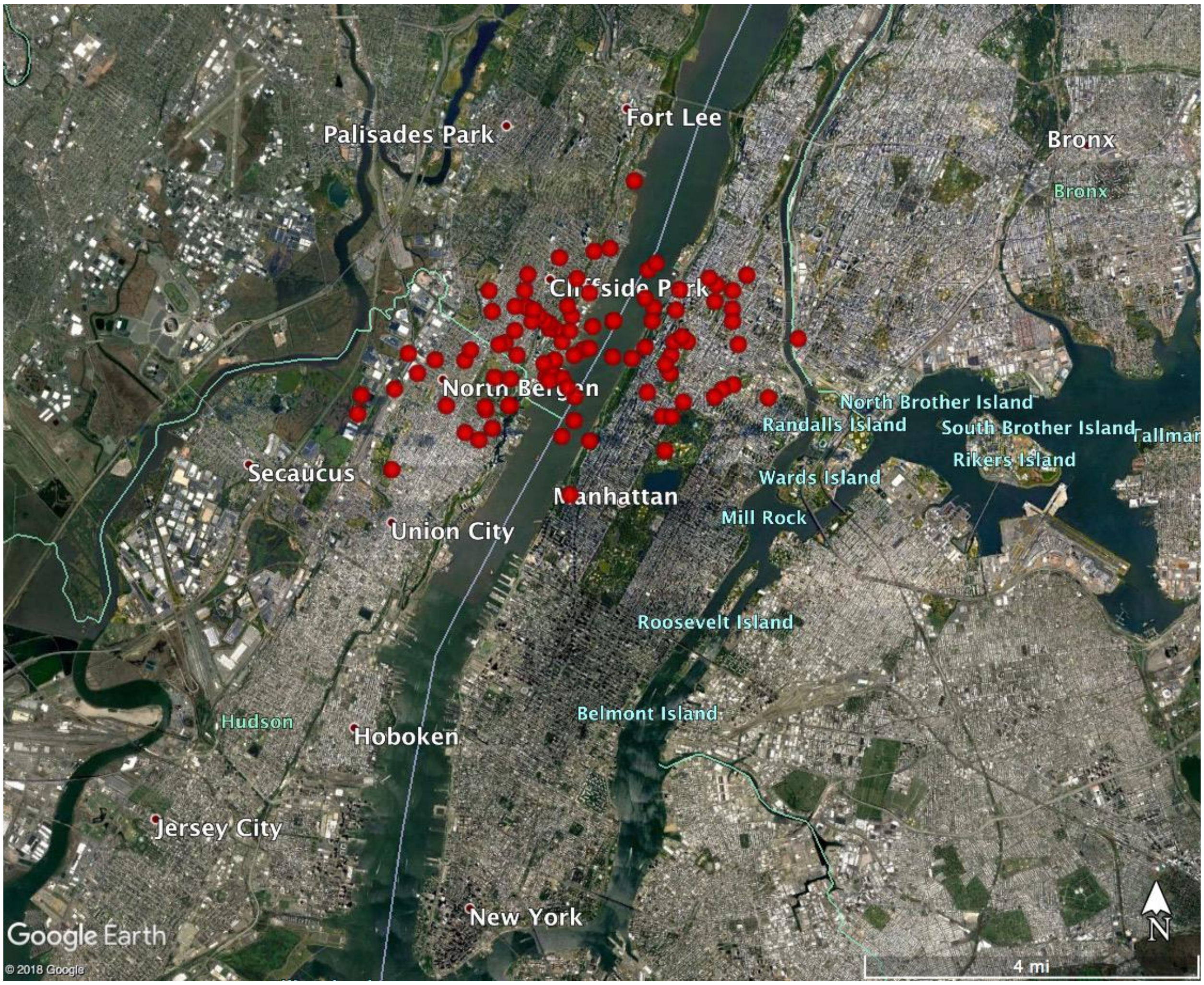


Figure 5- 23. Region of possible impact of smaller surviving object after deflection attempt.

ATTACHMENT 6: COMMENTS AND CONSIDERATIONS FOR PDC2021

GENERAL COMMENTS

- Media planning and media coverage were excellent. Regarding the exercise, the message came through loud and clear – this is an exercise, not a real event. Web features about the tabletop exercise (TTX), the Apophis session, and DART led to good reporting on all three.
- It's time to establish an *International Journal of Planetary Defense*. Ideally, this journal would be online-only and open-access – preferably low- to no-fee. We should see who might host the journal and consider assembling an editorial board.
- We should consider adding an "early-career" mixer to PDCs, perhaps coordinating with the Space Generation Advisory Council or the local AIAA chapter if held in the US. Might be able to find a corporate sponsor for the event.
- We should create an online, searchable archive of PDC documents.
- We could use more panel discussions – maybe one a day. Agency representatives could be handled as a panel, for example. Recent sessions on "communications to the public" or "public education and communication" have been weak. We could either mention communications in the call for papers and distribute any comms-related papers into other sessions or not solicit comms-related papers but feature a panel discussion on communication issues one day - with invited speakers. Disaster response might also be suitable for a panel discussion.
- Invited speakers might be a good way to start off each session strong.
- We need to show a slide before every morning and afternoon PDC session highlighting the day's events. Some attendees this year didn't know about lunches and other peripheral events.
- For the tabletop exercise, an exercise manager is a must. So-called press releases must be prepared in advance. (And are they necessary?) Clearly a huge team of people had access to the full details of the scenario well in advance of the PDC. Whoever is tasked with writing these releases needs to be a member of this larger team that is involved in mapping out the exercise. Perhaps the releases should be in an IAWN-approved format.
- Conference participants expressed frustration at the contrived nature of the hypothetical asteroid threat exercise, and at their inability to influence the exercise outcome. In general, the exercise goals and format should be re-examined in view of these and other thoughts.
- The realism of the hypothetical threat exercises could be enhanced by better incorporating uncertainties and associated statistical models, etc.
- Publishing the "Day 0" hypothetical threat exercise material online much farther in advance of the conference abstract deadline could provide more opportunities for researchers to perform meaningful studies on the hypothetical scenario.

COMMENTS ON THE EXERCISE

1. Solidifying the orbital solutions, hypothetical observations, and resulting inferred physical property bounds much earlier would help sort out potential issues in advance and allow all groups to provide better assessments.

2. We made some good progress in pre-planning and coordinating the physical property assumptions for each scenario day, which made for more realistic and consistent assessments among the groups. Hopefully we can continue to improve this level of consistency with more advance planning for future exercises.

3. When defining the object properties and uncertainties for each day, we should avoid simply taking the actual object properties and adding a contrived "uncertainty" range around that value. The actual

value should be permissible within an uncertainty range defined by a hypothetical observational capability but should not define the nominal value of the uncertainty range. Doing this effectively requires the evolution of knowledge throughout all scenario days to be planned together in advance, so that last-minute changes to later days don't contradict assumptions used for earlier days after it is too late to change them.

4. Dividing up the presentation emphasis between the days where either broader probabilistic results or more specific high-fidelity modeling and emergency response efforts were more relevant seemed to work well. Again, earlier completion of scenario details and results would help to avoid last-minute scrambles and confusion in consolidating the presentation materials among the groups.

5. Probabilistic risk assessment of uncertain mitigation mission deflections is a highly relevant aspect of the impact threat response problem, and we should plan to include those results in future scenarios. We had some very interesting and informative results to show for each of the proposed mitigation missions this year. These results would have been very pertinent to a realistic decision-making process comparing multiple options and demonstrated some of the important geo-political complications that could arise from such decisions. Unfortunately, these results ended up being omitted due to last-minute doubt about how they would be perceived or how they may complicate the storyline. For future exercises, we hope that we can plan for more discussion and understanding of these kinds of results among the teams earlier on in the process, so that they can be incorporated in a way that supports the mission planning and decision-making storylines.

6. Regarding the public role-play aspects of the scenario: It seems that there is difficulty in balancing the opposing goals of making the exercise an engaging participatory experience for the audience and media, and making the exercise have the most value for the core PD community. From the risk assessment perspective, having multiple storylines or on-the-fly results would be challenging, but could be done with enough pre-planning if it would add value. Precomputing results for alternate outcomes/decisions is certainly doable given enough lead-time, but it seems we struggle with having enough lead-time even for one fixed storyline. While that would probably add value to the audience-engagement goals, It's not clear whether the PD community would learn much more from multiple storylines than from doing a single fixed storyline. It may just dilute how well we are able to treat each assessment case. Generating new on-the-fly results remotely during the conference would be challenging, due to the size of the datafiles that have to be transferred to/from our supercomputers. Having a more dynamic scenario where we compute and respond to different outcomes on-the-fly seems like it would be better-suited to internal exercises among the key boots-on-the-ground groups, rather than to a large, publicized event where presentations and messaging need to be more polished (requiring more lead time). From our perspective, the value of the audience participation has mostly been insight into the kinds of questions people ask, and the kinds of issues that the public seems most concerned with (e.g., how resistant the public is to use of nuclear options even given considerable impact threat and possible lack of alternative options). That level of feedback may be less dependent on giving participants actual control over the outcomes. If there were more actual leaders involved, rather than participants acting in those roles, then the value of giving participants additional options and control may be more worthwhile. However, that is just from the standpoint of gaining feedback on risk assessment results, and there may be more value from other perspectives.

7. The announcements we use in PDC TTXs should not be called, or thought of, as press releases. They're not suitable as such. IAWN announcements, maybe. But not press releases.

8. We could have a concluding discussion at the end of our exercise to help create interest and collect creative ideas.