FEMA

NASA – FEMA Statement on the 2nd Joint Asteroid Impact Tabletop Exercise

In a letter from the U.S. Office of Science and Technology Policy (OSTP) to the Congress on 15 October 2010, OSTP reaffirmed U.S. Government roles and responsibilities in the event of an asteroid impact on the Earth. The crucial first step for any future asteroid mitigation or deflection effort is to detect and accurately track these celestial bodies. The National Aeronautics & Space Administration (NASA) has functioned as the lead entity to coordinate the detection and threat information [from all organizations] of near-Earth asteroids within the observation community. NASA notification procedures are set into motion only after the necessary observations, analyses, and characterization efforts have taken place to determine that a space object represents a credible threat.

Upon notification from NASA of an impending asteroid impact threat to United States territory, the Federal Emergency Management Agency (FEMA) takes the lead to notify appropriate Federal, state and local authorities and emergency response institutions utilizing existing resources and mechanisms. This could be analogous to our procedures for a large piece of space debris re-entering or hurricane warning procedures.

In May 2014, FEMA and NASA conducted a second joint collaborative "table top" exercise. Unlike the exercise of 2013, in which the team had a few weeks to prepare and respond to a small impact event, this year's exercise simulated the discovery of a [hypothetical] near-Earth asteroid 7 years prior to its impact on the Earth. For this scenario, a mitigation mission was mounted but was not entirely successful, as a 50-meter size fragment continued on a collision path with the Earth.

Organized by NASA, the exercise was supported by a team of experts on asteroid orbital dynamics and impact effects, including scientists and engineers from NASA's Jet Propulsion Laboratory, the Aerospace Corporation, and the Department of Energy's Lawrence Livermore and Sandia National Laboratories. The attached report provides details of the exercise scenario, the inputs provided by the NASA expert team, the reactions of the exercise participants, and the findings and recommendations provided by the exercise team.

Based upon the results of this exercise, we believe that more detailed studies should be conducted to adequately prepare the U.S. Government and its citizens in the event such a cataclysmic natural disaster were to occur. Future efforts should include establishing a regular interagency forum tasked with advising senior leadership on existing response plans, enhancing information flow leading up to and during such an event, and identifying methods and capabilities for better planning and preparation.

As discussed in the joint NASA-FEMA letter of February 2014, plans are moving ahead to form a Planetary Impact Emergency Response Working Group (PIERWG). This working group will continue the work initiated by the two tabletop exercises and keep NASA and FEMA leadership informed. Based upon FEMA's expertise, it is clear that there are established protocols for fully developing response plans at a national level. It is also noted that while the NEO impact scenario is not listed in the current Strategic National Risk Assessment (SNRA), this effort should continue at least at the current level (i.e., main POC at FEMA, continued situational awareness provided to NASA and FEMA leadership on the actions of the PIERWG). Planning analysis performed by the working group including improvement upon emergency notification procedures and public messaging shall complement the asteroid deflection and other mitigation efforts led by NASA.

Concurrence:

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27 JAN 2015
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2.19.15
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SUMMARY REPORT ON TTX#2:

TABLETOP EXERCISE FOR ASTEROID IMPACT EVENT

Report prepared for

NASA HQ Science Mission Directorate, Planetary Science Division

NEO Observations Program

September 2014

EXECUTIVE SUMMARY

A tabletop exercise (TTX) was held at the Headquarters of the Federal Emergency Management Agency (FEMA) in Washington, D.C., on May 20, 2014. The purpose of the exercise was to acquaint FEMA, members of the interagency Emergency Support Functional Leadership Group (ESFLG), representatives from NASA, the Department of Defense (DoD), the White House Office of Science and Technology Policy (OSTP), the Department of State, the European Space Agency (ESA), and other organizations (see Appendix) with the nature and evolution of an impending asteroid impact within the continental United States and to assess whether and how current processes and procedures for disaster warning and response might be employed in such an emergency.

The scenario used for this exercise differed from the one used for the 2013 exercise. Whereas the 2013 exercise assumed five weeks notice before impact, in this year's exercise the asteroid, ~140-300 meters in size, was discovered ~7 years before predicted impact. This advance notice enabled the development and execution of a space mission campaign to deflect the object away from an Earth impact trajectory. In this scenario the deflection mission was only partially successful: a major portion of the target object was deflected, but a ~50-meter fragment broke off and remained on a collision course with Earth. Though the 50-meter remnant was observed almost two years before impact, insufficient time remained to launch a second deflection campaign. The fragment was predicted to impact somewhere within a narrow region extending through Texas and into the Gulf of Mexico.

As the scenario evolved, the exercise team provided updates on the state of knowledge of the approaching asteroid, the design and results of the deflection mission, possible regions on Earth that might be affected by an impact, and the nature and consequences of the anticipated air blast and impact insults.

While this year's impact scenario is realistic, details of an actual impact threat and its evolution would be unique, as each asteroid, and its orbit, is unique. This scenario illustrates the type of information that would be available should a real impact threat develop.

Primary findings for the exercise were that responsible parties in the Federal government should:

- Perform strategic planning that links emergency management, domestic policy, national security, and scientific missions and provides actionable guidance for investment decision-making, analysis and operational planning;
- Establish a dedicated working group to plan for U.S. and international responses to and involvement in a NEO emergency;
- Develop communications protocols describing actions that will be taking place and agencies responsible for those actions; and
- Develop a communications plan for describing deflection options, the risk of failure, and the possibility of false alarms to the public.

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BACKGROUND

On February 15, 2013, the city of Chelyabinsk, Russia, experienced the effects of the entry into Earth's atmosphere of an asteroid estimated at 17 to 20 meters in diameter, where the overpressure from the entry and explosion of the object collapsed building walls, shattered windows, and injured over 1,000 people. The asteroid that caused this destruction was not detected by any system prior to atmospheric entry.

While this event raised public awareness of the potential for asteroid impacts with Earth, well before it occurred The Aerospace Corporation and NASA Headquarters had begun planning a tabletop exercise to acquaint components of the Federal Emergency Management Agency(FEMA) with the nature of asteroid impact events. That first NASA-FEMA tabletop exercise, held April 3, 2013, highlighted how knowledge of an impact risk might evolve over time and how an impact might affect people and property[1]. The exercise assumed that a threatening asteroid was discovered 30 days prior to impact.

This report provides details and results of the second NASA-FEMA tabletop exercise, which was developed and presented by the team identified in Appendix 2. The exercise took place on May 20, 2014, at FEMA Headquarters. The Jet Propulsion Laboratory (JPL) developed this year's asteroid impact scenario, positing an asteroid in an orbit about the Sun that is somewhat similar to that of the object that exploded over Chelyabinsk. However, the asteroid in this scenario is approximately ten times larger than the Chelyabinsk object, and it is discovered years in advance.

To begin this year's exercise, NASA Headquarters provided an overview of its Near-Earth Object (NEO) Observations Program, covering definition of key terms, the U.S. policy on planetary defense as defined in Office of Science & Technology Policy's (OSTP) 2010 letter to the Congress, knowledge of the current population of NEOs, the process for cataloging NEOs, key characterization assets such as the Arecibo and Goldstone radars, and current efforts to bring together space agencies that might be involved in an effort to deflect a threatening asteroid or comet.

NASA coordinates NEO detection and threat information (and essential follow-up observations) from all organizations within the international NEO observation community. NASA has instituted communications procedures, including directions for the public release of information. Roles and responsibilities for mitigation options are in an early stage of development and not yet ready for implementation. Consistent with OSTP's direction, NASA has taken the lead on analysis, simulation, and assessment of possible mitigation technologies.

[1] "Tabletop Exercise For Short Warning Near Earth Object Impact Event," NASA HQ SMD Planetary Sciences Division NEO Program Office, August 19, 2013.

EXERCISE SCENARIO

By definition, near-Earth objects (NEOs) include both asteroids and comets whose orbits approach the vicinity of Earth's orbit about the Sun. Potentially Hazardous Objects (PHOs) are a dynamical subset of NEOs that make a very close passage of the Earth—in fact, within 7.5 million km (5 million miles) of the Earth. For this scenario, such an object—an asteroid—is discovered on April 29, 2014 and given the designation 2014 TTX.

The orbit of 2014 TTX is typical for a Near Earth Asteroid: It's fairly eccentric and extends out to the main asteroid belt, its orbit is inclined 3.2 degrees relative to Earth's orbit, and it has an orbital period of 2.36 years.

Following post-discovery protocol, several observatories around the world conduct follow-up observations of 2014 TTX. These observations over the next several days and weeks, enable a more accurate determination of the asteroid's orbit. During this initial follow-up, 2014 TTX is more than 24 million km (15 million miles) distant and too far away to observe with planetary radar.

Starting on May 1, 2014, NASA's Sentry impact monitoring system begins reporting the possibility that this asteroid could hit the Earth in 2021. The orbit of the object is shown in Fig. 1, along with the position of the Earth when the impact would occur. The impact probability starts at 1-in-a-million; rises to 1-in-3000 on May 17, 2014; and reaches 1-in-500 at the end of May—a probability high enough to raise concern.

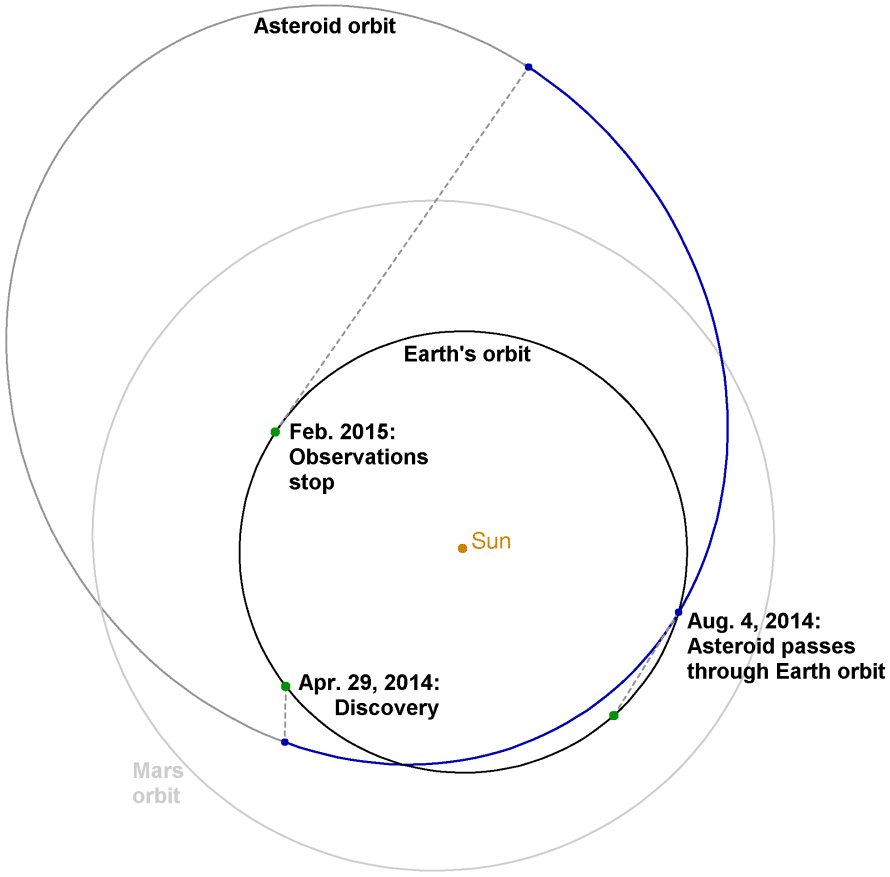

Figure 1. Orbit of hypothetical threatening asteroid 2014 TTX.

Based on its brightness, the asteroid's size is estimated at 120-300 meters. As observatories continue to track and provide more precise knowledge about its orbit, the possibility of impact with Earth in 2021 grows more likely. By June 2014, impact probability rises to ~1%, in early July 2014 it reaches 2%, and by early August it reaches 6%. At this point Federal agencies meet with international space agencies to discuss and consider the option of deflection of the asteroid from its impact course with Earth.

At this meeting, NEO scientists say impact could occur on September 5, 2021, when the orbits of Earth and the asteroid are expected to intersect. The exact position of the asteroid on September 5, 2021, is uncertain because its orbit is not yet known accurately enough at this time. However, experts can define a "risk corridor" across the globe showing where the asteroid's position is expected to intersect with the surface of Earth as follows:

Fig. 2 shows the progression of the object as it approaches Earth. Each point in the approaching band represents where the object could be given the best information available (actually, the object could be anywhere in that band, not just at one of the red spots shown). As seen, if the object is at some of the regions in the band, it would actually strike Earth, in others it would pass us by. The intersection of the band with the Earth defines the risk corridor shown in Fig. 3. Red dots represent the computed potential positions of the asteroid at impact, tracing a continuous line stretching from eastern Africa across the Atlantic through the West Indies, Gulf of Mexico, Texas, New Mexico, Arizona, Northern California and into the Pacific. If impact occurs, it will be somewhere within this risk corridor.

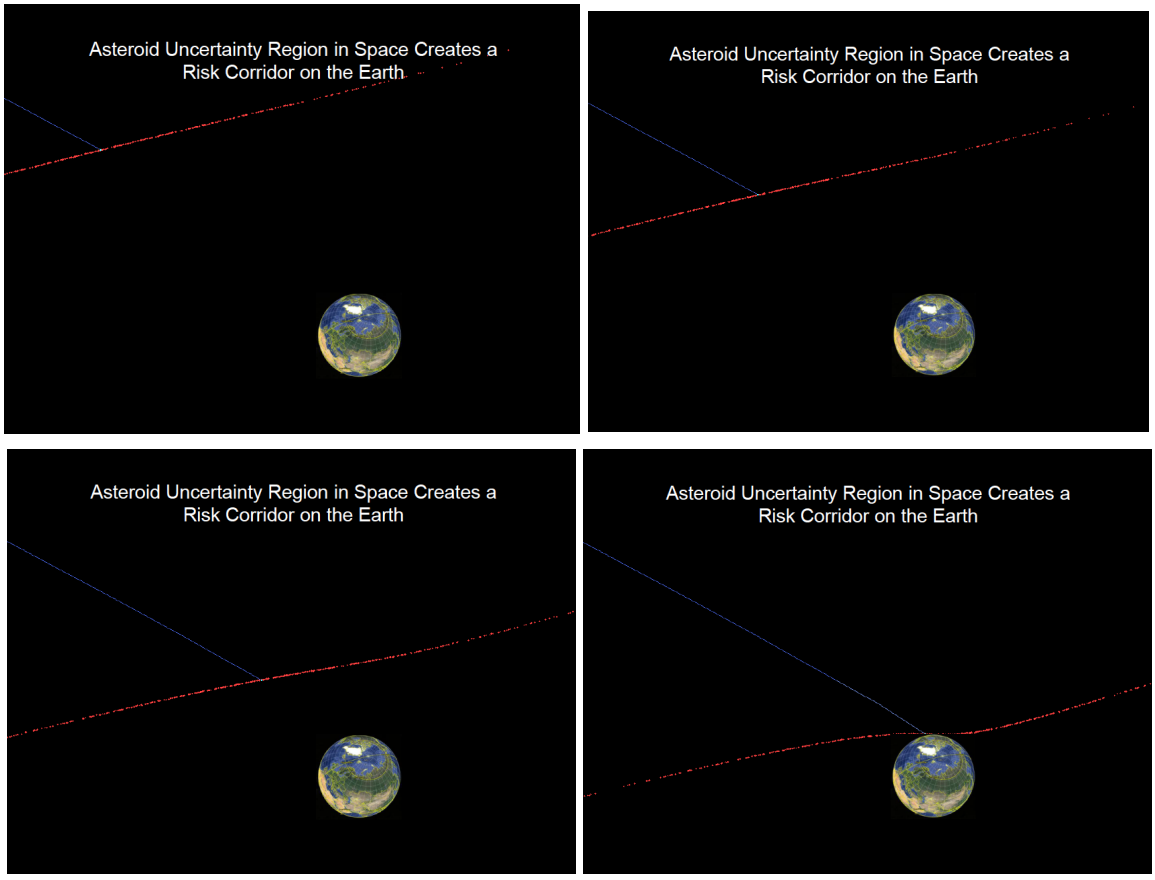

Figure 2. Illustration showing the band of possible locations of 2014 TTX as it approaches Earth based on the tracking data available on September 5, 2021.

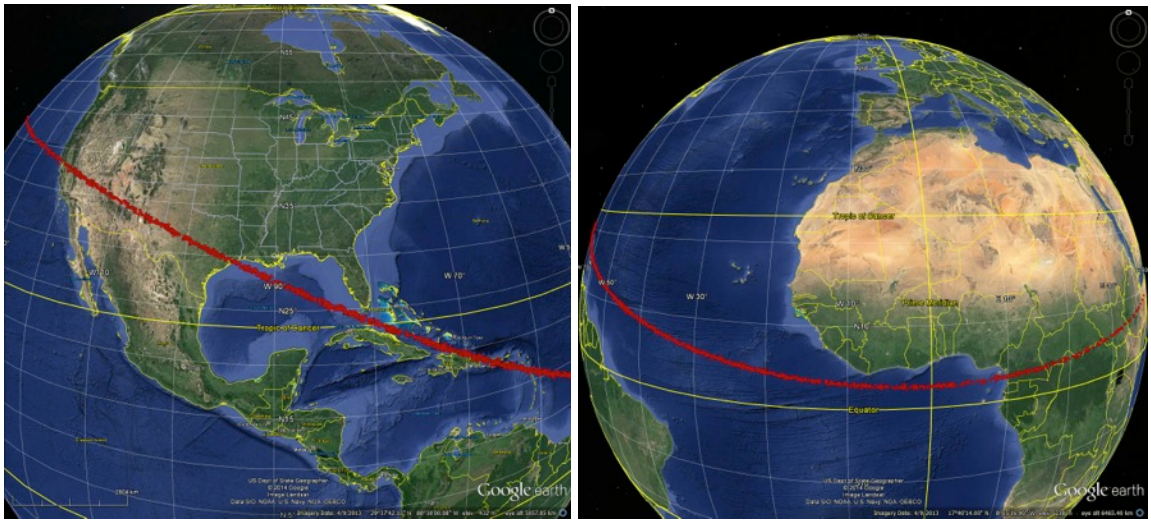

Figure 3. Two views of the risk corridor as of early 2015, a year after discovery. Impact probability increases from 1% to 35%. If impact does occur, it will be at some location within this corridor.

During these discussions, decision makers raise the question as to whether the likelihood of impact warrants serious concern or any direct action should be taken at this time. The point is made that a 6% probability of impact means that 94% of the time the object will actually miss the planet and not impact. Others note that impact risk is frequently eliminated as additional observations of an object are collected.

While there is agreement on these points, consequences of recent events show that impact of an object in this size range at any location on Earth (either land or water) would cause a regional disaster. Two asteroid impact events highlight possible consequences:

- The 2013 entry of a ~17 meter object over Chelyabinsk, Russia, that damaged buildings and injured over 1000 people. Experts note that the disaster could have been much worse if the asteroid had entered at a steeper angle.
- The 1908 entry of a ~40-meter object over Siberia that leveled trees over a 2000 square kilometers (770 square miles) area—an area larger than that of Washington, D.C. The blast was estimated to be equivalent to that of an explosion of ~3 to 5 megatons (MT) of TNT.

If 2014 TTX were to enter and impact, the energy released could be as large as 700 MT—almost 200 times the energy released by the Tunguska event. A land or ocean impact would have very serious consequences for people and property.

As a result, the decision is made that, despite the currently small chance that the object will strike the planet, observations to refine the size, shape, and orbit of the object should proceed at the highest priority, and NASA is ordered to work with the Department of Defense to begin developing a plan to deflect the object should such an effort be warranted.

As more observations of the asteroid are made in August and September 2014, uncertainty about the asteroid's future position decreases, and impact probability continues to rise. By the end of October it reaches 30%. At this time the asteroid is moving away from Earth. By February 2015, the asteroid is too dim to see from Earth, and impact probability has reached a plateau at 35%. Because uncertainty about the position of the asteroid at the time when its orbit intersects Earth has not been sufficiently narrowed, the risk corridor remains the same as shown in Fig. 3.

As Fig. 4 shows, in late 2015 the asteroid comes close enough to Earth to be observed again, and with new data impact probability jumps to 85%. By mid-January 2016, it reaches 100%. Development of a deflection campaign begins in earnest. Over the next few months, the risk corridor slowly shortens to the western hemisphere, still spanning from the West Indies to the Pacific (see Fig 5). The corridor continues to shorten as orbit projections and impact predictions get increasingly accurate, and by March 2018, the possible impact footprint includes just the Gulf of Mexico and Texas (Fig 6).

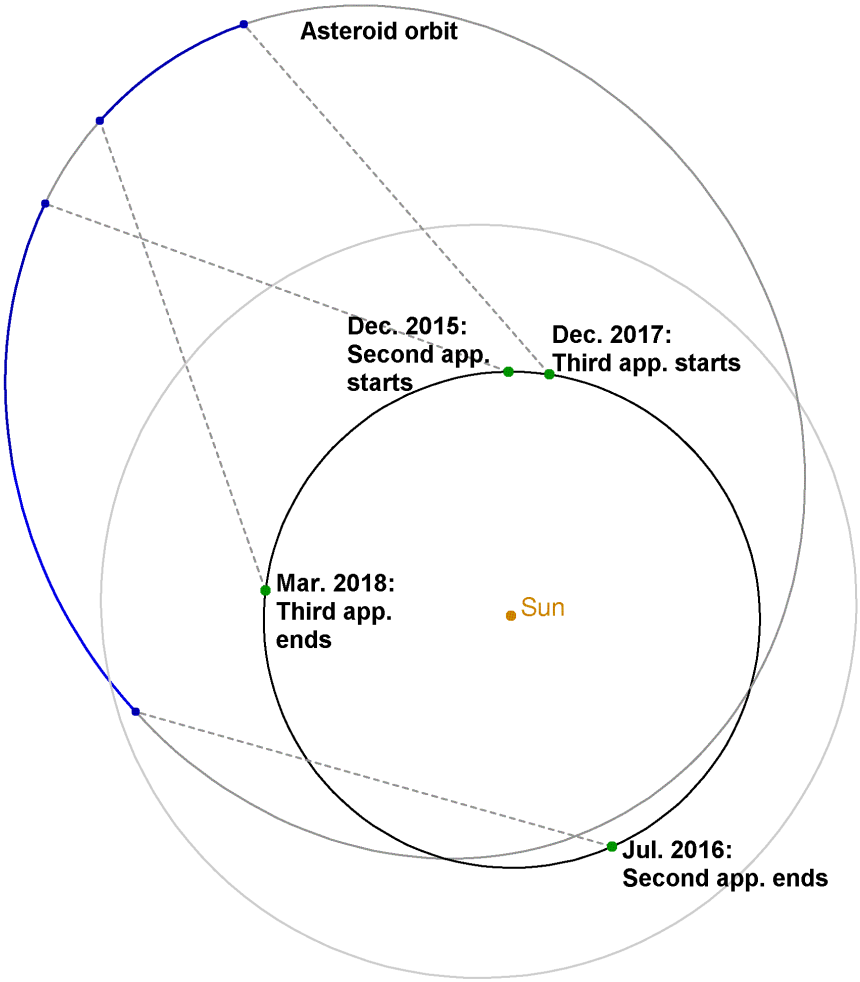

Figure 4. Second and third apparitions of 2014 TTX.

As the plan to deflect the oncoming object has matured, two techniques for deflecting the object are suggested. One possibility is to use a nuclear explosive; the second is to use "kinetic impactors," essentially striking the object with one or more spacecraft travelling at very high velocity relative to the asteroid, causing a change in velocity sufficient to deflect the object from its impact course with Earth. Studies show that detonation of a nuclear explosive in near-proximity to the object could achieve "robust" deflection of the object. The studies also show that using several kinetic impactors can do the job. In either case, the object would be intercepted on approximately March 1, 2019, about 2.5 years before the object would strike Earth if not deflected.

Figure 5. In January 2016, improved tracking data has shortened the risk corridor to that shown; impact probability is 100%.

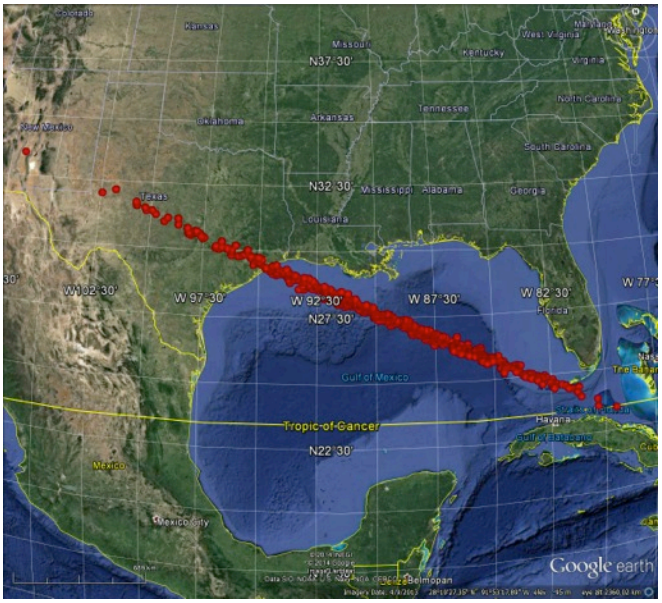

Figure 6. Risk corridor in March 2018, just prior to execution of deflection attempt; impact probability is 100%.

Based on concerns about the use of nuclear explosives, the decision is made to design a deflection campaign such that at least two kinetic impactors will strike the asteroid simultaneously. Accounting for the fact that the object could be larger than predicted and recognizing that failure of a launch vehicle or spacecraft could jeopardize the deflection mission, the decision is made to launch six interceptors, each on its own launch vehicle. Each launch vehicle will carry an impactor payload with sufficient mass to provide half of the 1.5-cm/sec velocity change (delta-v) required to deflect the object. To prevent a common hardware or software error from affecting all six vehicles, two separate agencies, the U.S. Department of Defense (DoD -- namely, the U.S. Air Force) and the European Space Agency (ESA), will design, build, and launch their vehicles. Multiple launch pads will be used to prevent interruption of the campaign should a launch vehicle

failure damage a launch pad. Launches will be coordinated such that all interceptors reach the asteroid at approximately the same time.

The DoD and ESA agree to reprogram existing launch vehicles for a deflection campaign. Unfortunately, insufficient time is available to develop and launch an observer spacecraft to rendezvous with 2014 TTX, characterize the object, and be on station to observe the deflection encounter, so this option was not actionable.

In August 2018, DoD and ESA each launch three kinetic-impactor spacecraft to the object. Five of the six impactors are successfully placed into the desired interplanetary trajectories. Two of the spacecraft fail in route (solar panels failed to open on one, and the second lost communication with Earth when the main antenna dish failed to deploy properly). Three are believed to have impacted 2014 TTX as intended on March 1, 2019. Fig. 7 shows the orbit of 2014 TTX, the path of the kinetic impactor spacecraft, and the location of asteroid at the point of intercept. The object was out of view from Earth at this point, and there is no visual or other confirmation of impact.

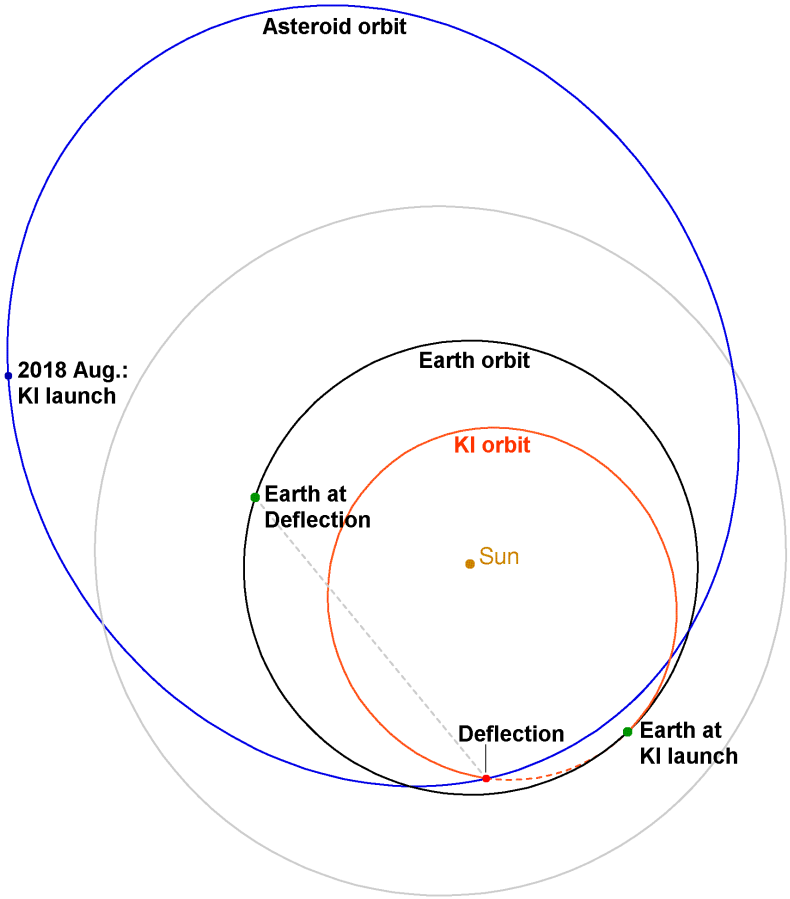

Figure 7. Location of 2014 TTX at launch and intercept by kinetic impactors.

When observers recover the object in December 2019, they determine that while a major part of 2014 TTX has been diverted away from Earth, a 50-meter fragment of the target asteroid received very little delta-v and appears to be in an orbit very close to the initial orbit. No one had anticipated such a development. Impact of the fragment with Earth is a definite possibility, but additional observations are required to estimate the orbit of the remaining object and predict an

impact location if it is to occur. The White House orders a crash program to design, build and launch a second intercept campaign just in case impact is predicted.

A subsequent review finds that there are no launch vehicles immediately available worldwide that have sufficient capability to deliver an intercept payload (likely a nuclear explosive, given the late date) to an intercept point a sufficient distance from Earth in the time available. As a result, deflection is not an option.

On February 9, 2021, approximately 200 days before the orbits of Earth and the fragment are expected to intersect, the impact probability is 20%. At six months before intersection, probability increases to 65%. At five months before intersection, impact probability jumps to 80%. At four months before intersection, it is 100% certain that the 50-meter fragment will impact Earth. Fig. 8 shows the final orbit of 2014 TTX as it approaches Earth impact in September 2021.

The impact risk corridor for the fragment shortens over the next few months, zeroing in on the Houston area. The corridor remains roughly 1000 km long and 80 km wide about a month before impact, straddling the coastline (Fig. 9). Note that the object will be between Earth and the Sun beginning on August 19, 2021, preventing additional optical observations beyond that point.

The information above was provided as read-ahead material for exercise participants; the tabletop exercise begins at this point, which represents August 5, 2021, one month before impact.

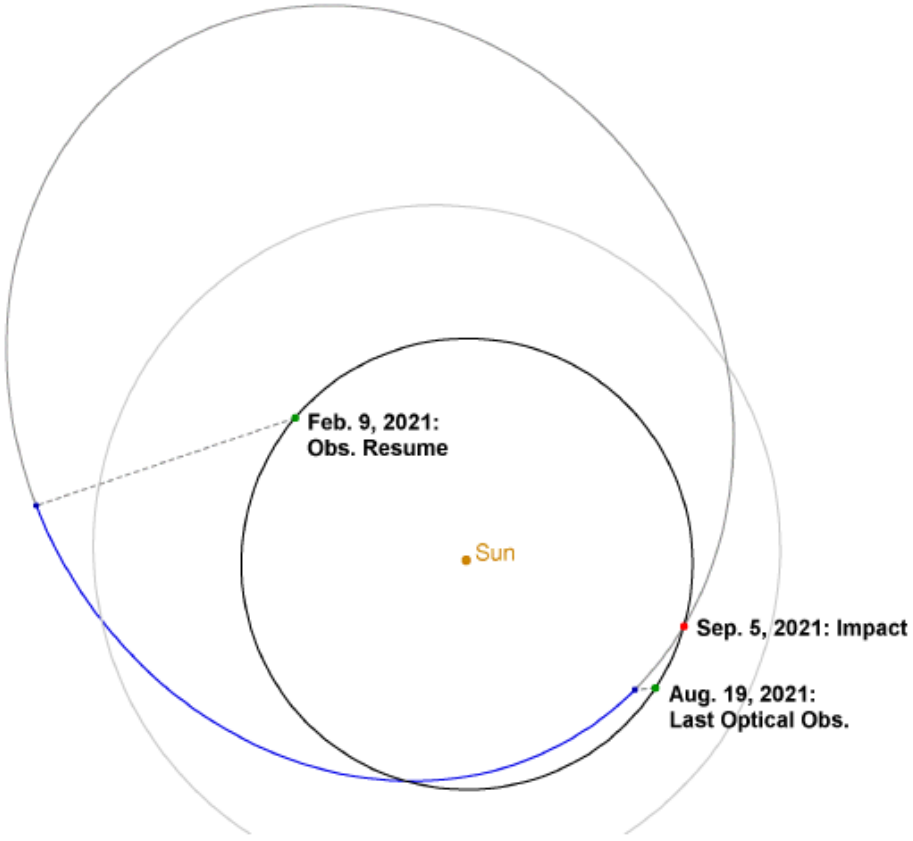

Figure 8. Final orbit of 2014 TTX.

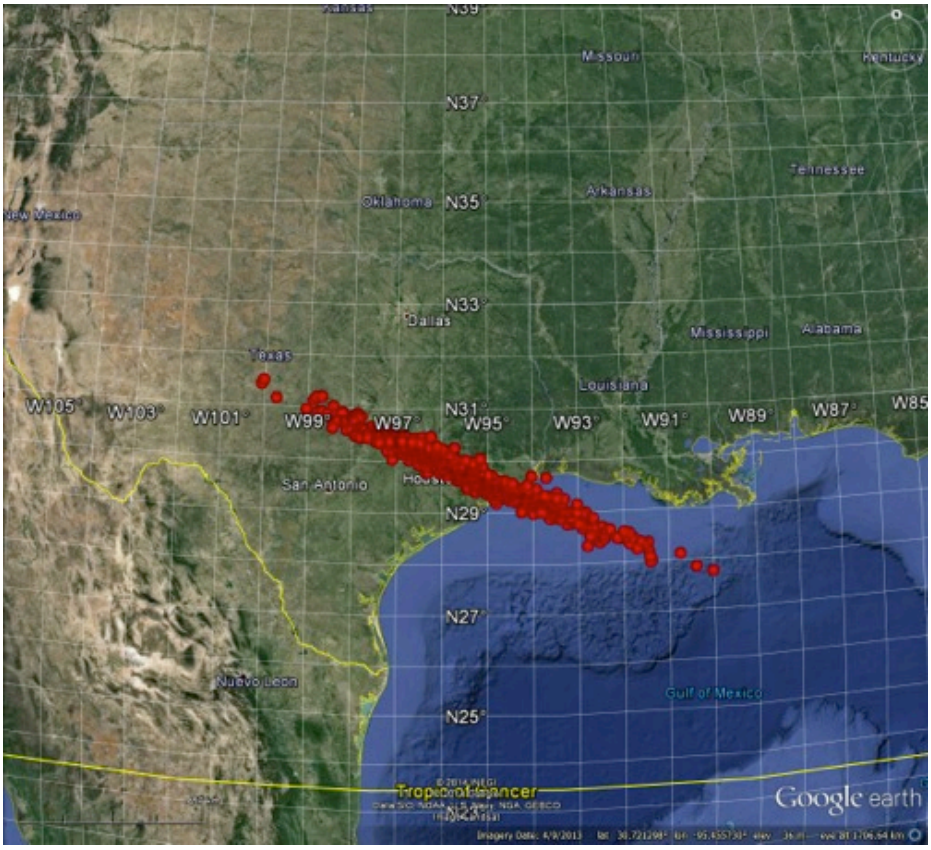

Figure 9. Risk corridor for secondary object about 30 days before impact based on best information available.

FIRST UPDATE: 30 DAYS TO IMPACT

It is now certain that the object will impact with Earth on September 5, 2021, shortly after noon local time (CDT). Impact will occur within a risk corridor approximately 30 kilometers (20 miles) either side of a line starting from about 200 kilometers (125 miles) south of New Orleans, Louisiana, in the Gulf of Mexico, and extending to the northwest about 1000 kilometers (625 miles) across Houston, Texas, to about 300 kilometers (190 miles) to the northwest of Austin, Texas.

Since the object will approach from the direction of the Sun, optical observations will not be possible in the three weeks prior to impact. However, NASA's interplanetary radar should be able to pick up the object approximately one week prior to impact and provide more precise measurements of its final trajectory, which should significantly narrow the impact risk corridor in the days prior to impact.

Initial Notification

In the event of discovery of an actual asteroid impact threat, the government could issue a notice like this one:

> The Federal Emergency Management Agency has activated the National Response Coordination Center to prepare for an imminent and certain large-scale, catastrophic asteroid impact event that will affect Texas, neighboring states, and possibly nations

bordering the Gulf of Mexico. The catastrophic event will occur at approximately noon local time on September 5, 2021 and will be caused by impact of an asteroid estimated to be about 50 meters (~160 ft) in size. Details of what is currently known about the approaching object and past efforts to deflect it from its impact course with Earth are included in this package.

This disaster will be unprecedented in recorded times and will seriously affect our nation's oil refining and other major industries, as well as the lives and property of many of our citizens. The President has directed FEMA to lead the response effort and to be prepared to execute with state and local officials plans to minimize/mitigate these effects.

Potential Damage

For this exercise, Sandia National Laboratories provided data indicating potentially impacted population and infrastructure damage as derived by location and distance from an air blast. The effects of a hurricane or a nuclear detonation were used as surrogates (analogs) to those caused by an asteroid impact. More precise data on effects were provided as part of the exercise.

At 30 days to impact, what is known about the object is:

- Entry speed: 15.4 km/s (34,500 mph, ~Mach 45)
- Size: 40-60 meters diameter
- Composition: Stone, density 2.2-3.3 g/cm^3
- Entry angle: 39.5° from horizontal

Given these entry conditions, a 10.6-megaton (MT; equivalent to 10,600,000 tons of TNT) airburst or impact cannot be ruled out. As Fig. 10 shows, the area within the contiguous U.S. that would be affected extends through the Gulf of Mexico and includes barrier islands and coastal regions from Texas to Florida.

Land Impact

Damage from this impact will be similar to that caused by blast waves generated by a nuclear explosion, resulting in mass distortion of buildings. Structures of heavily steel-framed, concrete reinforced, or earthquake resistant design will be best able to withstand the blast. Commercial structures are better able to withstand damage than residential structures. Actual damage is reduced as distance from impact grows.

In a 10-kiloton (KT) blast (approximately one thousand times smaller than that predicted for the current event), severe damage occurs up to 0.4 km (1,400 feet) away. Aboveground structures such as oil tanks will be moved from their foundations. Up to 0.5 km (1,600 feet) away, moderate damage is possible. Light damage would result at distances over 0.5 km, with broken glass and damage to parts, but equipment would be generally usable.

Impacts to industrial buildings and infrastructure systems are largely dependent on structural stability. Electrical utilities would potentially suffer similar damage to that sustained in any high wind situations from loss of overhead lines. The destructive effects are largely due to damage to suspension towers. As evident, underground electrical lines would have far less, if any, damage. Damage to gas, water and sewage systems is highly dependent on the surface structure, damage to structural foundations, and equipment used to run the systems.

The 50-meter (160 ft) fragment approaching Earth will be entering the atmosphere at nearly 56,000 kilometers/hour (35,000 miles/hour) and an angle of 40 degrees from the horizon. The density and strength of the object are not known. It could be as strong and dense as granite or as weak and porous as a pile of gravel. Due to these uncertainties, experts cannot say with certainty how big the explosion will be, or whether the object will explode in the atmosphere or hit the ground and make a crater. Emergency planners must consider all possible outcomes.

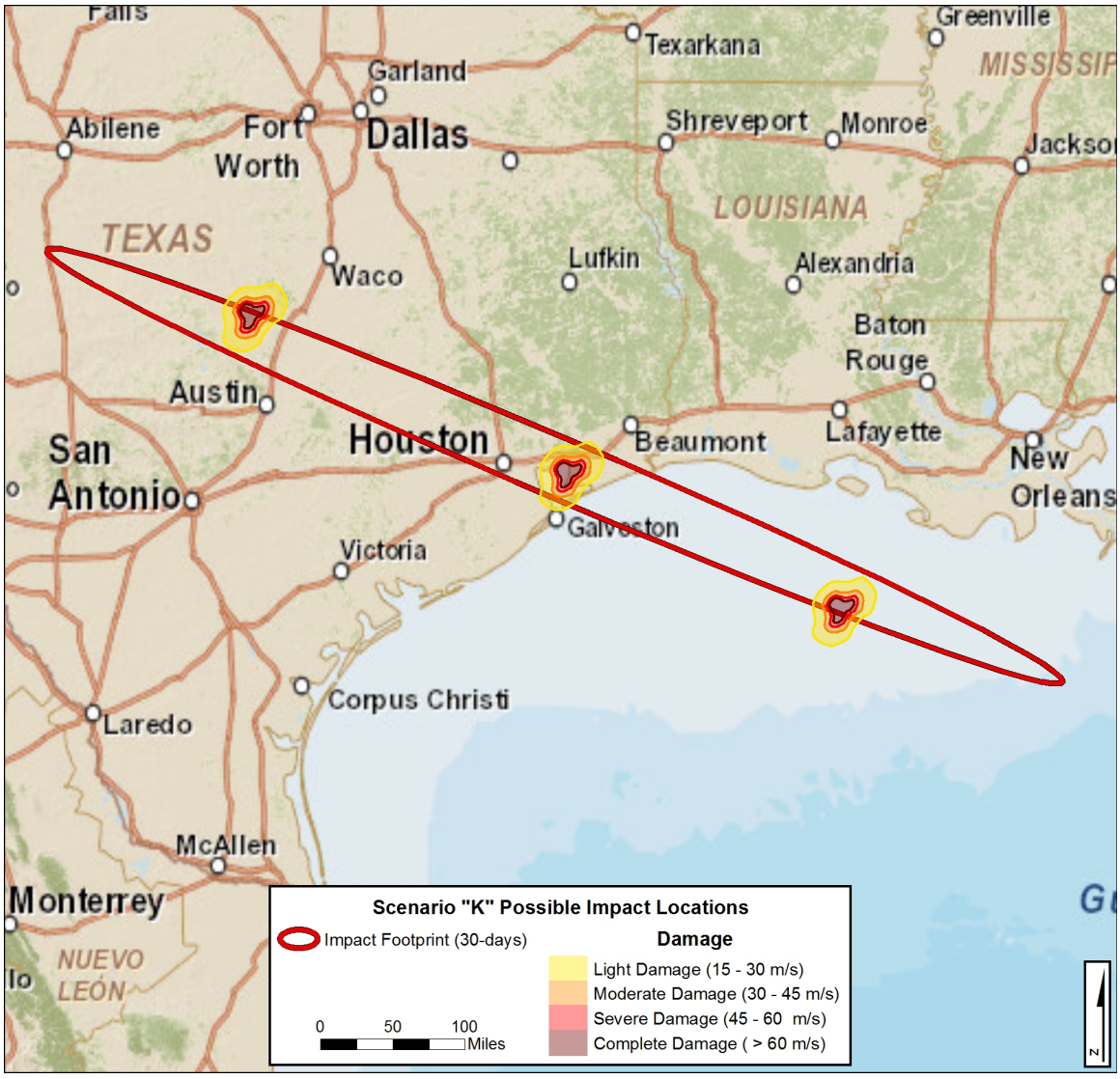

Figure 10. Risk corridor at 30 days before impact showing blast overpressure projections for three possible impact locations.

The worst case would be that the approaching object is already fractured and weak enough to explode at high altitude. A high-altitude explosion can spread its energy out over a larger area and will be more damaging than a crater-forming impact. The worst-case scenario posits a high-altitude blast equal to about 10.6 MT of TNT, as noted, approximately 1,000 times more energetic than the 10 KT case described earlier.

Experts say their best estimate is that the fragment is a slightly less dense 50-meter object. Even a relatively strong object of this size is likely to explode at high altitude; although it is possible some fraction of it could reach the ground and form a crater. This best estimate is almost identical to current understanding of the Tunguska explosion (the object that exploded is thought to have entered at the slightly shallower angle of 35 degrees).

Expected effects on the ground from a 2014 TTX impact can therefore be compared to the effects of the Tunguska event. The center map in Fig. 11 shows the area in which the Tunguska explosion destroyed forest over a 2000 square km (770 square mile) area, with the darker blue

indicating complete destruction (the maps are 60 km (37 miles) wide and 80 km (50 miles) high). This is compared to two computational experiments, based on assumptions considered to be realistic for the event, using a 15-MT impactor (left) and a 5-MT impactor (right). Wind speeds in the affected area could exceed 30 meters/sec (67 miles/hr) over an area up to 40 km (25 miles) wide, with peak winds exceeding 50 meter/sec (110 miles/hr).

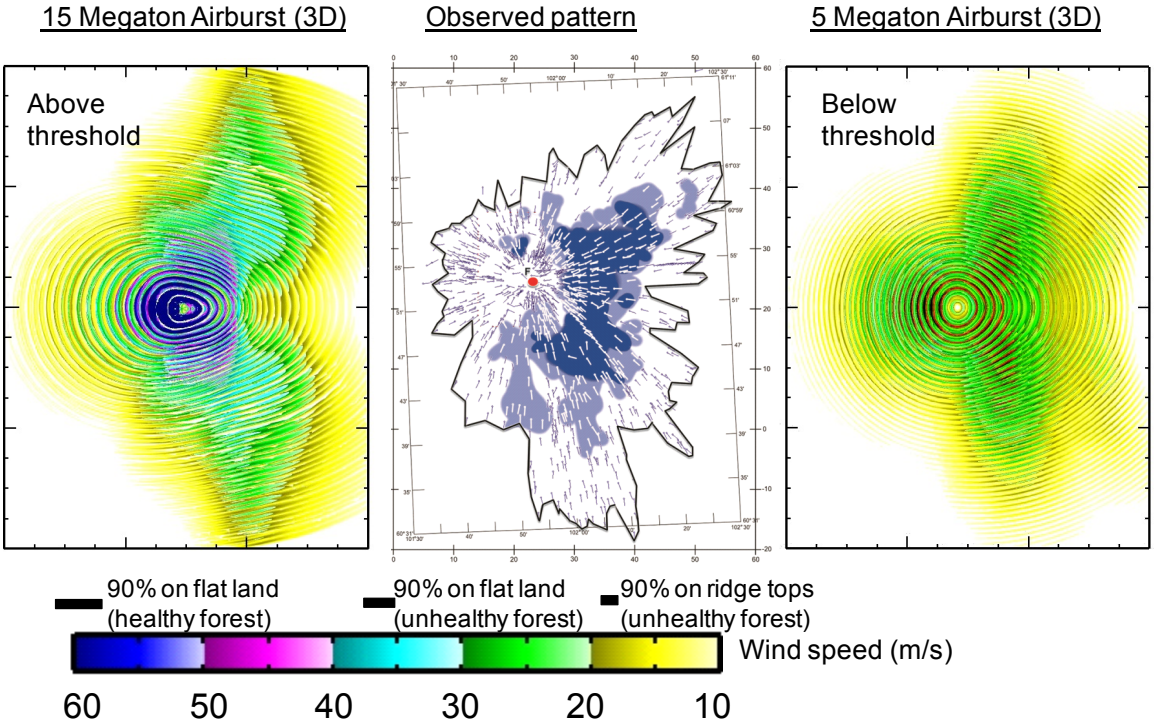

Figure 11. Possible ground areas affected by high-altitude explosion of hypothetical asteroid compared to that of the Tunguska event, entry of ~40-meter (~130-ft) size asteroid that affected a region near the Podkamennaya Tunguska River in what is now Krasnoyarsk Krai, Russia, on June 30, 1908.

Impact in the Gulf of Mexico

If the asteroid fragment should impact in the Gulf of Mexico, a tsunami would be created and would affect oil platform and other facilities located in the Gulf and coastal areas bordering the Gulf. Fig. 12 depicts a tsunami analysis performed by the Lawrence Livermore National Laboratory (LLNL) for the impending impact event showing maximum wave heights of one to three meters (3 to 10 ft) arriving at the coast one to 4.25 hours post-impact. An impact at the easternmost point of the risk corridor over the Gulf would produce a tsunami wave three meters in height, and would first reach the coast of Louisiana one hour after impact.

Damage results from a tsunami are somewhat analogous to storm surge damage resulting from a hurricane. The National Oceanic and Atmospheric Administration (NOAA) Coastal Risk Analysis provides a measure of tsunami run-up. Three-meter waves would flood inland up to 16 km (10 miles). For comparison, a tsunami caused by an earthquake has a line source (water is deflected along a line) and the wave from such an event propagates with more devastation. An asteroid impact is a point source, and much like ripples caused by a pebble thrown in water, the waves caused by an impact get smaller as they propagate.

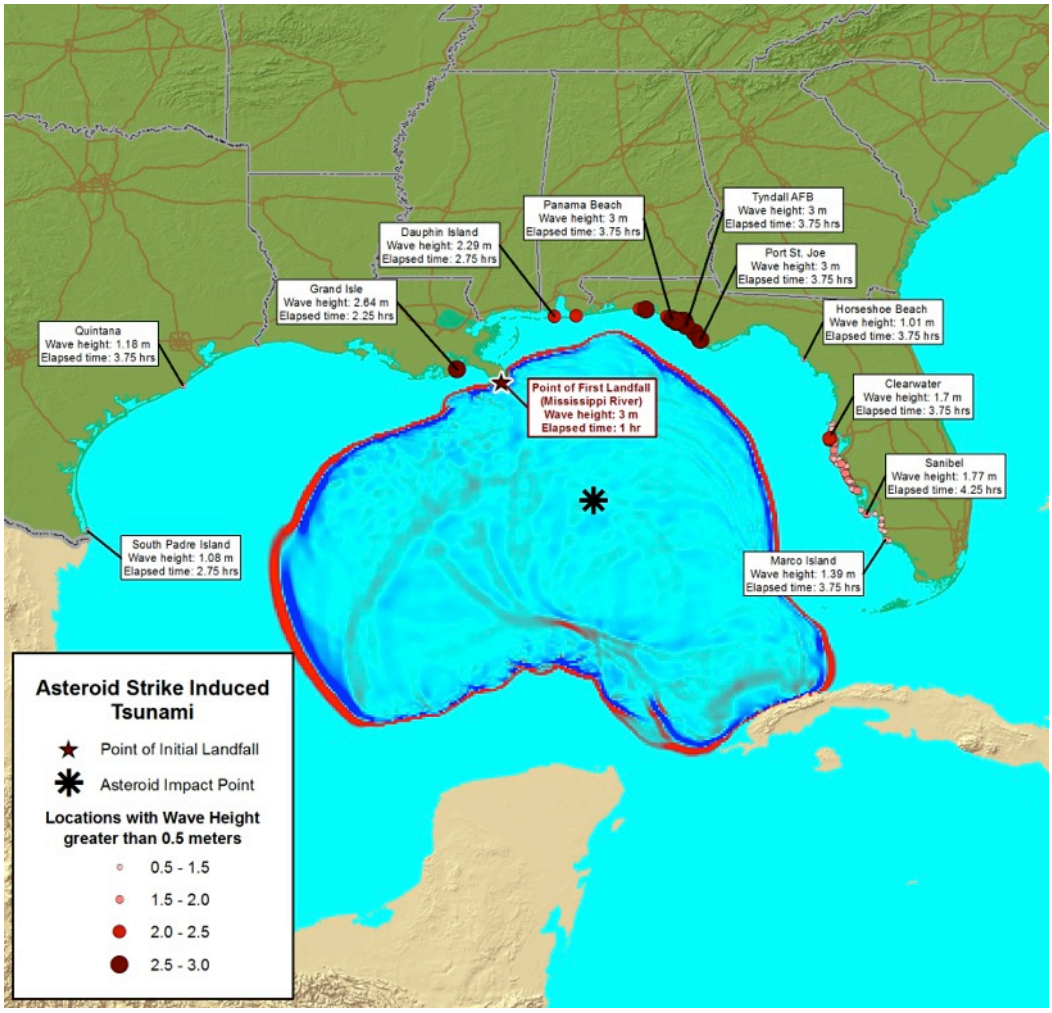

Figure 12. Asteroid strike-induced tsunami showing wave heights.

Public and Political Response

Most people who tune in to the news now know that an asteroid is headed for certain impact in the southwestern United States in a month's time. They heard about this asteroid before, when NASA first announced it posed a serious impact risk. Then they forgot about it. They heard about it again when DoD and ESA launched a mission to deflect the asteroid off its path toward Earth. Now they know that the mission was a failure. They don't know why, or what this failure means. Everybody wants to know: am I, my family, my community at risk? If so, what do I do?

Elected officials in Washington want to know: Why was the deflection mission not successful? Why was the fragmentation scenario not anticipated? How much money did we "waste" on this mission? Now what? Who's in charge? What's the plan to protect the American people in the face of this impending disaster? State and local officials want to know: Who's in charge? What do we do? Who's going to pay for this disaster? Members of the media want to know everything. The news cycle is non-stop, global, networked, 24/7.

All communications from the federal government must be clear, concise, and consistent. The government must widely publicize authoritative sources for information. In this case of an impending asteroid impact, those sources will be NASA and FEMA. NASA is responsible for

science information and forecasting of the impact, and FEMA is responsible for disaster planning and response.

DoD and ESA must take responsibility for the mission failure and explain what happened. NASA must be ready to explain how and why knowledge and understanding of the approaching object are reliable. FEMA will emphasize preparedness. FEMA hurricane preparedness-response plans and experience plus related behavioral studies will be useful to impact preparations.

In the White House, the President and the Science Adviser are well informed about the deflection mission and about impact mitigation planning. NASA and FEMA are providing the White House with daily updates, and the White House press secretary is relaying those updates in her daily media briefings. In Congress, a few members are well informed about NEOs, impact risks, and planetary defense. Even fewer are informed about plans for impact mitigation. Committees with jurisdiction, and even some without, are calling hearings to interrogate political appointees at NASA and FEMA.

The Governor of Texas has approved a State Emergency Management Plan and maintains good working relations with Federal officials. Texas has been afflicted by recurring disasters over the past ten years. These recurring stresses have eroded the resilience of affected individuals and communities. Texas is home to five of the top ten poorest communities in the nation: Raymondville, Rio Grande City-Roma, Eagle Pass, McAllen-Edinburg-Mission, and Brownsville-Harlingen. Four of these five are near the Gulf Coast and the border with Mexico. Communications must be bilingual in order to reach these and other communities in Texas.

While real estate prices are falling in areas located in the risk corridor, only a small fraction of property owners can afford to sell below market value and relocate. Some working-class and poor families who have options for temporary relocation with friends and family outside the area are moving, but most can't afford to stop working and are staying in place for now. Because most residents can't afford to relocate, the flow of air and motor vehicle traffic out of the state is manageable thus far.

Texas oil refineries, concentrated mostly along the Gulf Coast, account for more than a quarter of U.S. refining capacity. Pipeline and shipping operations could be disrupted by the impact. Texas has two nuclear power plants, including the South Texas Project (STP) Nuclear Generating Station on the Gulf Coast southwest of Houston. STP is almost 30 years old, and Texans are worried about the security of the nuclear facilities.

The challenge to all parties involved in communications about the asteroid impact and preparations for responding to it is to stick to a common narrative/message – clear, concise, accurate, consistent, comprehensive and timely information to meet the needs of all "publics." While it will not be useful to respond directly to counter-narratives and conflicting messages, it will be important to monitor the public discourse to ensure that official communications remain clear, consistent, comprehensive, fully transparent, and responsive to public needs.

FEMA Activities

Upon discovery of a potentially hazardous asteroid in 2014, the NASA NEO Program Executive provided a detailed briefing to FEMA Response Operations. The FEMA Response Directorate, joined by NASA, then briefed FEMA Executives on asteroid impact hazards. FEMA Executives have directed FEMA Response Operations to closely monitor the situation and provide monthly updates.

In June 2014, FEMA Response Operations (Response Ops) joined the Interagency Working Group on Near-Earth Objects and began monitoring the International Asteroid Warning Network (IAWN) and other networks for situational awareness. Response Planners at FEMA Headquarters began crisis action planning with federal agency partners, in accordance with the

Federal Interagency Operations Plan (FIOP). Under the auspices of the interagency Emergency Support Function Leadership Group (ESFLG), FEMA initiated FIOP Phase 1a[2] coordinating actions with Federal agency partners to:

- Establish clearly delineated agency responsibilities including appropriate lead agencies and notification protocols and standards;
- Review and assess evacuation and mass care strategies; and
- Identify critical national issues that may require establishment of dedicated Federal interagency functional planning teams.

In July 2014, NASA reported a 2% probability that TTX 2014 will impact Earth in September 2021. FEMA Response Ops briefed FEMA Executives on what this forecast means. By February 2015, probability of impact rose from 2% to 35%. NASA announced the date of Earth impact: September 5, 2021. The FEMA Administrator called for an Asteroid Impact Working Group to stand up and produce a plan with a countdown to impact.

From February – December 2015, FEMA Response Planning continued FIOP Phase 1a federal interagency planning activities, including FEMA regions within NASA's impact risk corridor (see Fig. 13). FEMA regional officials began dialogue with state partners and crisis action planning with regional federal partners, consistent with the existing National Response Framework and the Federal Interagency Operations Plan (FIOP) for All-Hazards. Elements of our existing plan would be leveraged to ascertain planning factors and operational requirements such as city IND plans and coastal hurricane evacuation studies, to include:

- Informing citizens about NEO impact hazards and supporting state, local, tribal and territorial preparedness and public messaging efforts;
- Conducting pre-impact analyses of likely consequences on the geography, demographics, populations and critical infrastructures of at-risk U.S. interests, including potential long-term effects; and
- Producing an Information Analysis Brief (IAB) for the ESFLG with input from the NEO community.

By January 2016, NASA reported that the probability of impact had increased to 100%, with risks almost exclusively to the United States. FEMA Response Ops maintained close coordination with NASA and kept FEMA Executives informed on a planned mission to deflect the asteroid from Earth impact.

Between January 2016 and December 2019, federal planning and preparedness activities intensified, as did those of state, local, tribal and territorial partners. Federal interagency crisis action planning increased to Phase 1b (elevated threat). At this point FEMA requested and received supplemental funds for the Hazard Mitigation Grant Program (HMGP), Homeland Security Grant Program (HSGP) and other assistance programs to expedite federal, state and local preparedness and mitigation efforts. FEMA also developed courses of action (COAs) in

[2] "During Phase 1 (Pre-Incident), local, state, tribal, territorial, insular area, and Federal entities determine existing logistics and resource capabilities, develop deliberate plans and procedures, and conduct training and exercises to validate existing plans. Phase 1 consists of three sub-phases, which range from steady state operations to the positioning of resources prior to the occurrence of an incident. Actions taken during Phase 1 are focused on awareness, preparedness, mitigation, and protection. During a notice incident, there may be an elevated threat (Phase 1b) and credible threat (Phase 1c) for which response actions must be taken and will be detailed in incident-specific annexes, as warranted." From **Response Federal Interagency Operational Plan**, July 2014, U.S. Department of Homeland Security (http://www.fema.gov/media-library/assets/documents/97362).

coordination with federal interagency functional planning teams and planning task forces and presented them to the ESFLG and Domestic Resilience Group (DRG) for decision-making on time-sensitive, pre-impact mitigation measures and post-impact responses.

Figure 13. FEMA Regions.

In December 2019, NASA announced the deflection mission was a partial success. However, a 50-meter object remained an Earth impact threat, and over the next several months, the probability of impact increased, reaching 100% about four months before impact. During this period, FEMA and federal agency partners increased readiness and crisis action planning to FIOP Phase 1c (Credible Threat).

At this point, the White House issued Executive Orders to Federal agencies on readiness measures for an imminent asteroid impact on the United States. FEMA conducted regular coordination calls with State and Territorial Governors, Tribal Executives and International emergency management organizations, and the FEMA/NASA team supported Department and White House press conferences and public messages with information to include estimated impact location(s).

On August 1, 2021, about one month before impact, FEMA activates the National Response Coordination Center to Level 1, with all interagency partners and all emergency support functions (ESFs 1-15) responding.

SECOND UPDATE: 8 DAYS TO IMPACT

NASA's Goldstone radar has been observing the 2014 TTX fragment over the last few hours. Using these observations, the NASA NEO Program's Sentry impact monitoring system confirms that the fragment will impact about two minutes after noon local time (CDT) on September 5, 2021. Radar data has significantly reduced the impact risk area. As shown in Fig. 14, precise orbit calculations place the impact point somewhere within a 90 by 40 kilometer (60 by 25 mile) oval centered approximately 12 miles southeast of downtown Houston, Texas, with the longer axis of the oval running from the southeast to the northwest of that point. The possibility of an impact in the Gulf of Mexico has now been eliminated. More radar observations will be collected in the next few days to further isolate the potential impact point and better determine the size of the object.

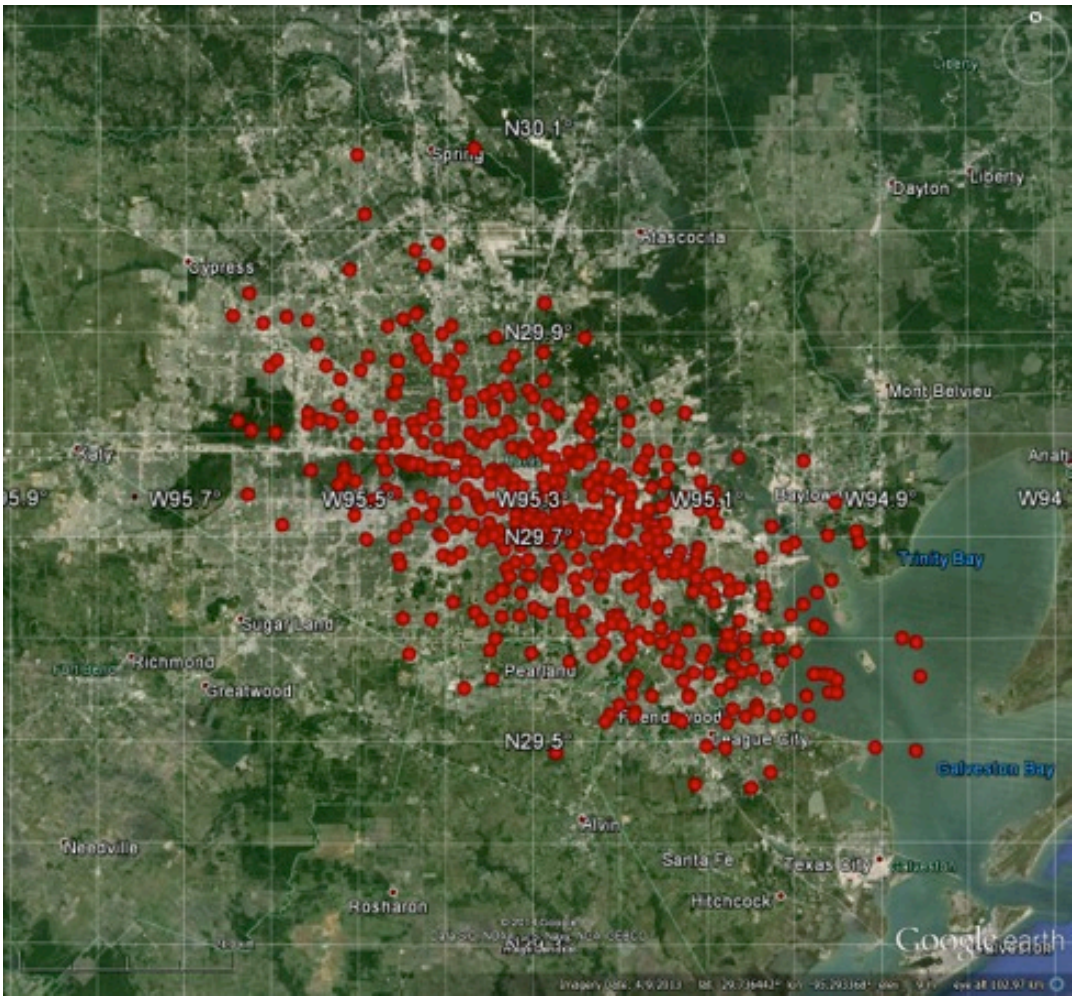

Figure 14. Risk corridor eight days before impact.

THIRD UPDATE: 6 DAYS TO IMPACT

By six days before impact, NASA experts are able to further refine the impact risk corridor, identifying possible impact locations to within 29 km, shown in Fig. 15. Radar imaging of the object confirms that it is approximately 50 meters (150 feet) in size. Experts say a significant portion of the object is likely to survive entry into Earth's atmosphere and devastate a ground area that could extend up to 25 kilometers in radius from the impact point. More radar observations will be collected in the next few days to further isolate the potential impact point and support terminal trajectory object disruption operations.

At this point, players in the exercise, led by FEMA, discussed options and timelines for response. ESFLG members reported out their assessments of how existing plans and processes might apply and offered recommendations for new processes or plans.

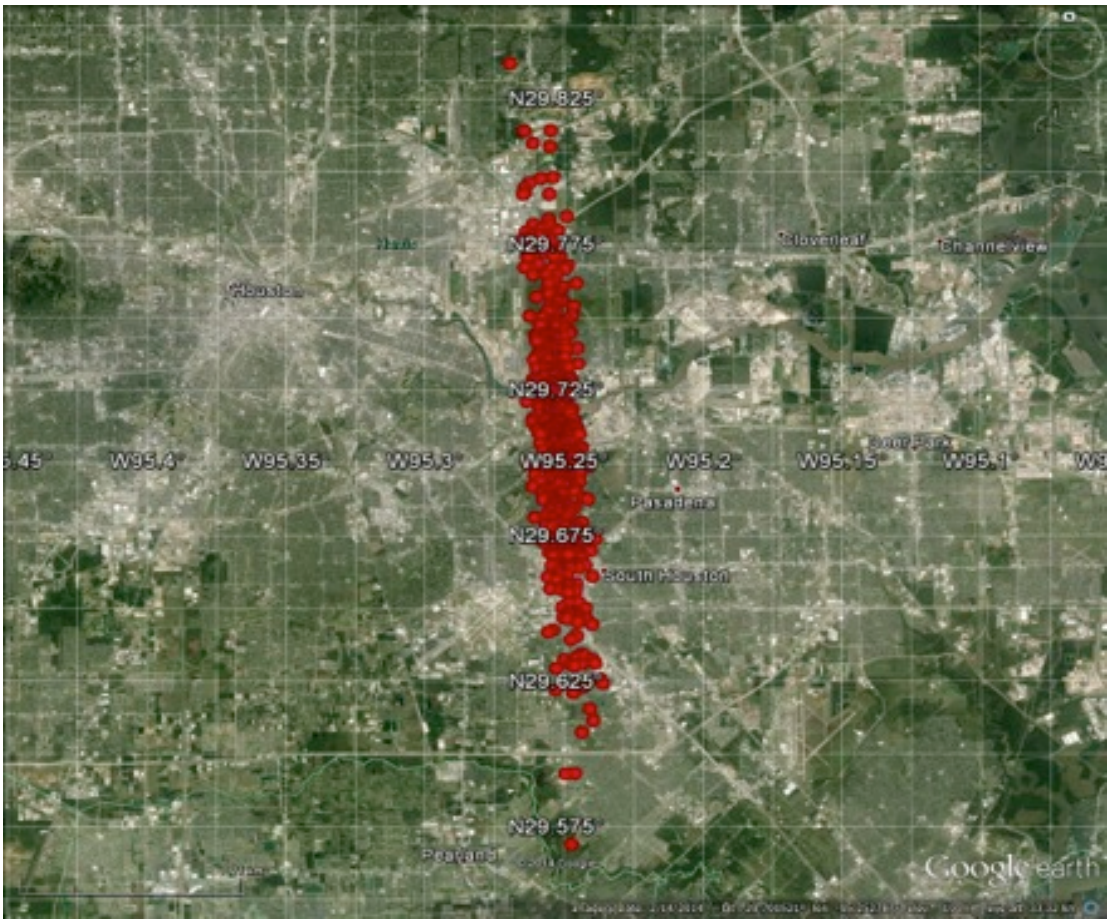

Figure 15. Risk corridor six days before impact.

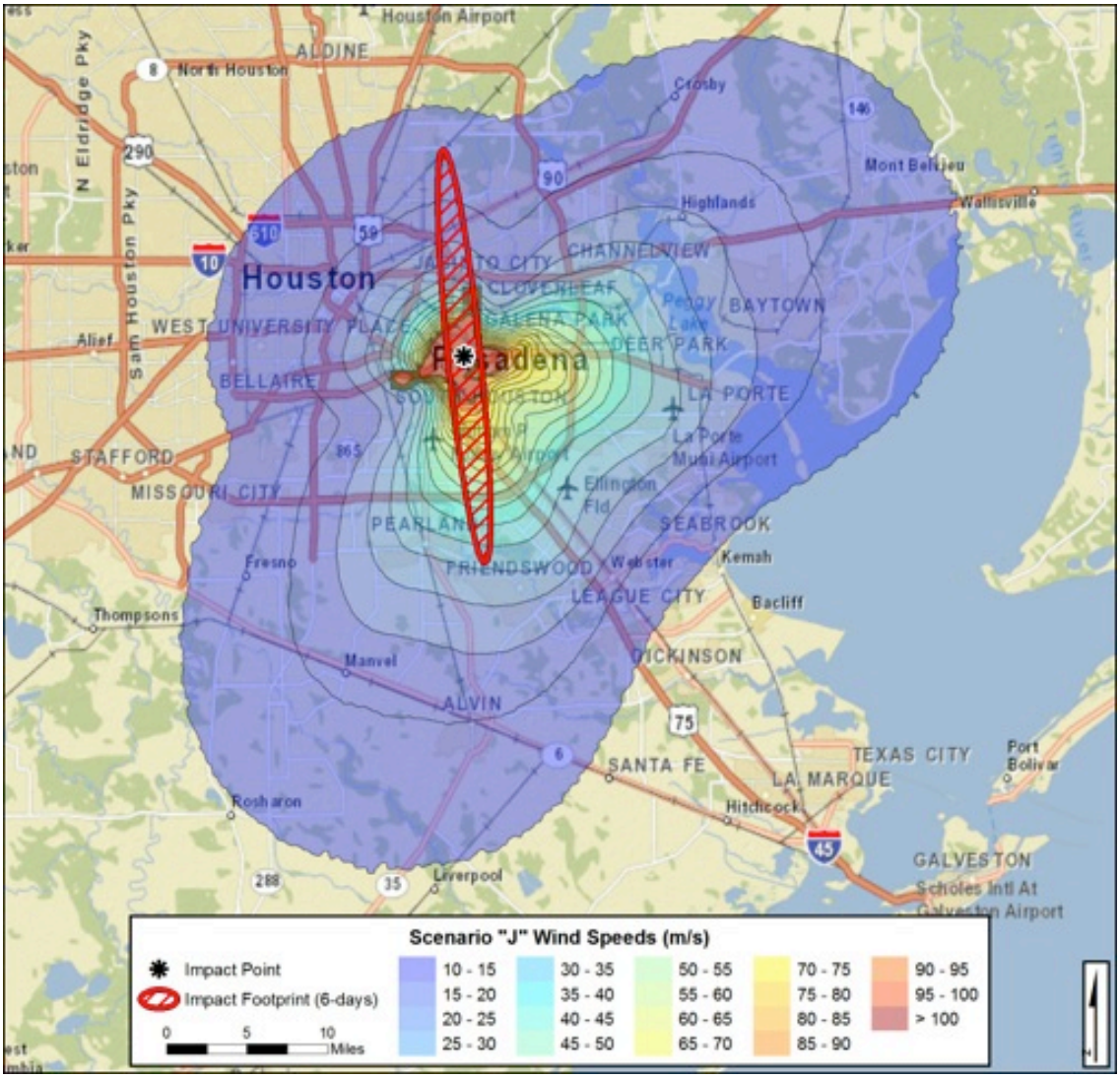

Figure 16. Wind speed projections for an impact at the center of the risk corridor (the red ellipse), near Pasadena, Texas.

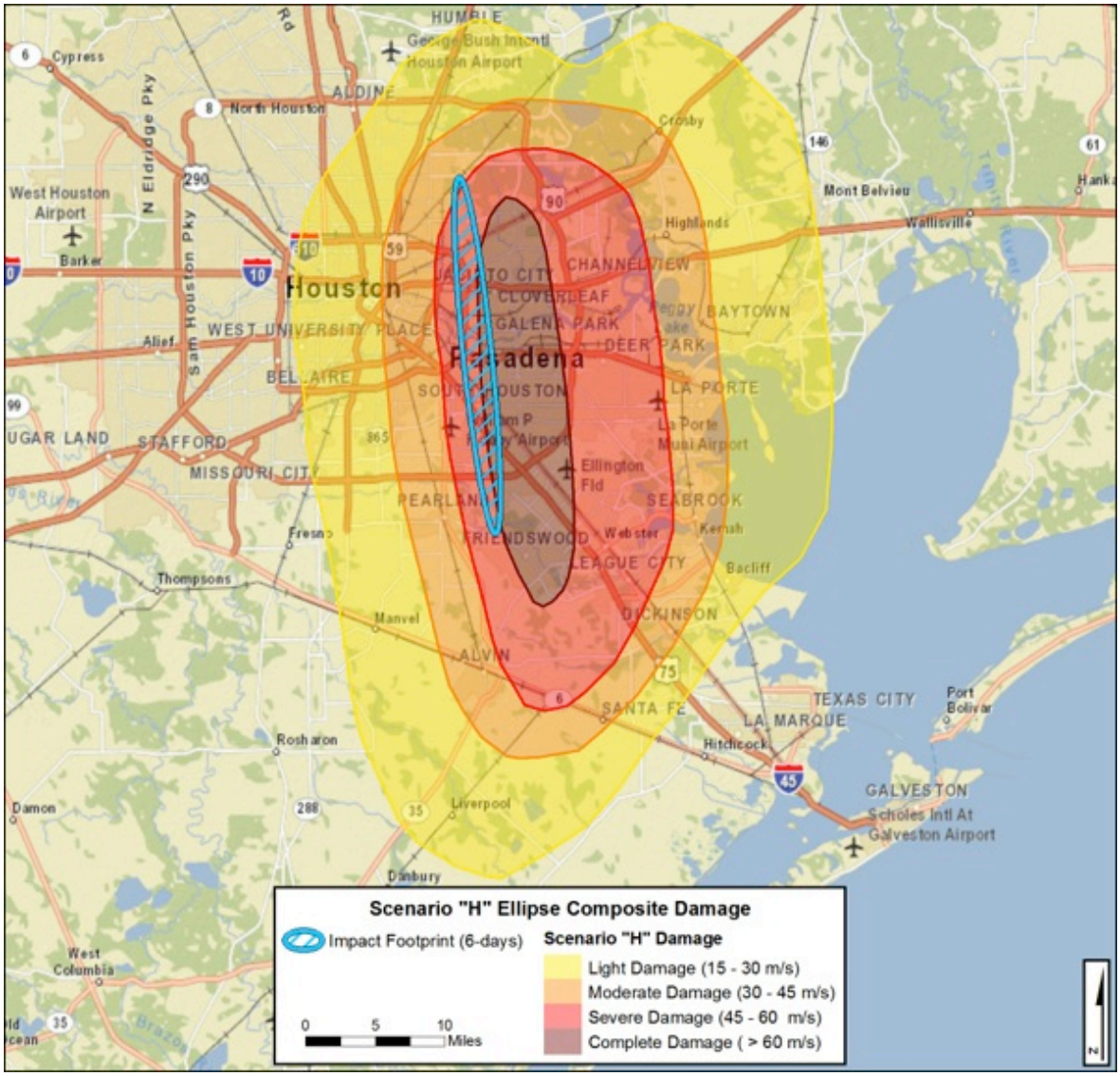

Figure 17. Area where moderate damage to complete destruction is possible given the risk corridor predicted six days before impact.

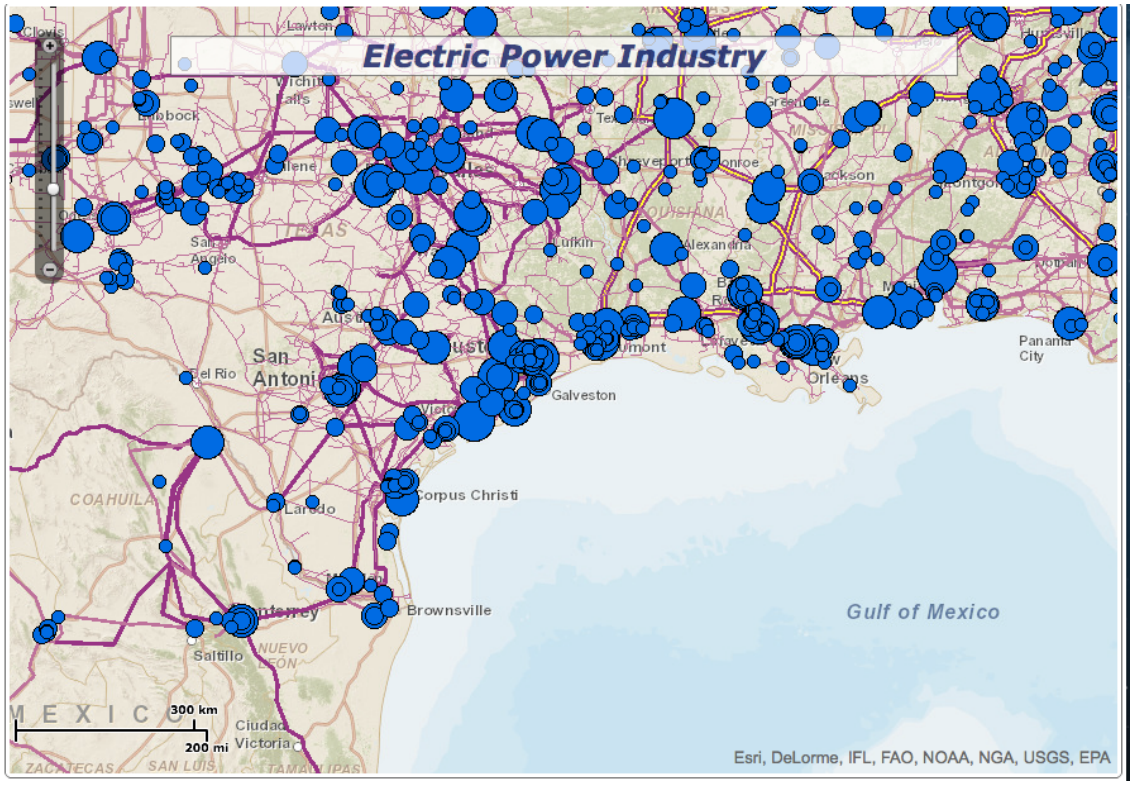

Figure 18. Locations of electric power facilities that might be affected.

OBSERVATIONS & RECOMMENDATIONS

Participants discussed several observations and recommendations during and after the exercise. These include:

- Long-term power outage will likely be one of the most serious effects of an asteroid impact. Given the large number of service providers, significant pre-event planning, including system redesign will be required. The oil and gas industry would likely push for fast track approvals to get their work moved elsewhere. Service providers would need to stockpile transformers to bring the power system back up after event.
- FEMA may need to use All Hazards response planning and elements of other existing plans (e.g., Improvised Nuclear Device (IND) plans, hurricane evacuation studies) to prepare the general population for effective response to an asteroid impact.
- Major problems could arise with regard to mass care, emergency assistance, housing, and human services. In the zone of major destruction, over 200,000 people might be displaced. Texas has lots of practice evacuating people since it deals with hurricanes. Local governments and the Red Cross can plan to operate shelters because of the lead-time available. Permanent relocation remains a challenge.
- A presidential declaration of emergency would be likely when the possible impact risk corridor of the asteroid is identified. The declaration could include a freeze in oil prices and a request that Congress appropriate progressive funding (over a maximum of 7 years prior to impact) to mitigate the consequences, including: building warehouses to safeguard personal, business, and government property; developing and implementing

plans for relocation of individuals/households and industries/businesses; and creating a standing task force to coordinate Federal, state, and private sector activities.

- The governor of Texas would likely declare a state of emergency when the impact risk corridor of the asteroid is identified and is refined. The declaration could freeze local prices on real estate (Government will guarantee purchase of destroyed homes), gasoline, water, food, etc.; modify laws to authorize the governor to impose mandatory evacuations and restrict access to potentially impacted areas; and modify laws to allow the governor to reprioritize the state budget to prepare for an asteroid impact event.
- Officials responsible for oil and hazardous materials response would follow the impact event like a major hurricane and work with the National Response Team, the Coast Guard, Rapid Response Team, etc. Post-impact mitigation will also likely be like the aftermath of a hurricane, involving cleanup of hazardous materials.
- Well-defined federal roles and responsibilities are key to successful planning and response.
- Mitigation capability lags behind detection and disaster response activities and creates a mitigation response shortfall due to budgetary constraints and time uncertainty of need to respond.
- The government needs to institutionalize planetary defense and bring FEMA, non-governmental organizations and the private sector into discussion with NASA.
- The event has global significance, and global response would need to be coordinated. For an event within the United States, the Department of State should be working with FEMA's Office of International Affairs on incoming offers of support from other countries and also with foreign nationals. Deflection efforts must be under international auspices so that everybody is aligned. The government should hope for international collaboration, but also expect and prepare for conflict.
- In consultation with the experts at FEMA, it is clear that there are established protocols for fully developing response plans at a national level. It is also noted that the NEO impact scenario is not listed in the current Strategic National Risk Assessment (SNRA). While not advocating a change, there is enough evidence to indicate that this effort must be continued at least at the current level (i.e., main POC at FEMA, continued situational awareness provided to NASA and FEMA leadership on the actions of the NEO Impact Response Working Group). It is recognized that from a response point of view, separate from NASA-directed deflection and or mitigation efforts, any plans other than previously directed development of emergency notification procedures, public messaging and the work of the working group will be limited in scope.

FINDINGS

Comments and suggestions area summarized in two main areas: 1) planning for how to deal with an actual asteroid impact emergency, and 2) the need for a well-considered plan for communicating necessary information and instructions to those who might be affected by an impact. Discussions also provided recommendations for the following:

PLANNING

Strategic planning across emergency management, domestic policy, national security, and scientific missions should be performed and provide actionable guidance for investment decision-making, analysis and operational planning.

Recognizing the international nature of any asteroid threat, a dedicated working group should be established to plan for U.S. and international responses to and involvement in a NEO emergency.

COMMUNICATIONS

A communications plan for describing deflection options, the risk of failure, and the possibility of false alarms to the public should be developed in coordination with existing emergency public affairs coordination entities (e.g., ESF-15 (Public Affairs)). The plan might include:

- Prototypes of warning messages that use well-known, colorful, visual hurricane alerts as a model
- Clear explanations of technical terms such as "impact probability," "impact corridor," and "deflection delta-V" using simple examples that children and adults in the general population can understand
- Ways to describe our ability to move or disrupt an asteroid, techniques that might be used, and possible outcomes of deflection/disruption attempts;
- Communications protocols describing actions that will be taking place and agencies responsible for those actions; and
- Information dispelling misconceptions about using existing missiles to destroy a threat just before impact.

The plan should stress that when communicating with the public about what might happen, it is important to stick to common messages and stay on message.

SUGGESTIONS FOR NEXT EXERCISE

The following comments and suggestions relate to planning for the next tabletop exercise:

- Planetary defense exercises with well-defined scenarios maintain focus on the issue, but they should generalize to distinct decision thresholds and activities for mitigation and for emergency planning and response. These depend on the level of preparedness and uncertainty existing when the threat emerges and evolves.
- We need an exercise with role-play—with checklists for year 5, year 4, etc.
- The next exercise could be two days long in Fall 2015, possibly on the West Coast. The exercise could go beyond the basics of asteroid impact and be more based on "tabletop" level exercises utilizing role players and simulated response level efforts. The second day might simulate the highest-level decision-making process, including presidential directive.
- The next scenario could start from impact and work backwards in time. This would highlight what's needed at impact and its aftermath and help clarify what can and should be done before impact.
- Non-governmental organizations and private sector representatives need to be included in planning efforts. Depending on the location of the next exercise, representatives from local and private sector agencies might be included.

APPENDIX I. ATTENDEES

Name	Organization
Nathan L. Adams	DHS OPS
William Ailor*	The Aerospace Corporation
Linda Billings*	National Institute of Aerospace
Mark B Boslough*	Sandia National Laboratories
Jess Bratton	FEMA, International Affairs
Uma Bruegman*	The Aerospace Corporation
Paul Chodas*	NASA Jet Propulsion Laboratory
Matthew Cummings	DoD
Meredith Drosback	OSTP
J. Elder	Department of State
Robert Farmer	FEMA
Kenneth Flynn	DHS OPS
Kenneth Friedman	Department of Energy
Bryan Giddings	NORAD-NORTHCOM
Lance Gilmore	FEMA/US&R
LtCol. Mike Gleason	Department of State
Waddy Gonzalez	FEMA ESF-6
Matt Gula	OASD Homeland Defense
Carol Hall	GSA Liaison to FEMA
Colette Hawley	Department of Education (DOED)
Harvey Hubbard	DoD/Joint Staff J-33
Michael Hurick	National Integration Center
William Irwin	USACE
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Barbara Jennings*	Sandia National Laboratories
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Rob Landis*	NASA HQ NEO Program
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Leviticus A Lewis*	FEMA Response Directorate, Operations Division
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Richard Passmore	European Space Agency
Dean Riewald	FEMA - U.S. Fire Administration
Bill Ryan	DHS OEC
Gordon Sachs	USDA Forest Service
Ronnie Screen	FEMA, Plans
Mangala Sharma	Department of State
Bobby J. Small, Jr.	Veterans Affairs
Peter Smalley	FEMA/US&R
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Gregory L. White	National Geospatial-Intelligence Agency
Chris Wolney	FEMA, Plans
Joshua Woodyard	EPA
Wheeler Young	Department of Labor, OSHA

*Member, Exercise Scenario Development Team

APPENDIX II. EXERCISE ORGANIZERS

The threat scenario was developed and presented by:

- Leviticus A. "L.A." Lewis, Chief, Field Operations Branch, Operations Division, Response Directorate, FEMA Headquarters (exercise design)
- Lindley Johnson, NEO Program Executive, NASA Headquarters (exercise design)
- Rob Landis, NEO Program Officer, NASA Headquarters (NEO program background)
- Paul Chodas, Ph.D., Senior Scientist, NEO Program Office, NASA/Jet Propulsion Laboratory (asteroid orbit design, approach scenario, impact probability analysis)
- Paul Miller, Ph.D., Associate AX-Division Leader, Asteroid Deflection Project Leader, Lawrence Livermore National Laboratory (asteroid deflection attempt)
- Nahum Melamed, Ph.D., Project Leader, Launch Vehicle Software, The Aerospace Corporation (asteroid deflection mission design)
- Mark Boslough, Ph.D., Principal Member of the Technical Staff, Sandia National Laboratories (atmospheric entry and impact effects)
- Barbara Jennings, Ph.D., Senior Member of the Technical Staff, Sandia National Laboratories (effects of entry blast and impact on infrastructure)
- Linda Billings, Ph.D., Consultant to NASA's Near Earth Object Observations Program, National Institute of Aerospace (public and political reaction and response)

William Ailor, Ph.D. (Principal Engineer, Center for Orbital and Reentry Debris Studies, The Aerospace Corporation) coordinated the development of this exercise. Uma Bruegman (Senior Project Engineer, The Aerospace Corporation) had project oversight responsibilities. The Exercise team and scenario development was supported by funding from the NASA NEO Observations Program.