PLANETARY DEFENSE
INTERAGENCY
TABLETOP EXERCISE 4

AFTER ACTION REPORT

5 August 2022

NASA Planetary Defense Coordination Office
PD TTX4
23-24 February 2022

NASA

FEMA

JPL
Jet Propulsion Laboratory
California Institute of Technology

Ames Research Center

APL JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

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PD TTX4
23–24 February 2022

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Exercise Overview

Exercise Name	The 4th Planetary Defense Interagency Tabletop Exercise (PD TTX4)
Exercise Dates	23–24 February 2022
Exercise Locations	A hybrid exercise with in-person participants at the Johns Hopkins Applied Physics Laboratory in Laurel, Maryland, and facilities in Raleigh and Winston-Salem, North Carolina
Scope	This exercise was a tabletop exercise (TTX) over one and half days at the locations listed above.
Focus Area(s)	Prevention, Protection, Mitigation, Response, and/or Recovery
Capabilities	Exercise multiple aspects of a potential asteroid impact, encompassing initial detection, uncertainty, damage modeling, notification, potential mitigation, ground preparation, and ground recovery
Objectives	• Increase the understanding by personnel of U.S. government institutions of near-Earth object (NEO) threats and their roles in mitigating that threat, and provide an opportunity to better understand the role of U.S. Space Command (USSPACECOM) • Test methods of communicating information both to and among decision-makers • Exercise post-impact protocols, including involvement of local government
Threat or Hazard Scenario	Asteroid impact to the continental United States (CONUS)
Sponsor	NASA Planetary Defense Coordination Office
Participating Organizations	Over 200 participants from the following organizations: • NASA headquarters (including Planetary Defense Coordination Office) • Johns Hopkins Applied Physics Laboratory • Jet Propulsion Laboratory's Center for Near Earth Object Studies • NASA Ames's Asteroid Threat Assessment Project • NASA Goddard Space Flight Center • Lawrence Livermore National Laboratory • North Carolina State Emergency Operations Center • Winston-Salem and Forsyth County First Responder Communities • Office of Science and Technology Policy/Executive Office of the President • National Space Council • National Security Council • Federal Emergency Management Agency (FEMA) • U.S. Space Command • U.S. Northern Command • National Science Foundation • Department of State
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Executive Summary

Background

The National Aeronautics and Space Administration (NASA) Planetary Defense Coordination Office (PDCO) was established in January 2016, to manage planetary defense–related activities across NASA as well as coordinate with both U.S. interagency and international efforts to study and respond to asteroid impact hazards.

Planetary defense encompasses all the capabilities needed to detect and warn of potential asteroid or comet impacts with Earth, and attempt to either prevent them or mitigate their possible effects. Planetary defense involves the following:

- Finding and tracking near-Earth objects (NEOs) that pose a hazard of impacting Earth. NEOs are asteroids and comets that orbit the Sun like the planets, but their orbits can bring them into Earth's neighborhood.
- Characterizing each NEO to determine its trajectory, size, shape, mass, composition, rotational dynamics, and other parameters to assess the likelihood and severity of a potential Earth impact, warn of its timing and potential effects, and determine possible means to mitigate the impact.
- Planning and implementation of measures to deflect or disrupt (break up) an object on an impact course with Earth, or to mitigate the effects of an impact if it cannot be prevented. Mitigation measures that can be taken on Earth to protect lives and property include evacuation of the impact area and movement of critical infrastructure.

In September 2021, NASA PDCO partnered with the Federal Emergency Management Agency (FEMA) Response Operations Directorate to sponsor the 4th Planetary Defense (PD) Interagency Tabletop Exercise (TTX). NASA PDCO retained the Johns Hopkins Applied Physics Laboratory (APL) to lead the project management, systems engineering, and subject-matter expertise as required, as well as execution of the TTX. On 23–24 February 2022, APL hosted the hybrid exercise, with in-person players at the APL campus in Laurel, Maryland, local first responders from Winston-Salem, North Carolina, and emergency management personnel from the North Carolina State Emergency Operations Center. Virtual players attended via ZoomGov, and videoconference lines connected the three sites with in-person players. The exercise drew wide participation from federal, state, and local agencies in planning for the preparedness for and response to a NEO impact scenario. It was the first effort at an end-to-end exercise for this type of disaster, which explored actions from the initial asteroid detection stage through ground response and recovery of the impacted region within the contiguous United States (CONUS). The exercise leveraged partnerships with FEMA, NASA Jet Propulsion Laboratory's Center for Near Earth Object Studies (NASA CNEOS), NASA Ames' Asteroid Threat Assessment Project (NASA ATAP), North Carolina State Emergency Response Team(s), and Winston-Salem/Forsyth County Local/County Emergency Response Teams (hereinafter referred to as the "Team") to accomplish a twofold purpose: (1) evaluate the technical, logistical, and operational challenges associated with planetary defense activities and (2) apply and implement protocols as defined

in the *National Near-Earth Object Preparedness Strategy and Action Plan* and the *Report on Near-Earth Object Impact Threat Emergency Protocols*. Specifically, the TTX sought to exercise multiple aspects of a potential asteroid impact, encompassing initial detection, uncertainty, damage modeling, notification, potential mitigation, ground preparation, and ground recovery. In so doing, the team identified the following core objectives for the TTX:

- Increase the understanding by personnel of U.S. government institutions of near-Earth object (NEO) threats and their roles in mitigating that threat, and provide an opportunity to better understand the role of U.S. Space Command (USSPACECOM)
- Test methods of communicating information both to and among decision-makers
- Exercise post-impact protocols, including involvement of local government

Additionally, embedded within each objective were clearly defined, measurable sub-objectives to ensure meaningful outcomes. The measurable sub-objectives, and accomplishment thereof, are described in Chapter 4.

The Exercise Planning Team developed a scenario aligned with the exercise objectives based on a simulated asteroid impact traversing over four distinct epochs, or periods of time, referred to as modules. The timeline was triggered upon NASA CNEOS's discovery of a hypothetical asteroid that could impact Earth in 6 months. As the events of the exercise unfolded, the exercise participants learned that the hypothetical asteroid would be on a collision course with Earth and would be large enough to cause substantial regional damage. To enable the participants to envision the scope, scale, and timing of a potential impact on Earth, the Exercise Planning Team leveraged visuals and models (both animated and static) describing asteroid trajectories and damage/impact risks on the ground.

Following is a summary of results from the exercise.

Summary of Results

PD TTX4 successfully fulfilled specific actions in the 2018 *National Near-Earth Object Preparedness Strategy and Action Plan* (Goal 5) and the 2021 *Report on Near-Earth Object Impact Threat Emergency Protocols*, and it provided critical information to inform future actions. A high-level summary of the results and identified gaps and vulnerabilities is provided below.

- NASA's current impact notification protocols are sufficient to disseminate key information to relevant agencies and decision-makers.
- NASA should serve as the trusted authority for public communications for at least the early detection stage of an impact scenario.
- Simulated visual graphics used to convey impact damage predictions during the exercise were helpful for decision-making and should be used during a real-life event.

- The National Response Framework (NRF) and the National Incident Management System (NIMS) have an expansive and flexible approach for a wide range of disasters, including an event such as an asteroid impact.
- Timely information sharing is critical for decision-makers.
  - To understand the risks associated with this type of event and convey them accurately to the public, it will be essential to have timely continuity of information sharing to ensure that risk is readily understood.
- Numerous lessons learned from the COVID-19 pandemic related to misinformation campaigns should be recognized and incorporated into future planning efforts.

The exercise revealed 11 identified gaps and vulnerabilities, as well as recommendations to remedy them. A high-level summary is presented below.

1. A short-warning NEO scenario poses challenges to mounting an effective national response. There is a critical need for capabilities for earlier asteroid detection and characterization.
2. The nation has a limited ability to image small, rapidly moving asteroids and should develop the capability for longer-range radar to obtain critical NEO information.
3. The nation has a limited ability to rapidly launch a NEO reconnaissance mission and should develop this capability.
4. Large parts of the U.S. government (USG) and the public are unfamiliar with an asteroid impact threat.
5. Only nascent strategies exist to address misinformation related to the asteroid threat scenario.
6. Without subject-matter experts (e.g., scientists, modelers) to describe the impact visualizations, the current format and structure of visuals makes them difficult to use for planning a response to the asteroid threat.
7. The USG processes that ultimately populate the NASA CNEOS fireballs webpage (https://cneos.jpl.nasa.gov/fireballs/) are neither designed for quick reporting nor used definitively to distinguish a natural bolide event from a foreign-state action. The page is also too detailed for broad consumption.
8. Minimal redundancy currently exists for NASA CNEOS and NASA ATAP NEO modeling capabilities/expertise.
9. Some agencies relevant to asteroid hazards have a limited understanding of the NIMS for ease of integration and coordination of preparedness and response efforts.
10. Understanding of the international legal and policy implications of using nuclear explosive devices (NEDs) for planetary defense in deep space or near-Earth space remains limited.
11. The NED-equipped intercontinental ballistic missile disruption option, including how to present the option, the probability of its success, and its overall effectiveness, is not adequately understood.

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Chapter 1. Introduction and Background

1.1 Objectives

The 4th Planetary Defense (PD) Interagency Tabletop Exercise (TTX), hereinafter referred to as PD TTX4, had three overarching objectives:

1. Increase the understanding by personnel of U.S. government institutions of near-Earth object (NEO) threats and their roles in mitigating that threat, and provide an opportunity to better understand the role of U.S. Space Command (USSPACECOM)[1]
2. Test methods of communicating information both to and among decision-makers
3. Exercise post-impact protocols, including involvement of local government

Each overarching objective had measurable sub-objectives to ensure meaningful outcomes. In addition, PD TTX4 helps fulfill a specific action in the 2018 *National Near-Earth Object Preparedness Strategy and Action Plan* (Goal 5) and the 2021 *Report on Near-Earth Object Impact Threat Emergency Protocols* by the Near-Earth Object Impact Threat Emergency Protocols (NITEP) Interagency Working Group.

1.2 Background

In September 2021, the National Aeronautics and Space Administration (NASA) Planetary Defense Coordination Office (PDCO) partnered with the Federal Emergency Management Agency (FEMA) Response Operations Directorate to sponsor PD TTX4. The event was held on 23–24 February 2022 at the Johns Hopkins Applied Physics Laboratory (APL) in Laurel, Maryland, as well as at state and local facilities in Raleigh and Winston-Salem, North Carolina. Some players participated in the exercise remotely.

PD TTX4 continues a pattern of joint NASA–FEMA exercises dating back to 2013. Each PD TTX has addressed a different type of asteroid impact scenario and focused on different aspects of the problem (Figure 1–1).

1.2.1 Purpose and Planning

The purpose of PD TTX4 was to assess the various challenges associated with a planetary defense response, to include exercising protocols as defined in the *National Near-Earth Object Preparedness Strategy and Action Plan* and the *Report on Near-Earth Object Impact Threat Emergency Protocols*, from the initial detection of an asteroid threat through ground response and recovery from an impact event.

[1] This was the first planetary defense tabletop exercise since the 2019 reestablishment of USSPACECOM.

Planning for this event took place over a period of ~6 months and included hybrid, virtual, and in-person meetings; teleconferences; planning workshops; reviews; and analyses of historical information from previous relevant events and exercises.

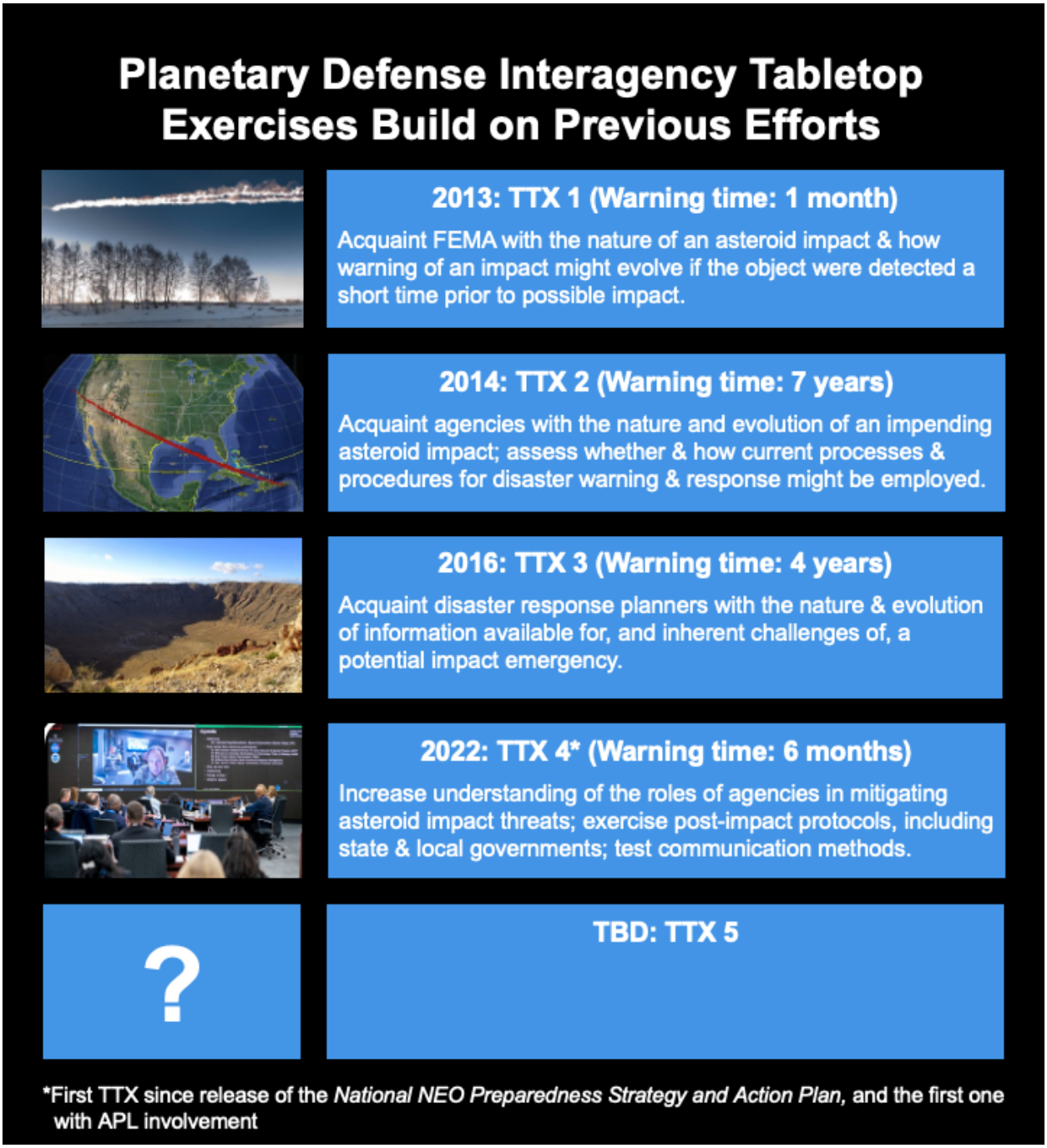

Figure 1-1. Planetary defense interagency tabletop exercises.

1.3 Exercise Planning Team

The following organizations were involved in the design and execution of PD TTX4:

- NASA PDCO: led TTX management, with coordination by the FEMA Response Operations detailee
- APL: organized, hosted, and led planning, execution, and documentation of the TTX across federal, state, and local institutions; provided subject-matter experts (SMEs) on asteroids, intercontinental ballistic missile (ICBM) mitigation, and legal/policy implications
- Jet Propulsion Laboratory's Center for Near Earth Object Studies (NASA CNEOS): designed the asteroid threat scenario; provided SMEs on asteroid detection, orbit determination, and impact uncertainties
- NASA Ames's Asteroid Threat Assessment Project (NASA ATAP): modeled the asteroid impact damage effects; provided SMEs on damage caused by asteroid impacts
- NASA Goddard Space Flight Center (GSFC): modeled launch opportunities for space missions; provided SME on asteroid mitigation and reconnaissance missions
- Lawrence Livermore National Laboratory (LLNL): modeled asteroid mitigation using a nuclear explosive device (NED)
- North Carolina State Emergency Operations Center (EOC): hosted and led execution at the state level
- Winston-Salem and Forsyth County First Responder Communities: led planning and execution at the local level

Agency descriptions can be found in Appendix A of this report.

1.4 Venues

PD TTX4 was implemented using a hybrid approach with in-person and virtual participation from three main venues located in Laurel, Maryland; Winston-Salem, North Carolina; and Raleigh, North Carolina. In addition to these three main locations, more than 40 federal-level attendees participated virtually from NASA, USSPACECOM, U.S. Northern Command (USNORTHCOM), Department of State, FEMA, the National Security Council, the National Space Council, and others. There were more than 150 participants from local public safety communities, to include first responders from fire and rescue, law enforcement, health and medical, transportation, emergency management, emergency medical services, public health, and others located in Winston-Salem, North Carolina. An additional 40 participants from the North Carolina Emergency Management Agency participated virtually from the state's EOC, located in Raleigh, North Carolina.

Facilitation of in-person and virtual participation occurred at these multiple locations over the course of 1.5 days, during which time real-world information sharing and situational awareness challenges were simulated and shared with all participants to elicit their SME-related input and feedback. More

detailed information regarding the structure and implementation of this TTX can be found in Chapter 2 of this report.

Figure 1-2. Participants in Laurel, Maryland.

Figure 1-3. Virtual participants in Winston-Salem, North Carolina. Virtual state-level participants also joined from Raleigh, North Carolina, and several other individuals joined on individual virtual call-ins.

Chapter 2. Exercise Structure

2.1 Structure

PD TTX4 occurred over a period of 1.5 days and was based on a simulated asteroid impact scenario spanning four distinct periods of time or modules. Each module covered a different period of time and focused on unique aspects of learning about, preventing, and responding to the hypothetical asteroid threat, with day 1 being set on the first day of the exercise. Participants received a short set of "Planetary Defense 101" briefings to provide a common background going into the exercise. North Carolina–based participants received this briefing earlier in the month during a 14 February 2022 meeting in Winston-Salem, North Carolina.

The emergency management core capabilities, which include prevention, protection, mitigation, response, and recovery, represent distinct critical elements necessary to achieve the specific objectives of each module. The objectives and aligned core capabilities were selected by the Exercise Planning Team.

As previously described, the overall objective of PD TTX4 was to assess the various challenges associated with a planetary defense response to a simulated asteroid impact threat by enabling participants to exercise all phases of the disaster scenario (initial detection, notification, potential mitigations, ground preparations, and ground recovery), from initial detection to the recovery stage. It included a diverse set of federal, state, and local agencies and was the first end-to-end exercise for this type (asteroid impact) of disaster.

Module	Description
0	Initial Detection ("Planetary Defense 101" and recap of read-ahead materials)
1	Early Mitigation Options (6 months before impact)
2	Early Preparedness (2 months before impact)
3	Final Preparedness (6 days before impact)
4	Response and Transition to Recovery (post-impact)

Each module had several injects (new information or questions) to generate discussion, which was captured using a data collection process that culminated in participant feedback forms. At the conclusion of each module, participants filled out feedback forms. At the close of the TTX, the team conducted a hotwash to gather final thoughts and overall reactions from participants.

2.2 Scenario

The following FICTIONAL, but realistic, scenario was used to help develop the exercise content and injects to prompt discussion and was NOT based on factual or social media information:

The scenario for PD TTX4 began with the discovery by astronomers of an asteroid designated as 2022 TTX that might impact Earth in 6 months. As the exercise unfolded, it became clear that the asteroid would impact Earth and was estimated to be large enough to cause substantial regional damage. The asteroid's potential size, its impact energy, and the detailed damage it would cause remained highly uncertain until just days before impact. Figure 2-1 is a timeline that was provided to participants as a read-ahead and illustrates the events likely to occur before the first day of the TTX.

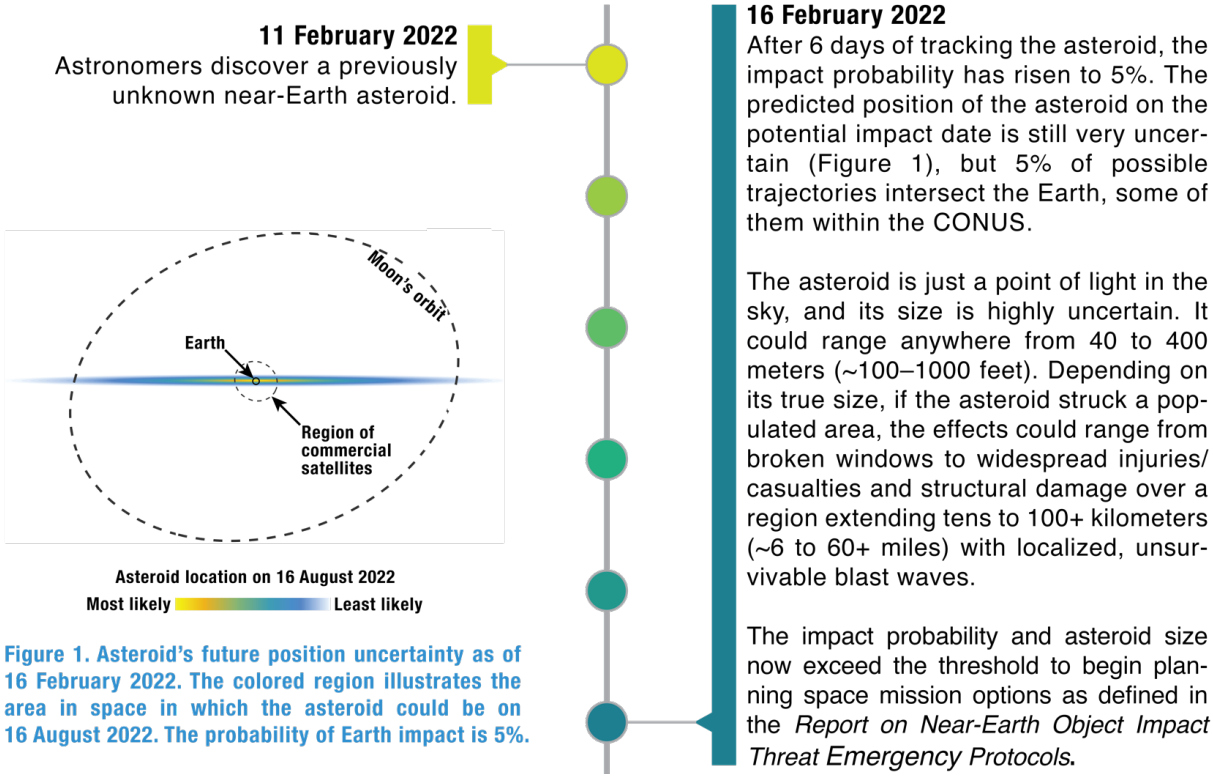

Figure 2-1. EXERCISE ONLY. Excerpt from the read-ahead materials providing the initial knowledge of the exercise asteroid to the participants.

A modified version of the guidance and processes recommended by the Homeland Security Exercise Evaluation Program (HSEEP) was used to plan, implement, and evaluate this TTX. Planning efforts also considered the capabilities-based planning process, a universal process developed by the Department of Homeland Security (DHS) and adopted by first responder groups. This approach allows for tracking and comparison of current capabilities as well as assessment of overall preparedness, and also supports the following improvement-related processes:

- Alignment with a structure and nomenclature that the public safety community at all levels routinely uses to assess their capabilities

- Alignment with DHS's Core Capabilities List, which supports the National Preparedness Goal
- Ability to use both quantitative and qualitative measures
- Distinct measurable elements because each capability comprises critical tasks
- Feedback provided to both the technology developer and the first responder
- Gathering baseline data and information for documenting performance and improvement, which can subsequently be used to plan for follow-on testing/spiral event

2.3 Planning

PD TTX4 required extensive planning and collaboration. Using the modified version of the HSEEP process (see Chapter 3), a core planning group was established with representatives from federal, state, local, and private partners.

2.4 Exercise Implementation Timeline

PD TTX4 was a dynamic, multimedia-facilitated event. The players moved through accelerated time and actively participated in five modules. Each module was led by a facilitator who offered a series of issues and questions for the players to respond to. Players explained the factors they would consider, decisions they would make, and actions they would take given the situation. Each module also included briefings by SMEs to inform the next set of discussions. Although the asteroid threat was hypothetical, discussions were based on existing NASA, FEMA, and other government plans, policies, and procedures such as the US National Near-Earth Object Preparedness Strategy and Action Plan, NITEP, and NRF.

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Chapter 3. Modules

As previously described, each module explored core capabilities as aligned with the key objectives described in the Objectives and Traceability Matrix. The core capabilities—prevention, protection, mitigation, response, and recovery—represented distinct critical elements necessary to achieve the specific objectives of each module. Upon completion of each module, the players were provided with a participant feedback form to fill out. A hotwash immediately followed the conclusion of the exercise on day 2, providing the players with the additional opportunity to speak freely, offer potential improvements, and share key insights.

3.1 Module 1: Early Mitigation Options (6 months before impact)

Module 1 addressed two of the TTX objectives, to "increase the understanding by personnel of U.S. government institutions of near-Earth object (NEO) threats and their roles in mitigating that threat" and to "test methods of communicating information both to and among decision-makers." Specific sub-objectives addressed in Module 1 were as follows:

- Educate participants on the nature of NEO threats
- Increase participants' understanding of necessary protocols required for timely notification and associated interagency planning
- Exercise established processes for space-based mitigation/reconnaissance mission requirements
- Assess each agency's high-level understanding of preparedness and response efforts for a NEO threat
- Assess the effectiveness of visuals and decision-aid tools/documents to communicate complex information to key decision-makers

Injects and discussions in Module 1 focused on initial communication of the asteroid threat, capability gaps, legal and policy implications of space mission mitigation options, and communication as knowledge of the threat evolved.

3.1.1 Scenario Details

Module 1 took place on scenario date 23 February 2022, 12 days post-discovery and ~6 months before impact. The module included seven injects. In injects 1.1 and 1.2, NASA CNEOS and NASA ATAP updated participants regarding impact predictions and the damage risk assessment:

- The impact probability has risen to 71%, and the impact risk corridor is now a narrow band that crosses the globe and includes most of the contiguous United States (CONUS).

- Potential damage remains very uncertain because of the large uncertainty regarding the estimated size of the asteroid—between 40 and 440 m—which could result in local to wide-scale regional damage.
- There is a 19% chance of impact damage in the United States.

In inject 1.3, the NASA PDCO issued a simulated notification of the potential asteroid impact per NASA Policy Directive 8740.1. In inject 1.4, the facilitator informed participants that incorrect information about the asteroid threat was being widely shared on social media.

Injects 1.5 and 1.6 focused on informing participants about space mission mitigation options and the international law and treaty considerations for use of a NED for planetary defense. Inject 1.5, presented by NASA GSFC, informed participants that asteroid deflection was not practical and highlighted the lack of current capability to launch on a timescale needed for a flyby reconnaissance or disruption mission. Inject 1.7 summarized the observational capabilities that could be used in the coming weeks and months after discovery to better characterize the asteroid and refine impact predictions.

Key discussion points in Module 1 included the following:

- Protocols for national-level interagency communication of a new asteroid threat
- Strategies for informing the public of an asteroid threat
- Which entity should provide updated information to the public at this point in the scenario
- Approaches to international coordination
- Strategies to combat misinformation
- Technology gaps for remote characterization of asteroids and for executing space mitigation missions
- Legal and policy considerations for launching a NED for planetary defense

3.1.2 Outcomes and Feedback

Discussion in Module 1 focused on national-level interagency communication of the asteroid threat, informing the public, and technology gaps for asteroid characterization and deep-space mitigation missions. Findings included the following:

- NASA's current impact notification protocols are sufficient to disseminate key information to relevant agencies and decision-makers.
  - The notification list in NASA Policy Directive 8740.1 could be updated to take better advantage of existing notification channels.

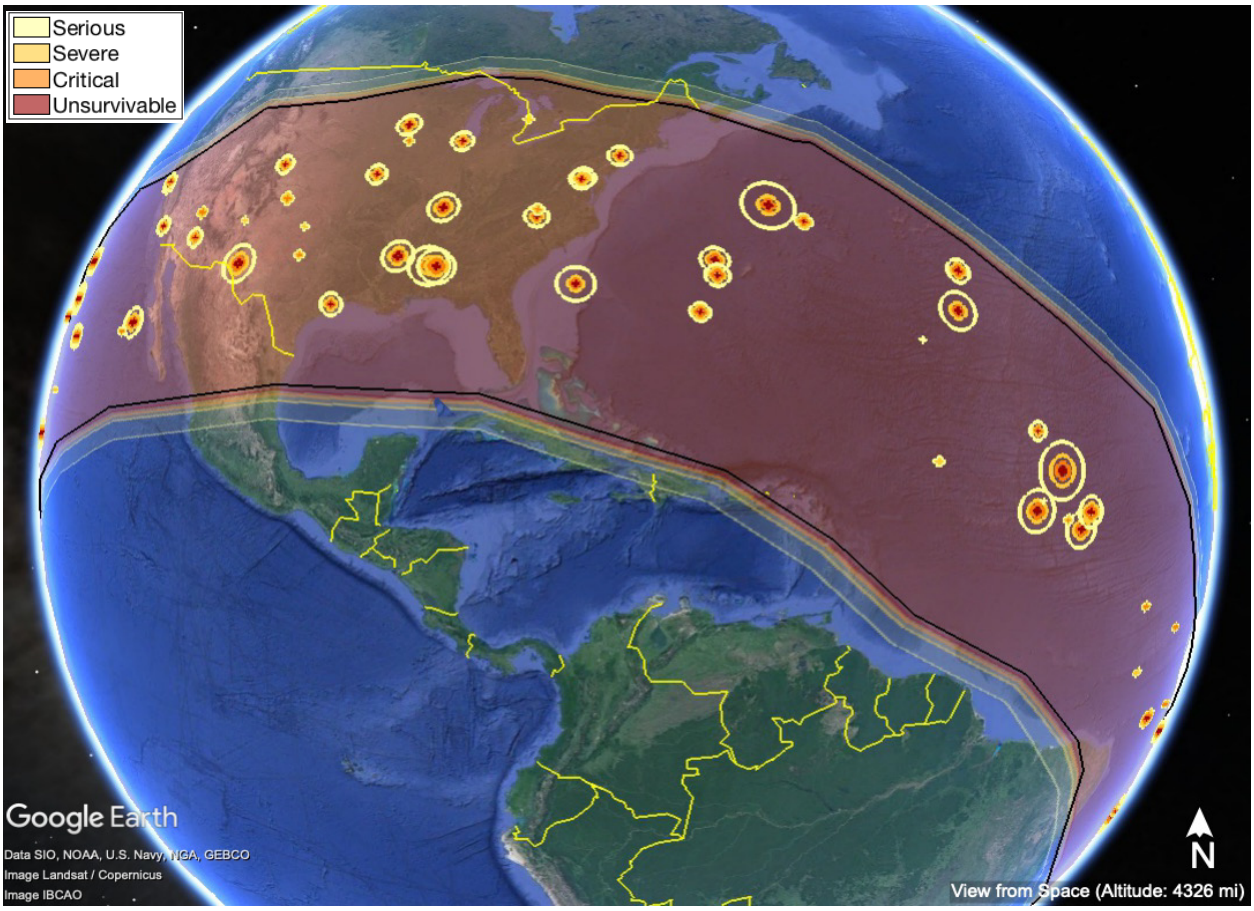

Figure 3-1. EXERCISE ONLY. Module 1 damage risk swath showing regions at risk of local ground damage in the case of an impact with hypothetical asteroid 2022 TTX. The yellow-to-red band spanning the globe shows the area at risk of impact. If the asteroid were to hit Earth, it would hit somewhere in that colored swath. The damage from the impact would cover a much smaller area. Concentric circles show examples of the extent and severity of damage expected, given the uncertainty regarding the asteroid orbit and properties at this stage in the TTX.

- There was general agreement that NASA should serve as the trusted authority for public communications at the early detection stage of an asteroid threat scenario.
  - Frequent public updates are recommended, and should include information about what we know, what we don't know, and when we will have new information.
- The visuals used to convey impact damage predictions were helpful.
  - SMEs should be on hand to help interpret and convey predicted/estimated damage to recipients.

Recommendations from Module 1 included the following:

- Improve capabilities for asteroid detection and characterization

- Increased warning time (i.e., finding the potential impact threat earlier) provides more options for deploying feasible space mitigation missions, and characterization capabilities also inform other elements of emergency response.
- Further studies of these technical capability gaps are recommended, to include dual-use possibilities with NASA and Department of Defense (DoD)/national security space organizations.

- Develop the capability to rapidly launch a reconnaissance mission
  - A reconnaissance mission can be used to inform a potential deep-space mitigation mission (increasing the probability of success) and/or reduce uncertainties regarding the asteroid's size and other properties earlier than may be possible with ground-based assets, thereby improving readiness for ground emergency response.
  - Further studies are recommended, including dual-use possibilities with NASA and DoD/national security space organizations.
- Improve understanding of international legal and policy implications for NED use for planetary defense
  - A future legal and policy-focused exercise or workshop is recommended.
- Mature strategies to address misinformation over the full duration of an asteroid impact scenario
  - The recommendation was to study public relations lessons learned from other crises, including the COVID-19 pandemic, and public information domains.

3.2 Module 2: Early Preparedness: 2 months before impact

Module 2 objectives touched on each of the overarching TTX objectives: "increase the understanding by personnel of U.S. government institutions of near-Earth object (NEO) threats and their roles in mitigating that threat"; "test methods of communicating information both to and among decision-makers"; and "exercise post-impact protocols, including involvement of local government." Key discussions began on bolide observation timelines, potential last-minute deflection options, communication and messaging, and evacuation planning. Facilitated discussion focused on interfaces between federal, state, and local officials and decision trees. Local and public safety decision-makers were advised that they now have only 2 months to prepare.

3.2.1 Scenario Details

Module 2 focused on early preparedness activities, including at the federal and state/regional level in North Carolina. Activities took place on scenario day 15 June 2022 (2 months before impact).

Module 2 was introduced with an inject reporting a bolide (a.k.a. "fireball") exploding over Japan the previous evening, which had been widely observed with announcements and misinformation spread

via social media. This inject led to a discussion of messaging, of potential misinformation, and of time-scales for information to travel from detection of a fireball through interior government channels, and then to be understood and announced as a fireball and not the result of some other malevolent event.

Participants were then advised that there was a 100% chance of impact of 2022 TTX into the CONUS, and that the impact would occur somewhere in northwest North Carolina. At this point in the scenario, participants received key updates from NASA CNEOS on the asteroid:

- Impact probability: 100%
- Impact date: 16 August 2022, 18:02 UTC (14:02 EDT)
- Impact risk corridor: North Carolina
- Approximate size: 130–1100 feet (40–340 m)
- Expected level of damage if impact occurs: local to regional
- Impact velocity: 15.5 km/s

The most important new data from NASA CNEOS were pre-discovery or "pre-covery" detections of the asteroid from sky images taken in 2015 when then-undetected asteroid 2022 TTX made a distant flyby of Earth. The asteroid was too distant and faint for a confirmed discovery at that earlier time, but now that it is known where to look in the image set for it, and apply enhancements to the images, a detection can be made and much earlier astrometric observations can be extracted, allowing a much more accurate orbit for the asteroid to be determined and more precise predictions of the impact time and point to be made. Further, there was a "non-detection" by the NEOWISE infrared telescope, by looking where the asteroid should be seen if it is large enough, which allowed an upper size limit to be placed on the asteroid.

A briefing from the NASA ATAP described the updated threat and hazard summary. The size and properties of the asteroid remained highly uncertain at this stage, so there was still a large range of possible damage. The primary hazard was from a large airburst or ground impact causing destructive blast waves and possibly thermal burns or fires; the blast radius could extend out ~100 miles, although the most likely size was 15–70 miles.

Table A-1. Potential blast damage severities and sizes.

Damage Level	Potential Blast Effects	Chance of Occurring	Damage Radius Range (miles)
Serious	**Shattered windows, some structure damage**	>99%	0–100 (avg. 50)
Severe	**Widespread structure damage**	~95%	0–50 (avg. 26)
Critical	**Most residential structures collapse**	~85%	0–30 (avg. 14)
Unsurvivable	**Complete devastation**	~60%	0–13 (avg. 5)

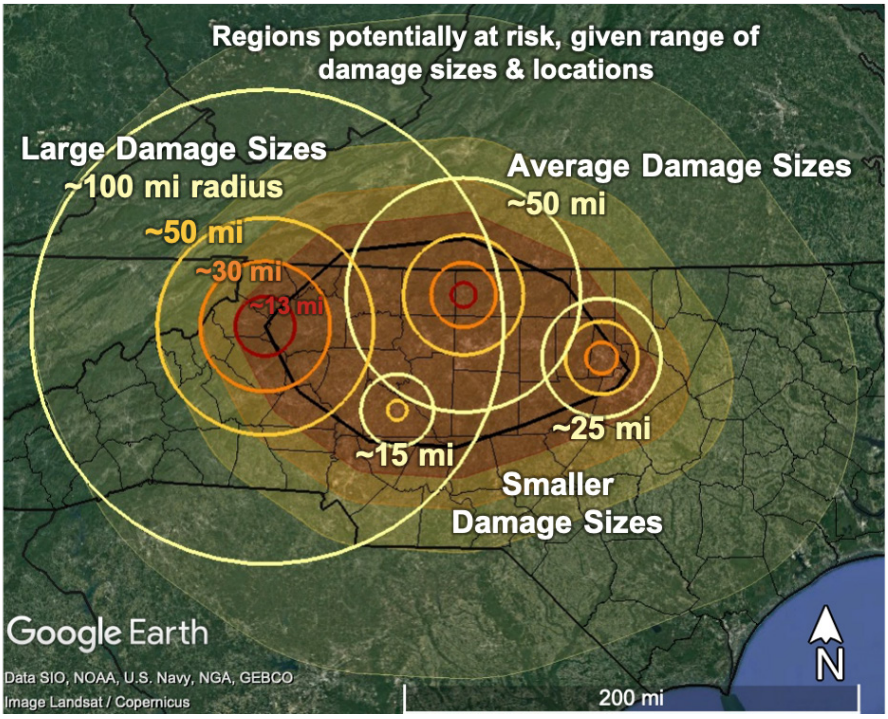

Figure 3-2. EXERCISE ONLY. Damage map for Module 2. The black irregular ellipse represents potential [ground] impact locations, with the extent of predicted potential damage levels shown in the orange shaded regions. Based on various potential sizes for the asteroid, various possible damage area sizes and severities are shown. The actual damage potential depends on asteroid size and trajectory factors.

The module included four injects followed by questions and discussion regarding fireball detection and reporting, notification procedures and communication between federal and state actors, preparation activities in North Carolina, and the role of state emergency managers. There was also much discussion about the potential last-minute mitigation efforts via intercept by an ICBM launched shortly before impact.

Key discussion points generated from the four injects included the following:

- Better timeliness of bolide identification and information dissemination
- Need for space assets designed to better characterize asteroids and risks for impact
- Decision path for a go/no-go for ICBM intercept
- Transition points to more state and local involvement

3.2.2 Outcomes and Feedback

Discussions focused around four crucial areas: timelines of bolide identification and detection of asteroids, messaging and communications, potential mitigation options, and information sharing and coordination as roles transition from federal to state and local authorities. A high-level summary of the considerations and proposed next steps is presented below.

Some key findings from Module 2 are as follows:

- An estimated damage/swath map should be provided in digital formats. This was done for the TTX and was a positive decision aid for local emergency managers.
  - It was suggested to continue working with a set of exemplar end users to determine what information is most usable and when it is needed by decision-makers at the operational levels responsible for critical infrastructure and evacuation
- It is imperative to explain what information is available and why the information is time-bound/limited, as well as to set expectations regarding updates throughout the entire timeline.
- Leadership emphasized that decisions should be made based on the best available information at the time, while acknowledging that new information may alter recommendations.

Some key gaps and recommendations from Module 2 discussions include the following:

1. The NED-equipped ICBM option is not developed well enough, including how to present the information, probability of success, and effectiveness/viability.
   - Recommend conducting a study to assess the technical feasibility and effectiveness of a last-resort NED-equipped ICBM intercept option and, assuming feasibility, explore implementation and policy challenges and unintended consequences
2. An asteroid threat is not widely familiar to the USG and the public.
   - Consider ongoing communications lessons learned from COVID-19 response and other similar large-scale events
   - Include public information officers (PIOs) to strengthen continuity of operations and emergency preparedness response plans.
3. Current data on the NASA CNEOS fireball webpage (https://cneos.jpl.nasa.gov/fireballs/) are not reported quickly enough to be used to definitively distinguish a natural bolide event from a foreign-state action, and are too detailed for broad consumption.
   - Recommend working with end users to make this information more understandable and ensure that it is updated in a more timely manner, perhaps by an authority that already has a 24/7 update system

3.3 Module 3: Final Preparedness and Readiness

The overarching objective of Module 3 was to “improve understanding of standard operating procedures for notifying and communicating information both to/from and among key decision-makers regarding NEO threats.” More specifically this module sought to do the following:

- Inform and educate participants on NEO threats

- Increase understanding within USG institutions of NEO threats and their potential roles and responsibilities in mitigating that threat (including the first opportunity to understand the roles of U.S. Space Force [USSF] and USSPACECOM)
- Identify knowledge and technology gaps
- Test methods of communicating information both to and among decision-makers
- Assess the effectiveness of visuals and decision aids
- Exercise post-impact protocols, including involvement of state and local governments

3.3.1 Scenario Details

Module 3 focused on final preparedness and readiness within the state of North Carolina. Activities took place on scenario day 10 August 2022 (day 2 of the PD TTX4) or 6 days before impact, and participants were advised that the City of Winston-Salem and Forsyth County are most likely to be severely impacted. At this point in the scenario, participants received key updates from NASA CNEOS, newly informed by planetary radar acquisition of the asteroid:

- 70 m (230 feet) in size
- Asteroid velocity of 15.54 km/s (34,700 mph)
- Approach elevation 64 degrees (26 degrees from vertical)
- Approach direction 37 degrees (from NNE)

During a briefing from NASA ATAP, participants learned that there could be a high chance of damage affecting hundreds of thousands of people in Forsyth County and potentially the surrounding counties. The primary hazard would be an airburst causing blast damage, ranging from shattered windows and structural damage to potentially unsurvivable destruction of buildings and infrastructure levels.

There were four injects followed by questions in Module 3 dealing with the ability of participants to interpret information/visuals, risks to critical infrastructure in the Winston-Salem region, and misinformation shared on social media. The fourth inject fast-forwarded the scenario to just 24 hours before impact and asked participants to describe priorities for the remaining time.

Key discussion points generated from the four injects included the following:

- Evacuation decisions: thresholds and compliance
- Federal support to state and local partners
- Urgent public communications
- How to counter ongoing misinformation
- Decisions regarding security concerns

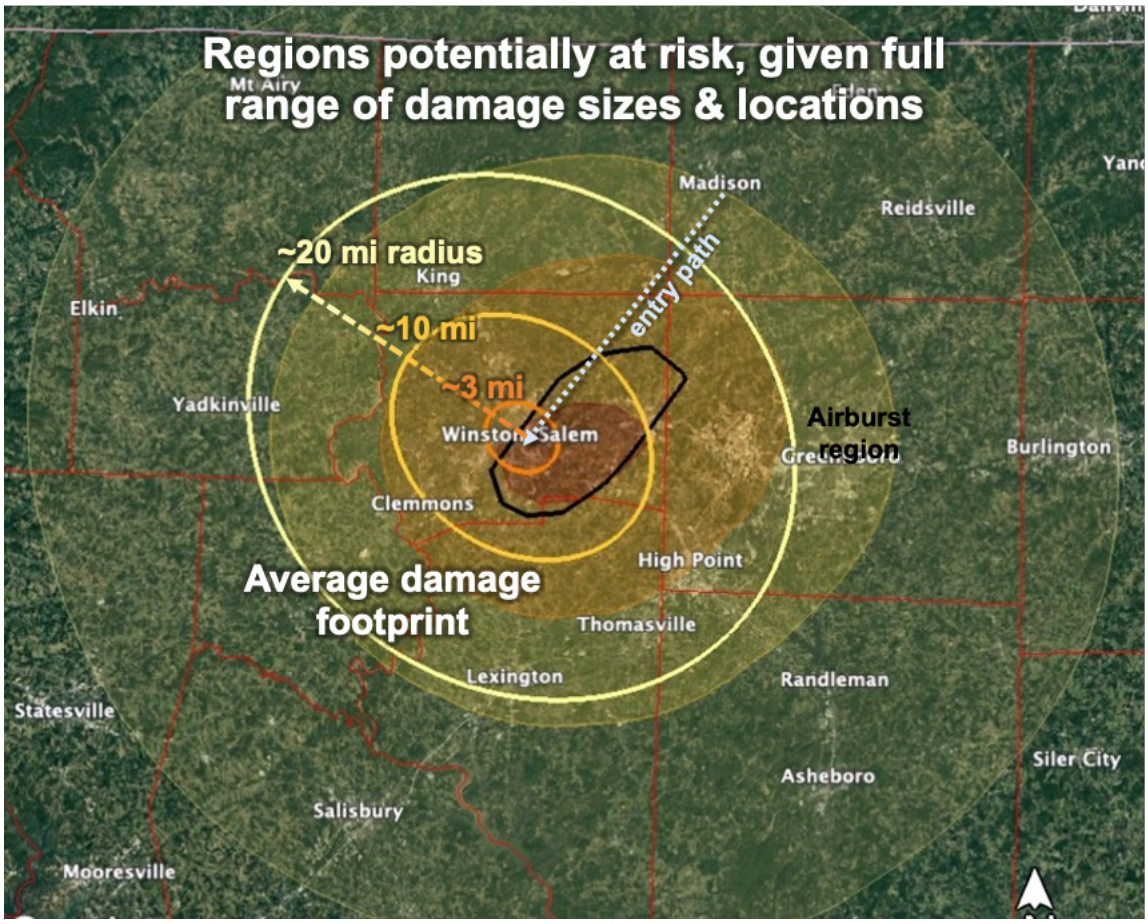

Figure 3-3. EXERCISE ONLY. Damage map for Module 3. The black ellipse represents the potential [ground] impact location, with the predicted potential damage levels shown in the orange shaded regions. The airburst would occur somewhere along the noted entry path. The color definitions are consistent with previous figures.

3.3.2 Discussion and Proposed Actions

Discussions focused around three crucial areas: asteroid characterization, messaging and communications, and information sharing and coordination. A high-level summary of the considerations and proposed next steps is presented below.

Asteroid Characterization

- Discussion: There are gaps in current capabilities to provide characterization of the impacting object for threat assessments through imaging of small, rapidly moving asteroids with planetary radar. Since the collapse of the dish at the Arecibo Observatory, Goldstone is currently the only facility with robust planetary radar capability.
  - Action: Explore and expand intentional dual use for longer-range radar for planetary defense and space domain awareness (SDA)

- Discussion: At this time, we have a single point of failure. For example, under the current circumstances, it would take approximately half a day to get radar observations with information regarding precise trajectory and size to support risk assessments from ATAP to PDCO. There is no redundancy for ATAP expertise and coding.
  - Action: Discuss how these capabilities can be enhanced and made more robust by other agency capabilities (e.g., Department of Energy [DOE] or other national laboratories) and incorporate effects models from existing DOE/DoD assessment capabilities into an integrated capability via the Modeling Working Group
- Systems for rapid reconnaissance with dual uses are needed (e.g., deep SDA sensors)

Messaging

- Discussion: Feedback from North Carolina–based participants indicated questions and concerns regarding accurate communication and messaging to the responder community about delays in determining size and the impact risk path. Specifically, participants accustomed to natural disasters such as hurricanes did not understand why more accurate impact information would not be available prior to 6 days to impact.
  - Action: This discussion indicated a need to test ways of communicating expected future uncertainty to the general public and increase overall outreach and education regarding asteroid incidents
  - Action: Utilize FEMA messaging and ready.gov information specific to how to prepare for an asteroid event (e.g., keep windows open to minimize overpressure)

Information Sharing and Coordination

- Discussion: The intelligence community and DoD have different reporting structures and information. For example, they would expect more detailed information, such as the number of expected deaths, physical damage, etc.
  - Action: ATAP should coordinate with other agencies through the Modeling Working Group to develop standard reporting data
- Discussion: What are the physiological effects of blast waves due to an asteroid airburst or impact?
  - Action: Need for a practical assessment of static and dynamic pressure events to more effectively communicate impacts of rapid pressure changes
- What is the point for transition of lead agency responsibilities from NASA to FEMA?
- There is a need for mutual aid agreements among nations.

3.4 Module 4: Post-impact

Module 4, "Immediate Response and Transition to Recovery," was developed to facilitate conversations evolving around objectives 2 and 3: "test methods of communicating information both to and among decision-makers" and "exercise post-impact protocols, including involvement of local government." Discussions during this module touched on all sub-objectives for TTX objectives 2 and 3.

Module 4 began with a high-level overview of the National Incident Management System's (NIMS) Incident Command System (ICS). For more information regarding NIMS and ICS, see https://training.fema.gov/nims/. A notional ICS structure was visually displayed for all locations to help depict how stakeholder leads and support components might evolve over the course of the scenario and into Module 4 (see Figure 3-4 below).

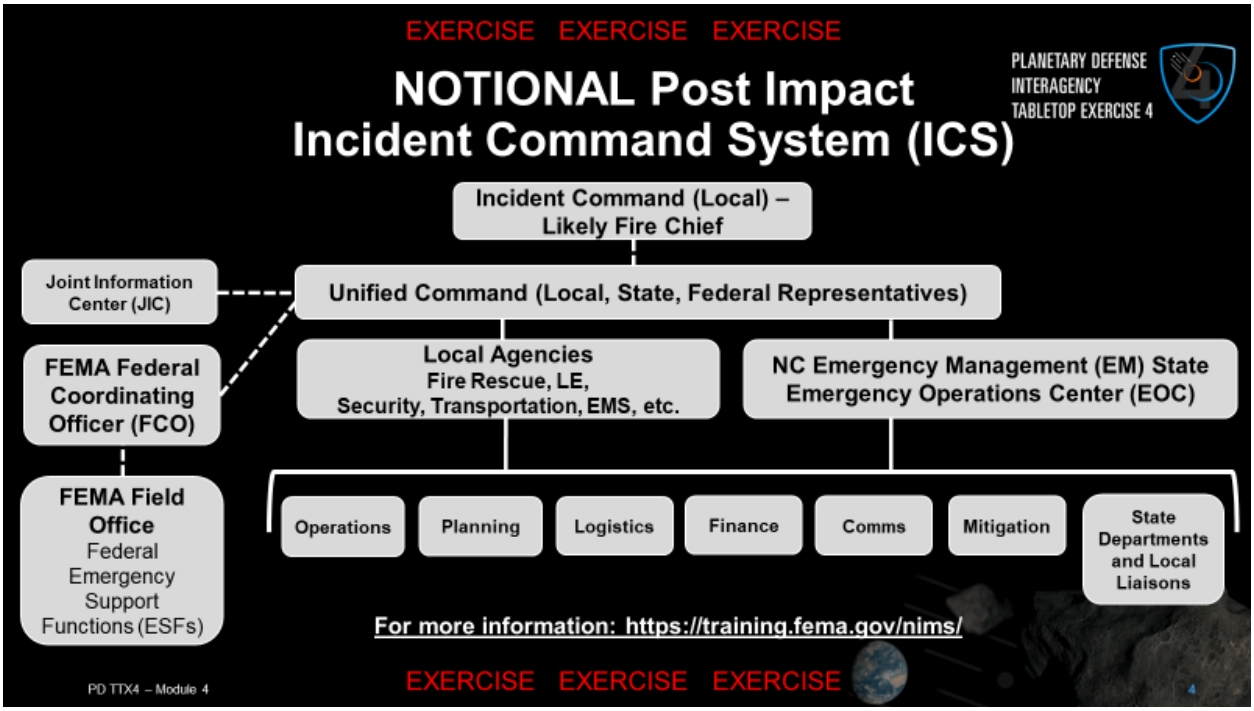

Figure 3-4. Notional post-impact ICS – *used only for the purposes of PD TTX4*.

3.4.1 Scenario Details

The Module 4 scenario took place on 16 August 2022 (day 2 of TTX) and represented the immediate hours post-impact. The injects and discussion for Module 4 were focused on the following:

- Acquiring post-impact situational awareness for informed decision-making
- Understanding risks and hazards in the post-impact environment
- Ensuring accurate public messaging
- Coordinating safety and security

The initial inject for Module 4 (inject 4.1) included several visuals to simulate the damage that would likely be observed post-impact, as well as modeling of the damage that was based on the asteroid airburst occurring at an altitude of ~8 miles, producing ~10 megatons of energy with a maximum peak overpressure of ~3.5 psi and maximum ground wind burst speed of ~66 mph. This inject was provided to participants at all three locations via a voice and video information-sharing platform. To help participants appreciate the level of impact and damage that would occur, inject 4.1 also included a short video clip from the Smithsonian Channel of the 1950s Doom Towns in Nevada that was constructed to help understand blast-related damage.

The visuals used to prompt discussions included simulated drone images of shattered windows, collapsed buildings and bridges, secondary fires, people trapped and waving for help, reporting from the public to Emergency Communications Centers (ECCs), and models of infrastructure damage. Figure 3-5 provides an example of the modeling that was developed and provided by Map Forsyth City-County Geographic Information Office for this module. Map Forsyth serves Forsyth County, North Carolina, and its municipalities and citizens (https://www.mapforsyth.org).

Interactive facilitated discussion was accomplished via voice and video communications between participants in Laurel, Maryland, the North Carolina State EOC and public safety and first responders who were colocated in Winston-Salem, North Carolina. Facilitation and on-site support were provided by personnel from On Target Preparedness (https://www.ontargetprep.com) and APL. The questions posed as a component of the 4.1 injects included the following:

- What additional information is needed to help understand immediate needs in the 24 hours after impact?
- Given the event type that the public safety community has never dealt with before, do you expect a different level of response and support to be available for immediate assistance?
- Would there be a fear of unknown risks and hazards (e.g., “Something from outer space has hit Earth. What does it contain?”)?
- What are your security-related concerns at this time?

Initial discussions resulting from these questions took place at all three locations and focused on acquiring information for situational awareness for both near- and long-term decision-making and expectations for resource needs. Discussion also included post-impact assessments and decisions that must be made to help the communities deal with damage, loss of life, and long-term impact to the environment in the area of impact (e.g., toxins from the blast and fires in the soil, water). Information was periodically shared between locations, which resulted in a highly interactive environment and allowed for information sharing among local, state, and federal participants.

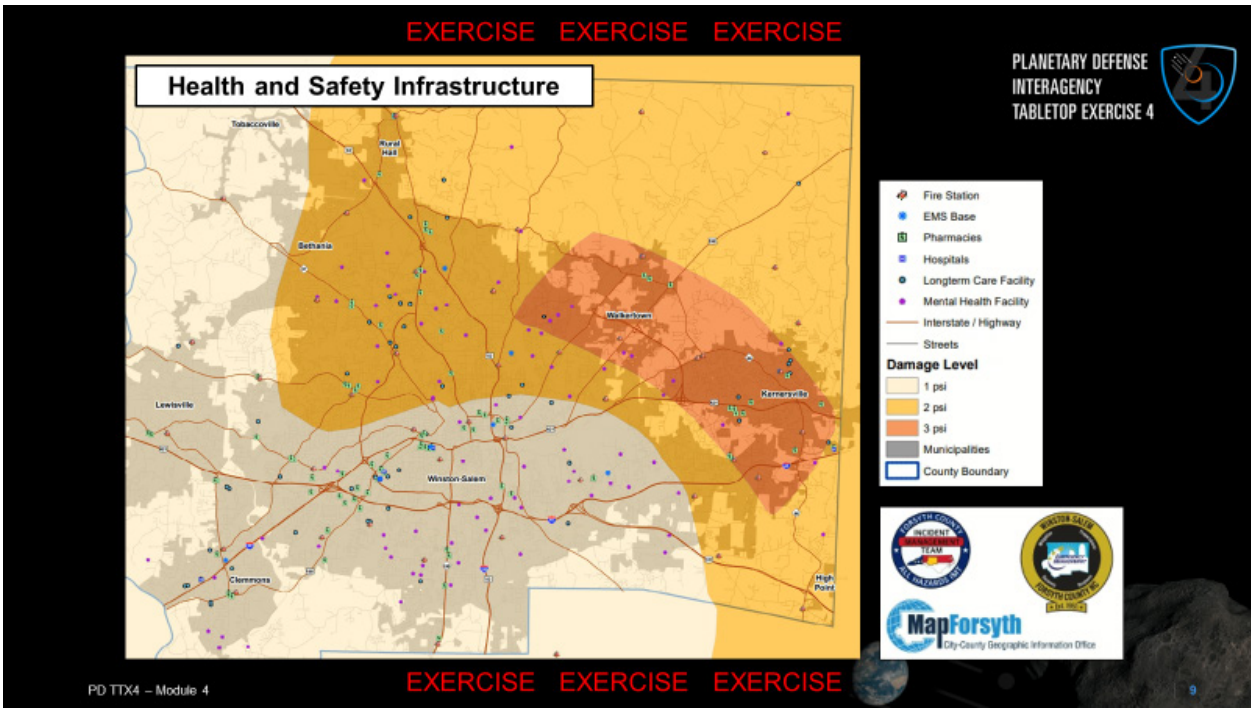

Figure 3-5. EXERCISE ONLY. Map Forsyth GIS (geographic information system) product that provided projected impact on health and safety infrastructure.

Inject 4.2 was then provided in a similar format as inject 4.1 so that it was received by all three locations simultaneously. Inject 4.2 was a simulation of misinformation that was being provided by someone known as "T.X. Asteroid" who was referring to themselves as a national expert. The simulated inject stated that T.X. Asteroid was warning people that the asteroid contained toxic materials from outer space, that those materials were spread throughout the region by the air blast, and that people should expect to experience radiation exposure–like symptoms. The following questions relevant to inject 4.2 were posed to participants:

- How could we get ahead of this type of false reporting?
- Who is the best voice of trust at this time?

General discussion took place regarding ongoing challenges with false information, with recognition that the best voice of trust depends on the local community, as well as recent events that may predispose communities to feeling a certain way or having certain beliefs. Therefore, it might be extremely difficult to identify a trusted voice ahead of time, but it likely would need to be someone already well known to the community.

After the misinformation discussion, participants from the North Carolina State EOC and the local public safety partners continued conversations regarding ongoing situational awareness and response and recovery operations, while the participants in Laurel, Maryland, held a generalized hotwash for the federal-level participants.

3.4.2 Outcomes and Feedback

During the closing of Module 4, the federal participants' discussion was refocused to finish conversations from some of the previous modules that were left pending. However, state and local participants in the two North Carolina locations continued their discussions, which were centered on the following themes:

- Transition to local command with federal support
- Understanding the extent of asteroid impact and damage to the local communities
- Need for consultation with experts to understand unique risks
- Predicting and determining resource needs
- Near- and long-term environmental impacts

Several key positive outcomes noted during the Module 4 discussion included (1) broad familiarity with the National Response Framework (NRF) and understanding that as the scenario evolved, more coordination was required between federal, state, and local partners, (2) agreement from participants about the need for continuity of information sharing so that risks are readily understood at all levels, (3) high level of interest and involvement from the scientific communities, and (4) repeated acknowledgment that lessons learned regarding public messaging from the pandemic should be incorporated into future planning efforts.

Some of the highlighted key outcomes from state and local participants for Module 4 included the following:

- It was reiterated that the PIOs need to be involved the decision-making discussion as early as possible.
- Incident Management Teams and emergency management professionals would be using all the same concepts that they use on a day-to-day basis but on a much larger scale.
- The MapForsyth team, NASA ATAP, and APL successfully collaborated in using data to develop relevant critical infrastructure maps.
- First responders expressed concerns regarding air-quality hazards.
- Participants understood the importance of identifying and using all resources available.
- The recent pandemic provided the school-system participants with assurance that students can be taught remotely (not ideal, but it can be done).
- Long-term care centers would require attention. They are already required to have evacuation plans, but their evacuation sites would likely be their sister campuses and possibly still in the impact area, so there was much discussion about where they would go.
- It was recognized that neighboring (e.g., regional) emergency management partners would need to be looped in as soon as feasible.

Chapter 4. Results, Recommendations, and Lessons Learned

4.1 Summary of Results

The exercise provided key information to inform future actions. A high-level summary of the results, recommendations, and overall lessons learned is provided below.

4.1.1 NASA's current impact notification protocols are sufficient to disseminate key information to relevant agencies and decision-makers.

In general, PD TTX4 participants felt that the current protocols used by NASA are appropriate for sharing key information to partner organizations and leadership. The following improvements could be made to strengthen the existing protocols:

- Notification lists should be updated to take advantage of existing notification channels. Discussions explored the effectiveness of the informational flow from NASA to the White House and to the executive branch agencies. An opportunity exists to refine the channels of communication and notification of potential impacts by, for example, possibly leveraging the White House Situation Room as a tool to complement notifications of individual agencies as identified in the *Report on Near-Earth Object Impact Threat Emergency Protocols*. Going forward, a recommendation is to ensure the bidirectional flow of information between NASA and the White House, which would then support the flow of vetted information to the agencies and contacts on the distribution list. Both notification chains—to and from the White House, and directly to the agencies—should be prioritized.
- As information flows to the appropriate command/operations centers, cross-coordination and communication among the key USG entities may be needed to shape the information for public consumption. Interagency communication protocols should ensure that the relevant agency points of contact are all working off the most accurate information, as curated from both NASA and the White House.

4.1.2 Participants agreed that NASA should serve as the trusted authority for public communications at the early detection stage of an impact scenario.

- Injects that described misinformation about the asteroid drove robust conversations about the need for a trusted voice to share asteroid impact updates and accurate information regarding its trajectory and damage probabilities. The participants widely agreed that NASA should serve as the most trusted voice at this stage, as it continues to have widespread credibility, and that the agencies would need to work closely together to synchronize messaging to effectively counter misinformation.

- Participants stressed the need for frequent public updates about what is known, what is currently unknown, and when new information will be available. Setting a cadence to issue regular communications to the public, even when there is no new information to share, helps to facilitate transparency while also alleviating misinformation and societal panic. In a real-life event, it will be imperative to designate a lead federal agency to manage and disseminate clear communications to the public in coordination with supporting messaging from other key institutions (such as FEMA), to plan for post-impact conditions, to explain what information is available, to explain why the information is time-bound or limited, and to set expectations regarding frequency and content of updates.

4.1.3 Simulated visuals, which were used to convey impact damage predictions during the exercise, were instrumental for the decision-making process and should be leveraged during a real-life event.

Participants were asked to weigh in on the visuals provided to them at the beginning of each module and share whether the data were easily understood and relevant to aid decision-making. The digitally formatted visuals displayed areas of risk, ground damage forecasts, impact severity, and damage footprint probabilities to the affected population. Participants noted that overlaying damage region maps over iconic and easily recognizable landmarks would help convey sense of scale more effectively. Additionally, participants welcomed insight from DOE regarding knowledge of secondary damage effects from nuclear blasts. In general, when the visuals were accompanied by explanations provided by the SMEs, the participants found the visuals useful in enabling critical decisions. However, without the SME explanations, the visual would be hard to understand.

- As the planning and preparation activities narrowed to North Carolina and the Winston-Salem/Forsyth County areas, the county geographic information system (GIS) mapping team, MapForsyth, NASA ATAP, and APL effectively collaborated to develop targeted critical infrastructure maps based on ATAP models of damage risk regions to aid decision-making around evacuation planning and logistics.
- During an actual NEO event, the participants would prefer to have SMEs on hand to interpret damage uncertainties and convey damage estimates, including how they relate to human life and health, and to explain how the numbers, angle of entry, and terms such as velocity translate to day-to-day planning at the human scale.

4.1.4 The National Response Framework (NRF) and the National Incident Management System (NIMS) have an expansive and flexible approach to accommodate a wide range of disasters, including an event such as an asteroid impact.

Stakeholders recognized the value of gaining broad familiarity with the NRF and the importance of coordination among federal, state, and local partners. Participants noted that substantial doctrine currently exists that should provide guardrails for executing planning and response measures in the event of an

asteroid impact. The NRF and NIMS were found to provide a strong foundation for disaster response activities because of their flexible framework and resulting applicability to inform unique incidents, such as an asteroid impact on U.S. soil. Participants also welcomed opportunities to further expand or stretch the NRF to accommodate nuances inherent in a NEO impact, such as psychological dynamics.

4.1.5 Timely information sharing is critical for decision-makers.

- As noted in section 4.1.2, the decision-makers emphasized that decisions should be made based on the best available information at the time, while acknowledging that new information may alter recommendations. Additionally, it was noted that as there are few primary channels of information feeding into the White House, including the Joint Chiefs, Science Advisor, DHS, Department of State, and others. Such channels should be exercised to flow NEO-related information directly to the White House. In particular, it would provide an opportunity to exercise the Science Channel because it is currently largely dormant or seldom used. To enable top-down information sharing, the White House would request input from each designated information channel and consider comments from those advisors regarding how other states/governments are reacting to or approaching this issue, to include how best to communicate with them or manage an influx of U.S. persons for safe harbor.
- To facilitate public understanding of the risks associated with this type of event and ensure that accurate information is relayed, consider sharing digital maps of the modeled regions (and related visuals) with the public to ensure that risk is readily understood at all levels. In so doing, because NASA is largely heralded as the trusted voice in this situation, it may be prudent for the agency to coordinate the dissemination of such information to the public, to also include sharing information about other space-related events occurring at the same time, such as bolide detections.

4.1.6 There are numerous lessons learned from the COVID-19 pandemic related to misinformation campaigns that should be recognized and incorporated into future planning efforts.

- As we learned from the pandemic, the trusted authority may shift with time, demonstrating that the public is fickle with regard to trust. Additionally, the trusted voice may not be the same in every community. We should consider identifying several trusted voices around the nation, from the top level down to the local level, to achieve the strongest link and connection to the public.
- Regular briefings could provide opportunities to address misinformation or other issues that arise in a timely, regular fashion. The solar eclipse event of 2017 could serve as an exemplar for outreach and engagement. Additionally, a rapid-response mission to capture images of the asteroid could also deflect and counter misinformation, given that there is transparency with the information gleaned.
- Consider hosting regular workshops specific to planetary defense and NEO threats to help address the gaps identified in this report.

- Take advantage of research that has been done about effective methods for countering misinformation, to include reaching out to active researchers in the field who may have insight into this topic.
- Explain information using common, nonscientific language to minimize confusion, and leverage PIOs to finesse the messaging.
- As we learned with the pandemic, ensure that the messaging channels convey information in a level manner, remaining wary of sounding overconfident. The risk of overconfidence is that it undermines the source's credibility if the messaging shifts or evolves in the future as a result of new or revised information/understanding.

4.2 Identified Gaps and Recommendations

The TTX identified a number of gaps, as well as recommendations to address them. A high-level summary is presented below.

4.2.1 A short-warning asteroid scenario poses challenges to mounting an effective national response.

- There is a critical need for capabilities for earlier asteroid detection and characterization. These capabilities would lead to longer warning times, which would provide more options for deploying feasible space missions, including asteroid characterization or reconnaissance missions, asteroid deflection missions, and asteroid disruption missions.

4.2.2 The nation has a limited ability to image small, rapidly moving asteroids.

- Develop the capability for long-range radar to obtain critical NEO information, such as orbit refinement, impact probabilities, and impactor size to facilitate response and mitigation efforts. The radar capability could also be leveraged across the USG entities and inform efforts and activities in cislunar space. Note that cislunar space requires additional, different sets of capabilities beyond deep-space/planetary radar.
- Explore use of DoD sensors to detect and image the asteroid to reduce uncertainties. Planetary defense and SDA have overlapping needs, which could be beneficially leveraged if planned from development through to operations.

4.2.3 The nation has a limited ability to rapidly launch a reconnaissance mission.

- Develop this capability. A timely reconnaissance mission would reduce uncertainties regarding asteroid properties, which would facilitate effective emergency planning and response on the ground and inform planning of deep-space mitigation missions, if feasible. A reconnaissance mission would also support the USG's public messaging campaign by enabling the public to see images of the asteroid. Research involving smaller, cheaper spacecraft such as Small-

Sats/CubeSats—developed beforehand and stored on standby or in space—may facilitate responsive launch when needed. Dual-use capabilities with NASA and DoD should be explored to develop responsive launch capabilities using common buses and interfaces.

4.2.4 The USG should explore dual-use capabilities for NASA and defense/national security organizations.

Overall, TTX participants recommend further studies of the capability gaps listed above, to include dual-use capabilities with NASA and defense/national security organizations. Additional dual-use areas to explore include the following:

- Advanced SDA (cislunar and beyond)
- Advanced targeting technology and mechanisms

In general, there seem to be significant opportunities for NASA and DoD to collaborate on responsive launch, common buses, expedited integration, advanced SDA, and advanced guidance and control. A workshop, or a series of meetings, to discuss these opportunities is recommended.

4.2.5 Large parts of the USG and the public are unfamiliar with an asteroid impact threat.

- Consider communications lessons learned from the COVID-19 response and other large-scale events.
- Include PIOs to strengthen continuity of operations and emergency preparedness response plans.
- Continue ongoing education and coordination with public safety communities at all levels.
- Continue collaboration among decision-makers, emergency responders, and impact damage modelers to develop damage risk metrics and visualizations geared toward supporting effective response decisions.
- Obtain additional information about what asteroid ground damage estimates from ATAP mean for those who have to make decisions about resource needs and staging of first responders near the impact area.
- Provide additional details on the population affected, particularly with regard to possible fatalities, to show how the impact will affect humans, not just buildings and infrastructure. Noting that this type of modeling may not be within NASA's focus, consider bringing in DOE, or others such as the Defense Threat Reduction Agency (DTRA), to conduct this type of analysis and modeling.

4.2.6 Only nascent strategies currently exist to address misinformation related to the asteroid threat scenario.

- See section 4.1.5. Study public relations lessons learned from other crises and public information domains.

4.2.7 Without subject-matter experts (e.g., scientists, modelers) to describe and orient others on the impact visualizations, the visuals are difficult to use for planning.

- Consider workshops with emergency response communities and ATAP damage modelers to increase responders' understanding of asteroid impact risk assessments and to increase ATAP's awareness of the emergency response community's needs. Furthermore, the participants agreed that the swath maps should be provided in digital form and perhaps posted on the NASA website for download. However, noting that this disaster is atypical and to reduce misinterpretations arising from the public release of the digital maps, consider retaining a NASA SME at the local/ground sites to provide rapid responses to questions about the impending NEO, explain assumptions that feed the modeling, and minimize confusion regarding the impact characteristics (i.e., whether the asteroid would strike the ground or explode as an airburst). Additionally, consider connecting ATAP with DOE and DoD agencies, such as the civil engineering experts at the Army Corps of Engineers, to determine how best to model damage risk assessments and report the full scope of risk with respect to expected deaths, second-order effects such as thermal and dust production, physical damage, critical injuries, and property damage. NASA is best positioned to cover the science relating to the asteroids, but the effects of an impact are highly multidisciplinary and complex.

- There could also be opportunities to work with commercial vendors and international partners to refine modeling data on size, trajectory, velocity, angle of attack, composition, etc., and to model the effects of executing certain mitigation strategies.

4.2.8 The USG processes that ultimately populate the NASA CNEOS fireballs webpage (https://cneos.jpl.nasa.gov/fireballs/) are neither designed for quick reporting nor used definitively to distinguish a natural bolide event from a foreign-state action. The page is also too detailed for broad consumption.

- Work with end users to make this information more understandable, and determine better ways to disseminate information to the public quickly.
- Develop capabilities and consider leveraging international sensors to update this page in a more timely and rapid manner to minimize misinformation through social media, perhaps by an authority that already has a 24/7 update system.
- Evaluate assets needed to accelerate bolide reporting from USG sensor data.

4.2.9 Currently there is minimal redundancy and robustness for NASA CNEOS and NASA ATAP modeling capabilities/expertise.

- Evaluate whether NASA CNEOS and NASA ATAP have sufficient resources for appropriate levels of personnel staffing and SMEs, especially in the event of an actual, real asteroid threat scenario.
- Investigate integrating the output of ATAP damage models with the modeling capabilities across relevant federal institutions such as DHS Science and Technology Directorate, DOE, and DoD, to increase opportunities for redundancy, and to support additional training.

4.2.10 Some agencies responsible for managing asteroid hazards have a limited understanding of the National Incident Management System (NIMS) to prevent, protect against, mitigate, respond to, and recover from incidents.

- Provide "NIMS 101" sessions as follow-up training (readily available online) and as part of planning for PD TTX5. NIMS provides stakeholders across the United States with shared vocabulary, systems, and processes to successfully deliver the capabilities described in the National Preparedness System. It defines systems and structures—including the ICS, EOC, and Multiagency Coordination Group (MAC Group)—that guide how personnel work together during incidents. As part of PD TTX5, the training and content could identify the responsibilities of all individuals who have roles in incident management or support, whether on scene, in an EOC, or through a MAC Group.
- Emphasize how best to mitigate risk by achieving greater preparedness.

4.2.11 Understanding of the international legal and policy implications of using nuclear explosive devices (NEDs) for planetary defense and terminal phase mitigations remains limited.

Participants were interested in exploring the full scope of legal and policy implications of pursuing a NED to disrupt an incoming asteroid. Participants also agreed that the policy and legal framework for utilizing a NED for planetary defense should be developed and vetted before humanity is confronted with an actual emergency and as part of routine contingency planning. Given that use of NEDs in space implicates international space law, there could be opportunities to work across the international landscape, to include not only Five Eyes nations and U.S. allies but also key United Nations entities such as the Committee on the Peaceful Uses of Outer Space (COPUOS), the United Nations–endorsed Space Mission Planning Advisory Group (SMPAG), and the International Asteroid Warning Network (IAWN), which are already assessing the issue. A future exercise or workshop should be organized that is dedicated to fully exploring the legal and policy aspects of deploying a NED to disrupt an asteroid. If usage of a NED is deemed technically feasible, it is incumbent upon the USG to ensure that legal, policy, and potentially negative side-effect considerations do not delay execution of potential mitigation options.

4.2.12 The NED-equipped ICBM disruption option, including how to present the option, the probability of its success, risks, and overall effectiveness, is not adequately understood.

- Conduct an in-depth study to assess the technical feasibility and effectiveness of a terminal phase, NED-equipped ICBM intercept option, and, if the study demonstrates feasibility, explore authorities, implementation, and geopolitical policy challenges, as well as unintended consequences. As part of conducting a feasibility study, determine the best entity to take on this work. There was general agreement that the technical study should be completed first.

4.3 Needs and Gaps Grouped by Emergency Support Function (ESF)

There were a number of high-level outcomes identified by participants at the Winston-Salem and Raleigh, North Carolina, locations group by ESF:

- **Health Care.** Often, hospitals remain operational until last possible moment. A full evacuation plan for hospitals should be drafted; consider the challenges of evacuating larger hospitals. Mass care services and evacuation discussions would need to start early, to include relocation of patients and related transportation considerations.
- **Public Information.** PIOs should be brought into the decision-making discussions as early as possible to ensure unity, relatability, sufficiency, and consistency of public messaging. PIOs could also be instrumental in breaking down language barriers among the SMEs, the public, and decision-makers, and in combating misinformation. Consider also that PIOs could serve as trusted voices for the community.
- **Incident Management Teams/Emergency Management.** Tap into the incident annexes and similar concepts as used on a day-to-day basis, and apply principles and targeted preparedness to managing federal and local responses to incoming asteroid threats. The TTX team gained significant ground response knowledge from the North Carolina state and local partners during this event.
- **Critical Infrastructure.** The exercise demonstrated successful collaboration between the MapForsyth team, NASA ATAP, and APL to use data to develop and model relevant critical infrastructure maps. Consider the need to shut down public utilities/public works (i.e., termination of water and sewer services) to facilitate evacuations.
- **Public Safety.** Planning and preparedness activities should consider that a significant percentage of residents will refuse to evacuate, despite mandatory orders from the governor. First responders expressed concerns regarding air-quality hazards, recovery from secondary damage from impact/air burst events (dams bursting, power outages, toxic chemical release, road/bridge destruction, etc.), long-term recovery, reunification for evacuated populations, and reentry/resettlement of the damaged regions.
- **Support (including Safety/Risk Management).** Participants understood the importance of ensuring the identification, allotment, and utilization of all resources available. There could also

be a need for a cohesive all-hazard base plan to account for sufficient planning for the safety of communities. Additionally, the preparedness plan may need to ensure that there is a sufficient number of law enforcement personnel to provide security for the evacuated areas.

- **Schools.** Schools, hospitals, and local government should be included as part of the local ground response plan. Remote instruction is also an alternative option to ensure continuity of learning.
- **Human Services Health Department.** Long-term care centers are required to have evacuation plans; however, because their evacuation sites may involve sister campuses still within the impact area, planning should consider alternative options for evacuations.
- **Liaisons.** Neighboring (e.g., regional) emergency management partners would need to be looped in as soon as feasible. Consider planning needs for evacuating people to other cities within the state versus evacuating to multiple surrounding states/jurisdictions and impact on air traffic control.

4.4 Benefits of the TTX Beyond Its Stated Objectives

- Successfully executed, for the first time, an end-to-end exercise opportunity using a hybrid virtual and in-person approach
- Provided opportunities for senior federal, state, and local decision-makers to discuss needs and solutions across the life cycle of managing a planetary defense threat
- Supported key partnership and engagement needs for the White House, NASA, USSPACECOM, and FEMA
- Provided a structured approach to capture decision-makers' input and feedback
- Met annual exercise requirements for many participants, which promoted participation

4.5 Participant Feedback Regarding Exercise Implementation and Logistics

- All briefs were deemed very informative. As expected, different end users had different views on the importance of some of the briefings. For example, several emergency management participants preferred more information on the asteroid damage modeling and less on deep-space mitigation, while federal decision-makers weighed those briefings of equal importance. Future exercises should consider the target audience and their information needs and state this before the brief for awareness and understanding the purpose of the brief.
- Very positive feedback (95% favorable) was received regarding the visual aids used during the TTX to describe the location, uncertainty, and extent of possible damage for broad consumption. Constructive feedback was provided by participants to help improve understanding the technical details underlying the modeling by key decision-makers. One suggestion for improvement included giving consideration to separating the maps showing the potential damage

region and the size of the expected damage. It was also noted that the narration of how to read these maps provided by NASA ATAP was invaluable.

- It would be helpful in future exercises to take a deeper dive into the emergency management lines of authority (e.g., NIMS and ICS) and include a brief on emergency communications that covers exercising specific communication paths between federal organizations; taking into stronger account the effects of chaos, panic, and deliberate misinformation; and inclusion of the communications offices from NASA, FEMA, and others as appropriate.

Appendix A. Participating Agencies, Organizers, and Attendees

The term "participant" encompasses many groups of people. The specific "groups" of participants involved in the exercise were delineated as follows, including their respective roles and responsibilities.

A.1 TTX Planning Team[2]

The TTX Planning Team was led by our sponsors, Lindley Johnson* (PDCO) and L.A. Lewis* (FEMA).

APL

Dipak Srinivasan*, Exercise manager

Emma Rainey*, Module 1 facilitator, SME

Angela Stickle*, Module 2 facilitator, SME

Anne Roberts-Smith*, Module 3 facilitator, SME

Ruth Vogel*, Module 4 facilitator, SME, Exercise Design

Aparna Srinivasan*, TTX evaluation lead, SME

Julee Rendon, On-site coordination in North Carolina

Patrick King, SME

Andy Rivkin, SME

Shannon Thornton, Logistics lead

Lisa Turner, Event coordinator

Justin Atchison, Nancy Chabot, Terik Daly*, Dawn Graninger, Liz Parkin, and Fazle Siddique, Data Collectors

JPL/CNEOS

Paul Chodas, Asteroid scenario, orbit modeling SME

Ryan Park, Asteroid scenario, orbit modeling SME

Davide Famocchia, Asteroid scenario, orbit modeling SME

NASA Ames

Lorien Wheeler, Asteroid impact risk modeling SME

Jessie Dotson, Asteroid property modeling SME

Michael Aftosmis, Asteroid damage simulations

NASA GSFC

Brent Barbee, Deep-space mitigation SME

[2] Authors of this report are indicated with an asterisk.

Lawrence Livermore National Laboratory

Megan Bruck Syal, Nuclear deflection and disruption modeling

North Carolina Local Emergency Manager

August Vernon

Planning Partners from On Target Preparedness

Doug Logan, Jessica Leins, David Hesselmeyer

A.2 Players

Players were personnel (e.g., first responders, emergency managers, public safety personnel) who have an active role in performing and/or discussing their regular roles and responsibilities. Players initiated actions in response to the events (both simulated and real).

Table A-1. Key participants.

Organization	Name/Title
Office of Science and Technology Policy (Executive Office of the President)	Matt Daniels, Assistant Director for Space Security and Special Projects
National Space Council (Office of the Vice President)	Madi Sengupta, Director, Civil Space Policy
National Security Council (Executive Office of the President)	Chris Cannizzaro, Director of Critical Infrastructure
NASA	Bhavya Lal, Associate Administrator for Technology, Policy, and Strategy
NASA	Lori Glaze, Division Director for Planetary Science
FEMA	Erik Hooks, Deputy Administrator
U.S. Space Command	LTG John E. Shaw, Deputy Commander
U.S. Northern Command	LTG A. C. Roper, Deputy Commander
National Science Foundation	Debra Fischer, Director of Division of Astronomical Sciences
U.S. Department of State	J. R. Littlejohn, Principal Deputy Assistant Secretary

A.3 Data Collectors

Data collectors for this exercise were assigned to observe, note, and document events and actions (e.g., sending and receiving communications, video quality and clarity, timeliness of information received, human performance factors) associated with the intended use of the technologies. Their primary role was to observe and document actions, discussions, timing, results, and end-user comments. The general objective was to document whether the players were able to work through the notification protocols and wrestle with actions and decision points along the sequence of events. Data collectors documented discussions and observations and provided a final core capability rating for each inject.

A.4 Other Personnel

Subject-Matter Exerts (SMEs). SMEs assisted players and participants by serving as technical experts and/or subject-matter experts during the event, providing briefings or answering questions throughout the exercise.

Observers/VIPs. Observers/VIPs were key stakeholders that were invited to observe the TTX. VIPs included participants such as elected and appointed officials, agency directors, and other leadership as identified and invited.

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Appendix B. Abbreviations and Acronyms

APL	Johns Hopkins Applied Physics Laboratory
ATAP	Asteroid Threat Assessment Project
CNEOS	Center for Near Earth Object Studies
CONUS	Contiguous United States
COPUOS	Committee on the Peaceful Uses of Outer Space
DHS	Department of Homeland Security
DoD	Department of Defense
DOE	Department of Energy
DTRA	Defense Threat Reduction Agency
ECC	Emergency Communications Center
EOC	Emergency Operations Center
ESF	Emergency Support Function
FEMA	Federal Emergency Management Agency
FIOP	Federal Interagency Operational Plan
GIS	Geographic Information System
GSFC	NASA Goddard Space Flight Center
HSEEP	Homeland Security Exercise Evaluation Program
IAWN	International Asteroid Warning Network
IC	Intelligence Community
ICBM	Intercontinental Ballistic Missile
ICS	Incident Command System
JIC	Joint Information Center
JWST	James Webb Space Telescope
LLNL	Lawrence Livermore National Laboratory
M&S	Modeling and Simulation

MAC	Multiagency Coordination
NASA	National Aeronautics and Space Administration
NED	Nuclear Explosive Device
NEO	Near-Earth Object
NIMS	National Incident Management System
NITEP	Near-Earth Object Impact Threat Emergency Protocols
NMCC	National Military Command Center
NORAD	North American Aerospace Defense Command
NRCC	National Response Communication Center
NRF	National Response Framework
PAIR	Probabilistic Asteroid Impact Risk
PD	Planetary Defense
PDCO	Planetary Defense Coordination Office
PIO	Public Information Officer
S&T	Science and Technology
SDA	Space Domain Awareness
SME	Subject-Matter Expert
SMPAG	Space Mission Planning Advisory Group
STRATCOM	U.S. Strategic Command
TTX	Tabletop Exercise
UNOOSA	United Nations Office for Outer Space Affairs
USG	U.S. Government
USNORTHCOM	U.S. Northern Command
USSF	U.S. Space Force
USSPACECOM	U.S. Space Command
WHSR	White House Situation Room

Appendix C. TTX Slides

Presentation materials from the 4th Planetary Defense (PD) Interagency Tabletop Exercise (TTX) are available at https://cneos.jpl.nasa.gov/pd/cs/ttx22/.

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Appendix D. Objectives and Traceability Matrix

In September 2021, the NASA Planetary Defense Coordination Office (PDCO) partnered with the Federal Emergency Management Agency (FEMA) Response Operations Directorate to sponsor the 4th Planetary Defense (PD) Interagency Tabletop Exercise (TTX). PD TTX4 included participation from federal, state, and local agencies in planning for the preparedness for and response to a near-Earth object (NEO) impact scenario. It was the first effort at an end-to-end exercise for this type of disaster, which explored actions from the initial asteroid detection stage through ground response and recovery of the impacted region within the CONUS. The exercise leveraged partnerships with FEMA, NASA Jet Propulsion Laboratory's Center for Near Earth Object Studies (NASA CNEOS), NASA Ames' Asteroid Threat Assessment Project (NASA ATAP), North Carolina State Emergency Response Team(s), and Winston-Salem/Forsyth County Local/County Emergency Response Teams (hereinafter referred to as the "Team") to accomplish a twofold purpose: (1) evaluate the technical, logistical, and operational challenges associated with planetary defense activities and (2) apply and implement protocols as defined in the *National Near-Earth Object (NEO) Preparedness Strategy and Action Plan* and the *Report on Near-Earth Object Impact Threat Emergency Protocols*. Specifically, the TTX sought to exercise multiple aspects of a potential asteroid impact, encompassing initial detection, uncertainty, damage modeling, notification, potential mitigation, ground preparation, and ground recovery. In so doing, the team identified the following core objectives for the TTX: (1) Increase the understanding by personnel of U.S. government institutions of near-Earth object (NEO) threats and their roles in mitigating that threat, and provide an opportunity to better understand the role of U.S. Space Command (USSPACECOM), (2) test methods of communicating information both to and among decision-makers, and (3) exercise post-impact protocols, including involvement of local government. The three objectives are provided in the following table, which also includes aligning objective statements to ensure measurable and meaningful outcomes. These objective statements are also provided below and include a designation ("X") to indicate which FEMA emergency management phase the sub-objectives aligned to.

Objectives		Objective Statements	Emergency Management Phase Addressed				
			Prevention	Protection	Mitigation	Response	Recovery
OBJ 1	**Increase the understanding by personnel and U.S. government institutions of near-Earth object (NEO) threats and their roles in mitigating that threat**	**1.1. Educate participants on the nature of NEO threats, to include discovery, tracking, characterization, and explicit quantification of uncertainty of a hypothetical asteroid impact**		X	X		

Objectives		Objective Statements	Emergency Management Phase Addressed				
			Prevention	Protection	Mitigation	Response	Recovery
		1.2. Increase participants' understanding of necessary protocols required for timely notifications and associated inter-agency planning and coordination for effective preparedness, response, and recovery missions		X	X	X	
		1.3. Assess participants' knowledge of their specific roles and responsibilities related to public alerts and warnings to communicate and implement an evacuation		X	X		
OBJ 2	**Test methods of communicating information both to and among decision-makers**	**2.1. Exercise established processes for space-based mitigation/ reconnaissance mission requirements in response to a NEO threat**			X		
		2.2. Assess each agency's high-level understanding of preparedness and response efforts in the event of a NEO threat			X	X	
		2.3. Identify gaps in understanding roles, responsibilities, chain of command, and whole-of community-response when multiple federal, state, and local partners are involved		X	X	X	X

Objectives		Objective Statements	Emergency Management Phase Addressed				
			Prevention	Protection	Mitigation	Response	Recovery
		2.4 Assess effectiveness of visuals and decision-aid tools/documents to communicate complex information to key decision-makers		X	X	X	
OBJ 3	**Exercise post-impact protocols, including involvement of local government**	**3.1. Assess each agency's awareness and understanding of their respective roles and responsibilities for alignment with the National Response Framework (NRF), the National Incident Management System (NIMS), and the Federal Interagency Operational Plans (FIOPs)**		X	X	X	X
		3.2. Review agency-specific public information and community messaging plans and procedures for consistency and alignment		X	X	X	
		3.3. Assess participants' understanding of a NEO impact as it relates to consequences to communities and infrastructure		X	X	X	X
		3.4. Gauge participants' response roles and responsibilities as they contribute toward being positioned for organizing and planning for major reconstruction and redevelopment necessary for recovery				X	X

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Appendix E. Outcomes and Objective Matrix Components

Module 0-1 Outcomes and Objective Matrix Components			
Module Component	**Discussion Focus**	**Identified Need/Gap**	**Objective Statements Addressed**
Planetary Defense Coordination Office (PDCO) Brief	It was noted that the notification of an asteroid threat had not been exercised since PDCO formation or NEO Preparedness Plan creation.	**Need:** Ongoing efforts to increase understanding for this type of threat and hold exercises more frequently	1.1
PDCO Brief	Participants asked whether the asteroid warning/impact was on the National Exercise List. Response: "not currently but plan to address."		1.1
PDCO Brief	A participant asked why 59% of asteroids are not found. It was explained that the capability is limited by funds. Technology has been ready and there has been advocation, but there currently are not enough resources available.	**Need:** Efforts to allocate resources that will increase asteroid tracking and reporting capabilities	1.1, 1.2
Asteroid and Detection Brief	A participant asked about what trips the alarm for notifications. PDCO representatives responded, explaining >10 m sized object, >1% impact probability triggers notifications. The hurricane analogy during this presentation resonated well, as did the description of the data flow, and it was discussed that planners and decision-makers could benefit from continued discussions to improve information flow development. Discussion was held regarding when notifications would be disseminated and by who at participating agencies, to include the need for graphics to improve understanding of what to expect.	**Need:** Proactive information regarding notifications and clarification as to why information would be limited **Need:** Determination of the balance of new information without inundating the public **Need:** Determination of who is lead agency and how that might evolve **Need:** Clarity regarding when notification and updates would be expected	1.1
Module 1 (Day 1) Inject 1.1: Update on 2022 TTX observations, probability of impact, impact footprint, and planned future observations Inject 1.2: Modeling inject by the Asteroid Threat Assessment Project (ATAP): Impact damage risk summary Inject 1.3: Simulated	Participants discussed the need to understand when the projected impact band on Earth would get narrower and therefore provide a better understanding of the impact area. Responses summarized that it could be months; the current situation was summarized as "we would have exhausted every sensor we have and this is what we would know."	**Need:** "Sharing all the information we have as soon as we can" (this is critical) and delineating communication protocol information leads and target audiences	1.1, 1.2
	Discussion was held explaining that NASA would share information, and the Federal Emergency Management Agency (FEMA) would engage with NASA when first alert is made. Participants agreed that NASA may be the trusted authority for the information and the key/lead for sharing updates with the public to begin with.		1.2, 1.3, 2.1, 2.2, 2.3
	Participants discussed lessons learned related to information sharing during critical events: (1) share what you know, (2) share what you don't know, and (3) share when you will know more.	**Need:** Ongoing adaptation of public information so that information/updates are consistent and provided clearly, early, and repeatedly	1.2, 2.3

Module 0-1 Outcomes and Objective Matrix Components			
Module Component	**Discussion Focus**	**Identified Need/Gap**	**Objective Statements Addressed**
notification Inject 1.4: Information shared widely on social media. Much incorrect.	For decision-making purposes, more information is needed to help understand risk and potential damage, and what that means as it relates to communities and infrastructure (e.g., what types of windows would be blown out, what casualties, deaths, and damage to roads and bridges would occur). In summary, more details are needed regarding the damage that is possible.	**Need:** Conveying the risk better at this point (early on in scenario) so that communities understand what to expect and when to expect updates	1.1, 1.2, 2.4
	Discussion was held regarding the critical need to keep people informed and build confidence that everything is being shared and people know where to go for authoritative information. Also referenced how daily public press conferences, and briefing updates including when new information would be available are needed. This helps prevent misinformation to some degree, but can never be fully prevented. It was stated that a known trusted voice of authority can help to address misinformation quickly on a daily basis as can an established routine for providing updates. Discussion also occurred regarding the need for “mobilizing scientists” to help and the potential that NASA comms or someone else would need to be leading this “mobilization” effort.	**Need:** Public information CONTINUITY and FREQUENCY; public information officers (PIOs) need to be providing updates with “ONE VOICE”	1.1, 1.2, 2.2

Module 0-1 Outcomes and Objective Matrix Components			
Module Component	**Discussion Focus**	**Identified Need/Gap**	**Objective Statements Addressed**
Module 1 (Day 1) Continued	Some participants were unclear as to when this would become a national-level emergency event and who makes that decision. There would be notification to the Office of Science and Technology Policy and the White House Situation Room (WHSR) as well as the Science and National Security Advisors and various other leadership. The White House would provide overviews but look to NASA for technical expertise. Various discussions were held about eroding trust in government by some, but it was agreed that NASA seems to have public trust currently and thus may be best the lead. Comment was made that the PDCO media releases have been important to establishing NASA as a trusted source that can help combat misinformation. Discussion was also held regarding the possible need for a reconnaissance/flyby mission that would show the world what the asteroid looks like and allow other countries see the unencrypted spacecraft data. Participants acknowledged the need for communication and coordination with international partners in which the State Department stated they coordinate with NASA for Space Mission Planning Advisory Group (SMPAG). We could request a United Nations Office for Outer Space Affairs (UNOOSA) meeting. There is also potential to use State Department operations center to disseminate information. It was acknowledged that transparent communications are critical for public confidence—all of this depends on the asteroid—when new information is available. NASA can set those expectations, but we need to work with other agencies and maybe improve the communication there. It was discussed that it is likely that trust in communications would most likely be acquired at the community level (e.g., fire chief). Participants understood the critical need to work with PIOs and related professionals as well as the need to be thoughtful regarding the messaging to ensure people don't panic/flee/run as a first overreaction, which is likely due to very complex and unfamiliar information.	**Need:** Clarity regarding who has lead for public communication at this point. Limited understanding by some federal partners of the role and responsibilities of the public information offices and who they coordinate **Need:** Research into the potential usefulness of reconnaissance missions **Need:** Discussion and decisions pre-event regarding who the lead will be; the National Incident Management System, and how it provides an overall framework for all partners, is not well understood by some of the federal participants	2.3

Module 0-1 Outcomes and Objective Matrix Components			
Module Component	**Discussion Focus**	**Identified Need/Gap**	**Objective Statements Addressed**
From Day 1 Hotwash • A potential missed opportunity to discuss notification channels more clearly • Important to make sure that clear and simple terms are used to ensure everyone is on the same page • Important for people to have a general science understanding on the topic without overwhelming them • The use of simple analogies really shined in this section • Need to be careful about the risk corridors and investigate the secondary effects (infrastructure, etc.) • Noted that the damage and risk swaths are misleading; make sure to keep updating them continuously with consistency • Reminder that we have a special relationship with Canada; North American Aerospace Defense Command (NORAD) would need to be involved, and high-level discussions would need to take place			
Module 1 Continued into Day 2			
Module 1 (Day 2) Inject 1.5: Modeling inject Inject 1.6: Policy considerations for NED deflection or disruption Inject 1.7: Observational capabilities for future observations	Discussion was held regarding the need for clarification that if the asteroid is in pieces, disrupted, or partially disrupted. Participants acknowledged that many unknowns and probabilities are under study, we would not be in a position to deploy a NED, and multiple launch vehicles would be involved. Coordination is needed across NASA, the Department of Energy (DOE), and the Department of Defense (DoD) (all would endorse multiple missions if used, but mission success is unknown at this time).	**Need:** Understanding of what can be developed without nuclear explosive device (NED) component (to mitigate risk but avoid the pretext pitfalls). Within this context of the discussion, there is also a need to consider that anything we do, others (e.g., other countries) should be allowed to do. **Need:** Ongoing considerations regarding international policies and precedence, to include agreed-upon transparency measures	1.1, 2.1, 2.3
	During the policy presentation, discussion occurred regarding the consideration of NEDs for planetary defense, and the potential that doing so could be seen as a pretext to maintaining that capability. If others were building this capability for planetary defense, the United States would likely be concerned and not support it. This pretext argument is an important one to consider; even the logistics for a spacecraft mission are not clear for this scenario—to have a spacecraft available, to commandeer a launch vehicle, the availability of NEDs, etc. PDCO representative stressed that the rarity of asteroid impact events needs to be considered in the larger context of the world and other threats—that even with detection working, there may be one detection per century that would require action, and this rarity should be weighed against other threats.		1.1, 1.2
			1.1

Module 0-1 Outcomes and Objective Matrix Components			
Module Component	**Discussion Focus**	**Identified Need/Gap**	**Objective Statements Addressed**
	During the policy presentation, it was asked "if we would find it acceptable even in a crisis like this?" Transparency mechanism would be critical for long-term precedence. Detecting all objects would be better than being in this situation. PDCO agreed and stated they are working on that capability. It was noted that budgets for NASA are not the same as for DoD. If DoD sees value in this, they could help with advocacy for funding of this capability.	**Need:** Further discussion about and research into whether smaller, cheaper spacecraft could perhaps be developed for this reconnaissance mission capability—perhaps stored in space and ready to go when needed	1.1
	Discussion took place regarding the value of a reconnaissance mission based on the fact that detection is critical. Questions were posed regarding what could be done to lower uncertainties. Benefits to understanding the cost of reconnaissance missions versus having a launch-on-demand planetary defense mission available were also discussed.		1.1, 1.2
	Concerns were raised that developing a NED capability could lead to distrust and that, therefore, messaging would be important. It was suggested that messaging should emphasize that this is to save the world, not just the U.S., but others say this will also not play well or would be distrusted. It was stated that we should compare the statements "The U.S. is going to do it to protect 'us'" versus "The U.S. is going do it to protect the world."	**Need:** Agreement and a way forward that incorporates critical international cooperation **Need:** More discussions by decision-makers to determine best message and approach for NEDs (e.g., anything we permit ourselves to do, we must allow others to do. What transparency measures would we want to invoke to ourselves and others)	1.1, 1.2, 2.2
	Participants agreed that regular communications updates would be critical and that efforts would be fighting misinformation, including state-sponsored misinformation.	**Need:** A plan for deciding who the trusted voice and the lead would be, to be included in communications protocol and public information plan	2.3
	There was discussion around expecting a lot of help with combating misinformation as cislunar capabilities expand, but it was agreed that a source of factual information could be useful in the future and should be considered.	**Need:** Establishment of a rapid-response mission to see what the asteroid looks like and to provide early understanding and situational awareness	1.1, 1.2, 2.1

Module 2 Outcomes and Objective Matrix Components			
Module Component	**Discussion Focus**	**Identified Gap or Need**	**Objective Statements Addressed**
Inject 2.1: A fireball has been reported over Japan	It was explained to participants that data about fireballs can be accessed by the public on the Center for Near Earth Object Studies (CNEOS) website. However, it is important to note that this information is more for science purposes rather than for public information. It is also important to note that updates are not done immediately.	**Need:** More timely data on fireball and threat information, with the purpose of the information clearly stated on the CNEOS website to avoid misuse/misunderstanding by the public	2.3; 2.4
	Discussion took place that U.S. Space Command (USSPACECOM) should be able to quickly distinguish a fireball from a human-made event and push this information to the National Military Command Center (NMCC)/WHSR. FEMA representatives explained how they would have initiated establishing the National Response Communication Center (NRCC) and set up the Joint Information Center (JIC); PIOs from federal partners would be coordinating message continuity in the JIC. It was noted that releasing data can be challenging, and it was recognized that a lot of reviews, edits, and approvals are needed for public messaging continuity.	**Need:** Improved processes and efficiency in making public information available quickly **Need:** PIOs at follow-on events, workshops, and exercises; developed and exercised public information plans regarding asteroid threats	2.3; 2.4
	FEMA representatives relayed the importance of everyone relaying information in plain language and emphasized that NIMS was established to help with this challenge. They noted that communications about the COVID-19 pandemic suffered from this lack of plain language at times.	**Need:** Further discussion with NASA regarding the need to be transparent—not being too confident but rather explaining what we know, what we don't, and what we are doing	2.2; 2.3; 2.4
	Participants discussed how data are transferred from government sensors to NASA and questioned whether this could be streamlined.	**Need:** Research to understand data and sensor needs, what's available, and what potential improvements could be made **Need:** Follow-up discussion to better understand what sensors could aid in this mission and to ensure all available are being used	1.1?
Inject 2.2: Modeling and simulation (M&S) inject provided to participants to discuss updated	Discussion was held regarding the potential use of archived information and whether that information is accurate enough for decision-making for a threat such as this.	**Need:** Research to understand what is currently being done and what might be needed for archive improvements to enable pre-coveries more quickly and efficiently	2.4

Module 2 Outcomes and Objective Matrix Components			
Module Component	**Discussion Focus**	**Identified Gap or Need**	**Objective Statements Addressed**
trajectories and impact locations	FEMA participants explained how typical alerts and notifications happen and what contingencies are in place. Discussion was then held regarding testing of understanding the levels of the information that would be disseminated, especially given that this is very complex describing an unfamiliar scenario.	**Need:** Updated notification process indicating that the governor would have direct communication with FEMA and show the FEMA communications process and protocols **Need:** Assessment of levels of understanding for public information and public safety understanding related to this type of scenario	1.2; 1.3
Inject 2.3: M&S inject: 100% chance of impact into North Carolina, but the exact area at risk remains unknown…advised that they now have only 2 months to prepare	Participants discussed how the potentially affected area is still very large, with much of the area ("risk swath") completely unaffected. FEMA participants described the challenges associated with this and how this would limit decision-making at this time. It was acknowledged that public safety personnel would need to be prepared for large-scale evacuations from multiple locations and for multiple community types. North Carolina participants relayed questions to the federal participants asking for a summary of what federal support would be available. FEMA delineated their role to include full engagement at this point, similar to a hurricane event. North Carolina participants also expressed concern regarding the continuity of operations and government, acknowledging that it would be very difficult for North Carolina leadership to know where to reposition and shelter at this point.	**Need:** Review of relevant appendices in NRF and FIOPs to determine what adaptations may be needed for this type of scenario, and clarification of who the lead agencies are as this type of event evolves **Need:** Ongoing workshops, training, and exercises to improve preparedness efforts for public safety personnel and critical decisions that would be needed	2.3; 3.1
	Based on participant discussion, it was unclear how decision-makers in North Carolina would get critical information and from which organization. There was discussion about whether handoffs of digital maps used for the modeled damage regions would be helpful, and in which formats. Participants in North Carolina expressed difficulty with understanding the maps and models without explanation to translate the data into usable information for their decision-making purposes.	**Need:** Ongoing work with the scientific community and public safety personnel at the state and local level to understand digital information needs and limitations	2.2; 2.3; 2.4

Module 2 Outcomes and Objective Matrix Components			
Module Component	**Discussion Focus**	**Identified Gap or Need**	**Objective Statements Addressed**
	Because of the financial impacts, as well as the distractions, misinformation, etc., DoD brought up the potential opportunity for U.S. adversaries to take advantage of vulnerabilities. It was acknowledged that it would be a challenging time and there would also be a need to manage an overreaction that could cause more damage. Participants expressed concern that lessons learned from Starfish Prime were forgotten and that there would be substantial risk to our DoD/intelligence community (IC) assets, which could also give the pretext for an adversary to be a "good Samaritan" and try something similar, but end up degrading infrastructure as an "unintended consequence" (https://www.smithsonianmag.com/history/going-nuclear-over-the-pacific-24428997/).	**Need:** Further policy discussions on establishing international nuclear "rules of the road" for this very low probability scenario	1.3; 2.3
Inject 2.4: Discussion of space accountability standards, potential space mitigation options (nuclear)—explore asteroid disruption via U.S. launch of a NED	Discussion was held regarding sea-based system considerations versus land-based, and it was agreed it would be good to examine both. Participants also discussed the need to use a nuclear or a kinetic impactor, but scientific participants felt it would be difficult to accomplish without a nuclear impactor.	**Need:** More discussion and further examination of both sea and land systems	1.2; 2.1
	Discussion occurred about the fact that the White House would be asking for advice and input and would need translation to ensure understanding of the technical components.	**Need:** Ongoing training for this type of scenario, critical given that the science advisory positions in the White House are rotational	1.2
	During discussions, it was clarified that USSPACECOM does not control NEDs; rather, that is U.S. Strategic Command's (STRATCOM) responsibility. Legal discussions were also held regarding launching an intercontinental ballistic missile (ICBM) (likely multiple), and it was noted that launching an ICBM creates more legal issues and can cause concerns, to include secondary effects that could make a bad situation worse. Participants acknowledged that there is challenging guidance, control, and navigation, and that an ICBM is not designed to do this, with national and global effects potentially. There would be "a lot of hurdles to overcome" to see this option as viable and technically feasible.	**Need:** Additional research regarding the feasibility and impact of an ICBM approach	2.1

Module 2 Outcomes and Objective Matrix Components			
Module Component	**Discussion Focus**	**Identified Gap or Need**	**Objective Statements Addressed**
	Several participants expressed concern regarding the limited capabilities that provide for an alert 6 months out but then at 2 months out, the asteroid size is still unknown.	**Need:** Exploration of what more could be done for early and ongoing detection and tracking (for example, whether dual-use technology could be an option)	2.1; 2.2
General comments from Mod 2 Day 2	FEMA has preexisting structures in place for this disaster. Their response is clear, and they know exactly what they need to do. But do all other federal partners given this threat type? There is a need to ensure consistent messaging. Make sure that agencies are agreeing with one another, and make sure that all important things are consistent – too many acronyms can lead to confusion. DoD's role would be purely supporting; they would not be taking the lead. There may be other events going on that DoD would need to support. DoD is very good at rapidly characterizing events as man-made versus natural phenomena, but they are not good at public messaging. USSPACECOM: We need to figure out how to release the data. It needs improvement. PDCO: We experimented with this before. We posted rapidly to Twitter via Asteroid Watch. We had coordination from trusted sources. But this needs proactive planning. There are extraordinary time delays due to vetting. The ASAT test described earlier took a week to get out. We could agree to something in advance to speed up approvals. Early detection is still identified as one of the most important things needed.		

Module 3 Outcomes and Objective Matrix Components			
Module Component	**Discussion Focus**	**Identified Gap or Need**	**Objective Statements Addressed**
Inject 3.1: Updated PDCO notification memo; coordination of federal, state, and local governments in unifying their efforts around messaging and evacuation	Participants discussed what radar is currently available other than Goldstone.	**Need:** More research regarding radar options; current planetary radar capabilities are very limited	1.1; 1.2; 2.2
	FEMA delineated that at this point in the scenario, their standard plans would be in action, including positioning teams outside the projected impact zone, using regional contacts and liaisons, and making emergency declarations with plans to follow with a major disaster declaration.	**Need:** FEMA working with partnering agencies to understand what adaptations are needed to current plans to address an asteroid threat	2.3
	Discussion was held regarding notification verbiage and how some of the terms meant different things to different participants.	**Need:** Determination of what values such as velocity and angle mean to public safety decision-makers and ensuring standard taxonomy is used for understanding	2.4

Module 3 Outcomes and Objective Matrix Components			
Module Component	**Discussion Focus**	**Identified Gap or Need**	**Objective Statements Addressed**
	Participants discussed how identifying populations at risk occurs and also how damage information might not be relevant to different populations. It was recognized that this isn't the sort of modeling that NASA typically does. Given the information presented, some participants did not understand the danger of atmospheric overpressure to human life. This was especially true at the state and local levels, where this type of information would be critical. There were discussions about when to evacuate and when to shelter in place, etc., as well as discussion about the differences between what was presented and what is actually needed for decision-making purposes. It was recognized that for local planning purposes, officials would need information to help estimate deaths and critical damage to property and key infrastructure, as well as much detail as possible for understanding what resources they would need. It was also noted that some participants believed that a "pressure wave doesn't sound so bad" (just leave the windows open and it will be OK, etc.). Therefore, this verbiage might be misleading.	**Need:** To convey the damage region in language that explains how it affects humans, not just buildings **Need:** To identify and work with those who do this type of impact modeling to provide better understanding (DOE may have resources to help) **Need:** PIO representation at follow-on events/exercises, as well as planning in anticipation of expected information delays and consequential dismay regarding the lack of new information between 2 months and 6 days	2.3; 2.4
Inject 3.2: Misinformation, public messaging, and public trust	Discussion took place to better understand who the lead is for developing messages to the public, and who is the communication lead overall. It was agreed that NASA would provide initial information but would start to transition to FEMA and the impacted state/region and local officials. FEMA acknowledged that they would coordinate federal support for disaster operations, like they do for other disasters, including all coordination of federal partners under the NRF.	**Need:** Investigation into the potential need to adapt current plans to include asteroid threats **Need:** Public information representation/expertise involvement in plan development and follow-on events/exercises/workshops (repeated expressed need)	2.2; 2.3; 3.1
	Participants from North Carolina reached out to the federal participants in Laurel, Maryland, via voice/videoconference, to request scientific consultation to help better understand the threat and some of the terminology being used. Discussion then followed regarding the need to provide subject-matter expertise on location to local decision-makers given the unfamiliarity with the threat scenario. Discussion included participants acknowledging that planning will need to be done for a worst-case scenario but also scalable.	**Need:** Scientific expertise/consultation on location and provide for next event/exercise and consider including in work that needs to be done related to updates for preparedness and response planning.	2.3; 3.1; 2.4

Module 3 Outcomes and Objective Matrix Components			
Module Component	**Discussion Focus**	**Identified Gap or Need**	**Objective Statements Addressed**
Inject 3.3: Movement/logistics and staging of resources	FEMA representatives stated that they would be following their normal procedures. North Carolina participants relayed information that they were using geographic information system (GIS)-based mapping capabilities to understand the impact to North Carolina communities and infrastructure. Discussion continued related to evacuation, public safety, health facilities, etc.	**Need:** As mentioned before and reemphasized in this module, consideration needed to happen regarding the adaptation of plans to include this type of threat, and it is CRITICAL to include considerations to integrate and use local data and mapping capabilities during late preparedness and early response efforts.	3.1; 3,2; 3.3; 3.4
Inject 3.4: Evacuation and sheltering (t−24 hours)	Additional discussions took place with the North Carolina State Emergency Operations Center (EOC) in which they reported that they would have things staged and in place. They felt that this was relatively good warning time for a disaster in comparison to other events but expressed that a major challenge is the unknown area impact. Local public safety personnel discussion was focused on safety and security for both humans and infrastructure. They acknowledged that planning evacuation for 100,000+ people would be overwhelming.	**Need:** Public information plans that include a message that conveys and clarifies confidence and also transparency about operations; sharing what is known and what is not known helps to set expectations	2.3; 3.1
	Local participants from North Carolina reached out to federal participants in Maryland asking questions related to first responder concerns and the need to understand what to expect, as well as asking for clarity regarding likely damage to people and property.	**Need:** On-site expertise first responder and local decision-making; position expert on-site for next event/exercise **Need:** Develop and incorporate asteroid threat 101 training into emergency management curriculum	2.4; 3.1

Module 3 Outcomes and Objective Matrix Components			
Module Component	**Discussion Focus**	**Identified Gap or Need**	**Objective Statements Addressed**
	Discussion among federal participants demonstrated some confusion in understanding what this event would actually be. For example, participants questioned whether the impact was a single "thing" hitting the ground (which probably is not the case) or an asteroid splitting apart and then hitting unexpected parts of North Carolina (also not clear) or a binary object.	**Need:** Agreement and then continuity of information shared regarding the threat and impact definitions. Clarification and understanding are critical at the state and local levels so they can position the right resources in the right location, as well as for understanding what to plan for regarding recovery efforts. It is important to note that first responders do not care about orbits but rather what will actually happen when the asteroid hits. There seems to be a disconnect between what information is really needed and what is useful for the various groups involved.	3.2; 3.3; 3.4

Module 4 Outcomes and Objective Matrix Components			
Module Component	**Discussion Focus**	**Identified Gap or Need**	**Objective Statements Addressed**
Inject 4.1: Understanding the damage (slides)	Module 4 begin with an inject that summarized damage done with the impact. This information was provided via a hybrid slide presentation to all participants and included an Incident Command System (ICS) chart that acknowledged that it would be an evolving situation with local officials in charge post-impact. Explanation and discussions on how the NIMS and ICS are used for organization-based preparedness and response efforts took place. This information was new to some of the federal participants at the Laurel, Maryland, location.	**Need:** NIMS 101 and ICS 101 training for some federal partners not familiar with these systems, as well as adaptation of plans to include this threat scenario so it is represented and exercised accordingly **Need:** Access to data for impacted communities to understand actions and resource needs, as well as assurance that this information, which would be shared among local, state, and federal decision-makers should be readily understood	3.1; 3.2; 3.3; 3.4
	The facilitator for the North Carolina local participants provided an update on decisions being made and concerns expressed via a virtual brief to the federal participants in Laurel, Maryland. Representatives from FEMA acknowledged that they are dependent on information from local and state officials for situational awareness, which supports their understanding of resource needs. FEMA representatives also acknowledged that "Every disaster is unique" and that they are accustomed to adapting policies, procedures, and systems accordingly.		

Module 4 Outcomes and Objective Matrix Components			
Module Component	**Discussion Focus**	**Identified Gap or Need**	**Objective Statements Addressed**
	Questions arose during discussions regarding what is unique to this disaster. Discussions were then held regarding the lengthy timeline as well as questionable understanding of the material from space that impacted Earth. Participants acknowledged that this could allow for misinformation and a lack of understanding what comprises asteroids. Representatives from the PDCO pointed out that it is relatively common to have meteorites, which are the building blocks of the planets, land on Earth. However, others pointed out that this contrasts starkly with the talking points from earlier in the exercise where they have been saying we have no idea what the asteroid is made of.	**Need:** Proactive public messaging regarding asteroid components, to help avoid misinformation and fear as the event evolves. **Need:** Consistent verbiage to describe this event as well as earlier communication to the public (i.e., before impact) that asteroids are made of the same things that mostly comprise Earth	3.2; 3.3
Inject 4.1: Understanding the damage (slides)	The following discussions took place in the Winston-Salem and State EOC locations and were related to federal participants in Maryland via facilitators: • Who is doing damage assessment? • How soon can people return? • What is the air quality like? Dust, debris? • Is there an agricultural impact? • Is there radiation? (Current understanding is no but was unsure) • How do we attempt rescue? • Would there be a need to assess injuries differently for any reason? • Looting concerns would raise the need for back up security resources. What would be available to local officials to support security needs?	**Need:** Additional planning and 101 training related to the questions posed, to include being proactive in understanding what determines when people can return to the area, what dust/debris is present, and what the air quality/local agricultural effects are **Need:** Regional, state, and local training to start understanding what preparedness and response would look like for this type of event	3.1; 3.3
Inject 4.2: Media misinformation regarding asteroid toxicity	Discussion arose again that experts would be needed for consultation at the local and state level. An inquiry was posed to NASA regarding whether they have PIO experience in working state and local events. FEMA would be ensuring PIO support is available as well. The National Science Foundation stated that the science community would step up as well. PDCO representatives stated that an option could be looking into the use of local scientists and meteorologists, who can also be trusted resources.	**Need:** Specific training for the NASA PIO similar to what FEMA and other federal PIO partners have, so they can coordinate and communicate effectively **Need:** Amplified messages and dissemination of correct and understandable information; also determination of whether demos could be useful, or usefulness of comparisons to nuclear blasts	3.1; 3.2; 3.3
	FEMA representative stated that the COVID pandemic has taught us messaging is complicated and that it is crucial for people to get information from people they trust. This could be very community-specific and event-specific. It was also added that “trust can be fickle with the public.”		

Module 4 Outcomes and Objective Matrix Components			
Module Component	**Discussion Focus**	**Identified Gap or Need**	**Objective Statements Addressed**
General comments	FEMA deputy administrator recommended enhanced partnerships with the science and technology (S&T) communities.		
	Look into dual-use technologies by starting conversations with NASA, DOE, National Reconnaissance Office, DoD, U.S. Space Force		