



## 2015 IAA Planetary Defense Conference

# Conference Summary and Recommendations

### 1.0 Introduction

The 2015 International Academy of Astronautics (IAA) Planetary Defense Conference was held on April 13-17, 2015 in Frascati, Italy. This was the sixth 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, and Flagstaff, Arizona in 2013. The conference became associated with the IAA in 2009.

In addition to the IAA, the conference had six major sponsors, ten additional sponsors, and eight partnering organizations. Sponsors and major sponsors provided funds that helped cover major conference expenses and, in some cases, enabled prizes for the best student papers and scholarships to help cover travel and lodging expenses. Names of sponsoring organizations are given in Attachment A.

A total of 245 individuals representing 21 different countries attended the 2015 conference. Attendees included 16 members of the press. The conference included a total of 81 oral presentations plus 25 short oral introductions of poster papers. A total of approximately 80 poster papers were accepted and posted at the conference. Figure 1 shows conference attendees.



*Figure 1. Conference attendees.*

Members of the Organizing Committee, listed in Attachment B, held monthly telecoms to organize the conference and develop the program given in Attachment C and summarized in Section 3. In general the conference followed a format similar to that for the previous conferences: the conference was single track, meaning that sessions were sequential, and

participants were able to attend all of the sessions offered. This feature was seen by many as a very positive characteristic of the meeting in that it gave each participant the opportunity to become familiar with virtually all aspects of planetary defense, including what we know about asteroids, how we might deflect a threatening object, the effects of an asteroid impact, and response to an asteroid impact disaster.

Each session was organized by the chairs of that session. Chairs were free to set time limits for presentations and to dedicate one or two time slots to short presentations highlighting poster papers. Presentations were generally limited to 12 minutes each (presenters in Session 1 were allocated 17 minutes), with three additional minutes allocated for questions. Oral poster presentations were limited to three minutes each. A meeting timer was used to assure that speakers stayed within allocated time limits.

Each presenter provided both briefing charts and a paper, which could be either a full-length paper or an extended abstract. Papers are available at the conference website, <http://pdc.iaaweb.org>.

The highlight of the conference was a tabletop exercise that included updates on the progress of a hypothetical seven-year asteroid threat and asked participants to help develop possible responses to the threat. More details on the tabletop exercise are given in Section 3.

At the end of the conference, attendees were asked for their input for findings and recommendations that should be carried forward in this summary report. This material is included in Section 4 of this document.

## 2.0 Summary of Sessions

As previously noted, the conference was a single-track conference and all attendees were able to attend all presentations. A brief summary of topics covered in each session is given below.

### 2.1 Session 1: International Programs and Activities

Presenters in this session summarized projects and programs that are currently funded or are being seriously considered for funding by space agencies or governments. These included projects supported by the European Space Agency (ESA) as part of their space situational awareness (SSA) program, a status report on the NEOShield project funded by the European Commission, a proposal for a Russian effort to build a system for detecting and monitoring hazardous asteroids and comets, recent enhancements of NASA's Near Earth Object Observation program and how they relate to planetary defense, and results of initial steps to establish an Asia-Pacific asteroid observation program.

### 2.2 Session 2: Discovery, Tracking, Characterization

Presenters provided updates on the status of existing and evolving systems for discovering and characterizing asteroids, in addition to the latest information available on the number of near Earth objects (NEOs)<sup>1</sup> and their physical properties. Twenty presenters provided 13

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<sup>1</sup> A Near-Earth Object (NEO) is a small solar system body (e.g., asteroid or comet) whose perihelion distance (the closest it comes to the Sun) is less than 1.3 AU (1 AU is the mean distance of the Earth from the Sun, equal to approximately 150 million km). For more information, see:

<http://neo.jpl.nasa.gov/neo/groups.html>

minute presentations and an additional 15 gave short verbal introductions to their poster papers. Key findings reported are:

- Ground-based assets (including the Large Synoptic Survey Telescope (LSST), Panoramic Survey Telescope and Rapid Response System (Pan-STARRS1 and 2)) are limited by optical viewing limitations intrinsic to ground-based systems and by themselves cannot complete a search for NEOs as small as 30-50 meters for many years.
- Status of the Pan-STARRS1 and Pan-STARRS2 systems. Pan-STARRS1 has discovered nearly 1700 NEOs to date and is now discovering 50 to 100 NEOs per month with good weather. Pan-STARRS1 discovered more than half of the new comets discovered in 2014. Pan-STARRS2 is expected to become operational by the end of October 2015.
- Increased recognition that impacts of objects smaller than 140 meters, the current goal of our discovery efforts, could still destroy a city and cause a regional disaster. Some suggested that the goal of our discovery and tracking efforts should be increased to locate and track objects in the 30-50 meter size range, the size range of the objects that caused the Tunguska and Meteor Crater events.
- Research shows that effective discovery of objects in the 30-50 meter range would require both ground-based and space-based assets.
- As has been demonstrated by the NEOWISE mission, a space-based infrared (IR) telescope has excellent capabilities for NEO discovery, and orbiting a more capable instrument of that type should be a top priority, particularly if we plan to make searching for smaller threatening asteroids a goal.
- Adding space-based IR telescopes (e.g., Sentinel, NEOCam) to the ground-based capabilities would increase the discovery rate substantially.
- A system of small, relatively inexpensive wide-field telescopes such as the proposed Asteroid Terrestrial-impact Last Alert System (ATLAS) and NEOSTEL Fly-Eye sensors could discover ~60% of asteroids on an impact trajectory and provide a short-term warning, potentially enabling evacuation of areas that might be affected.
- Development and maintenance of an image archive from large telescopes, asteroid surveys (e.g., Pan-STARRS), and cooperating observatories, along with a related search tool to look for moving objects, would assist with recovery of prior, but unrecognized, observations of potentially threatening objects.
- The importance of focusing characterization efforts on the NEOs most relevant to planetary defense: potentially hazardous asteroids (PHAs), having close approaches to the Earth in the near future, and NEOs most accessible for reconnaissance and deflection-test missions. Important physical parameters include those enabling the object's response to non-gravitational forces (mainly to the Yarkovsky effect) to be estimated and the future dynamical evolution to be modeled, and the suitability of potential deflection techniques to be assessed.
- The 2029 Earth encounter of Apophis has such a strong scattering effect on its trajectory that post-2029 predictions are only possible in a statistical sense, and impacts in the following decades are hard to rule out. Mapping the orbital uncertainty to the 2029 close approach and computing the resulting keyholes, i.e., the locations at the 2029 Earth encounter leading to a resonant impact at a future close approach, shows that impacts are still possible after 2060 with probabilities up to few in a million.
- While the observing window for sub-200 meter NEOs, which can cause severe regional damage, can be very limited, characterization data for this population is still very sparse. It is important to be prepared to interrupt routine astrometric

follow up to do characterization soon after discovery. Moreover, recent enhancements to NASA's NEO Observations Program have led to a large increase in NEO discovery rate over the past year. The new survey efforts are yielding close Earth encounter predictions, which in turn provide substantial opportunities for characterization of very small NEOs.

- The resolution of radar imaging of NEOs is rapidly improving: the Arecibo facility can provide images of NEAs with resolution as fine as 7.5 m in line-of-sight distance (Arecibo currently observes roughly 70 NEAs per year); the Deep Space Network's ~450 kW X-band Goldstone Solar System Radar transmitter on the 70-m DSS-14 antenna can provide images with resolution as fine as 3.75 m for NEAs passing within < 10 lunar distances of Earth (DSS-14 currently observes roughly 30 NEAs per year); a new 80 kW C-band transmitter installed on the 34-m DSS-13 antenna as part of the DSN Aperture Enhancement Project can now be used for high-resolution radar imaging (bistatic mode; resolution  $\geq 2$  m) of objects passing within a few lunar distances (expected observational return: a few NEAs per year).
- The study of meteors can help infer the chemical and physical properties (composition, structure, mass, porosity, density, etc.) of their parent NEOs.
- There appears to be a systematic association of relatively high values of the Near-Earth Asteroid Thermal Model (NEATM) fitting parameter  $\eta$  with M-type asteroids and high radar albedos, suggesting that  $\eta$  is a potentially useful tracer of metal content in asteroids. The NEOShield results also imply that there are many metal-rich asteroids, possibly also in the NEA population, that have not yet been identified as such. The proportion of metal in an object is important for mitigation-relevant considerations of object density and robustness.
- NEOShield-2, a successor project to NEOShield, has secured funding from the European Commission for 2.5 years from March 2015. NEOShield-2 will focus on technological development and maturation tasks, which will serve to minimize the necessary preparation time for a NEO deflection mission, and be of benefit to the design of NEO reconnaissance and sample return missions for the purposes of mitigation-relevant physical characterization. The project contains work packages for observational work on mitigation-relevant NEO targets and associated data reduction and analysis, and includes an interface to ESA's Space Situational Awareness NEO Coordination Centre.

### 2.3 Session 3: Deflection and Disruption Techniques

Fifteen papers were presented in this session. Speakers discussed the effects that kinetic impactors and nuclear explosives would have on a NEO and the overall effectiveness of each approach (note that political or other considerations for use of nuclear explosives were not addressed in this session). Key points from these presentations were:

#### Kinetic Impactors & Nuclear Explosives

- In priority order, orbit, mass, composition, porosity, shape, structure, and spin rate are the asteroid characteristics required to reduce the uncertainty in the effectiveness of kinetic impact or nuclear explosive techniques for deflection missions.
- Since the ejecta from impact of a kinetic impactor spacecraft will be essentially normal to the surface at the impact point, uncertainty in an asteroid's shape leads to uncertainty in the ejecta component ( $\beta$  or the beta factor<sup>2</sup>) of momentum transfer

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<sup>2</sup> The beta factor ( $\beta$ ) is the ratio of momentum imparted to the asteroid to the momentum of the incoming impactor spacecraft.

for a kinetic impactor. As a result, a “conservative” beta factor should be used in the development of mitigation attempts using kinetic impactors.

- For small asteroids, kinetic impact is surprisingly effective, and would be even more effective for volatile-rich bodies. For larger bodies, the nuclear option may be the best available, particularly if warning times are short. Figure 2 shows regions where each option is most effective.
- Comparisons of the effects of kinetic impactors and standoff burst nuclear explosives on asteroids predict that standoff burst nuclear explosives are more effective for deflecting a NEO. Presentations also discussed how a nuclear explosive might instead be used to disrupt an asteroid.
- The effectiveness of standoff nuclear explosions is affected by the composition of the asteroid and the spectrum of the energy released by the explosive device. While much of the energy of a nuclear standoff burst would be wasted through radiation into empty space, the momentum change imparted to the object by a single nuclear explosive device would still be far in excess of that imparted by a single kinetic impactor.
- A Hypervelocity Asteroid Intercept Vehicle (HAIV) was described that would combine a kinetic impactor with a nuclear explosive follower. The kinetic impactor vehicle would create a crater and the trailing explosive device would detonate in the crater, effecting a subsurface detonation. Preliminary indications are that the technique could increase the efficiency of the nuclear explosive over that of a contact or standoff burst.
- Effectiveness of both kinetic impactor and nuclear deflection must be predicted using models with resolutions appropriate for each approach.
- Existing nuclear explosives could be used to deflect NEOs.

#### Directed Energy Systems

- With long warning times, planetary defense could be feasible using directed energy systems, but more time would be required to evolve and mature critical components. The most effective system would include a space-based capability. The time required for effective operations of such a system would depend on the size of target object and the power delivered to the target. An additional area suggested for future work would use directed energy systems to excite the natural resonance frequency of a rotating monolithic M-type asteroid and use that effect to fracture and disrupt the asteroid.
- The topography of an asteroid can limit the deflection capability of an ablation technique such as using a laser or mirror to heat a portion of an asteroid to create thrust from the expelled mass. Using topography-based targeting of the beam could minimize the reduction in deflection capability due to these effects.



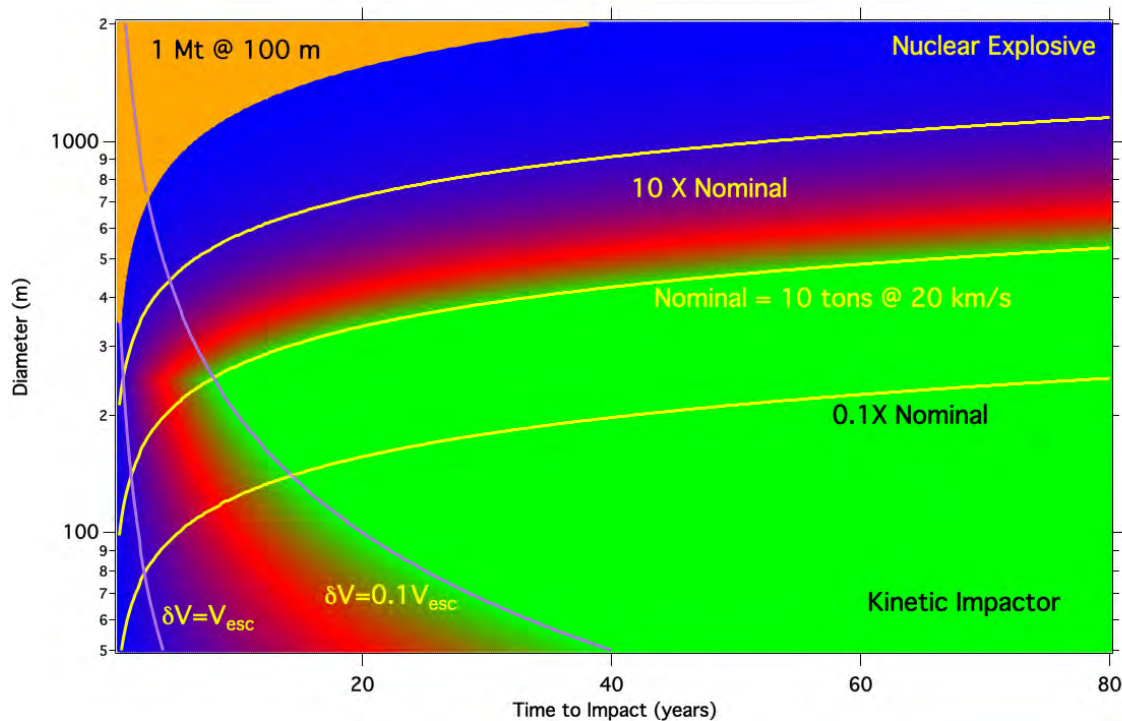


Figure 2. Approximate regimes of effectiveness for a single kinetic impactor (10 tons at 20 km/s, green) and a single 1 Mt standoff nuclear explosive to deflect an asteroid from impacting Earth. Details are discussed in the Dearborn, et al. presentation.

## 2.4 Session 4: Mission and Campaign Design and Execution

Speakers in Session 4 discussed missions related to planetary defense that are planned or in the design stage. Specifically:

- A joint NASA-ESA Asteroid Impact and Deflection Assessment (AIDA) mission that would demonstrate the ability to modify the orbital path of the secondary asteroid ("Didymoon," of the 65803 Didymos binary system) using a kinetic impactor and obtain scientific and technical results that can be applied to other targets and missions. The nominal impact date would be in October 2022. The mission would include an orbiter (ESA's AIM spacecraft) of asteroid 65803 Didymos. The orbiter would arrive prior to NASA's Double Asteroid Redirection Test (DART) kinetic impactor vehicle and would characterize the Didymos system, test a deep-space optical communications system, release a lander on Didymoon to analyze its deep interior, and measure the effects of the kinetic impact on the moon and its orbit.

The session included several presentations providing details on aspects of the AIDA mission. These included:

- Overview of the NASA DART vehicle, which would impact Didymoon. Data from the impact would enable estimation of the beta factor for the impact and long-term study of the dynamics of the debris cloud.
- Techniques for measuring the effects of the impact on Didymoon's orbit and calculation of the velocity increment imparted by the impact.
- Models of the evolution of Didymoon's orbit after impact of the DART impactor.
- A method to determine the fate of ejecta after a hypervelocity impact. This has been used to predict safe zones where risk is minimized for the observer spacecraft.

- Use of a bistatic, low frequency radar to determine the interior structure of Didymoon.

Other presenters discussed:

- A space experiment that would look at measuring the motion of boulders on the surface of an asteroid or small body after an impact to develop the science requirements for an asteroid seismology mission. The technique could help refine the internal structure of an asteroid.
- The relevance of ESA's Philae and MASCOT landers to planetary defense. MASCOT is a small lander containing four scientific instruments that will be delivered by Japan's Hayabusa 2 mission. MASCOT is contributed to JAXA by DLR (German Aerospace Agency) and CNES.
- Establishment of a five-year partnership of NASA Centers and DOE/National Nuclear Security Administration's National Laboratories that will analyze three design reference asteroids and missions and compare the effectiveness of standoff nuclear explosions and kinetic impactors. The study will look at asteroids in the 100 to 1000 meter size range with concentration on asteroids greater than 140 meters in size. Separate case studies will be developed for different asteroid types, such as for Bennu, an S-type asteroid, a downsized Bennu, an asymmetric shape, and asteroid 2008 EV5. The work will be documented, and the team plans to build a "playbook" for decision makers.
- A proposed baseline for the design of a gravity tractor demonstration mission that would use asteroid 2000 FJ10 as the object to be moved. The nominal mission duration would be six years, with approximately two years dedicated to the deflection. The mission proposes to launch a ~1160 kg spacecraft in 2026 using a Falcon 9.
- Uncertainties that would affect the success of a deflection mission. While the primary focus is on the nuclear explosive, the gravity tractor, and kinetic impactor techniques, there are uncertainties that must be accounted for in virtually all techniques. An example is the uncertainty in the size, shape, and density of a target asteroid, which can lead to possible masses differing by orders of magnitude. Uncertainties also arise because of differing models used to predict effects of impact by a kinetic impactor or nuclear explosion, orbit propagation, and several other factors. Mission planners must recognize that these uncertainties exist and plan for them.
- A vision-based navigation system for close characterization, observation, and landing on asteroids.
- Threat mitigation tools designed as part of the NEOShield project. These include tools that are designed to assess the risk of NEO impact, evaluate the effectiveness of proposed deflection attempts by impulsive and slow-push techniques such as gravity tractor and ion beam shepherd, and evaluate risk mitigation strategies. The presentation discussed the application of these tools to the asteroid threat case defined for the conference (2015 PDC).
- Design of a mission using an ion beam directed from a nearby spacecraft to gently nudge asteroid 2015 PDC away from a high consequence impact location.
- Design of missions to rendezvous with and intercept 2015 PDC, and results showing how the cloud of fragmented asteroid pieces would evolve.
- A description and possible uses of a solar sail spacecraft for visiting one or more NEOs, possibly delivering a kinetic impactor, or as a sample return vehicle.

- Robotic missions to small bodies and their potential contributions to planetary defense. Consistent with NASA's Grand Challenge to "Find all asteroid threats to human populations and know what to do about them," NASA's asteroid initiative would allow insight into the physical properties of NEAs and provide scientific and engineering data that would assist in the development of planetary defense missions and strategies.
- NASA's Asteroid Redirect Mission (ARM), which would demonstrate and test an enhanced gravity tractor technique that would include augmenting a spacecraft's mass using a multi-ton boulder removed from the surface of the asteroid to be tracted. The augmented mass of the spacecraft would increase the gravity tractor effect.
- A project that established requirements for a crewed, round-trip mission to an asteroid and used an automated system to determine the accessibility of known asteroids. The study found that for a total mission duration of 450 days or less, at least an eight-day stay at the asteroid, and total mission Delta-V of 12 km/s or less, there nearly 1400 known asteroids offering at least one mission opportunity that meets those requirements. About 50 of these can be visited round-trip with less Delta-V than that required for a round-trip to lunar orbit. Nearly 600 can be visited round-trip for less Delta-V than that required for a round-trip to the lunar surface. Discoveries of even more mission accessible asteroids are expected.
- A conceptual "billiard-ball" mission that would capture an asteroid smaller than 10 meter in size and maneuver it to collide with a larger asteroid. Candidate asteroids that could be used have been identified and the proposal includes a launch in 2021 with capture of the small asteroid by 2024 and impact with the larger asteroid in 2029.
- Two proposals developed by the NEOShield project for missions to demonstrate deflection of an asteroid using a kinetic impactor. The first would enable validation of deflection and accurate estimation of the  $\beta$  factor using two spacecraft, one as an observer, the second an impactor. The second mission would impact an asteroid (asteroid Itokawa is proposed) and use the change in its spin rate to determine the  $\beta$  factor.

## 2.5 Session 5: Consequences of Impacts

The session was introduced with an update on the risk assessment for small (meters to tens-of-meters in size) NEOs. Recent analyses show that the risk of damage caused by airburst events, events where small asteroids deposit most of their energy in the atmosphere, is greater than previously thought for two reasons: 1) estimates of the number of NEOs in the 10 to 40 meter size range has doubled, and 2) airbursts are significantly more damaging than previously thought. Predictions are that ~20 meter asteroids (Chelyabinsk-sized) pass within the orbit of geosynchronous satellites once every two years and within lunar orbit once a week, and that a Tunguska-sized (~40 meter) asteroid passes within lunar orbit several times a year. As a result, surveys for threatening asteroids should transition to smaller, short-warning asteroids.

Other presenters discussed:

- A new, free, open-source tool for modeling asteroid breakup during atmospheric entry and simulation of the trajectory of the object and its fragments after breakup.
- Development of a method using dimensionless parameters that characterizes the ability of an entering body to survive an atmospheric entry and have surviving fragments reach the ground.



- An overview of a new NASA project focused on planetary defense and a discussion of the sensitivity of ground damage predictions to asteroid breakup modeling assumptions. Results show that a spherical airburst model can be used to bound the effects of a steep entry case when local flow conditions don't interact with the ground and can be a guide for when a higher fidelity model is required for shallow entry.
- A new method for estimating what happens when an asteroid impacts in water. The technique was used to predict wave generation, wave propagation, and onshore consequences of the 2015 PDC exercise scenario. The physics in the model include air and water, phase transformation, convection, mixing, and more.
- Predicted Asteroid Distribution to 2100 indicating nations at greatest risk of asteroid impact and nations with a disproportionate risk due to their high population should include potential asteroid impact in their national security response planning.
- New parameterization formula to characterize entering bodies. The results can be used to predict and quantify fallen meteorites and speed up recovery of their fragments.

## 2.6 Session 6: Disaster & Mitigation Planning & Public Education

Speakers in Session 6 discussed policy and legal issues that might affect future mitigation plans; educating the public and the media on NEO detection, impact effects, mitigation missions, and impact warnings; and disaster simulation and response exercises. Specific topics were:

- Public outreach for the NEOShield Project, which includes the NEOShield website and its use as influenced by major events such as asteroid close approaches, social media (Facebook, Twitter), and two-way communication via conference visits and a comic cartoon contest.
- Understanding risk communication and information needs for managing the response to hazardous NEOs. While there has been impressive progress on risk communications for the NEO hazard, more needs to be done to prepare leaders, responsible agencies, the media, and the public for the NEO threat. Much of the work to date has been top down about what to do, etc.; more needs to be done to understand the public's perspective and needs. Communications should compare NEO hazards with known hazards (e.g., tornado, hurricane), anticipate and address controversies, utilize a clear emergency terminology to avoid confusion, and color-code threat systems.
- Means of educating the public about the impact hazard. It was noted that the quality of content presented in TV documentaries has increased significantly. It was recommended that members of planetary defense community continue and increase efforts to be part of high-quality TV documentary productions about the impact hazard. In addition, it was recommended that: distribution lists be established that link the planetary defense community with target groups such as teachers; that the community use existing websites with significant outreach (e.g., Wikipedia) to publish high quality information about the impact threat and planetary defense; that planetary defense topics should be included in school curricula (preferably Geography); and that the community should reach out to science museums to include something on planetary defense.
- Speedy response to events. Should an event occur (such as a bright meteor or impact), leaders and the public demand a speedy response (hours, not days), and a good team needs to be "at the ready" to respond. The initial characterization need

- not be very detailed, but should answer basic questions such as was it a space rock or space junk, how big was it, did it impact, etc. Relevant information can be gathered from social media, all-sky networks, web cams, and other resources.
- Observations and recommendations relating to communication across expert/non-expert boundaries. Communications should be clear and concise and stay away from jargon, probabilities, and the like. Messages must be timely, comprehensive and accurate. People communicating information should be open, transparent, and sensitive to knowledge, opinions, and beliefs of their audience. Communicators should stick to the facts, avoid speculation, acknowledge and explain uncertainties, and address all questions and concerns respectfully. Communities communicating both technical and nontechnical aspects of planetary defense should use terminology that is both accurate and understandable to those with other backgrounds.
  - Is it legal to launch a nuclear explosive for planetary defense? There are arguments for and against establishing a special legal regime for using nuclear explosives for planetary defense, but this could be done. However, it appears it may not be necessary under current space law regulations.
  - A two-day, asteroid impact simulation that considered an impact over the Swiss-German border. The ESA-sponsored exercise was to acquaint response agencies and prepare a response strategy for a possible asteroid impact. The exercise demonstrated the need for plans as to how and to whom information would be distributed and for clarification of ESA's internal decision-making process. A full workshop is being planned.

### 3.0 Threat Response Exercise

The primary goal of the exercise for the 2015 conference was to explore the decision-making process for dealing with the threat in a way that might represent the process that might actually be followed in the event of a real threat. To do this, the exercise development team (see Appendix D) injected information on the threat posed by fictitious asteroid 2015 PDC prior to the conference and just before lunch on each day of the conference. The information provided prior to the conference was to encourage individuals to use that information to conduct their own research into the threat and its possible outcome. Several attendees used the hypothetical asteroid threat as the basis for papers and presentations at the conference.

As individuals registered at the conference, each was randomly assigned and given a colored lanyard corresponding to one of four syndicate groups:

Group 1: Political Leaders of nations that might be directly affected by impact,

Group 2: Political Leaders of nations that would not be directly affected by impact,

Group 3: Residents of areas that might be directly affected by impact, and

Group 4: The media.

In addition, three attendees were selected as World Leaders, individuals whose role was to make decisions as to what actions should be taken given the information presented at each phase in the evolution of the threat. Five to seven Expert Advisors were also identified who would provide expert advice and counsel to the World Leaders as they deliberated on their decision. Both the Expert Advisors and World Leaders changed as the threat evolved. Figure 3 shows the World Leaders and Expert Advisors at the end of the day on Thursday.



*Figure 3. From the left, World Leaders Lindley Johnson, Cathy Plesko, and Bhavya Lal, and Expert Advisors Paul Chodas, Nahum Melamed, Josh Dozor, and Barbara Jennings.*

Groups 1 through 4 were invited to meet during lunchtime and breaks to develop their perspectives on the threat and recommendations for actions that could be taken. Each group selected a group member to present condensed version of their thoughts to the World Leaders at the end of each day.

The last day of the conference was dedicated to completing the tabletop exercise, and three injects were provided on that day to see the scenario through to either an impact or a successful deflection. It should be noted that the exercise was designed, and injects in the form of press releases (see Attachment D) were drafted, prior to the conference so the outcome and details were predetermined.

A quick summary of the observations and comments from the exercise groups as the scenario developed is included in Attachment D.

## 4.0 Recommendations

### 4.1 Increase Discovery Rate for Small NEOs

Results show that the risk from airbursts of asteroids in the 10 to 50 meter size range is greater than previously thought due to the nature of the energy released by entry of these smaller bodies and by revised estimates of the population of such objects. This new information increases the likelihood of unexpected impact of a small (less than 140 meters in size) asteroid and the possible consequences. The Chelyabinsk event, caused by entry of a body ~20 meters in size, and the Tunguska event, caused by a ~40 meter asteroid, are examples of airbursts of objects in this size range.

Given this, and the fact that currently only a small fraction of the estimated total population of such objects has been detected and catalogued, the NEO detection community should modify the goal of NEO search efforts to include finding a much higher percentage of the small objects, objects down to 30 to 50 meters in size, over the next 10 to 15 years. Adding space-based IR telescopes to current and planned ground-

based capabilities would significantly increase the discovery rate of smaller NEOs. The FlyEye and ATLAS observation techniques will improve knowledge of the diversity of object populations and provide at least some warning of an impending small object impact by objects approaching Earth from the night side.

Development and maintenance of an image archive from large telescopes, asteroid surveys (e.g., Pan-STARRS), and cooperating observatories, along with a related search tool to look for moving objects, would assist with recovery of prior, but unrecognized, observations of potentially threatening objects. Such “precoveries” can help refine our estimate of an object’s orbit and, thereby, more quickly resolve the threat level of a newly discovered object.

#### **4.2 Test and Verify Deflection Technologies**

Recent research confirms that kinetic impactors and nuclear explosives (sub-surface, surface, and stand-off burst) are the most effective means currently available for deflecting an asteroid, and that existing nuclear explosives could be used to deflect NEOs. A nuclear explosive might also be used to disrupt an asteroid. Analyses of nuclear explosive techniques and missions should continue, but since nuclear devices are considered a mature technology, there were no calls for testing a nuclear device for asteroid deflection. Testing of non-nuclear aspects of deflection (e.g., targeting high velocity intercept of small asteroids) could benefit both nuclear and/or kinetic approaches.

Previous conferences have recommended that missions be conducted to test and verify humanity’s ability to move an asteroid. A highlight of this conference was to hear presentations on mission concepts related to planetary defense and, in particular, considerable detail on two proposed missions that include such goals.

The joint NASA-ESA Asteroid Impact and Deflection Assessment (AIDA) mission, which will measure the effect of a kinetic impactor on a moon of a binary asteroid, and NASA’s test of the enhanced gravity tractor concept as part of its proposed Asteroid Redirect Mission (ARM), which would utilize a boulder from the target asteroid to increase the mass of the gravity tractor, would both help lower uncertainties of these two deflection techniques and give confidence about capabilities to move an asteroid in a controlled way. Both of these missions have significant science benefits and are representative of how we can build confidence in deflection technologies by merging the two interests.

#### **4.3 Develop Framework for Use of Nuclear Explosives for Planetary Defense**

While researchers discussed technical results showing nuclear deflection is several orders of magnitude more effective per mass or per mission than kinetic impactors, there were no general discussions of the many nontechnical issues associated with the decision to actually use such devices for planetary defense. As was highlighted by the tabletop exercise, many public perspective and geopolitical complexities must be resolved should nuclear explosives be proposed for such use. A framework for timely, coordinated decision-making on the use of such devices for planetary defense should be developed.

#### **4.4 Reduce Uncertainties for Deflection/Disruption**

A major focus of the conference was the effect of uncertainties on a deflection effort. An example is the uncertainty in a distant object’s size based on optical telescope observations, where there can be a factor of two uncertainty in the diameter of an asteroid. This translates to a factor of eight uncertainty in its volume, and even greater

uncertainty in its mass, which is a critical factor in knowing how much mass needs to be sent to move the object. Speakers noted that a space-based infrared telescope could reduce the size uncertainty and, as has been demonstrated by the NEOWISE spacecraft, play a key role in helping to locate and characterize small asteroids.

Other uncertainties include the density of an object, its water content, and whether the object is a solid mass or a conglomeration of smaller, loosely connected masses. Techniques and missions to probe the interior of an asteroid are early in their development and are worthy of continued development. Continued research is needed to understand the diversity of asteroid materials and composition, and their effects on the performance of kinetic impact and nuclear deflection options.

If time allows, precursor missions can reduce uncertainties in a target object's size, shape, and rotation rate and can help refine orbit estimates. A pre-designed precursor spacecraft that could be launched quickly would provide very useful information to the designers of deflection spacecraft and missions. Such a mission could include small satellites to help refine the asteroids physical characteristics. Furthermore, the efficacy of flyby precursor missions should be assessed, because rendezvous opportunities are often sparse.

#### **4.5 Increase Understanding of Impact Effects**

For potential impacts of small NEOs, there will be a need to decide whether there should be a deflection effort or we should evacuate the affected area, "take the hit," and deal with the consequences. This decision will require accurate estimates of the insult from the impact (e.g., tsunami size, ground area affected) and its consequences. While consequence prediction codes are improving, there is a need to assure that codes are providing comparable results. A standard set of test cases should be developed for comparison and validation of prediction tools. In addition, codes that predict consequences of an entry and impact do not predict the short-term effects on the environment, critical communication infrastructure, or space-based assets. New models provide information on materials lofted into the atmosphere after an impact, and this information could be used to investigate these effects. These consequences could increase the overall cost of an impact for comparison with the overall investment in planetary defense and should be included in research efforts as models allow.

#### **4.6 Build International Cooperation on Planetary Defense**

Planetary defense is an international issue that will require international decision-making and support. International collaboration on AIDA and similar missions, as well as involvement of all space-faring nations in the Space Mission Planning Advisory Group (SMPAG), should be supported.

#### **4.7 Develop Risk Communication Plan**

Based on perspectives and concerns raised during the hypothetical threat exercise, there could be much distrust and misunderstanding when an actual threat is discovered. Such misunderstandings could affect development and execution of both deflection and disaster response actions. This amplifies the need for 1) continuing and increased efforts to provide ongoing and factual information on NEOs to the public and leadership, and 2) the development of protocols and guidelines for providing information announcing the threat and providing status during the evolution of the threat and its response. Periodic surveys of public understanding of the asteroid threat and testing response approaches might be considered.



**SPONSORING ORGANIZATIONS**

**Primary Sponsors**

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National Aeronautics and Space Administration (NASA)  
Airbus Defense and Space  
The Aerospace Corporation  
Space Dynamics Services (SpaceDyS)  
International Academy of Astronautics (IAA)  
The Planetary Society

**Sponsors**

Lawrence Livermore National Laboratory  
Association of Space Explorers  
International Astronomical Union (IAU)  
Secure World Foundation  
B612 Foundation  
United Kingdom Space Agency (UK Space Agency)  
Applied Physics Laboratory  
GMV Aerospace and Defence  
Ball Aerospace & Technologies Corporation  
Emergency Asteroid Defence Project (EADP)  
Southwest Research Institute (SRI)

**Partners**

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United Nations Office of Outer Space Affairs  
American Institute of Aeronautics and Astronautics (AIAA)  
Centre National d'Etudes Spatiales (CNES)  
Sandia National Laboratories  
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\*Conference Co-Chair

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Eric Christensen	Rob Hermesen	Patrick Michel
Lorenzo Cibirin	Daniel Hestroffer	Marco Micheli
Lilly Clayton	Matthew Holman	Ljuban Milasin

## ATTACHMENT C

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Didier Morancais  
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Oliver Morton  
Martin Muller  
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Joseph Wasem  
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Robert Weaver  
Robert Weryk  
Thomas Widemann  
Bong Wie  
Lance Williams  
Wolfgang Wittholt  
Makoto Yoshikawa  
Yang Yu  
Anatoly Zaitsev  
Yun Zhang  
Ben Zimmerman

### TABLETOP EXERCISE SCENARIO & OUTCOME

The primary goal of the exercise for the 2015 conference was to explore the decision-making process for dealing with the threat in a way that might represent the process that might actually be followed in the event of a real threat. The exercise was based on the evolution of the threat posed by a fictional asteroid, 2015 PDC. Information on the discovery of the threat in 2015 and its evolution over the seven years simulated in the exercise was provided in the form of mock press releases prior to and during the conference (it was assumed that the press releases would be issued by the International Asteroid Warning Network, IAWN, a UN approved organization that brings together existing asteroid detection resources worldwide). During the conference, experts provided background and additional information on the threat and possible consequences of impact. The press releases and supporting briefings are provided below.

The tabletop exercise was developed by the team below:

**William Ailor**, The Aerospace Corporation, Team Lead  
**Brent Barbee**, NASA, Scenario Design  
**Mark Boslough**, Sandia National Laboratories, Atmospheric Entry Blast and Impact Effects  
**Souheil Ezzedine**, Lawrence Livermore National Laboratory, Ocean Impacts and Tsunami Modeling  
**Barbara Jennings**, Sandia National Laboratories, Infrastructure Effects  
**Paul Chodas**, NASA JPL, Asteroid Threat Design  
**Victoria Friedensen**, NASA, Media & Communications  
**Debbie Lewis**, Axion (Alderney), Ltd, Exercise Planning & Delivery  
**Nahum Melamed**, The Aerospace Corporation, Asteroid Deflection/Disruption Mission Planning  
**Margaret Race**, NASA SETI Institute, Scenario Design  
**Richard Tremayne-Smith**, Conference Co-Chair

Each day of the exercise, conference attendees were involved in discussions of the threat, and reactions to the threat from four different perspectives:

- 1) Leaders of nations that might be directly affected by an impact;
- 2) Leaders of nations that would not be directly affected by an impact;
- 3) Members of the public who lived and worked in at-risk areas, and
- 4) The media.

Individuals were randomly assigned to play the roles of individuals with each of the four perspectives, and each group provided short summaries of their discussions and responses.

In addition, three individual were selected to play the roles of “World Leaders,” individuals with the authority to approve actions that should be taken after each update. Representing a structure that might be used should an actual threat be discovered, the World Leaders were assisted in their decision-making by a panel of experts in several areas: the asteroid threat, the nature of the insult should the asteroid impact, consequences of such an event to buildings and infrastructure, design of a space mission to deflect or disrupt an asteroid, asteroid deflection techniques, and the media.

The sections below provide the information presented at each of the seven injects (Injects 5 through 7 were presented on the last day of the conference), short summaries of the inputs from the four groups, and the responses of the World Leaders. Additional details on the



## ATTACHMENT D

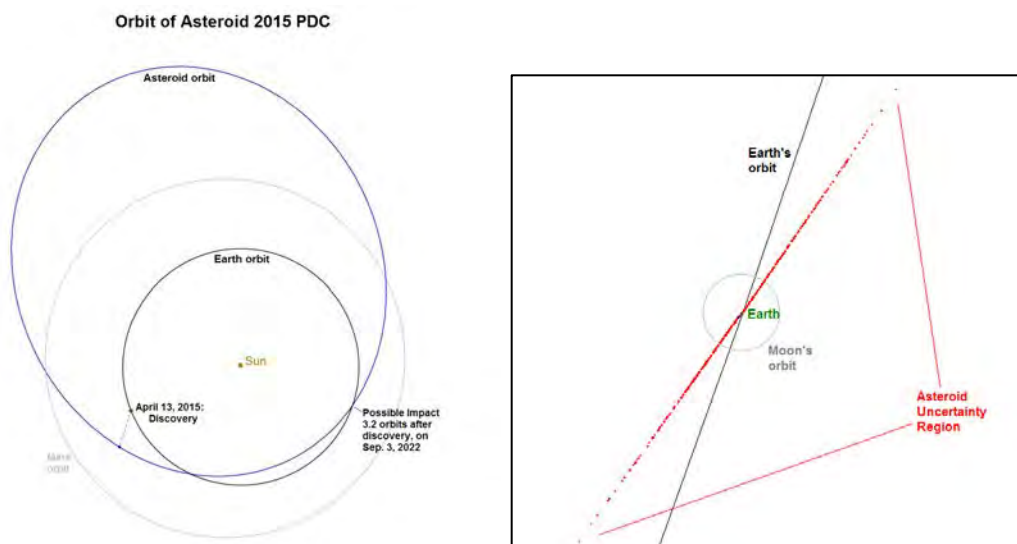
scenario, as well as videos of presentations and summaries, are given on the conference website, <http://pdc.iaaweb.org>.

**INJECT 1. JUNE 9, 2015****PRESS RELEASE****NEWLY DISCOVERED ASTEROID POSES SMALL THREAT OF EARTH IMPACT**

A recently discovered near-Earth asteroid is predicted to pass very close to the Earth on September 3, 2022. The asteroid, designated 2015 PDC, was discovered on April 13, 2015, and has been tracked continuously over the last two months by observatories around the world. Predictions for the asteroid's encounter in 2022 indicate that, while unlikely, an Earth impact cannot be ruled out. The current likelihood of impact is about 0.9% or 1 chance in 110, according to the International Asteroid Warning Network (IAWN), a worldwide partnership of agencies that detect, monitor and track potentially hazardous asteroids.

This asteroid's encounter should be no cause for public concern, since an actual collision is very unlikely: the chances are 109 out of 110 that the asteroid will safely pass by our planet. As 2015 PDC continues to be tracked by astronomers around the world through the rest of 2015 and into early 2016, its orbit will be better refined and in all likelihood, the possibility of impact will be eliminated.

The brightness of 2015 PDC suggests that it is between 140 and 400 meters (460 to 1300 feet) in diameter, but it is too distant for astronomers to make a more accurate estimate. The asteroid approached to within 0.2 AU (29 million kilometers or 18 million miles) of Earth on May 12, but it is now receding from the Earth and will not approach our planet again until the close approach in 2022. The image below on the left shows the orbit of 2015 PDC relative to the orbit of the Earth, along with the positions of the Earth and asteroid when the asteroid was discovered. The image on the right shows a zoomed-in view of the intersection point of the two orbits, along with the current uncertainty region of the asteroid when the Earth crosses the asteroid's orbit in 2022 (Moon's orbit to scale).



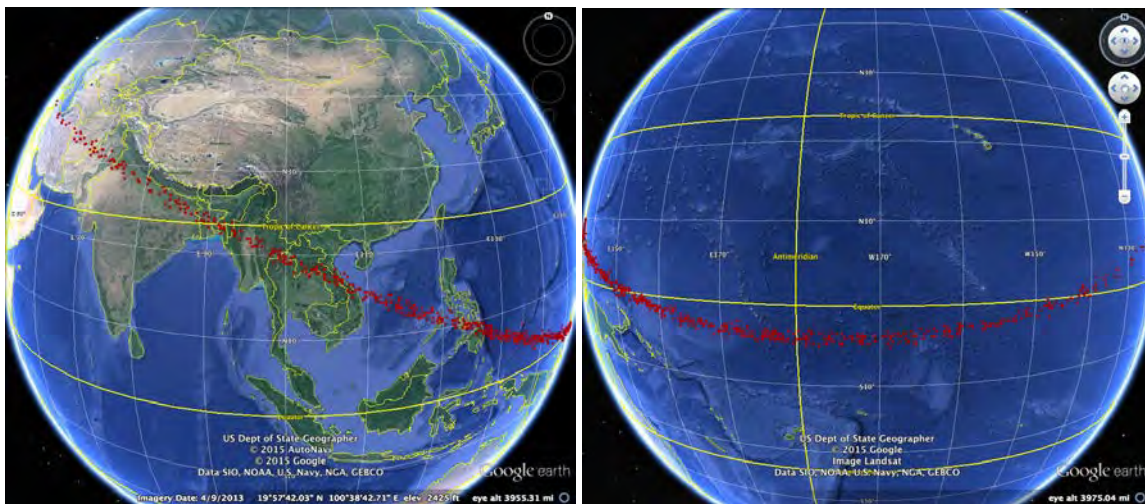
The current best estimate for the close approach distance in 2022 is about 30,000 km (19,000 miles). At the time of closest approach to Earth, the asteroid is predicted to pass inside the ring of geosynchronous satellites.

## ATTACHMENT D

2015 PDC has reached a rating of 2 (yellow) on the 0-to-10 Torino Scale, indicating that it merits special attention by astronomers. 2015 PDC is not the first asteroid to reach Torino level 2: asteroid (99942) Apophis reached level 2 and moved up to level 4 in late 2004 before additional observations uncovered in sky-image archives eliminated the possibility of impact in 2029. IAWN astronomers are actively searching the archives for similar serendipitous pre-discovery images of 2015 PDC, but none have been found to date because the asteroid has not approached close to Earth in over 20 years.

IAWN, established at the direction of the United Nations in 2013, links together the institutions that discover, monitor, and physically characterize the potentially hazardous NEO population. The IAWN partners include the Minor Planet Center (MPC), which maintains an internationally recognized clearinghouse for the receipt, acknowledgment and processing of all NEO observations, and NASA's NEO Program Office<sup>1</sup> and the European NEODyS group<sup>2</sup>, which specialize in high precision orbit calculation and computation of impact probabilities.

The IAWN partners have published details on the parts of the Earth that might be directly impacted should asteroid 2015PDC actually collide with Earth. The pair of images below shows the preliminary "risk corridor" traced by the red dots which extend from the eastern Pacific Ocean, through the South Pacific, the Philippines, South China Sea, Southeast Asia, Myanmar, Bangladesh, India, Pakistan, Afghanistan and through Iran.



For more information, visit: <http://neo.jpl.nasa.gov/pdc15/day1.html>

<sup>1</sup> <http://neo.jpl.nasa.gov>

<sup>2</sup> <http://newton.dm.unipi.it/neodys/>

### COMMENTS FROM SYNDICATE GROUPS

#### *Political leaders of affected nations*

- Leaders more interested in next election.
- Leaders are upset that had to learn about threat from a press release
- Most don't have space capability
- Iran assumes that this is a hoax and to be an action against Iran. Pakistan worried India would be given lead
- Since some are not yet part of the process and wondering why should they believe this is a real event

#### *Political Leaders of nations not affected*

- These things (close approaches) seem to always happen and just come close, so many don't care much at this point.
- Astronomers watching, people aware, but general feeling is that people don't know enough to worry at this time
- Several nations that might be affected note the location of possible impact points and are suspicious that threat is a hoax by the Americans for political reasons.

#### *Public in threatened areas*

- Public is cynical and many are uneducated. Why should we worry?
- Nothing said about what could happen.
- Some asking "Did Americans make this up to scare us?"

#### *Media*

- Sensationalistic, crazy headlines. Crazy graphics of an impact, etc.
- Social media: no control of message
- So much uncertainty, why make public announcement at this time?

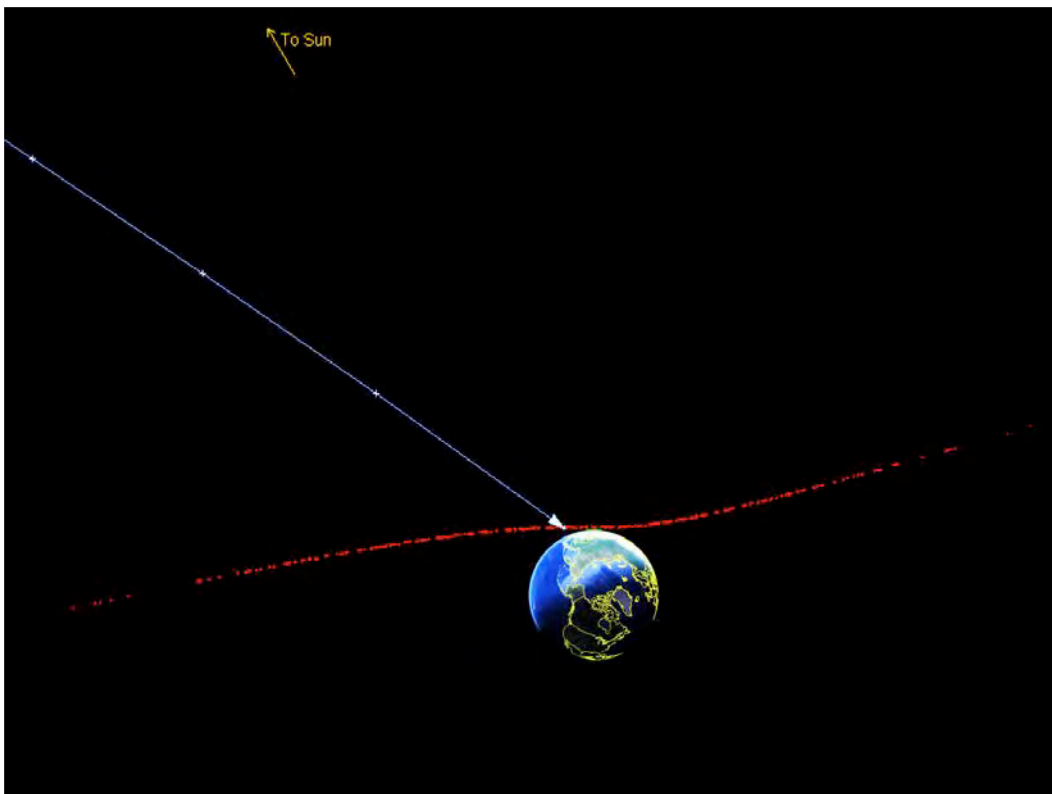
#### *World Leaders*

- At this time, missing basic information on how serious would impact be
- Current world leaders (on panel) from countries not affected. Need leaders from affected nations. [World Leaders changed as exercise progressed]
- What can be done at this point? Could deflect, 7 years left, but very early now. Mission designers could begin planning. Large uncertainty in orbit and size of objects; could take the hit if small enough. Should begin to coordinate launch capabilities of space-faring nations. Should have first cut at mission plan.
- What does UN offer? IAWN passed info through UN system.
- Need better data ASAP. What resources necessary to improve estimates? Space-based IR survey observatory would be essential to providing data on tracking and size of object. Could be some "precovery" information (information not noticed on previous observations) from NEOWISE—need to check. Media: Already spent billions on discovery tools. Why is that not enough?
- Launch capability might not be the problem, the payload to be launched is the problem.
- There's concern that if a deflection is attempted, could we make the situation worse? Would there be an effort to retarget for political or other reasons for another region or nation? Is there a liability for space faring nations? Needs to be investigated.
- No decisions made; want first cut at mission plan; coordination discussions with space-faring nations initiated.

**INJECT 2. APRIL 4, 2016****PRESS RELEASE****ASTEROID'S CHANCE OF IMPACTING EARTH IN 2022 NOW 43%**

After almost a full year of tracking asteroid 2015 PDC, it has become increasingly clear that the asteroid poses a serious risk of impacting Earth on September 3, 2022. Based on the latest set of tracking observations, IAWN now estimates the likelihood of impact at 43%. Further updates to this estimate will not be possible for eight months, as 2015 PDC passes on the other side of the Sun as viewed from Earth, and will not be observable.

Asteroid 2015 PDC was favorably positioned for observation last August through October, and it was observed extensively. Those observations did not eliminate the possibility of impact, as had been expected. Instead, they led the IAWN to raise its impact probability estimate from 5% at the beginning of August to 30% in October. More observations in February and March of this year increased the probability of impact to 43%. The diagram below shows the possible positions of the asteroid in red at the time of the potential impact. The blue line indicates the direction of motion of the red region, with tick marks at one-hour intervals.



IAWN has released estimates that the blast caused by the entry and impact of 2015 PDC could create a crater 5 to 7 km (3 to 4 miles) in diameter and up to 500 meters (1600 ft) deep and generate a 6.8-magnitude earthquake. The impact would immediately cause damage over an area of approximately 70,000 square kilometers (27,000 square miles,

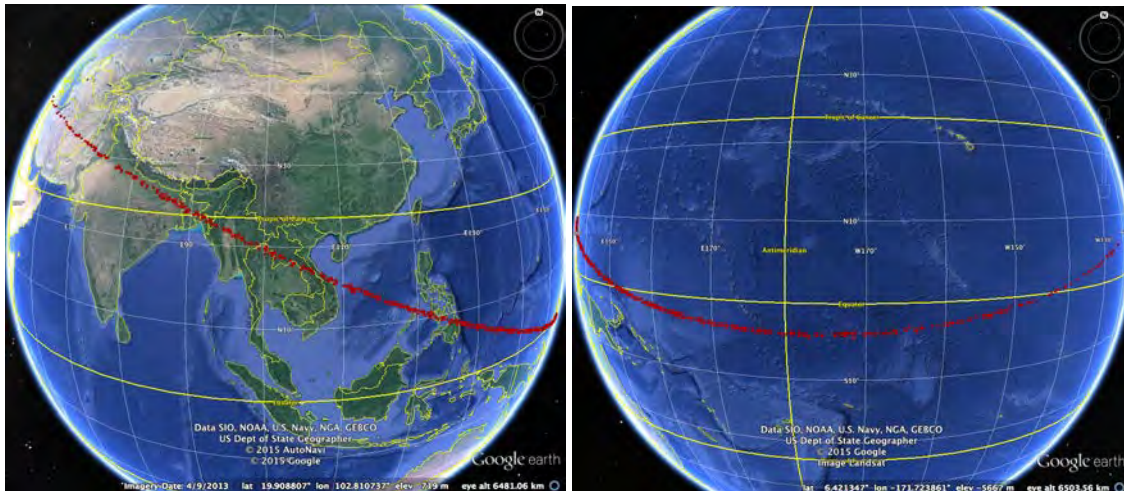


## ATTACHMENT D

about the size of the Republic of Ireland). If the impact location is in open ocean, it would create a tsunami as high as 10 meters (30 feet) that could inundate populated coastal areas with waves as high as 3 to 4 meters (10 to 13 feet). A near-shore impact would generate a much stronger local tsunami. Preliminary simulations suggest that an ocean impact would affect a far larger area than a land impact, but with less predictability. All nations with Pacific coastlines are vulnerable to tsunami damage, but the magnitude at a given location critically depends on impact location because of impact angle and ocean depth.

As background, IAWN notes that the asteroid that entered over Chelyabinsk, Russia in 2013 was estimated to be 17 to 20 meters (56 to 66 feet) in size, much smaller than 2015 PDC. That event released energy of approximately 500 kilotons of TNT. Should the object in the estimated size range of 2015 PDC enter our atmosphere, it could release energy of as much as 2250 megatons (Mt) of TNT (about 4500 times more powerful than Chelyabinsk) and would be the largest explosive event in recorded history.

The IAWN partners have released the image shown below of the updated risk corridor, now somewhat narrower than several months ago, but following the same path.

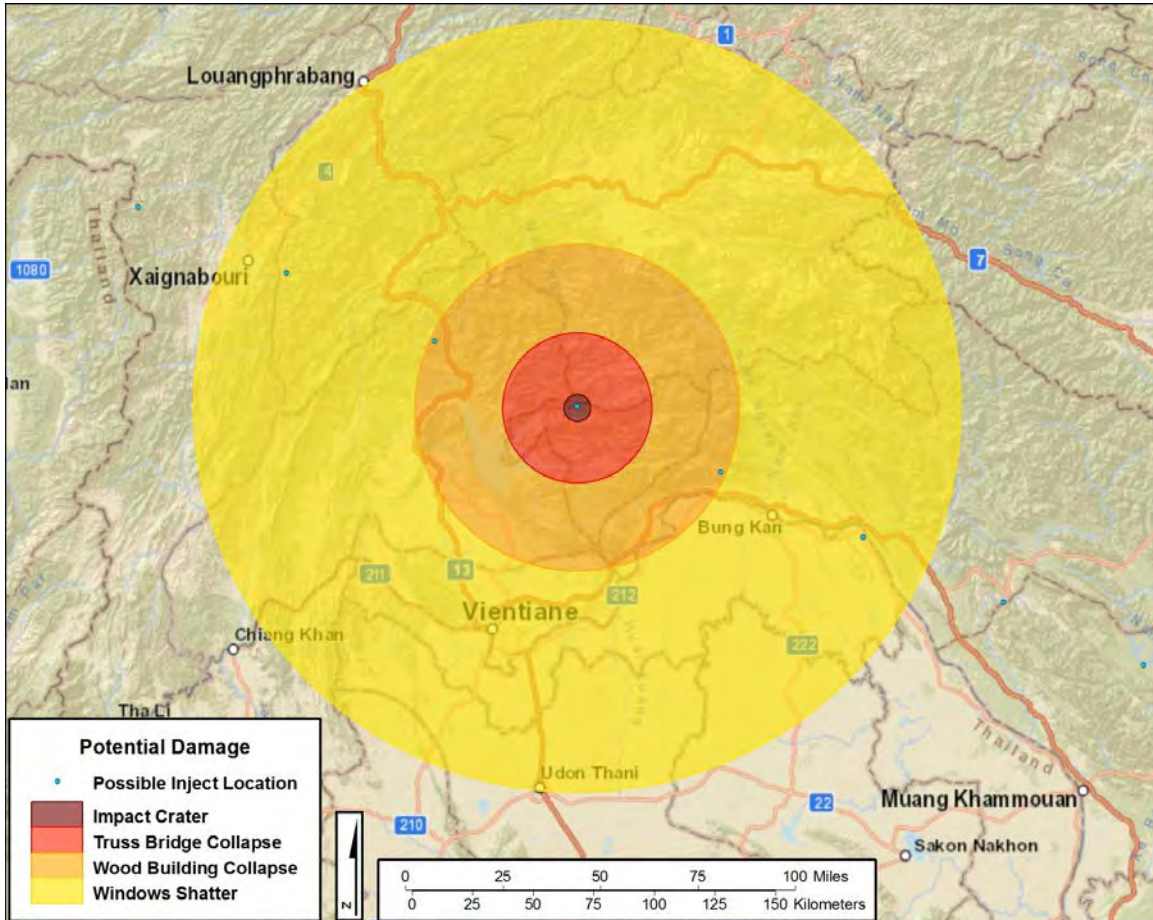


In September, the impact probability for 2015 PDC rose high enough that several space-faring nations began studying how this asteroid might be deflected using Kinetic Impactor (KI) missions. The launch opportunity for these missions would be about three years from now, in August 2019. The size of 2015 PDC is still very uncertain, and it is possible that many such missions will be required, working in tandem to carry out a successful deflection.

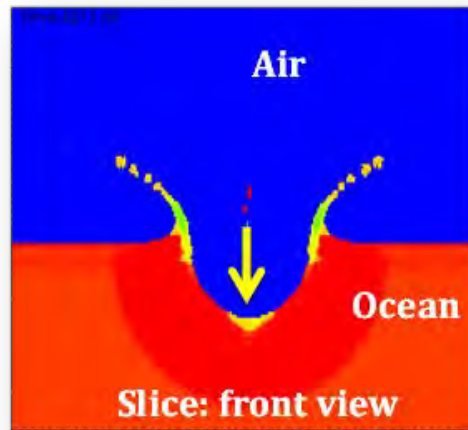
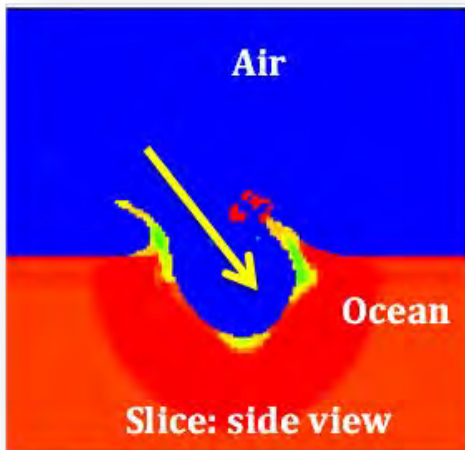
For more information, visit: <http://neo.jpl.nasa.gov/pdc15/day2.html>

## SUPPORTING INFORMATION

Anticipating questions from the World Leaders, the Panel of Experts provided preliminary information in the figures below on the nature of an impact from an object in the predicted size range.

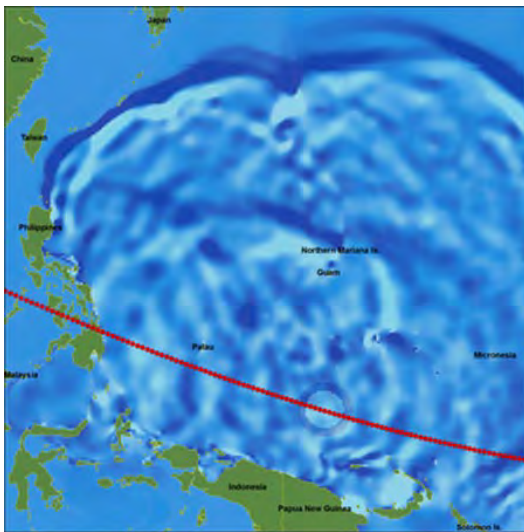


*The damage zones for a land impact were derived from the Purdue Impact Simulator, which use Glasstone and Dolan's scaling laws for nuclear explosions and the potential damage from the resulting winds generated from an airburst.*



*At this point the greatest threat is from a tsunami. The angle of impact is a strong factor on the formation of the resulting tsunami wave.*

## Western Pacific



Steep entry: strong

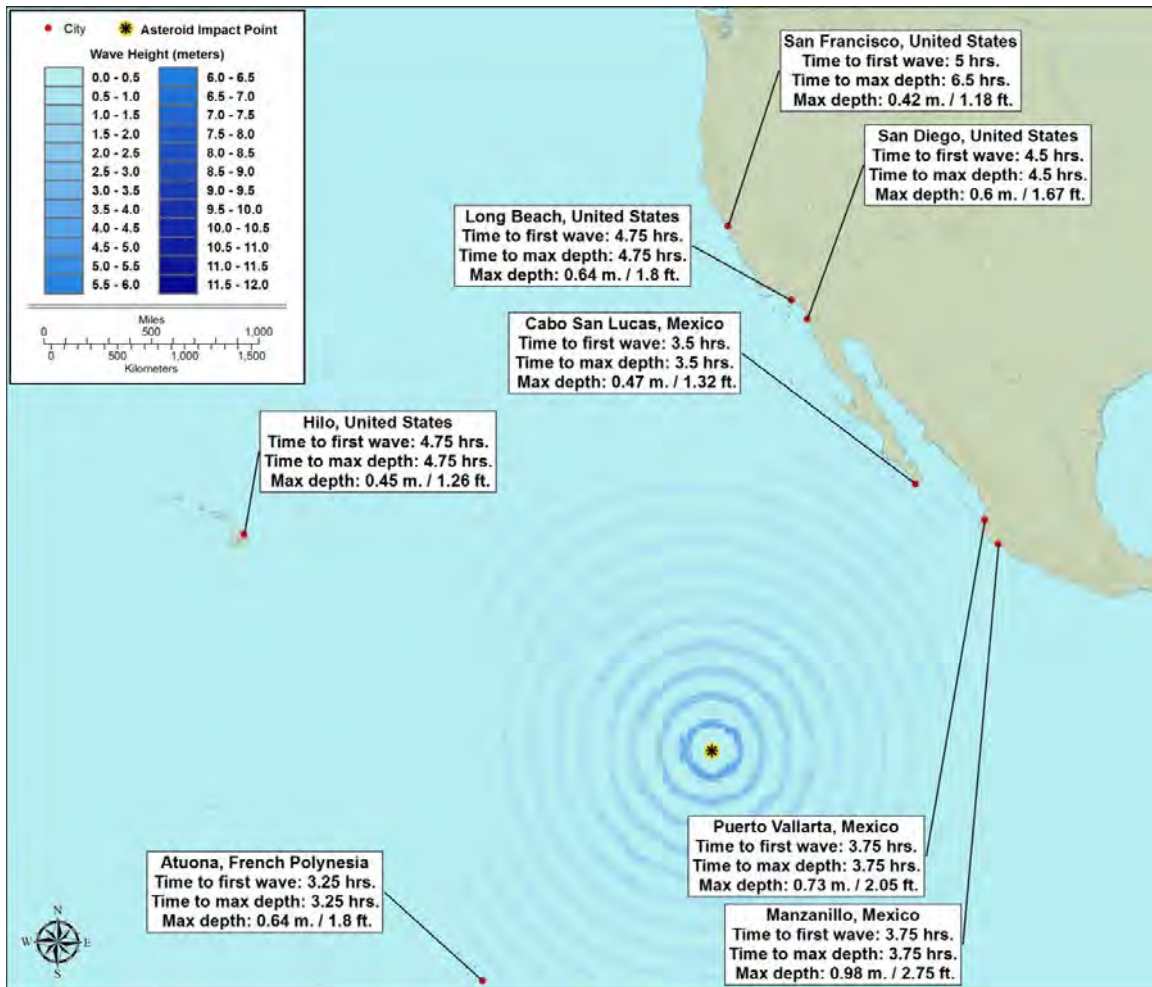
## Eastern Pacific



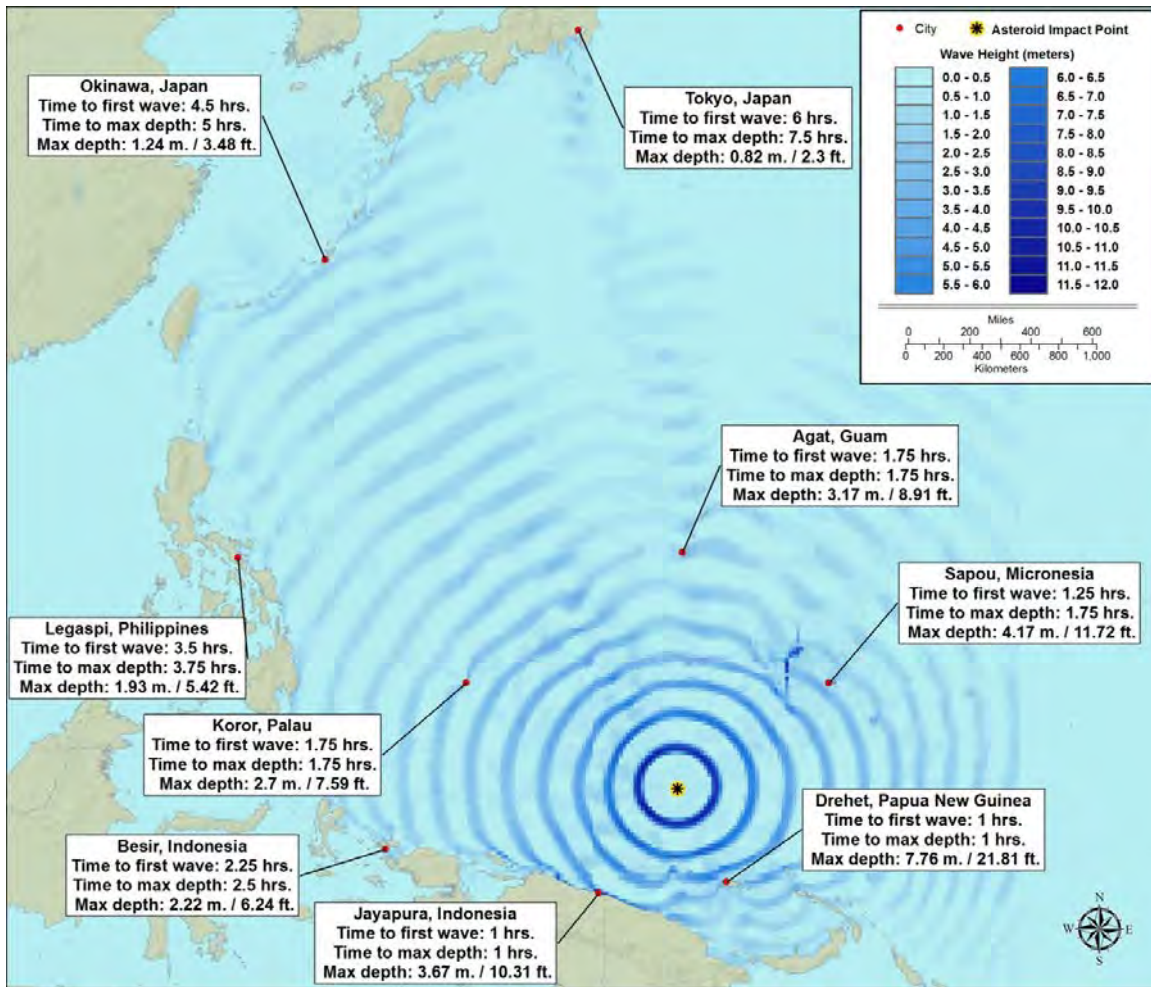
Grazing entry: weaker

*Tsunami strength depends on entry angle, which depends on impact location and varies from near-grazing to 72°. A steep impact will have more severe results.*





*The graphic above shows the resulting tsunami wave heights and time from impact on the east Pacific. Damage from this impact would generate waves extending from San Francisco to South Polynesia.*



*This figure illustrates the potential tsunami wave height and time to shore resulting from an impact of a fragment in the western Pacific.*

## COMMENTS FROM SYNDICATE GROUPS

### *Political leaders of affected nations*

- Some concerned that impact probability is high enough for action by spacefaring nations
- India, Pakistan, Iran worried that space-faring nations won't take action since doesn't directly affect them. They might consider their own recon mission.
- Can existing spacecraft already in space be retargeted to take a look?
- Affected nations don't trust space-faring nations or a "super-committee of the UN" to make the right decisions. Who is executive authority that would make decision?
- Concerned that any funding sent to help countries in risk corridor to develop disaster response plans will be ineffectual due to corruption. Response could be ineffective as a result.
- Countries raised proposals for sharing cost of deflection campaign by a percentage of GNP of each nation.
- Recognizing that an ocean impact is possible, all Pacific Rim countries should be engaged in discussions about response to a possible tsunami.



## ATTACHMENT D

- Nations generally accept the possible use of nuclear explosives, but want veto power.
- There is concern about kinetic impactors and if a mistake leaves the object still on an impact course, but a new location becomes the target. How many required? Will that cause conflicts in region if insufficient deflection?
- Some nations are starting an asteroid awareness day to begin to inform public on asteroids, etc..

### *Political Leaders of nations not affected*

Offering technical & humanitarian support; asking nations affected to start planning and begin discussions with neighboring countries on handling refugees, providing access for assistance, etc.

- Nations are worried about mass migration, how to stage resources, military involvement
- Rumors are the major nations are preparing unilateral nuclear options; no cooperation yet. The process for making decisions needs to be explained.

### *Public in threatened areas*

- Not enough information out, scaring us, Public experiencing feelings of panic
- Property values falling in some areas near ocean. Who do we sue?
- Pacific nations talking about paying for mitigation.
- Some think US is lying about the threat
- There is a massive public holiday and religious ceremony near the time of impact in a country in risk corridor. Surely this is not coincidence. God is angry. Some religious sects believe this is punishment for sins, want to die as martyrs.
- Why are nuclear explosives not on the table?
- China has its own capabilities and will partner with India to solve problem.

### *Media*

- Why are we not hearing about nukes or gravity tractor?
- Should people begin to evacuate?
- Financial markets being affected in China in India
- Twitter: “We’re all going to die” message is common
- Impact insurance scams available all over the place

### *World Leaders*

- Leaders know every country will be impacted to some degree; need to get the world involved in disaster response and long-term disaster mitigation. Global stability could be affected. Clearly entire world will be affected—ports, economic hubs, infrastructure. National territories
- What is likelihood of success? Will need good integration effort. Single kinetic impactor has minimal possibility of success; must use multiple devices; nuclear explosives could do job. Must build in redundancy. This will be a political decision. Is here legal basis for such a decision? Will nations decide for themselves?
- Many different cultures affected. Disaster response must work together to coordinate actions and minimize panic. Huge panic possible. Consequences of panic could be worse than impact. What should be done to minimize?
- Is an early launch opportunity available for an observation mission? Can a flyby mission do this, or is rendezvous necessary and possible? SMPAG has developed package to observe and improve tracking that could enable a quicker launch.

## ATTACHMENT D

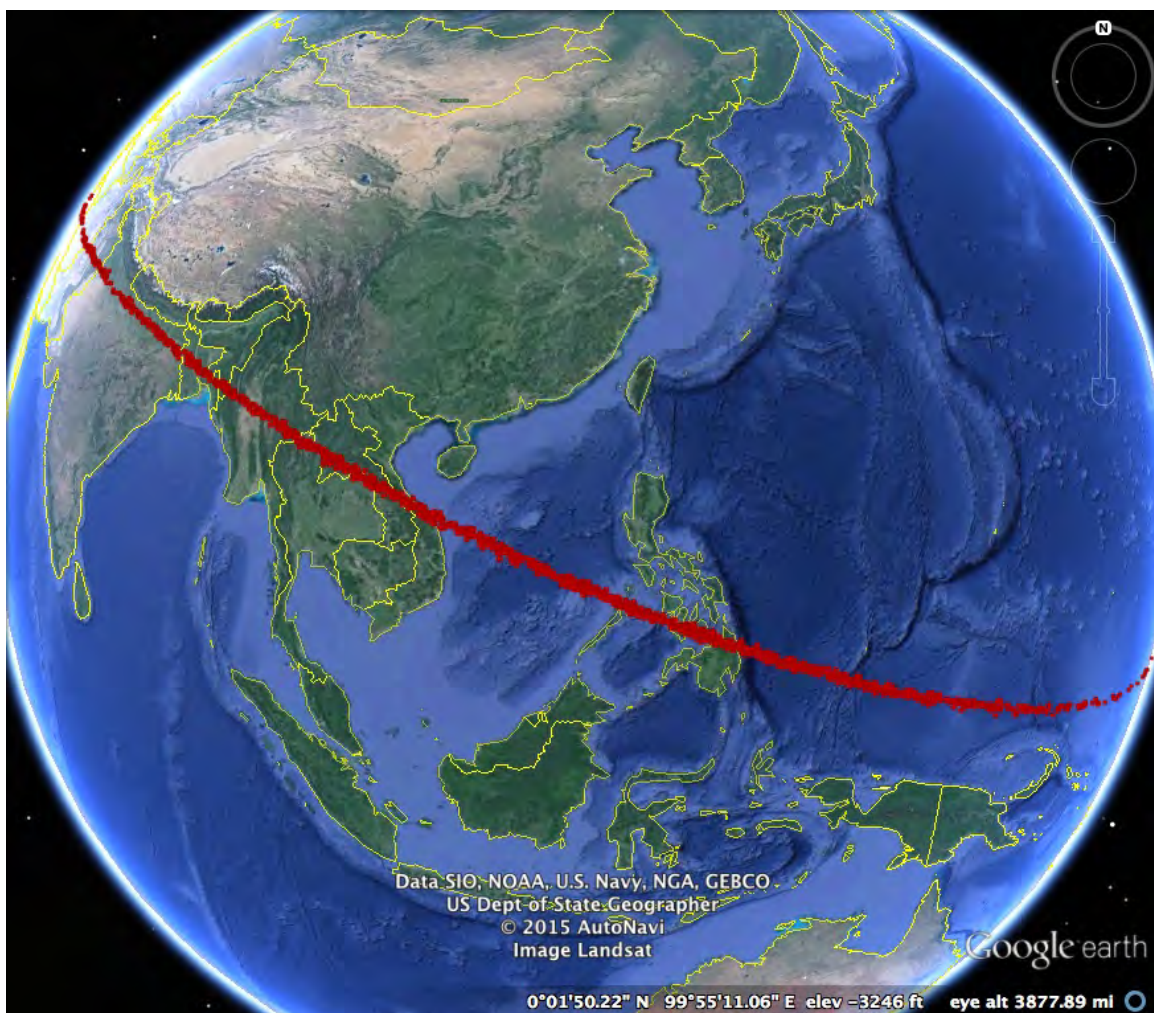
- Is there a space observatory that can be used to improve orbit? Spitzer Space Telescope is well situated to see this.
- KIs simple and ready to go; launch vehicles availability a major concern. Detailed planning awaits better data.
- Mission success: requires multiple spacecraft; large uncertainty on affects on asteroids.
- Emergency management community concerned about lack of certainty at present. Each nation will plan to shut down assets. What resources are available in each affected nation? What assets must be protected?
- If storm hits in Hawaii, should rebuild now, or wait until there are better predictions?
- World Leader: All countries affected: World must act to prevent impact. Inviting affected nations to join SMPAG to help develop options. Will release all models and predictions of consequences to all nations. Want all nations to work together.
- Need a complete list of launch capabilities and mission designs. Need fast response on these items. Want to stop individual actions.
- SMPAG will play important role. Be ready to make difficult decisions. Technical entities move at full speed now, but recognize might need to cancel. UN Security Council will accept what member nations want to do.

INJECT 3: DECEMBER 27, 2016

**PRESS RELEASE**

**ASTEROID 2015 PDC IMPACT NOW CERTAIN**

Based on new tracking observations obtained over the last month, IAWN has determined that asteroid 2015PDC is on a course that will definitely impact Earth on September 3, 2022. While the exact location of the impact cannot yet be determined, unless the asteroid is deflected, it will impact somewhere along the risk corridor defined by the red dots on the image below.



Nations currently at risk from direct effects should there be a land impact or an airburst are: Philippines, Vietnam, Laos, Thailand, Myanmar, Bangladesh, India, Afghanistan, Pakistan, Iran, Iraq and Turkey.

## ATTACHMENT D

Nations at risk from a tsunami in the Pacific or South China Sea include all those with coasts on those bodies of water, including Malaysia, Thailand, Cambodia, Vietnam, Indonesia, Philippines, China, Taiwan, Japan, South Korea, North Korea, Russia, Papua New Guinea, Australia, New Zealand, Canada, United States, Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Colombia, Ecuador, Peru, Chile, and all island nations and territories in the Pacific. Weaker tsunamis may propagate into other ocean basins but are not expected to be dangerous. The probability and consequence-weighted risk is greatest for equatorial western Pacific nations (Southeast Asia and Oceania).

IAWN emphasizes that until a more extensive set of tracking observations is available, the specific location of the impact point will not be known. The asteroid will be observable through the first half of 2017 and in late 2018/early 2019, although large telescopes will be required to make these observations. World leaders are meeting in Frascati, Italy to assess options for deflecting the object and to initiate planning for emergency response and humanitarian aid in case of an impact.

For more information, visit: <http://neo.jpl.nasa.gov/pdc15/day3.html>

### COMMENTS FROM SYNDICATE GROUPS

#### *Political leaders of affected nations*

- Rise in civil & political unrest and initial waves of migration from nations along threat corridor
- Some unaffected and neighboring nations are expressing objections to taking refugees from some communities
- Financial investment way down in nations that might be affected; there is concern about how incomplete information is affecting their economies
- The economies of affected nations are drastically compromised, people are out of work, and unrest is increasing. The world's economy is also affected
- Pacific rim nations are against nuclear explosives. People in these areas feel like guinea pigs for the scientific community
- Pakistan and India are working on an agreement on working together on nuclear option. India disagrees with decision to use kinetic impactors and is proceeding on its own; might launch their own interceptors using nuclear explosives.
- Nations need assistance to relocate families and deal with expected influx of refugees and threat progresses.

#### *Political Leaders of nations not affected*

- Want to know how they can help affected nations.
- Want to know what happens if deflection fails? Concerned about possibility of impact of a secondary object that might affect them
- There is concern that nations will take advantage of situation to advance their own agendas (e.g., China take over Taiwan, Iran develop its own nuclear explosives and claim it's for its own protection against asteroid).
- Increased pressure to slow relocation from affected states.
- Financial institutions might increase interest rates because of growing economic problems and risk of impact.
- Some still believe the threat is a concocted story to destabilize Islamic states.

## ATTACHMENT D

### *Public in threatened areas*

- Concerned about who will look after large numbers of poor who don't have access to resources
- Beach Club in Manila—I want to repair damage from recent storm. Can I get loans now?
- Hong Kong—what's impact on global & local economy of major disaster in this area?
- Will British Government look after its people?
- Will US stick to commitments to Pacific territories?
- What assistance will be available to relocate families?
- We spend all this money on technology, why can't we do better in understanding the risk and exactly where the asteroid will hit? Is there something you're not telling us?

### *Media*

- "Thumper" will hit in 6 years.
- There is a claim (denied) that presidential election in US has slowed efforts.
- Total of 7 KIs planning. What if that's not enough? Why isn't nuclear option considered? Should throw everything at this.

### *World Leaders*

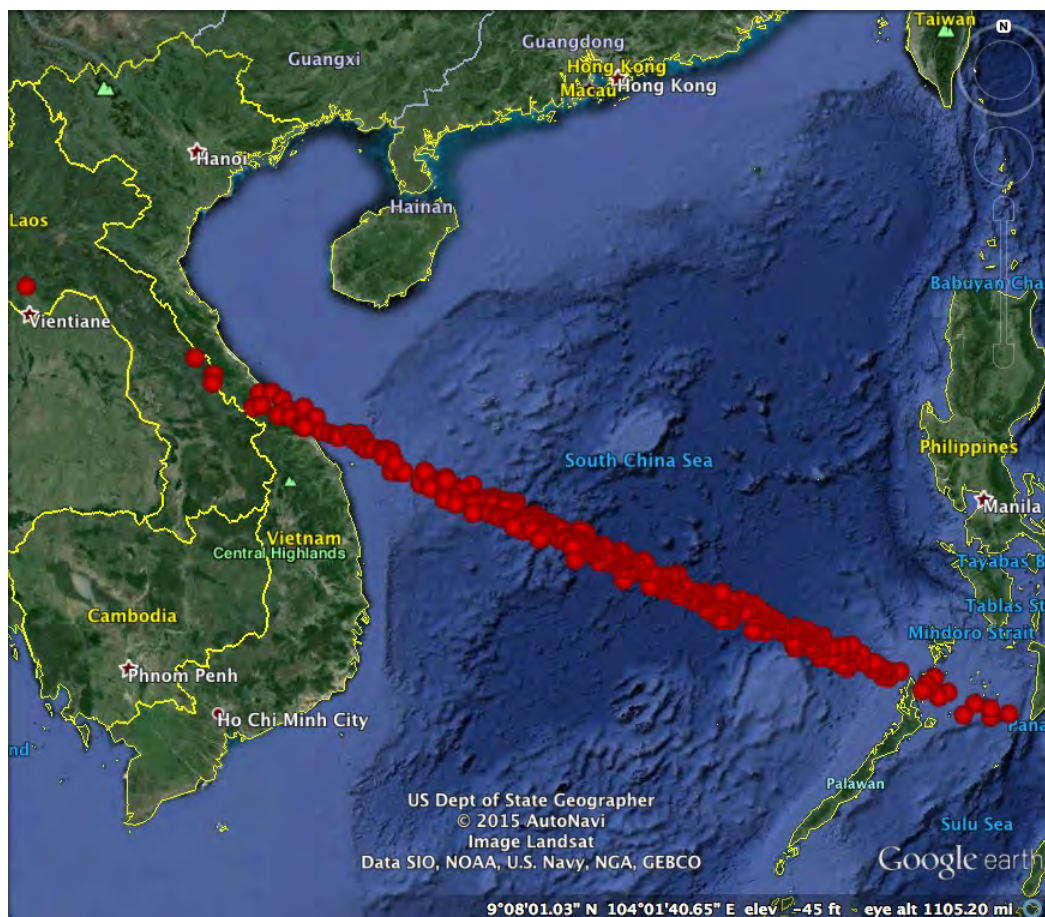
- India: Disruption is better than deflection. Will do it themselves if necessary.
- Can we send S/C out to reduce uncertainties? Response: Very difficult orbit. Can't launch now.
- Are 7 impactors enough? Response: Three can deflect. Others are for redundancy. When can nuke be launched?
- Why was decision made to use kinetic impactors? Response: Considering nuke now as backup. Confident the KIs can do the job.
- Launch opportunities available after KIs impact? Response: Could send observer to see consequences of deflection effort (March 2020 launch with Venus flyby will arrive 1.5 years after KI encounter).
- Ground-based observations possible? Response: Difficult due to Sun & cloud of debris. If all fails, must launch nuke very quickly.
- Won't know precise impact area until last month or so. Radar last seven days. Sufficient time to evacuate?
- Should have had an **international response council** working together on nuclear option that could be launched in 2020 if KIs fail.
- Disaster management: Task forces being established. Human services looking at mass migration & evacuation. Move and close down operational infrastructure, maintain some critical systems in risk areas.
- Could rendezvous mission carry nuke if deflection not successful? Response: Looking at this.
- Philippines: Disaster already happening: Currency fallen by 50%, feeling devastation along corridor. Declaring loans from US null and void.
- India: International groups handling assistance and aid too bureaucratic. 170 Million affected. Need to refine estimates. We will have to do what is needed to do protect our people.



INJECT 4. AUGUST 1, 2019PRESS RELEASE**NATIONS OF THE WORLD WILL SEND SIX SPACECRAFT TO DEFLECT ONCOMING ASTEROID 2015 PDC**

Several nations with space launch capabilities have joined the effort to deflect oncoming asteroid 2015 PDC. A total of six Kinetic Impactor (KI) spacecraft are scheduled to be launched toward the object later this month. All six are designed to strike the asteroid at very high relative velocities over a seven-day period in early March 2020. Successful impact of at least four KI vehicles will move the object away from Earth impact.

Based on an extensive set of tracking observations taken over the last two years, IAWN has determined a much more accurate trajectory for asteroid 2015PDC, and the potential impact location on September 3, 2022 has now been isolated to the South China Sea. The impact time would be 3:51 UTC or 11:51am local time. The red dots in the image below trace the extent of the possible impact locations, the so-called “impact footprint.” Unless the asteroid is deflected, it will impact somewhere within this region.



## ATTACHMENT D

Although the trajectory of 2015 PDC is now quite well known, the size and mass of the asteroid are still very uncertain. IAWN estimates the asteroid is 150 to 250 meters (500 to 800 feet) in diameter, but it could be as large as 400 meters (1300 feet) if its albedo (reflectivity) is very low.

The six interceptor missions should be more than enough to deflect the asteroid away from its collision course, but the precise size of the deflection cannot be predicted because it depends very much on the uncertain size and mass of the asteroid. The size of the deflection will also depend on secondary factors such as the amount and direction of ejecta produced by the impactors, the so-called beta factor.

The impactor spacecraft will hit the asteroid at a closing velocity of about 15 km/s (9 miles/sec), and they must deliver a total velocity change of about 20 mm/s (1 inch/s) in order to move the trajectory away from impacting the Earth.

The effectiveness of the deflection effort will be difficult to assess directly from the Earth because the asteroid will be basically on the other side of the Sun, and too close to the Sun for observations. The deflected asteroid should be observable again in July 2020.

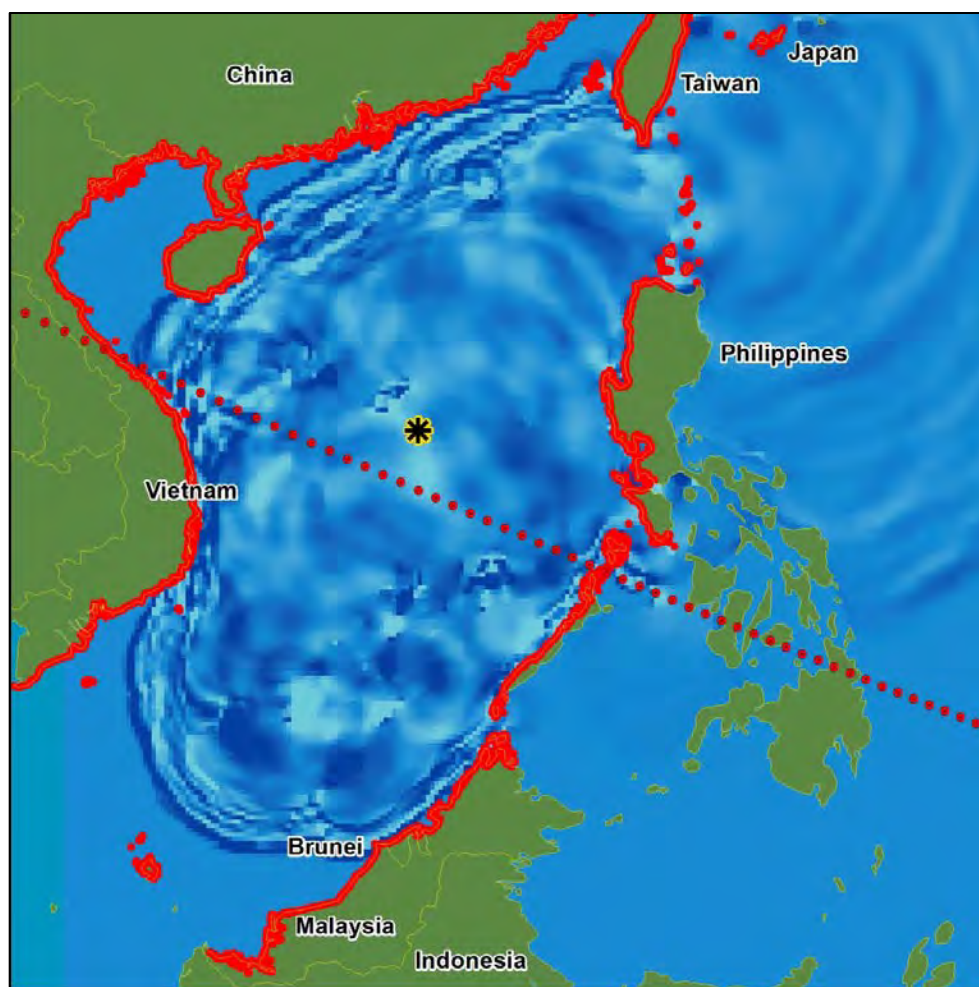
Because of the difficulty of observing the deflection from the Earth, an observer spacecraft will be launched to fly by the asteroid shortly after the Kinetic Impactors have completed their missions to assess the effectiveness of the deflection effort.

For more information, visit: <http://neo.jpl.nasa.gov/pdc15/day4.html>

### SUPPORTING INFORMATION

At this point the risk corridor includes a water impact of the fragment in the South China Sea. The map illustrates the impact corridor (denoted by the red dots). The object could impact at any point along the corridor. The table shows the population at risk of the resulting tsunami.

## ATTACHMENT D



Country Name	Estimated Population within 5km of Shoreline (2020)
Brunei	215,886
China	40,044,535
Hong Kong	7,640,921
Indonesia	102,906
Japan	53,472
Macao	601,679
Malaysia	7,396,489
Philippines	12,067,546
Taiwan	5,565,213
Vietnam	10,037,728
<b>Total Estimated Population</b>	<b>83,726,375</b>

### COMMENTS FROM SYNDICATE GROUPS

#### *Political leaders of affected nations*

- Tsunami are regular things and effects are understood, we'll handle like tsunami.
- Want to know what plans are available. If mission fails, compensation?
- India says the world community should do nothing or use a nuclear device. India will probably send its own nuclear explosive missiles and strengthen borders to prevent mass exodus from Bangladesh and Pakistan into India.
- Is act of God if we interfere? If we don't interfere? How will and impact or tsunami affect agriculture?
- There is a possibility of tremendous consequences for agriculture and infrastructure in the heavily populated area affected.
- Public opinion in these nations is in favor of sending observer spacecraft and a nuclear device if needed.

#### *Political Leaders of nations not affected*

- Nations asked IAA to create series of workshops on options and analyses. Concern that six launches will create debris and following impactors will miss. Serious consequences. China will send ships to Taiwan to protect; Islamic nations believe plot against them; Political unrest. China decided to launch nuclear device to save world. Nations applauding China's action.
- Some believe whole thing is scam to get money to industry
- The world's economy is affected; there is concern about a global recession
- Tremendous outflow of funding, some governments reconsidering support

#### *Public in threatened areas*

- Now want to move back over us—leave nature to its course

#### *Media*

- Want to know who decided against using nuclear explosives.
- What happens if there's a failure? Who's liable if fails? Is there liability if there is inaction?
- Want solid probability of success to report to public.
- Need information on global effects.
- Is there time to launch mission if current mission fails.

#### *World Leaders*

- India has 1100 people/sqkm and looking at options: Do nothing: could handle tsunami. Current effort: could shift impact to populated area, do tremendous damage. Third is nuclear option: Should do nothing or launch nuclear option. Response : Very high probability impactors will work. India doesn't believe high enough. Will proceed on its own. Will share analysis with SMPAG and expects others will join. Response: Economic consequences of land impact is manageable. Tsunami is also very bad. Now have time to evacuate area (~70,000 sqkm) once defined accurately.
- China: 54 million affected by tsunami; very difficult to evacuate. Have port cities, chemical plants, etc., that would pose substantial risk if damaged. Would support

## ATTACHMENT D

India's launch efforts of nuclear device. China constructing roads and transportation options for regions affected. Need to evacuate Hong Kong, must plan for this.

- Must plan for providing aid to people in transit now and who are currently staying.
- If small enough, maybe we could take the hit. Should look carefully at tsunami problem.
- US will work with India and China on nuclear option in case larger that we think or kinetic impactor campaign not successful.
- Want timeline for KIs and blow-by-blow description of effort.
- Is mass migration from coastal areas inland? Yes, could be strong migration.
- Space-capable nations have been working options in SMPAG and will inform space-capable nations of best options and will inform UN on campaign that is recommended as most reliable.
- Some concern about some nations' abilities to control law and order in their nations.



INJECT 5. JANUARY 18 2021

**PRESS RELEASE**

**DEFLECTION MISSION PARTIALLY SUCCESSFUL, THREAT FROM  
SMALLER OBJECT BEING ASSESSED**

Images from the spacecraft sent to observe the impacts of the deflection spacecraft confirmed the successful impact of three of the high-speed kinetic impactors, but found that the deflection broke asteroid 2015 PDC into two pieces. The larger piece was successfully deflected enough that it will not impact the Earth, but a second, smaller fragment, roughly 60 to 100 meters (200 to 300 feet) in size, received only a partial deflection and may still be on an Earth-impact trajectory.

Ground-based observations of 2015 PDC resumed in November 2020, but the object was still very far from Earth and the small fragment was very faint. After over two months of tracking, the trajectory of the fragment is still not known with much accuracy. IAWN has determined that current probability of impact of the fragment is 54%.

IAWN has released the image below showing the impact footprint of the fragment. Nations that could be directly affected by the impact of the fragment are: Vietnam, Laos, Thailand, Myanmar, Bangladesh, India, Afghanistan, Pakistan, Iran, Iraq and Turkey.



Assuming a worst-case fragment size of 100 meters (300 feet), the impact would produce an explosion with energy of about 50 Megatons, much smaller than that predicted for the

original object, and the region of total devastation would also be much smaller. If the fragment impacts on land, wood frame buildings would almost completely collapse out to a radius of 10 km (6 miles), and windows would shatter out to a radius of 25 km (16 miles). The equivalent earthquake magnitude would be 5.3, and a crater between 1 and 2 km (0.5 and 1.2 miles) diameter would be created. This would be approximately 10 times more energy than that delivered by the 30 to 50-meter (100-160 feet) asteroid that damaged over 2000 square kilometers (800 square miles) of forest in Siberia in 1908.

If the fragment impacts in water, it would produce a tsunami, but it would be considerably smaller than a tsunami from the original object. At 270 km (170 miles) from the impact point, the tsunami height would be about 1 meter (3 feet), and it would drop to 25 cm (1 foot) at a distance of 1000 km (600 miles). The tsunami is no longer a Pacific-wide threat but if it strikes near a coastline there is potential for widespread regional destruction. The worst-case impact would be in the South China Sea.

For more information, visit: <http://neo.jpl.nasa.gov/pdc15/day5-1.html>

### COMMENTS FROM SYNDICATE GROUPS

#### *Political leaders of affected nations*

- Failure of mission is no longer act of god, but act of man. Now more at risk of war than from impact.
- Nuclear disruption is possible and India is considering launch of a nuclear mission on its own. Other nations in the region are suspicious and threaten a response and concerned about accident that could lead to nuclear explosion on Earth.
- Affected nations want to be part of process.
- Some decisionmakers believe it makes no sense to make moves, etc., given uncertainty in impact point.
- Should consider taking the hit depending on final impact point.
- Concerned that negative media is causing greater fear and unrest than might be the case; leaders are giving and sponsoring seminars with factual information from trusted individuals.
- Give info on what to do to their people. How to shelter. What they can do to prepare (e.g., stockpile food and water)

#### *Political Leaders of nations not affected*

- Hearing that some affected nations are considering failed deflection attempt as an act of war by unaffected nations. Expect unaffected nations to fix the problem they caused.
- Nations are demanding direct monetary assistance to build evacuation and medical facilities along risk corridor. These will be provided when impact location more resolved.
- Nuclear nations planning for launch nuclear explosives; no agreement on this yet.
- Could be number of small fragments that could be a risk.
- Currently not a single, unified voice for non-affected nations

#### *Public in threatened areas*

- Very divided points of view by different communities

## ATTACHMENT D

- The public is very divided on what should be done. Farmers will likely stay until 24-hour notice. Tribesmen don't want to leave—they will lose property that they've held for generations to other tribes. Some would look for shelter close by.
- Blame people who tried and failed.
- If people want to leave, there will be mass migration to China—no other place to go. Fearing mass migration, China is tightening borders.
- Entrepreneurs look at this as opportunity to make money. Build cheap homes at high prices. Relocation assistance at high prices. Tourists will want to come and see sights before destroyed.
- Factory owners will not leave until best information is available, but concerned that skilled workers will move with families. Many will shelter in place.
- A critical Hindu holiday is near the possible impact date
- People want to know what they must do and when, as well as how long they would be away if they need to move

### *Media*

- Trying to bridge gap in information distribution
- Facts out in neutral way is goal
- Using reliable sources of factual information
- Looking at past long timeframe events for guidance on communicating evolution timeframe and timeline, end game, etc. (e.g., Y2K)
- Want everything grounded in truth and in multiple forms to reach multiple communities (e.g. religious, social).

### *Risk communication*

- People (media, public, professionals, governments) need info fast. Must be accurate, relevant, updatable
- Need strategy to assist and includes lessons learned from past experiences
- Have organized approach to risk communication. Work with IAWN to build template for risk communication.
- Monitor rumor mill and provide factual information.
- Understand and publish how different cultures are feeling and interpreting the risk
- IAWN good place to house factual information from many perspectives
- Have panel from multiple perspectives (poor, illiterate, religious, etc.) review information before it goes out

### *World Leaders*

**India** worried and has plans to 1) launch nuclear option & propose summit to show and discuss plan; 2) in close contact with neighboring countries on humanitarian aid; 3) working with world leaders on civil defense and disaster mitigation.

**China** grateful that object that will impact is smaller than original. Has concerns with tsunami, but believes it will be manageable. Does not believe nuclear option is warranted. Would not support nuclear detonation in near-Earth space. Will work with others on space missions. Preparing relief and assistance to nations in impact areas.

**US** pleased to have participated in successful deflection effort. Actions lowered probability of impact. Preparing to assist affected areas. Use IAWN as primary source of objective info. Wait for follow-up observation to refine threat before taking action.

**UN** brings "clustered approach" for disaster response. Modular and scalable. Nations not supported by UN unless asked. Joint information center must coordinate and approve all press releases. IAWN could be participant. Multiple parts of this cover

## **ATTACHMENT D**

logistics, funding, response. Has been used in past disasters. Could be set up with no notice.

Possible to disrupt object with short warning. Considering intercept three months prior to impact.

INJECT 6. FEBRUARY 4, 2022**PRESS RELEASE****SMALL FRAGMENT OF ASTEROID 2015 PDC WILL IMPACT IN THE  
REGION OF BANGLADESH, INDIA OR MYANMAR**

Based on the most recent tracking observations of the fragment of 2015 PDC, IAWN announced that the smaller fragment will impact the Earth on September 3, 2022 at about 03:50 UTC. The predicted location of the impact is almost certainly in India, Bangladesh, Myanmar, or northern Thailand, as indicated by the image below. It is virtually certain that this will be a land impact or airburst.



Although the asteroid had not been observed for a year because it was on the other side of the Sun as viewed from the Earth, it just recently became observable again, and new observations confirm that the asteroid fragment is still on a collision course with Earth. Further observations over the next two months should dramatically shrink the size of the impact ellipse, and by May the impact location will be identified to within 100 km (60 miles) or so. Observations should continue until a month before impact, when the asteroid will move too close to the Sun as viewed from the Earth. A more accurate prediction will be available when the asteroid comes within range of the Goldstone radar about 7 days before



the impact. The larger and more powerful Arecibo radar facility cannot observe this asteroid because the asteroid will not pass within its pointing window.

The size of the fragment is still uncertain. Evacuation and shelter-in-place plans must assume worst-case estimates of an asteroid as large as 100 meters with impact energy of up to 50 Megatons.

### COMMENTS FROM SYNDICATE GROUPS

#### *Political leaders of affected nations*

- Not getting aid that was promised by non-affected nations. People are poor and need assistance now to be able to move animals, get ready, etc. Need food and supplies now o help them survive impact & aftermath,
- Militaries must understand each other to be sure don't misinterpret what's going on.
- Military must be able to control evacuation; restrict access to damage area, etc.; provide medical support; work with local governments
- Must develop priorities for moving equipment and supplies

#### **Civil Protection, Nations Affected,**

- Can deal with disaster of this magnitude
- Have long warning and danger of panic; recommend program to avert panic. Assure public we can handle; regulations in place to minimize corruption; keep local, people not familiar with area could aggravate problem. Keep calm, we can handle.
- Can't rule out coastal impact; looking at downwind affects & risks of blast on existing structures (homes and buildings); effects of topography (liquefaction), how to survive for people who stay. Using IAWN as storehouse of information.

#### *Political Leaders of nations not affected*

- World ready to support affected nations
- Negotiations with India regarding their support and international community would help offset costs.
- International community will help manage shutdown of nuclear facility, if necessary.
- Could put India on Security Council, but not yet agreed.
- Nations should assure security of foreign-owned interested in vicinity.
- People who want to die streaming to area; adventure cruises to observe the impact are in planning
- Assessing safety of spacecraft and ISS

#### *Public in threatened areas*

- Tribesmen will wait; farmers organizing "Paul Revere" type communication in case lines down, etc. Will there be fires? Will there be support in case people from cities evacuate to farm areas?
- Poor have few resources for evacuation and want relief now. They trust religious leaders more than political.
- Rich people want to help and want to know how relief will be coordinated. Want to be sure videos are prepared to show illiterate people what to do.

## ATTACHMENT D

### *Media*

- Lots of new info out on situation. Bridging gap between technical info and public. Misinformation is major problem. NGOs can help combat this.
- Proactively pushing info out. Visual info important to cross language barriers; Building communication links between space agencies and media for info.
- Posting all information on averting impact.

### *World Leaders*

**India:** had summit on lack of trust, signed bilateral agreements on nuclear device; will launch nuclear device if fails, US will also launch. Preparing for worst-case situation. Total population affected very large. Relief will be very difficult. Will open border between India and Bangladesh and will work on long-term support and assistance. Large use of cell phones area in use and will be used, more planned. Will need help with shutdown of nuclear reactors.

**China:** Happy with bilateral with India on nuclear prep. Ready to help. Factories focusing on low cost cell phones for poor, medicines, etc.

**US:** Making Goldstone available as needed. Working with India on heavy launch vehicle to backup India's launch. Will provide aid by sea.

**UN:** Disaster planning in progress. Need to shutdown ports, infrastructure.

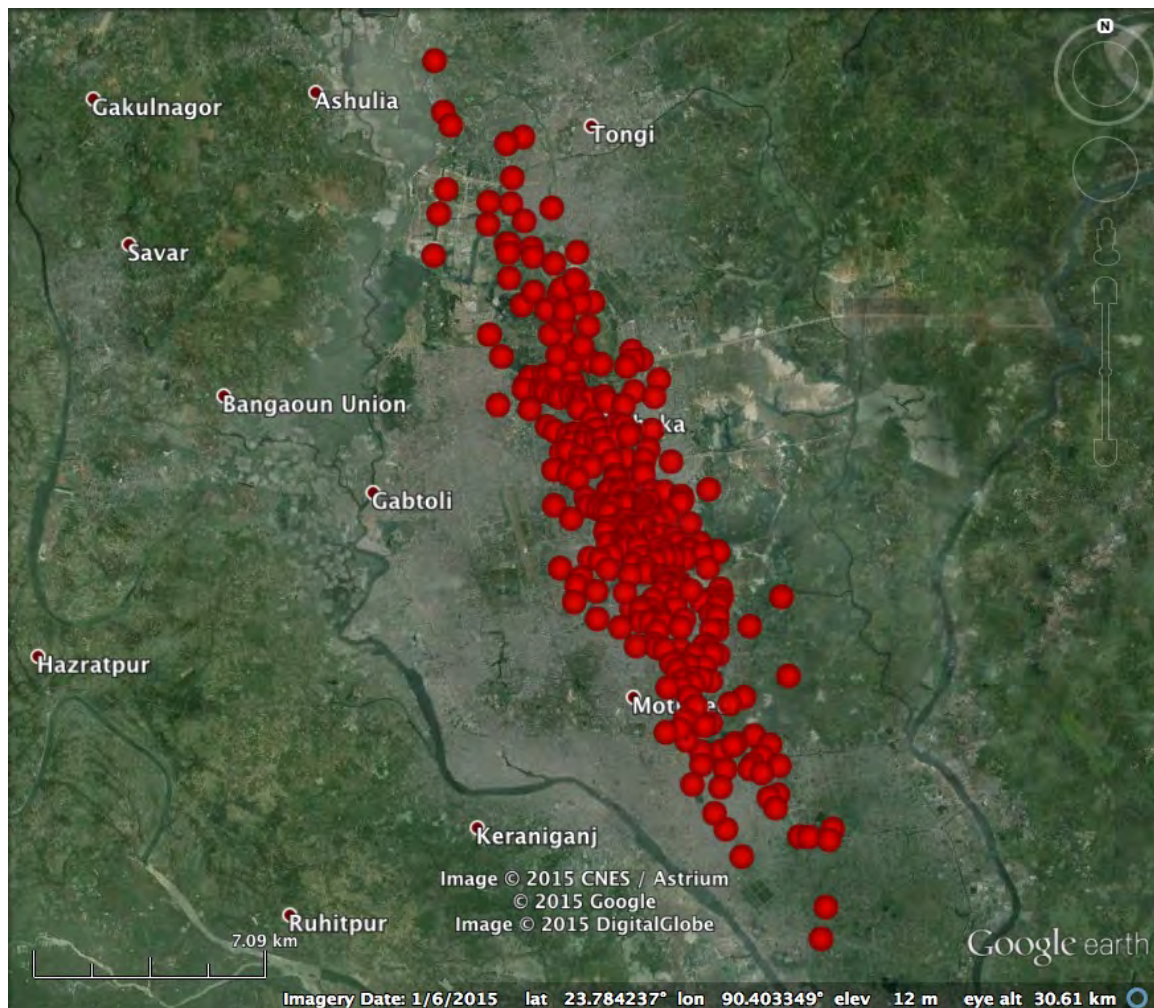
Launch Community preparing launches of nuclear devices.

INJECT 7. AUGUST 27, 2022

**PRESS RELEASE**

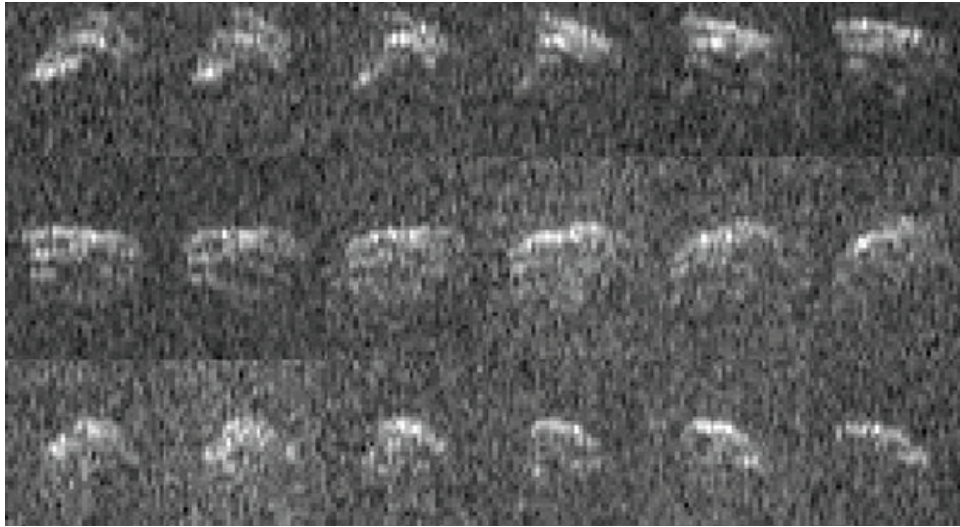
**ASTEROID 2015 PDC HEADED FOR IMPACT NEAR DHAKA,  
BANGLADESH**

Based on radar measurements from NASA's Goldstone station, IAWN predicts that the fragment of 2015 PDC will enter the atmosphere on September 3, 2022, and that the impact and/or major blast from the entry will be in the vicinity of Dhaka, the capital city of Bangladesh at 9:50 am local time. Dhaka is the 10<sup>th</sup> largest city in the world and more than 15 million people are estimated to live in the greater Dhaka area. The image below shows possible impact locations.



## ATTACHMENT D

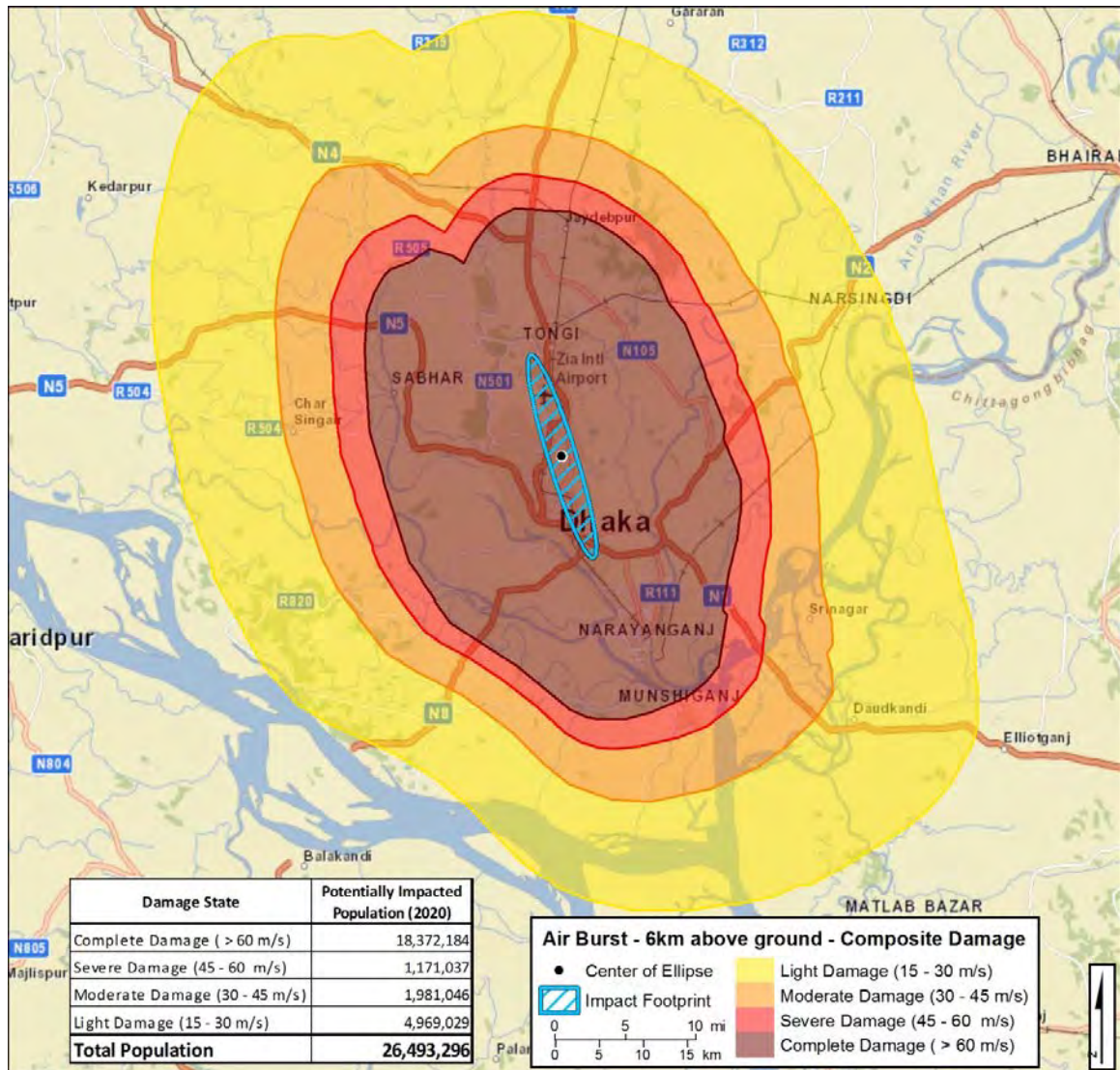
Radar measurement of the asteroid fragment reveal that it is about 80 meters (260 feet) in diameter. The first radar mages of the object are shown here:



The fragment will enter the atmosphere at about 16 km/s (almost 36,000 miles per hour) at an angle of about 36 degrees from the horizontal. The energy produced by this entry will most likely be about 18 Megatons, but a crater-forming impact is very unlikely. The object will almost certainly explode in the atmosphere as an airburst, much like the Tunguska explosion of 1908.



## SUPPORTING INFORMATION



The fragment is 80 meters in size and will enter the atmosphere at about 16 km/s (almost 36,000 miles per hour) at an angle of about 36 degrees from the horizontal. The energy produced by this entry will most likely be about 18 Megatons, but a crater-forming impact is very unlikely. The object will almost certainly explode in the atmosphere as an airburst. This shows the zones of maximum possible damage for any impact location within the uncertainty ellipse.

## COMMENTS FROM SYNDICATE GROUPS

*Disaster Management*

- Regions must ask for help.
- Evacuated entire risk area. Now a quarantine zone. No entry.
- Regions now asking for assistance to recover and rebuild.



## ATTACHMENT D

- How would an active rainstorm affect impact and ground consequences?  
Fireball will reach ground and would not be affected by monsoon. However disaster relief will be impeded.
- Need to be very careful when presenting information: trying to be clear can present information in confusing way.
- With enough advanced warning (~6 days) people should be able to safely evacuate and industry can accomplish safe shutdown of operations.
- Time for continuity of operations is difficult to determine; exact damage is an unknown.

Need to be very careful when presenting information: trying to be clear can present information in confusing way.

### *World Leader*

- **India:** Looks like border areas not affected. This is good news for disaster relief.

### HOT DEBRIEF

At the end of the exercise, participants were asked to give their thoughts on aspects that could be improved, on things they liked, and on things they learned from the exercise. A summary follows:

#### THINGS THAT COULD BE IMPROVED

- Invite real politicians to participate
- Need breakout rooms for discussion
- Don't need to co-opt every lunch
- Need more cultural info about possible impact sites
- Would like to have input (i.e., after outcomes and decisions from each inject) affect future injects
- Group size was a problem; some people migrated from groups; there were better discussions in smaller groups.
- Compositions of groups changed a bit over week.
- People in groups should be consistent with their actual expertise.
- Difficulty to react in real time
- Need data sheets on areas affected, etc.

#### POSITIVE THINGS

- Stepping out of real roles and into other areas
- Scenario was multifaceted and had great detail
- Liked that everyone could and did participate
- Good number of subgroups
- Having groups pre-assigned was good.
- Having experts present data on what would result if NEO did impact was good.
- Experiencing a realistic exercise was good. Liked having entire week so had time to think.
- Complexity caused people to think.
- Small group interactions were good.
- Meeting different people.
- Social-political inputs great.
- Learned about complexity of problem.

#### TAKEAWAYS

- Have missions preplanned would be helpful
- Communications at all levels is very important
- Need assets in another part of solar system to provide input
- Seeing how easy it is to get communications wrong, even in this controlled situation
- Learned about linkages to UN and IAWN and how they would be involved
- Accuracy of information and communications is critical.

## **ATTACHMENT D**

- Should think some aspects in advance of a real event and look at all possibilities, including that some aspect of a mission might fail
- That the problem will change with time. First was all about asteroids, then became disaster response
- Understanding commitment to solve problems
- Failed deflection missions can mean many things