NASA – FEMA Statement on the 3rd Joint Asteroid Impact Tabletop Exercise

Pursuant to direction from the U.S. Office of Science and Technology Policy (OSTP) directing the National Aeronautics and Space Administration (NASA) to lead and coordinate the detection and hazard estimation of near-Earth asteroids and comets and to coordinate with other federal agencies in developing mitigation or response plans, NASA collaborated with the U.S. Department of Homeland Security's Federal Emergency Management Agency (FEMA) on this joint exercise.

Upon notification from NASA of an impending asteroid impact threat to United States territory, FEMA is responsible for notifying appropriate Federal, state and local authorities, and emergency response institutions, utilizing existing resources and mechanisms. This is analogous to procedures for a large piece of space debris re-entering Earth's atmosphere or hurricane warning procedures.

The third FEMA-NASA Near-Earth Object Impact Tabletop Exercise (TTX#3) was held at The Aerospace Corporation on October 25, 2016. The first[1] and second[2] were held at the Department of Homeland Security's Federal Emergency Management Agency (FEMA) Headquarters on April 3, 2013 and May 2, 2014, respectively. The purpose of each exercise was to acquaint disaster response planners with the nature and evolution of information available for, and inherent challenges of, a potential asteroid impact emergency.

TTX#3 was based on a postulated threat that could be posed by a modest-sized asteroid discovered four years prior to possible impact. The exercise development team, consisting of experts in asteroid orbital dynamics and impact effects, presented representative NASA-collected data and analysis of impact potential in a series of example press releases to the participants. These were presented at intervals during the exercise, as progression of the threat evolved with the probability of impact determined to be increasing. Exercise participants, who represented national, state, and local disaster responders, were invited to consider disaster mitigation and response activities at each update. The exercise featured long-periods of time in which the object was not observable, due to its position in space relative to the Sun and Earth, a circumstance that was especially problematic for emergency planners. For this exercise, the 100-300 meter object presented a certainty of impact, with the uncertainty being whether it would impact land or the ocean (and potentially causing a tsunami). The attached report provides details on the exercise scenario, reactions of the exercise participants, and summarizes key points of discussion and recommendations from that exercise.

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[1] "Tabletop Exercise for Short Warning Near Earth Object Impact Event," Summary Report for NASA HQ SMD Planetary Sciences Division NEO Program Office, April 29, 2013. https://doctorlinda.files.wordpress.com/2014/02/final-report-neo-impact-ttx-3-81913.pdf

[2] "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.

One outcome of the exercise was the understanding that effective government response to this hazard would require close interagency communication and collaboration between NASA and FEMA, as well as other government agencies. NASA and FEMA will present the results of this exercise to the Planetary Impact Emergency Response Working Group (PIERWG) to continue to develop situational awareness among the member agencies. Furthermore, the OSTP-NASA convened Interagency Working Group for Detecting and Mitigating the Impact of Earth-bound near-Earth asteroids (DAMIEN) will address notification processes and decision thresholds as recommended in the *National Near-Earth Objects Preparedness Strategy*.[3]

Based on the results of this exercise, we believe that while solid progress has been achieved, further work is to be done in the areas of detection, orbit characterization, international coordination, and communication with the public.

Concurrence:

5/2/17

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[3] National Science and Technology Council, 2016. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/NSTC/national_neo_preparedness_strategy_final.pdf.

Summary Report
3rd FEMA-NASA
Near Earth Object Impact Tabletop Exercise (TTX#3)
October 25, 2016

Executive Summary

The third FEMA-NASA Near-Earth Object Impact Tabletop Exercise (TTX#3) was held at The Aerospace Corporation on October 25, 2016. The first[1] and second[2] were held at the Department of Homeland Security's Federal Emergency Management Agency (FEMA) Headquarters on April 3, 2013 and May 2, 2014, respectively. The purpose of each exercise was to acquaint disaster response planners with the nature and evolution of information available for, and inherent challenges of, a potential asteroid impac emergency.

TTX#3 was based on the threat that could be posed by a fictitious, modest-sized asteroid discovered four years prior to possible impact. The exercise development team presented representative NASA-collected data and analysis of impact potential in a series of example press releases to the participants; these were presented at intervals during the exercise, as progression of the threat evolved with the probability of impac determined to be increasing. The last updates showed that the hypothetical impac would occur near North Los Angeles, California, in the Pasadena area. Exercise participants, who represented national, State of California, and local disaster responders, were invited to consider disaster mitigation and response activities at each update. This document provides details on the exercise for TTX#3 and summarizes key points of discussion and recommendations from that exercise.

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[1] "Tabletop Exercise for Short Warning Near Earth Object Impact Event," Summary Report for NASA HQ SMD Planetary Sciences Division NEO Program Office, April 29, 2013. https://doctorlinda.files.wordpress.com/2014/02/final-report-neo-impact-ttx-3-81913.pdf

[2] "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.

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1. Introduction

NASA's Planetary Defense Officer presented an overview of the Planetary Defense Coordination Office (PDCO)[3] and the latest information on the status of activities to detect potentially hazardous asteroids (asteroids that might one day impact Earth) including worldwide activities related to Near-Earth Objects (NEOs - natural objects such as asteroids and comets that have orbits that will bring them within 30 million miles of Earth's orbit). Figure 1 shows that the number of known Near-Earth Asteroids (NEAs) continues to increase as more sophisticated observation resources are brought online. As of the date of TTX#3, 15,008 asteroids were known NEOs, with 1740 asteroids rated as potentially hazardous (in orbits that pass within 5 million miles of Earth's orbit); 106 Earth-approaching comets have also been discovered, but none are classified as hazardous.

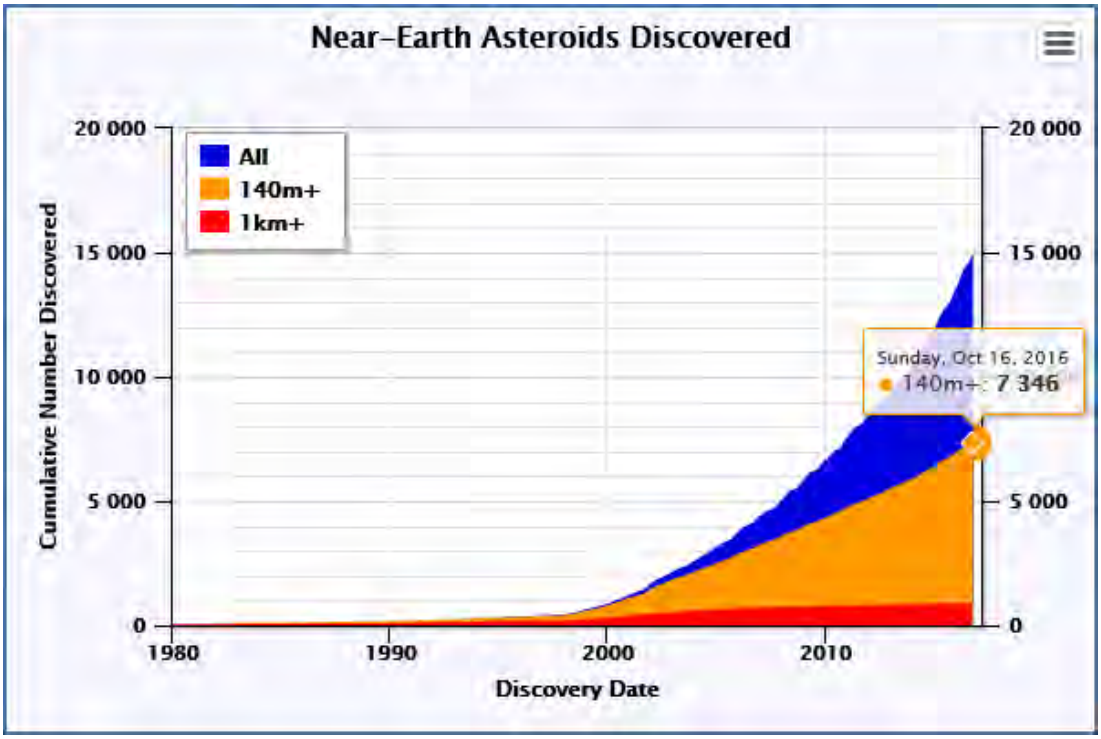

Figure 1. Known population of Near Earth Asteroids.

The sharp increase in the number of known NEOs after 1998 is a result of Congressional direction that NASA detect at least 90% of the objects 1-km and larger that could threaten Earth, and that requirement was met in 2010. An impact of an object in this size range could lead to a worldwide disaster; however smaller objects are also capabl of causing serious local or regional disasters. The airblast from the 1908 Tunguska event, estimated to have been caused by the entry of an object of only 30 to 50-meters in size, leveled a forested area covering over 2000 km^2 (770 square miles) while the

[3] see https://www.nasa.gov/planetarydefense/overview

February 15, 2013, Chelyabinsk event caused by entry of a 17 to 20-meter sized object caused over 1600 injuries and damage totaling over $33 Million.

Figure 2 shows a record of atmospheric events due to entries of small asteroids that occurred from 1994 to 2013. Note that the record includes the Chelyabinsk event, but that these types of events, generally involving objects somewhat smaller than the Chelyabinsk object, are not at all uncommon.

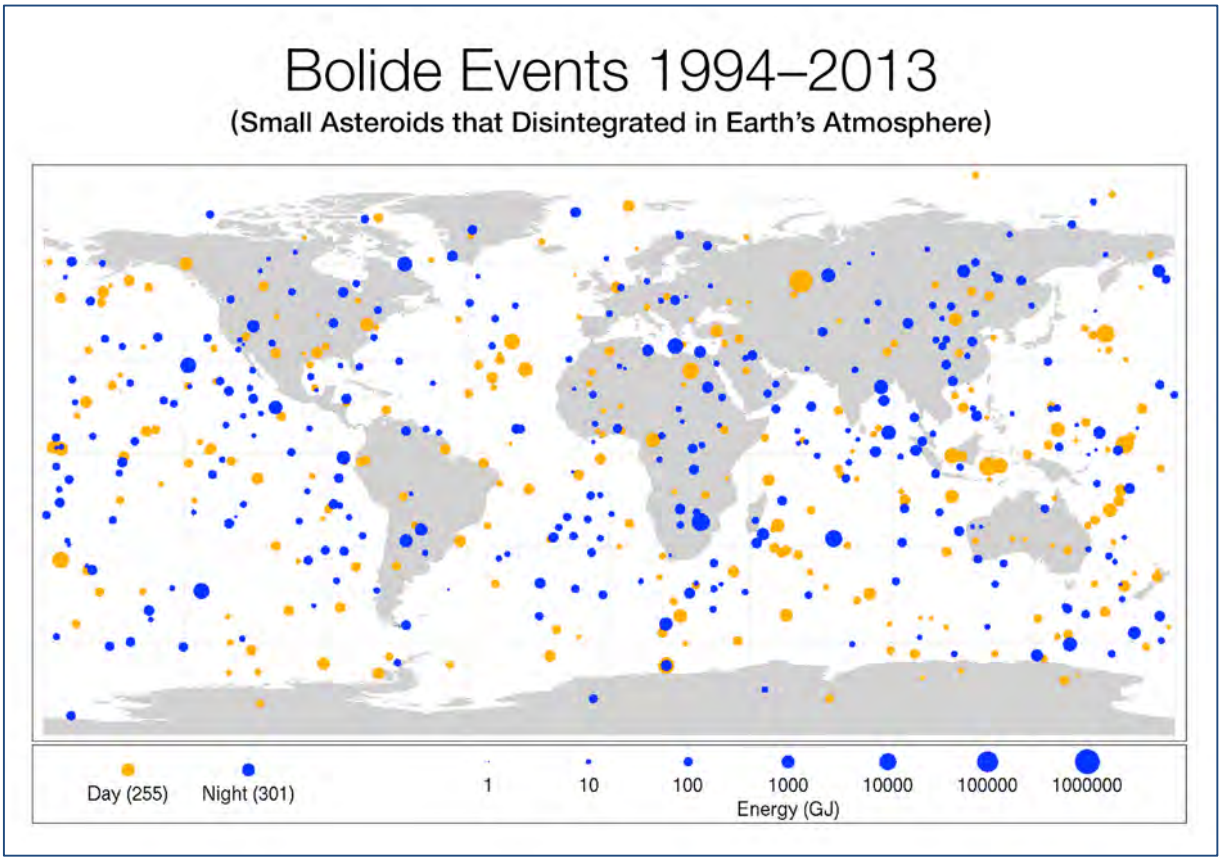

Figure 2. This diagram maps the data gathered from 1994-2013 on small asteroids impacting Earth's atmosphere to create very bright meteors, technically called "bolides" and commonly referred to as "fireballs." Sizes of red dots (daytime impacts) and blue dots (nighttime impacts) are proportional to the optical radiated energy of impact measured in billions of Joules (GJ) of energy, and show the location of impacts from objects about 1 meter (3 feet) to almost 20 meters (60 feet) in size. (Image courtes NASA)

2. Pre-Exercise Directions

The overall goal of exercise was to inform officials concerned with emergency response on the unique and challenging aspects of an asteroid impact and determine whether, and how, existing Federal Interagency Operational Plans (FIOPs, which describe coordinated federal response to a wide variety of contingencies) and annexes might apply to this type of disaster. The initial assumption is that consequences of any NEO impact event would mirror the consequences of a major earthquake, tsunami, or hurricane (perhaps occurring all together), and that the FIOP developed for an Improvised Nuclear Device

(IND) might also be used as a starting place. FEMA, which has regulatory responsibility for disaster response planning, would use the most applicable set of plans based on information received from the planetary science community to guide the overall federal response. This would be particularly true in a no-notice scenario.

Questions to be considered by participants were:

1. Where is the impact likely to occur? How do we ensure and evaluate the accuracy of the prediction?
2. How would we effectively communicate with our stakeholders, including local officials, the general public, and the media, about the predicted impact?
3. How would we best position ourselves as the credible source(s) for information?
4. What is our process for notifying and working with federal, state, and local partners?
5. How would we share information and work with our international partners?

Questions posed to State and federal officials—the State Emergency Managemen Operations Director and FEMA Federal Coordinating Officer (FCO):

1. How would someone in your position/role approach this scenario?
2. Do you anticipate requesting federal assistance as soon as an impact in the United States is predicted?
    a. Would Emergency Management Assistance Compact (EMAC) support likely be sufficient?
    b. Would you activate your National Guard units? If so, when? For what purpose?
    c. Would you recommend to the Governor to request either an Emergency Declaration or a full Major Disaster Declaration under the Stafford Act[4]?
3. What additional information from the science community could help you make initial decisions?
4. Initial warnings indicate that there are two possibilities for impact: one over land (impact or airburst) and one at sea off the coast (tsunami possible). How is your planning process affected by the uncertainty of the impact location?

3. Exercise

The exercise was designed to represent a realistic threat and to proceed with information available on a timeline as such a real threat might progress. While the

[4] A United States federal law designed to bring an orderly and systemic means of federal natural disaster assistance for state and local governments in carrying out their responsibilities to aid citizens. Congress' intention was to encourage states and localities to develop comprehensive disaster preparedness plans, prepare for better intergovernmental coordination in the face of a disaster, encourage the use of insurance coverage, and provide federal assistance programs for losses due to a disaster. (source: Wikipedia)

threat is realistic, it was emphasized that it might not be fully representative of an actual event in that:

- The warning time could be much longer or shorter, or that an impact could occur with no warning, given our current detection capabilities,
- The threatening object could be larger or smaller than that used for the exercise,
- The warning time for a larger object might be longer than that portrayed here,
- The warning time for a smaller object might be shorter or there might be no warning (e.g., Chelyabinsk, Tunguska), and
- Consequences of an impact could be less for an object this size than those presented by the exercise (e.g., an ocean impact far away from land might create only a relatively small tsunami).

Information on the threat was presented via status briefings and press releases as it might be presented for a real threat event, and presenters updated predictions on possible consequences consistent with information on the threat available at the time (note that press releases and related information would likely be made available whenever new observations allow, likely much more frequently than presented here). The information presented in the First Inject below was included in the read-ahead packet distributed to attendees. The press releases and the full set of charts presented to participants during the exercise are provided in Appendix B and C, respectively.

There was considerable discussion by exercise participants after presentation of details behind the first press release (First Inject, Section 3.1) and the third Press Release (Third Inject, Section 3.3). Notes collected during these discussions are presented immediately after the details of what is known about the threat and possible consequences of impact were presented. In addition, a "hot wash" was conducted on the day following the exercise to collect additional comments and recommendations. This information is collected in Section 4.

3.1 First Inject

3.1.1 Threat Description

As noted, a potentially threatening asteroid designated 2016 TTX was discovered on October 1, 2016, and observers worldwide confirmed the discovery. Predictions made shortly after discovery revealed that the asteroid was a potentially hazardous asteroid and would come close to Earth, with a small chance of impact on September 20, 2020. The size of the object, based on the albedo (light reflected by the body), was estimated to be between 100 to 300 meters. As more observations were collected and the orbit refined, by October 13 the probability of impact rose to 1%, and increased again to 2% on October 26.

Figure 3 shows where Earth would be in its orbit on September 2020, with the area highlighted by the red dots the possible locations of the asteroid that day based on propagation of the uncertainty in the tracking data on October 24, 2016. Figure 4 shows the uncertainty region as the asteroid approaches Earth in 2020; the length of the uncertainty region is about 2 million km, but the size would shrink as additional tracking data becomes available. If 2016 TTX were to impact Earth in 2020, it would strike only at a single point along the line created by the red dots as they cross Earth.

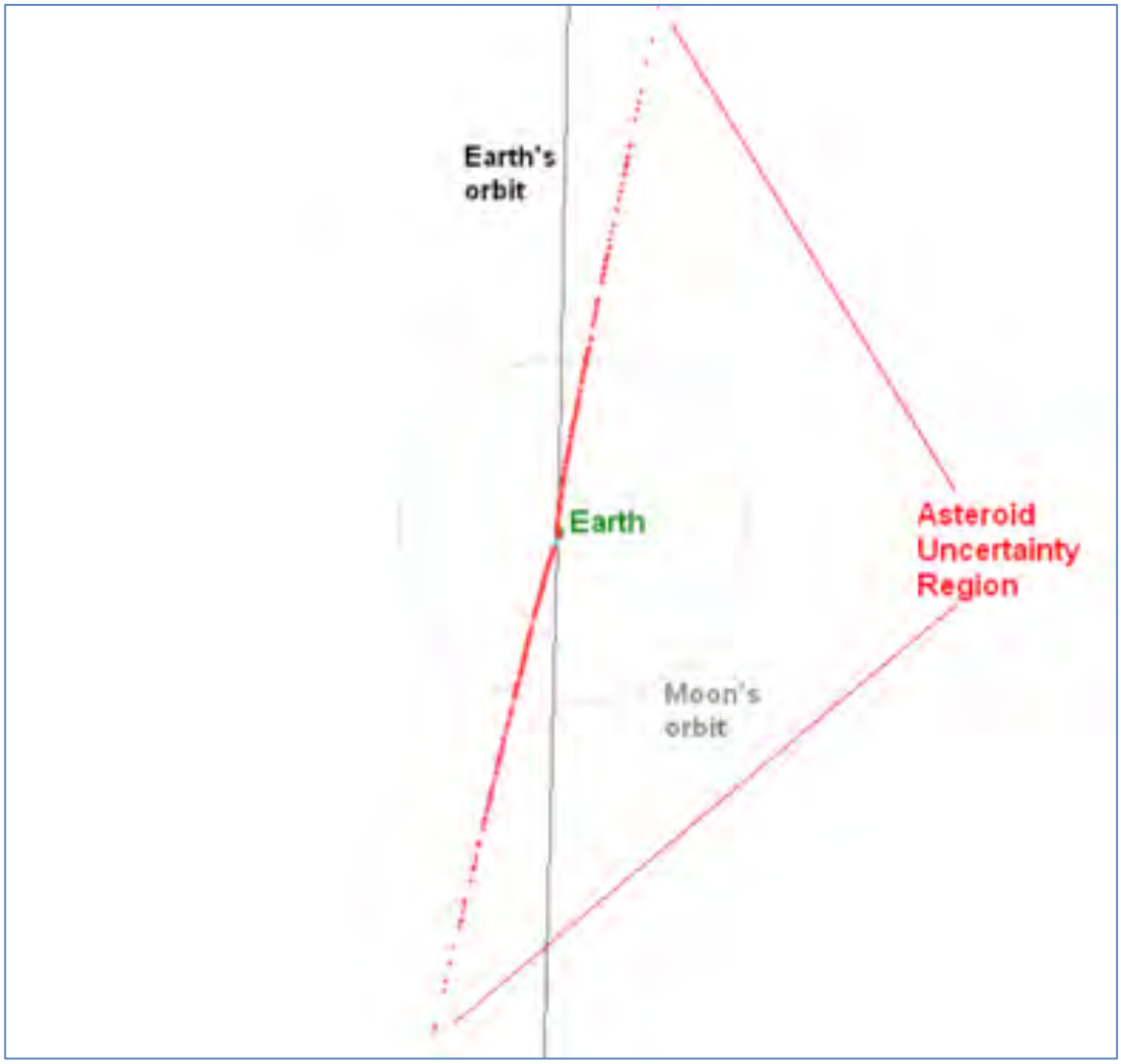

Figure 3. Uncertainty Region and Risk Corridor it forms shortly after discovery. Each red dot represents a possible asteroid position which then forms a continuous line connecting the dots. The approaching asteroid could be at any point on this line when it reaches Earth on September 20, 2020.

Based on this information, NASA's Planetary Defense Coordination Office (PDCO) published a so-called "risk corridor" – a long narrow region across the Earth where impact might occur. The path of possible impact points extends halfway around the globe, stretching from the Pacific Ocean, diagonally across the continental United States from southern California to New Jersey (see Figure 5). It then continues across the Atlantic Ocean and on to Africa.

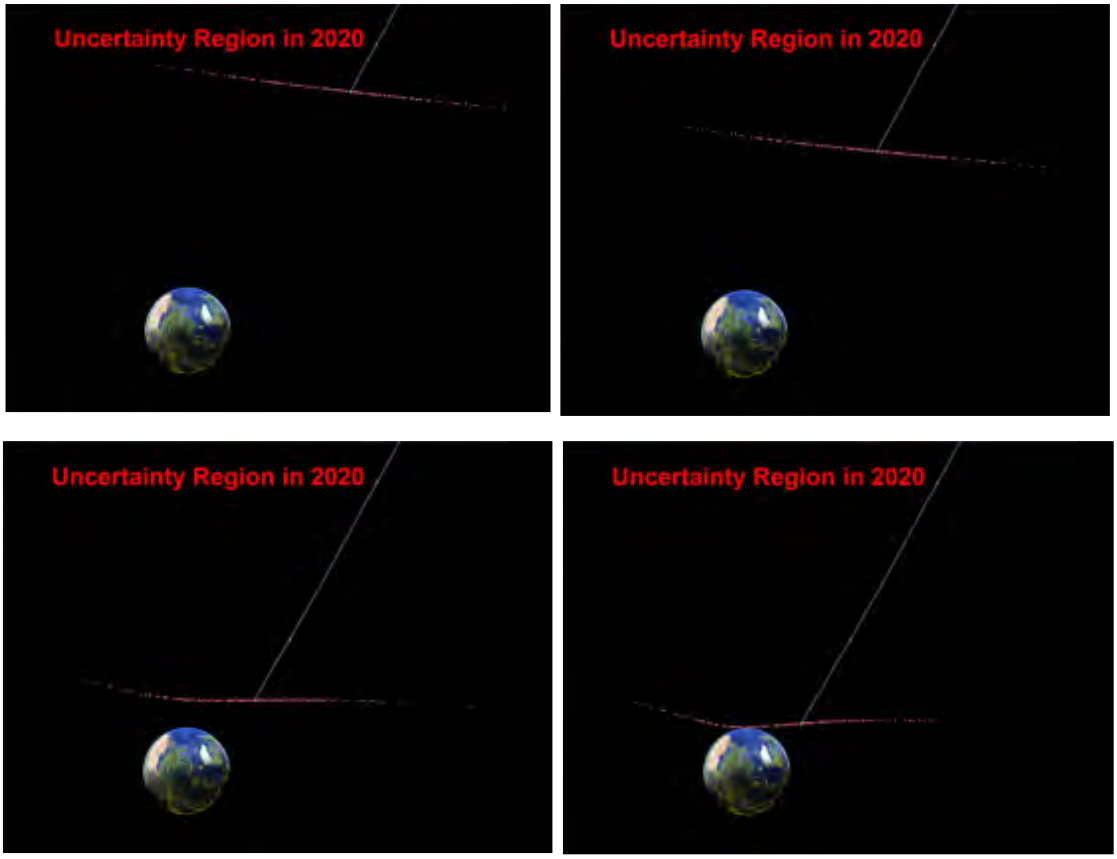

Figure 4. Sequence showing the uncertainty in the location of the asteroid as it would approach Earth based on initial observation data. Based on this data, the asteroid could be at any point within the region of space defined by these points.

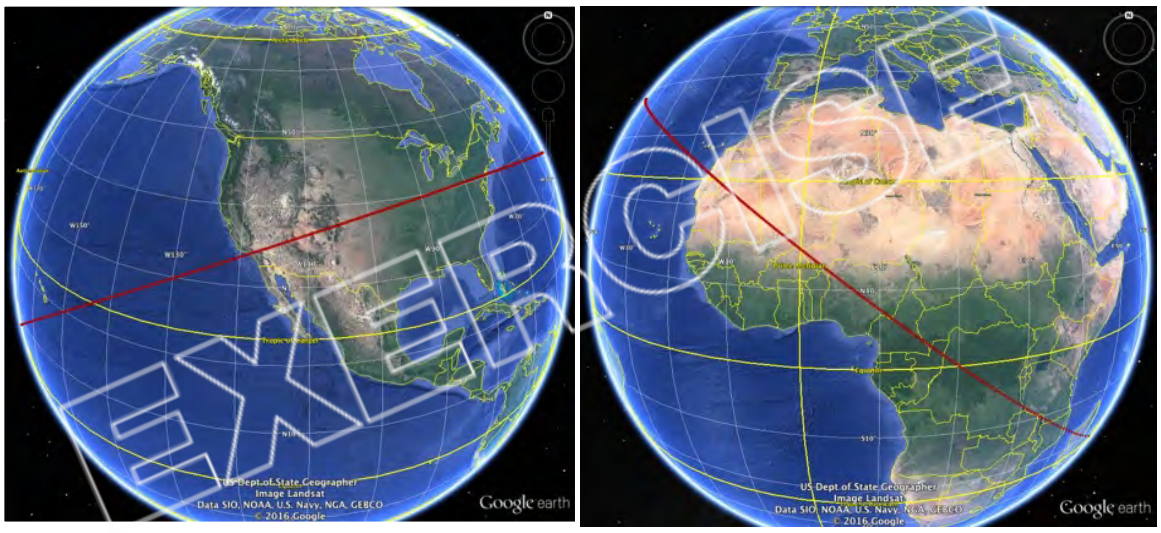

Figure 5. The red line indicates where the uncertainty intersects with Earth. Actual impact, were it to occur, could be at any point on the red line. Note that it extends around more than half of the globe.

At this point, four years to impact, the probability of impact would trigger a meeting of the UN-endorsed Space Mission Planning Advisory Group (SMPAG) [5], where representatives of the world's national space agencies begin considerations of possible missions to launch - first to fly by the object to get a better estimate of its size and improve orbit predictions, and then a campaign to deflect or disrupt the oncomin object. The possibility of impact would also trigger a notification to international disaster response agencies.

3.1.2 Participant Discussion

Th disaster responders' comments and questions given the level of risk and preliminar data available four years before possible impact included the following:

- Th initial predicted risk corridor makes this event a global issue.
- How would the United States be involved if an impact were predicted to occur outside of US territory?
- The amount of advance notice for the impact makes this scenario unique from other natural disasters. What emergency response and recovery actions would be appropriate to take in the four years before impact in this scenario?
- There would likely be pressure from our stakeholders to have a detailed incident-specific strategy.
- Would the Stafford Act be sufficient for an advance-warning impact event? Would new legislation be required for advance response efforts?
- The NEO impact hazard will soon be added to the Strategic National Risk Assessment (SNRA). (Accomplished with release of National NEO Preparedness Strategy on 30 December, 2016.)
- How would federal support to mass evacuations be adapted to this scenario?
- Planning efforts should account for the estimated worst-case scenario.
- With so much advance warning in this scenario, we would be able to plan for both incident response and recovery.
- An asteroid hazard playbook should be developed, similar to already known practices with other natural disasters.
- The Deflecting and Mitigating the Impact of Earth-bound Near-Earth Objects (DAMIEN)[6] national strategy (in development) will help define roles in the federal response to a predicted asteroid impact,
- Conspiracy theories and the spread of inaccurate information would likely occur during the periods of the scenario when the asteroid is unobservable.
- A systematic requirements review, including budget, metrics, and manpower, will likely be required for asteroid characterization and deflection missions.

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[5] IAWN/SMPAG Report, http://www.unoosa.org/pdf/pres/stsc2015/tech-12E.pdf

[6] Johnson, Lindley, "Planetary Defense Coordination Office Update, Slide 32, " June 30, 2016. http://www.lpi.usra.edu/sbag/meetings/jun2016/presentations/johnson-neo.pdf

- The nuclear deflection method would require the involvement of the Department of Energy and possibly the Department of Defense.

3. Second Inject

As the exercise scenario progresses, on January 10, 2017, approximately three months after discovery, NASA provides a second press release (see Appendix B). Based on new measurement data, the probability of impact on September 20, 2020 has risen to 65%. The press release notes that the object will now go behind the sun for several months and will not be observable from Earth. Updates on the threat will not be possible until the object emerges on the other side. The risk corridor remains the same as that shown in Figure 5; an expanded view of the risk corridor as it crosses the United States is shown in Figure 6.

The size of the object is now estimated to be between 100 and 250 meters, and observations to determine composition indicate that the asteroid is a stony, "S-class" object, probably with some metal content.

It has also been announced that SMPAG would start to plan possible deflection mission activities based on the International Asteroid Warning Network (IAWN)[7] assessment exceeding the established threshold of a 1 percent or greater probability of impact of an NEO within the next 50 years and the object being greater than 50 meters in size.

Figure 6. Expanded view of the risk corridor crossing the United States.

[7] International Asteroid Warning Network, http://iawn.net/

3.3 Third Inject

3.3.1 Threat Description

On November 25, 2017, a year after the hypothetical discovery, the object has been reacquired and additional observations have reduced orbit uncertainties and raised the impact probability to 100%. The impact will now occur somewhere in the 800-kilometer (500-mile) long region pictured in Figure 7. Estimates of the size remain between 100 to 250 meters (300 to 800 ft). A space mission to gather more information on the object is being developed to be launched in March 2019 and would reach the object eleven months later.

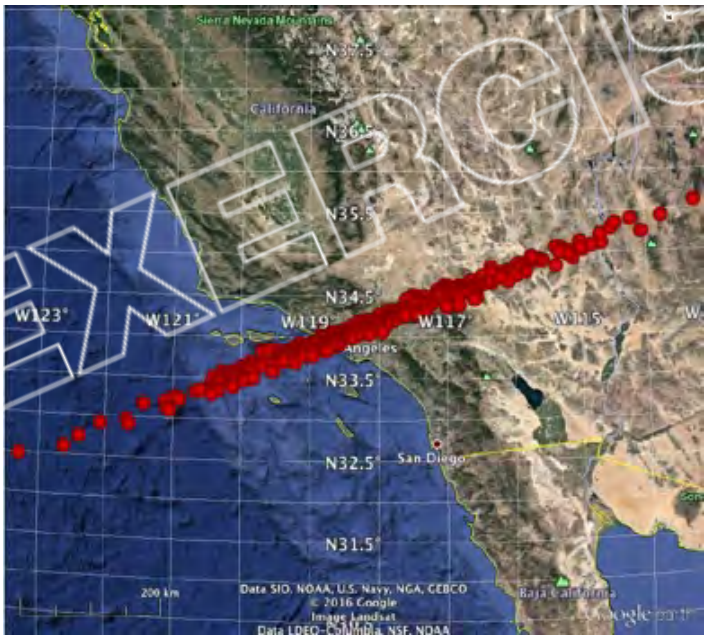

Figure 7. Region of possible impact one year after discovery.

SMPAG has concluded that diversion of the asteroid would take many tens of kinetic impactor missions, and launch and deflection payload resources will not be available in time for a deflection effort, so impact is inevitable. [Note that in an actual case, early and serious planning would be conducted to develop a strategy for deflecting the object. The exercise would be similar for a failed mitigation attempt (e.g., launch vehicle fails to deliver deflection payload); consequences of a failed attempt that moved the object to a new impact point were not considered in this exercise.]

Detailed estimates now show the nature of the insult and the area affected. These conclude that the area affected will be roughly the same for both an airburst (like that of the Chelyabinsk event but much larger) and a surface level burst. Figure 8 shows the possible damage area and consequences (recall that the actual impact would be at a single point on the map, not across the entire band). Impact could also be in the ocean just off the coast of Los Angeles, and worst-case estimates are that maximum local wave heights at the coast would be between 6 and 10 meters (32 ft), and flood heights in low areas would be between 0.5 and 1 meter (1.5 and 3 ft). As Figure 9 shows, affected areas would extend from Oxnard to San Clemente, with the area most affected lying between Malibu and Santa Monica. Figure 10 shows the probability of casualties for the impact

corridor assuming the largest size estimated for the asteroid and that the population is not evacuated.

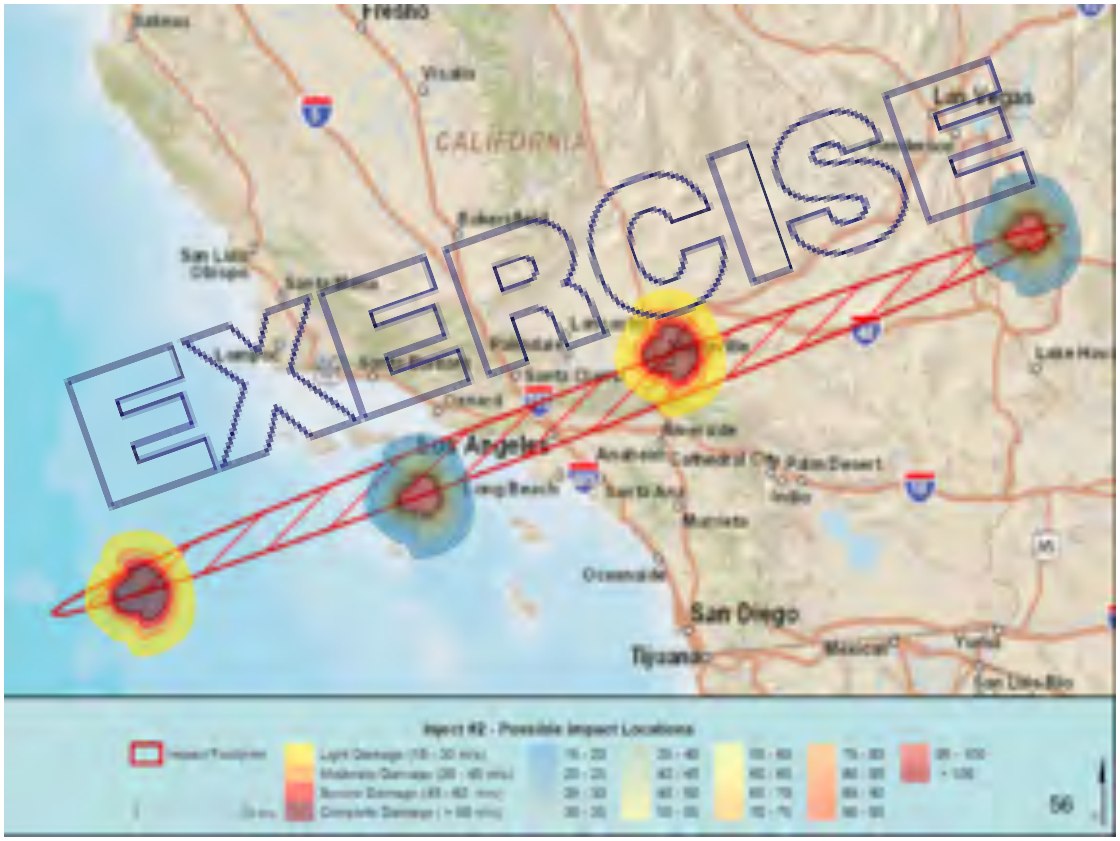

Figure 8. Possible damage areas and consequences.

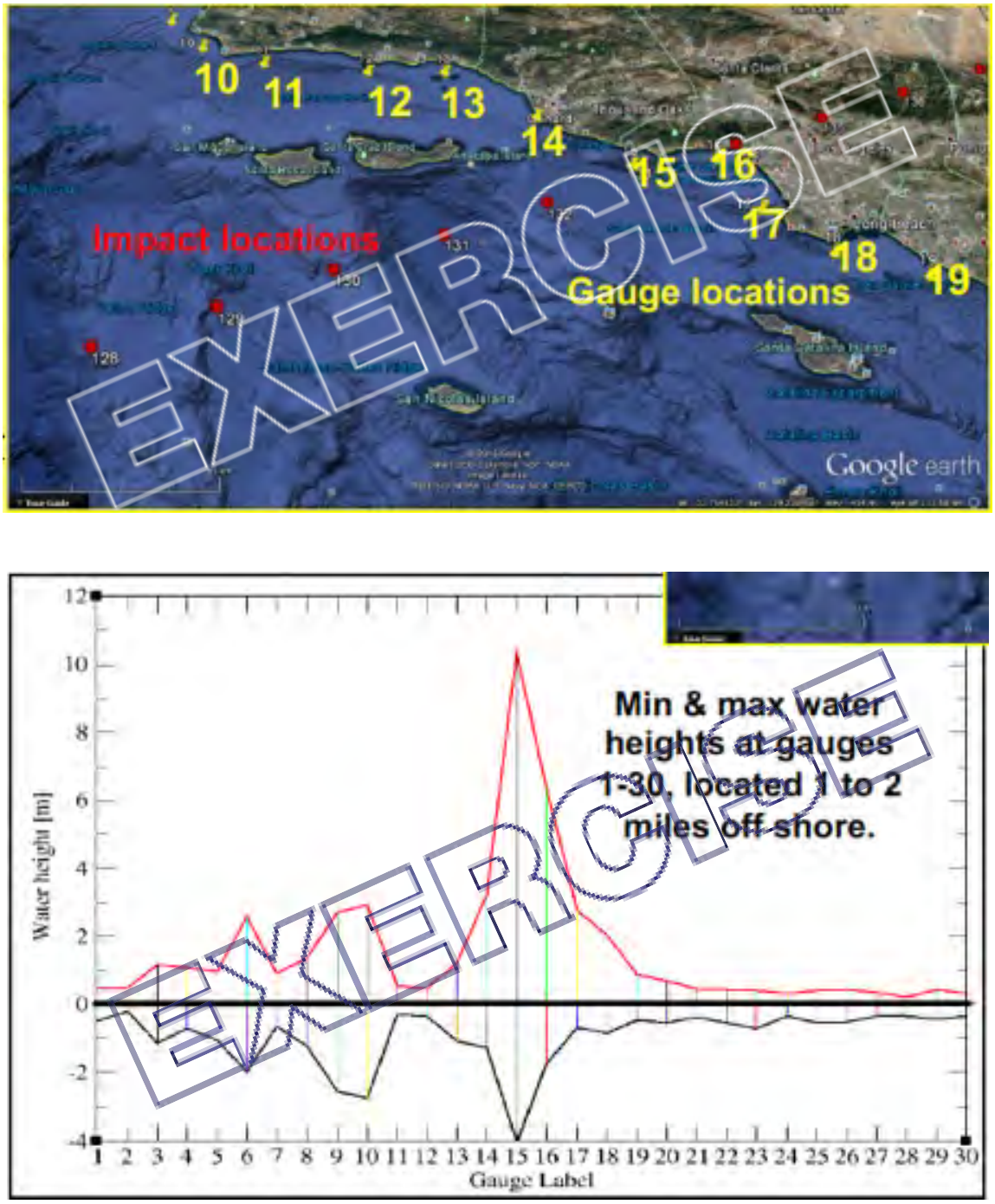

Figure 9. Top: Gage locations used for estimates of wave heights. The red dots are possible impact points used to estimate maximum wave heights. Bottom: Minimum and maximum wave heights for a 300-m asteroid impact in the ocean.

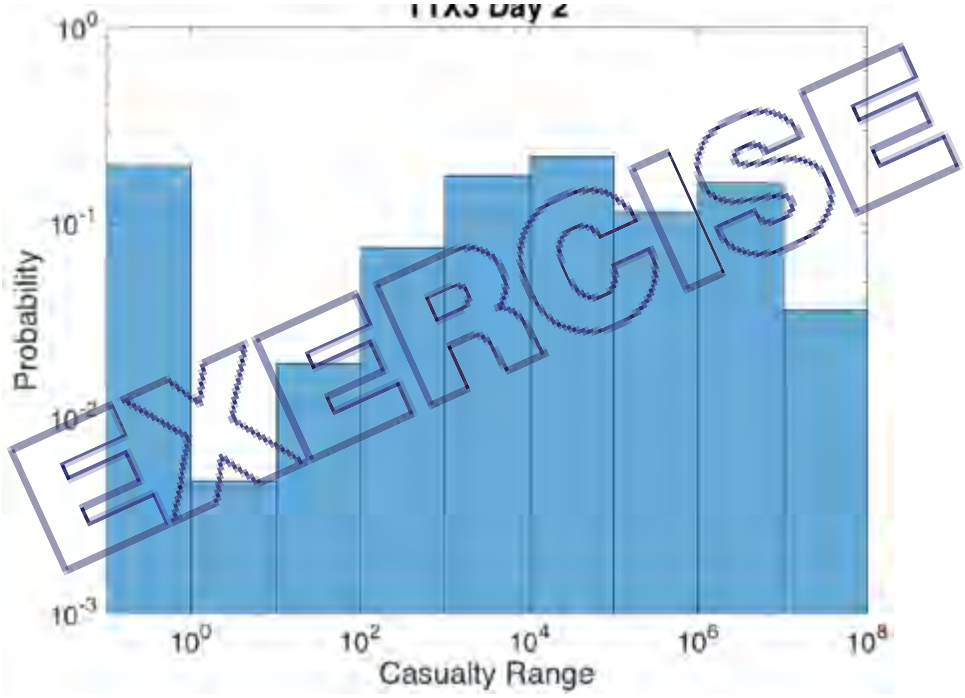

Figure 10. Casualty risk histogram given current threat corridor, a worst-case size of the asteroid, and assuming no evacuation. The chart merges the probability of impact along the risk corridor (total impact probability is 100%) with the population affected by the impact. For example, if the impact is in the ocean, there is a high probability that the number of casualties would be low. As the threat corridor crosses land, the populatio at risk increases.

3.3.2 Participant Discussions

The exercise participants discussed actions to be taken at this point, still almost three years before certain impact, noting the potential national economic consequences of por closures, loss of refineries, power generation, residences and other resources, and the requirements to evacuate and relocate large numbers of people and supportin infrastructure such as transportation, hospital, retirement facilities, water, power, and the like. They agreed that serious planning would need to begin. Topics and questions raised during the discussion are given below:

- Impact is now certain to take place in, or off shore of, Southern California.
- Even though the impact area will be relatively small in size, there will be national social and economic implications.
- Planning needs to begin even with two years to go until impact.
- As with other disasters, the state would be the lead in incident response and recovery; the federal government would provide support.
- At what point in this scenario would an Emergency Declaration or Major Disaster Declaration be approved, releasing federal funds?
- Would other sources of funding, such as FEMA grants, be available to states and other entities to assist in preparation and planning for a predicted impact?
- In this scenario, the state of California would be able to refer to its extensive tsunami plans to supplement its planning for this incident.

- Special consideration would need to be paid to the Port of Long Beach, as it is the largest port on the West Coast and activity there affects all of U.S. Closing the port will have serious effects on the national infrastructure.
- Special consideration would also need to be paid to the petroleum production and oil rigs in the risk corridor.
- Insurance of private property would also be an issue. Is a new State policy a possibility to insure private property in this context of risk?
- Joint messaging would need to account for unreliable information that is likely to spread.
- How would evacuation plans account for vulnerable populations, such as the homeless, and those in hospitals, nursing homes, and critical care?
- There will be a need to build awareness without causing panic.
- What preparedness information would we message to the public?
- How do we gain the trust of the public as reliable sources of information?
- Coordination is paramount with all of those involved, from regional emergency managers to scientists.
- The response will need to be clearly sequenced.

3.4 Fourth Inject

On March 10, 2020 (~6-months before impact), additional observations and data from the successful fly-by mission combine to narrow the predicted impact region to the 40 by 20 km (25 by 13 mile) region in the Northern Los Angeles area shown in Figure 11 (again, the object could impact anywhere within the region where the red dots are located). Th information from the fly-by has also refined the asteroid size estimates to roughly between 100 and 120 meters (300-400 ft) and confirmed that the object has a stony, metal-rich composition.

Solar glare now prevents further optical observations before impact, and refined estimates of the impact point must await radar observations by a planetary radar facility such as Arecibo first (with greater range) and then Goldstone, which will become possible about one month before impact.

Figure 12 shows the worst-case hazard zones, with a detailed breakdown of the insult based on an assumed individual impact point presented in Figure 11. The casualty risk assessment, Figure 13, shows that without evacuation, a very large population would be at risk.

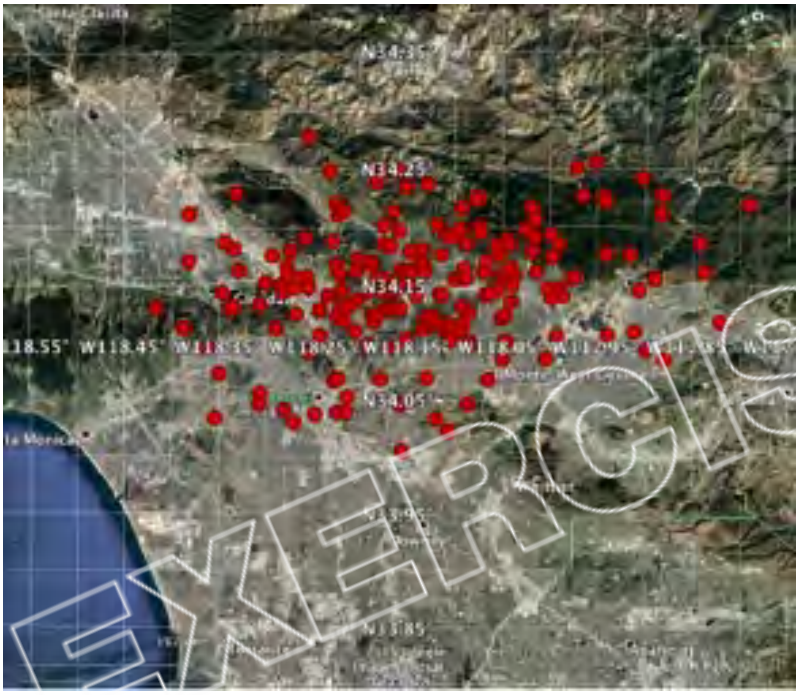

Figure11. Impact area predicted six months before impact.

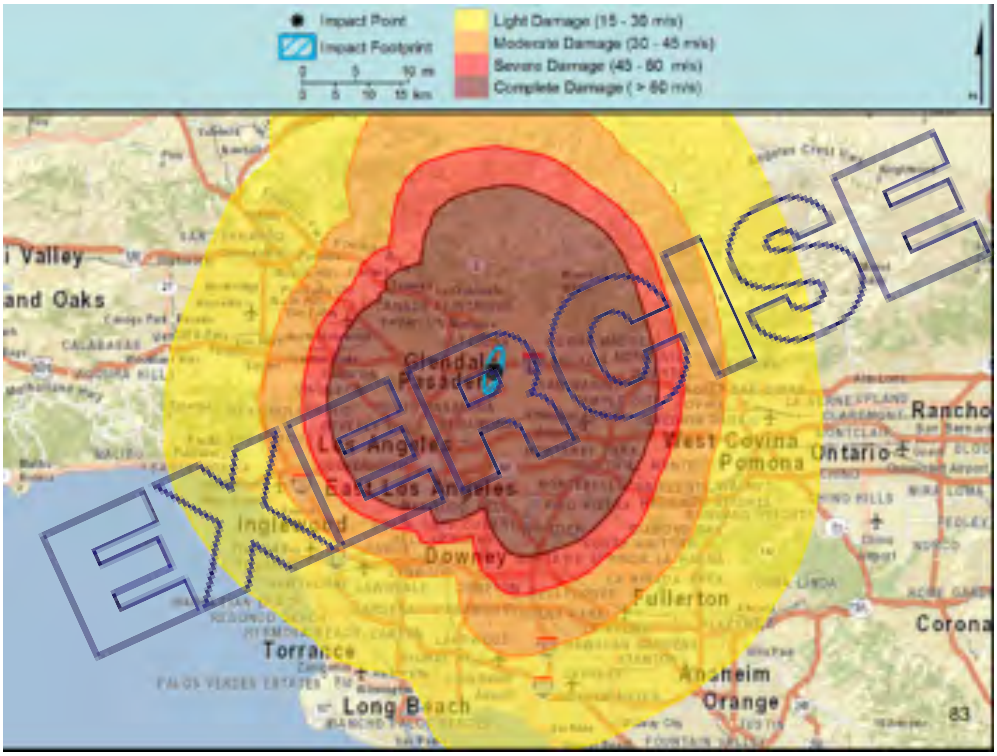

Figure 12. Worst-case hazard zones around assumed impact point.

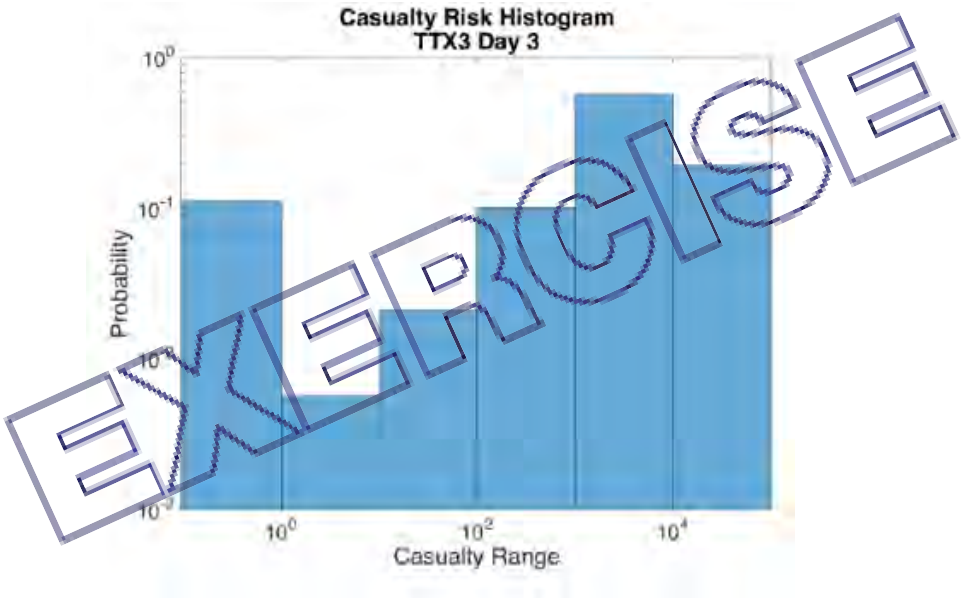

Figure 13. Casualty risk histogram assuming no evacuation and most probable size of asteroid. Over 75% probability of greater than 1,000 casualties.

As expected, a major disaster would also affect transportation and other infrastructure in this area, and presentations included predicted effects to critical transportation, electrical, natural gas, petroleum, chemical, water, ports and rail, health and retirement and emergency response facilities. Detailed charts are given in Appendix C.

At this point, attendees discussed the type of actions required to prepare for a land impact and its aftermath, and these comments and recommendations are included in Section 4.

3.5 Final Impact Estimate

The object became visible to radar 22 days before impact, and the impact point location was refined to be in the region of the red dots shown in Figure 14, which is centered in Pasadena, California, very near the Rose Bowl.

Figure 14. Base on radar observations, the impact locations was refined to that shown.

4. Post-Exercise Feedback

Comments and points of discussion at the conclusion of the exercise are grouped into three categories: Disaster Response, Specific comments, questions, and recommendations are listed below.

4.1 Comments Regarding This Exercise

- This scenario demonstrated that a disaster with so much advance notice will require federal, state and local officials to address unique and complex concerns at a national level. Questions include:
    - How much would it cost to repair Los Angeles?
    - What is the long-term impact to the nation if the Port of Los Angeles is inoperable for an extended period of time?
    - What will the government's role be in regulating private insurance in the predicted impact area?
    - What are the implications of economic and social flight from the predicted impact area in the years before impact?
    - How will we address critical infrastructure concerns?
    - What challenges will we face when implementing evacuation orders (note that State and local officials are the ones making all evacuation decisions, FEMA only supports)?
        - Will states require federal assistance to house displaced evacuees?
        - Will the state want or encourage all citizens to stay in California?
        - Will the state provide temporary housing for those who wish to return to the impacted area?
    - These issues should be discussed in the national strategy being developed by the Interagency Working Group for Detecting and Mitigating the Impact of Earth-Bound Near Earth Objects (DAMIEN)[8].
- We would benefit from involving the FEMA Recovery Directorate in future exercises and meetings (e.g., the DAMIEN Working Group).
- The questions above have far reaching social and economic impacts which extend far beyond California.
- FEMA Office of External Affairs and NASA Office of Communications should work in close coordination.
- FEMA and NASA should brief this TTX to members of DAMIEN and the Planetary Impact Emergency Response Working Group (PIERWG).[9]
- This TTX benefited by the participation of members of FEMA Office of External Affairs and NASA Office of Communications.

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[8] Drew, Benjamin A., "Detecting and Mitigating the Impact of Earth-bound Near-Earth Objects (DAMIEN)," Office of Science and Technology," https://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST/9.25A Drew A..pdf

[9] See "Planetary Impact Emergency Response Working Group (PIERWG) Charter," August 2015. https://www.nasa.gov/sites/default/files/atoms/files/signed_pierwg_charter_10212015.pdf

- Consider hosting a media teleconference at future exercises.
- In this scenario, what is the total cost including homes and infrastructure?
- This scenario has national policy ramifications, both social and economic. For example, how much does it cost to rebuild a major US city?
- Planning for an impact would start by consulting existing procedures for earthquakes, fires, tsunamis, nuclear event, etc.
- Emergency managers who participated in this exercise indicated that the scientists provided sufficient information to begin decision-making in this scenario.

4.2 General Comments

- An asteroid impact would require that many agencies at all levels of government work together toward a common goal.
- The exercises have consistently improved and TTX#3 contained adequate and necessary information for emergency managers to begin decision-making within the scenario.
- Participants would like more details on mitigation techniques and planning options, including the use of nuclear explosive devices.
- A two-day exercise would have allowed for the presentation of more details in some areas and more discussion of options.
- Participants would like to understand the economic impacts to businesses and residences better, including insurance implications.
- International collaboration would be expected and welcomed.
- Buy-in from community leaders would be expected and welcomed.
- This type of hazard may warrant national policy changes to enable more public investment in in-space sensor technology development to allow early detection and characterization of potential threats.

4.3 Informing the Public

- There is a need to improve the communication of risk corridors.
- The 2-year gap in observations in this scenario would likely cause much confusion in the public.
- Historical anecdotes would be helpful to inform public and reduce the number of doubters.
- Public messaging should address public safety far in advance of a predicted impact.
- Communicators should account for those in the public who may distrust the government or who otherwise do not believe official sources.
- Simple visuals to explain complex concepts used in this scenario would be beneficial. The racetrack analogy used in TTX#3 was cited as an example of effectively explaining how two orbiting objects can come together.
- In some cases, the location of a threatening object might prevent observational data necessary for refining the predictions. These situations will need to be carefully explained to the public and decision makers.

- A short 3 to 5-minute video of the exercise as a gateway to other information might be useful way to socialize the threat and response.
- We should consider establishing some standard messages for an impact event, similar to the "National Atmospheric Release Advisory" messages.
- In this scenario, FEMA should message about their specific efforts to protect communities and critical infrastructure to allay fears and address any misinformation.
- We should aim to be as prepared as possible to respond publicly to a predicted impact.
- Consider media teleconferences for future exercises.
- We should publicize NASA's web resources as credible and up-to-date sources of information on this hazard.
- Other relevant resources, such as research papers, should be searchable and accessible.
- A mobile phone app with planetary defense-related games could be quite effective in educating the public on the hazard.
- A realistic dynamic simulation of a hypothetical event, such as that presented in TTX#3, using high-end computer graphics techniques could be orders of magnitude more effective in public messaging than text and still images.
- We should consider using a term other than Potentially Hazardous Asteroid (PHA) so we do not imply an immediate threat; e.g., High Interest Asteroid (HIA) or High Interest Object (HIO).

4.4 Future Exercises

- Consider use of social media to expand awareness of the exercise and the hazard more broadly and efficiently. Also consider other ways to promote these exercises in media.
- It was invaluable having emergency managers in the room. We should try to increase state and local participation in future exercises.
- The two-year TTX schedule seems to be sufficient, but should we do something in the gap years as well?
- A repeat of this exercise, possibly at the national level and modified for an East Coast threat, should be considered for presentation in D.C. in the next 3-4 months. Representatives of utilities, transportation, community leaders, insurance companies, legal professionals, and other interests should be invited to participate. This might be most useful after the new administration is in place.
- We should consider involving representatives from foreign governments, United Nations, International Red Cross, etc. in future exercises.
- We should provide more insight into the operational scenario, particularly in terms of how command, control and communication between multiple players from different organizations are carried out.
- We should consider involving deflection opportunities in future exercise scenarios.
- Future exercises should be two days long and have participants break-out in groups after the first notification four years out, so groups can discuss the scenario.

- Future exercises should include Homeland Security representatives, emergency response representatives, and members of the DAMIEN group.
- The frequency and content of briefs and press releases should be exercised more thoroughly.
- Materials for pre-reading have enhanced these exercises.
- FEMA Office of External Affairs and NASA Office of Communications should be involved in all future exercises.

5. Recommendations

- Since messaging is so challenging, a global, multi-stakeholder campaign for promoting awareness and educating the public in all aspects of the NEO threat could be an invaluable public service.
- Communications will be very challenging for an actual event. We should exercise the communication part in more detail. Clearer and simpler material should be developed for public distribution.
- There should be increased visibility of these exercises within FEMA.
- The public should be aware of FEMA's participation in these exercises, as it will help the public develop some confidence in our ability to deal with such an emergency.
- If such a threat is discovered, there will likely be uninformed and inaccurate information posted on the Internet and in media. We should continue to publicize and develop trusted and authoritative sources of information. For an actual NEO impact threat, the possibility of standing up a trusted NEO Threat TV Channel or a single Internet website focused on the situation should be considered.
- A workshop for members of the media to inform them of the asteroid impact hazard should be considered.
- See Appendix D for a summary of a table top exercise conducted as a follow-on to Tabletop #3 for NASA and FEMA public affairs and communications professional staff.

APPENDIX A. Organizers and Attendees

Organizers

The team below developed TTX #3. Specific contributions were provided by:

William Ailor, The Aerospace Corporation, Exercise Script and Coordination
Mark Boslough, Sandia National Laboratories, Physical Effects of Impac
Paul Chodas, NASA Jet Propulsion Laboratory, Asteroid Threat Desig
Barbara Jennings, Sandia National Laboratories, Infrastructure Effects
Lindley Johnson, NASA Headquarters, Overall Guidance
Leviticus A. Lewis, FEMA Headquarters, Overall Guidance
Donovan Mathias, NASA Ames Research Center,
Nahum Melamed, The Aerospace Corporation, Deflection Modelin
Paul Miller, Lawrence Livermore National Laboratory,

Attendees

NAME	POSITION, ORGANIZATION
David Agle	Public Affairs Officer, NASA JPL
William Ailor	The Aerospace Corporation
Josie Arcurio	FEMA Region IX External Affairs
Linda Billings	Public Communications Consultant, NASA HQ
Mark Boslough	Sandia National Laboratories
Dan Bout	California Governor's Office of Emergency Services
Craig Burkhard	Asteroid Threat Assessment Project, NASA-Ames
Laurie Cantillo	Office of Communications, NASA HQ
Paul Chodas	Director, Center for NEO Studies, NASA JPL
Casey Deshong	FEMA Region IX External Affairs
Kelly Fast	NEO Observations Program Manager, NASA HQ
Victoria Friedensen	PDCO Program Executive, NASA HQ
Phil Groves	IMAX
Barbara Jennings	Sandia National Laboratories
Lindley Johnson	Planetary Defense Officer, NASA HQ
Tara Kane	FEMA HQ
Zigmond Leszcczynski	The Aerospace Corporation
Leviticus Lewis	FEMA HQ
Maj. Timothy Locke	USAF AFSPC SMC/ADYT
Donovan Mathias	Asteroid Threat Assessment Project, NASA Ames
Veronica McGregor	Public Affairs Officer, NASA JPL
Nahum Melamed	The Aerospace Corporation
Paul Miller	Lawrence Livermore National Laborator
Roy Nakagawa	The Aerospace Corporation
Jan Osburg	RAND Corporation
Tim Scranton	FEMA Region IX
Melissa Wiehenstroer	FEMA Presidential Management Fellow, NASA HQ

APPENDIX B. Press Releases

EXERCISE – EXERCISE – EXERCISE

This message is released as part of an exercise in a fictional scenario.

TTX 3 Official NASA Notification, Inject 1

On October 1, 2016, an object estimated to be about 100-250 meters in size, based only on its observed brightness, was discovered by astronomers at the Catalina Sky Survey of the University of Arizona, Tucson. Information on the detection of the object and its calculated orbit was provided to the NASA Planetary Defense Coordination Office (PDCO) by the International Astronomical Union sanctioned Minor Planet Center, hosted by the Smithsonian Astrophysical Observatory in Cambridge, MA. Based on observations conducted worldwide since then, the NASA Jet Propulsion Laboratory's Center for Near-Earth Object Studies (CNEOS) (www.neo.jpl.nasa.gov) has calculated a 2 percent possibility of impact (equivalent to a 98 percent probability of no impact) on September 20, 2020.

Data currently available on 2016 TTX are insufficient to enable experts to say exactly if impact might occur in 2020 and if so, where impact would occur on Earth's surface. The area of Earth where impact might occur – which experts refer to as a "risk corridor" – now stretches across the United States, the Atlantic Ocean, and Africa. Further observations of 2016 TTX are critical to enable asteroid experts to more precisely determine its future orbit path, assess the size of this object, and determine its other characteristics – for instance, its composition and the object's rotation rate – to narrow the possibility of if and where it could impact the Earth and what the effects could be. Once observers are able to collect more data on the object, asteroid science experts will perform analysis to determine if the object is actually on an impact trajectory and if it is large enough to do significant damage at Earth's surface.

For most of its orbit around the Sun, 2016 TTX is inside Earth's orbit, making its position as viewed from Earth in the sunward half of the sky. 2016 TTX is therefore difficult to see by ground-based telescopes. However, observers will be able to track it in the night sky until January 2017, when it will become too dim to be seen. NASA will collaborate with its partners in other US government agencies and the International Asteroid Warning Network to obtain addition information on 2016 TTX and will issue updates on what is determined about the object and its future path as significant data become available.

This message is released as part of an exercise in a fictional scenario.

EXERCISE – EXERCISE – EXERCISE

EXERCISE-EXERCISE-EXERCISE

This message is released as part of an exercise in a fictional scenario.

TTX 3 press release, Inject 2

Asteroid 2016 TTX probability of impact in 2020 rises to 65 percent

January 10, 2017, Cambridge MA – The International Asteroid Warning Network (IAWN) announced today that based on nearly a hundred observations worldwide over the past three months experts calculate that the Potentially Hazardous Asteroid (PHA) 2016 TTX now has a 65 percent probability of impact with Earth on September 20, 2020. Furthermore, the asteroid has moved into the glare of the Sun and will not be observable for several months.

2016 TTX, now estimated to be between 100 and 250 meters in size, was discovered by astronomers at the Catalina Sky Survey of the University of Arizona, Tucson, on October 1, 2016. Observations last November also revealed that the asteroid is a stony "S-class" object, probably with some metal content.

Last October, based on the observations of 2016 TTX available to that point, the Jet Propulsion Laboratory's Center for Near-Earth Object Studies (CNEOS) (http://neo.jpl.nasa.gov) estimated a 2 percent probability of impact (or a 98 percent probability of no impact) on September 20, 2020. The asteroid has been tracked almost continually since then, and its orbit path into the future continually refined. As the range of possible positions of the asteroid in 2020 has increasingly converged toward the point where the Earth will also pass, the impact probability has risen. With the additional data now in hand, CNEOS estimates the probability of impact has reached 65 percent.

It has also been announced that the Space Missions Planning Advisory Group (SMPAG), a forum of the world's space agencies, would start to plan possible deflection mission activities based on the current IAWN warning exceeding the established threshold of a 1 percent or greater probability of impact of an NEO within the next 50 years and the object being greater than 50 meters in size.

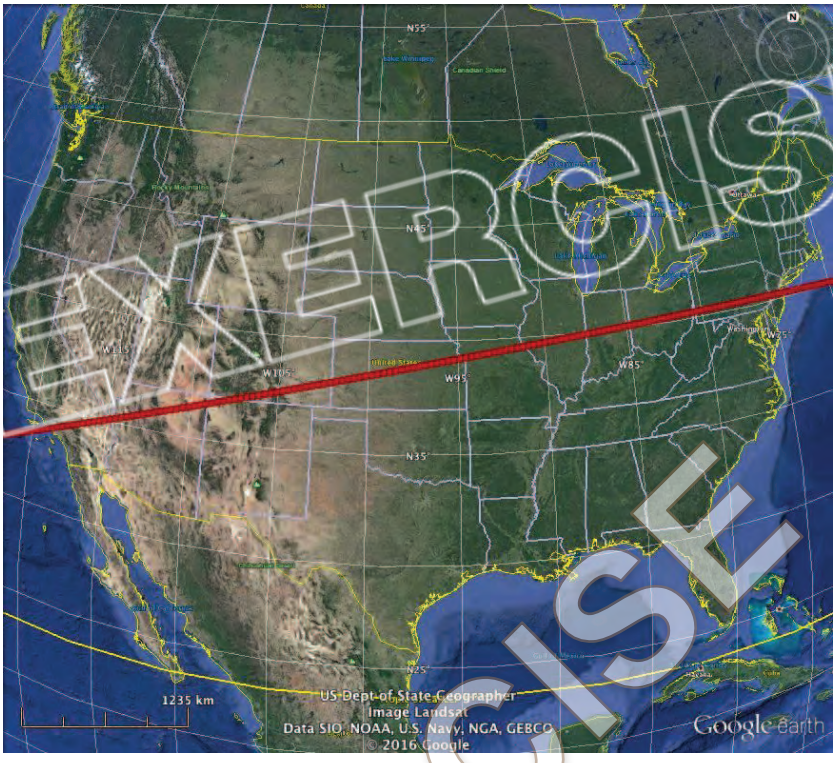
NASA's Planetary Defense Coordination Office (PDCO) has also published a so-called "risk corridor" – a long narrow region across the Earth where impact might occur. The path of possible impact points extends halfway around the globe, stretching from the Pacific Ocean, diagonally across the continental United States from southern California to New Jersey (see diagram below). It then continues across the Atlantic Ocean and on to Africa.

This message is released as part of an exercise in a fictional scenario.

EXERCISE – EXERCISE – EXERCISE

EXERCISE-EXERCISE-EXERCISE

This message is released as part of an exercise in a fictional scenario.



Since the risk corridor passes across U.S. territory, NASA's PDCO will work with the U.S. Federal Emergency Management Agency (FEMA's) National Response Coordination Center on planning for terrestrial preparedness and mitigation. To support mitigation planning, experts across the country will work on modeling the characteristics and effects of different types of impact – atmospheric impacts over water or over land and surface impacts on water or on land, all of which are possibilities at this point. "The more we can learn about this asteroid, the better able we will be to accurately predict the precise location of impact as well as impact effects," said Lindley Johnson, NASA's Planetary Defense Officer.

For most of its orbit around the Sun, 2016 TTX is inside Earth's orbit, making its position generally sunward as viewed from Earth. 2016 TTX has now entered that part of the sky and cannot be observed by ground-based telescopes. 2016 TTX has now moved too close to the Sun and is lost in its glare, but it will re-emerge in June. Once astronomers observe the asteroid again, orbit experts will update the impact probability predictions, either eliminating the risk of impact or confirming that an impact could still occur and provide update of the extent of the risk corridor. The IAWN will announce those results as soon as they are available.

This message is released as part of an exercise in a fictional scenario.

EXERCISE – EXERCISE – EXERCISE

EXERCISE – EXERCISE – EXERCISE

This message is released as part of an exercise in a fictional scenario.

TTX 3 press release, Inject 2:

Asteroid headed for impact near Southern California now moving out of view

November 25, 2017, Cambridge MA – The International Asteroid Warning Network (IAWN) announced today that based on hundreds of observations gathered worldwide over the past year experts now conclude that asteroid 2016 TTX will impact somewhere in the Southern California or nearby Pacific Ocean region on September 20, 2020. Because the asteroid has again moved far away from the Earth and into the glare of the Sun, no further updates will be possible until it re-emerges nearly two years from now.

Astronomers at the Jet Propulsion Laboratory's Center for Near Earth Object Studies (CNEOS) concluded last June that an Earth impact was nearly certain, and since then have narrowed down the area of likely impact, first to the western hemisphere, then to the western United States, and now to an ellipse stretching across southern California and the nearby Pacific Ocean (see below).

2016 TTX is believed to be a stony and possibly metal-rich asteroid roughly 100 to 250 meters in size. It was discovered just a year ago by astronomers at the Catalina Sky Survey of the University of Arizona, Tucson.

This message is released as part of an exercise in a fictional scenario.

EXERCISE – EXERCISE – EXERCISE

This message is released as part of an exercise in a fictional scenario.

Experts say an object of the estimated size and composition of 2016 TTX could break up and explode as it streaks through the atmosphere, but a few large fragments would likely survive and impact the ground. However, they calculate that the explosion (called an airburst) could release as much as 450 Megatons of TNT equivalent energy. The resulting air-blast will likely cause total destruction within a 20-kilometer (15 mile) radius and produce major damage over a 40-kilometer (25 mile) radius from the center of the ground-point of the blast.

The U.S. National Aeronautics and Space Administration (NASA) will launch a spacecraft to 2016 TTX that will do a fast fly-by of the asteroid and collect data that will enable a more in-depth characterization. The tentative launch date for the mission, called BOSSSA – Body dynamics, Orbital path, Size, Shape, and Structure Assessment – is March 21, 2019. The spacecraft is scheduled to encounter the asteroid in February 2020. "The more we can learn about this asteroid, the more accurately we can predict both the precise location of impact and the impact effects," said Lindley Johnson, NASA's Planetary Defense Officer.

To support impact mitigation planning, experts across the country are refining their models of the characteristics and effects of different types of impact – atmospheric impacts over water or over land and surface impacts on water or on land, all of which are still possibilities at this point. Because the impact will occur in the United States, NASA's Planetary Defense Coordination Office (PDCO), which is a member of the IAWN, has the lead on providing up-to-date information on 2016 TTX. The U.S. Federal Emergency Management Agency (FEMA) has activated its National Response Coordination Center (NRCC) to prepare for a large-scale catastrophic event that is now certain to occur unless the asteroid could be deflected while still in space.

"The President of the United States has directed FEMA to lead the response effort and be prepared to execute with state and local officials plans to minimize and mitigate the effects on human life and critical infrastructure," says NRCC Director Leviticus Lewis. "The PDCO will work closely with FEMA and continue to coordinate observations of and communications about 2016 TTX as the information becomes available," says NASA Planetary Defense Officer Johnson.

Asteroid 2016 TTX spends most of its time inside Earth's orbit, placing it in the sunward part of the sky as viewed from Earth and making it difficult to see from ground-based telescopes. 2016 TTX has now moved out of view but it will come back into view in October 2019. 2016 TTX will then remain observable from October 2019 until March 2020, after which time CNEOS will further refine its prediction of where the impact could occur. The IAWN will then announce those results.

EXERCISE – EXERCISE – EXERCISE

This message is released as part of an exercise in a fictional scenario.

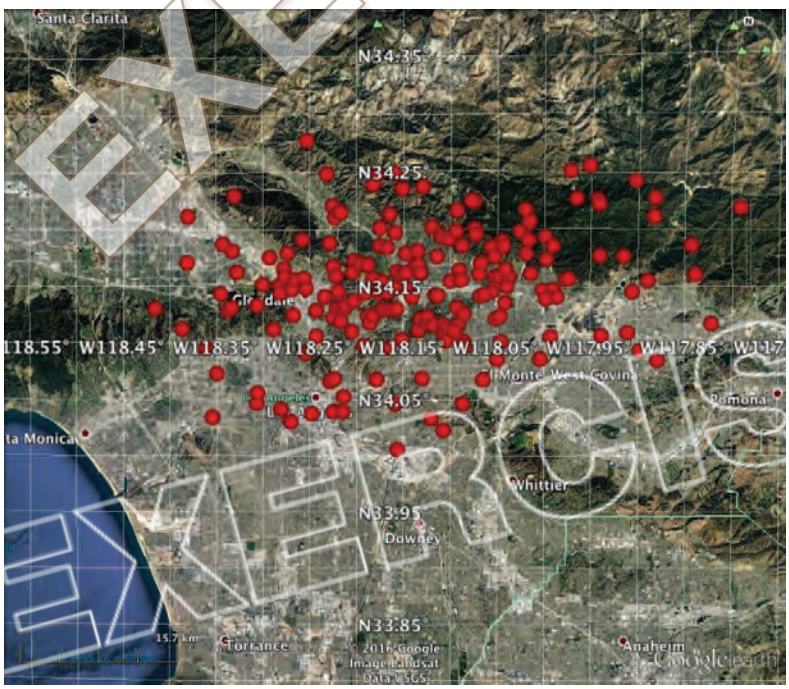
TTX 3 press release, inject 3

Asteroid impact will occur in greater Los Angeles area September 20th

March 10, 2020, Cambridge MA – The International Asteroid Warning Network (IAWN) announced today that based on observations taken worldwide since October 2016 and now by a spacecraft fly-by, orbit prediction experts have determined that the September 20, 2020, impact of asteroid 2016 TTX will occur over land in the greater Los Angeles area.

The U.S. National Aeronautics and Space Administration's (NASA's) BOSSSA (Body dynamics, Orbital path, Size, Shape, and Structure Assessment) spacecraft flew by 2016 TTX in February, collecting data that experts used to improve their predictions of the location and effects of the impending impact. The BOSSSA data confirms the asteroid is roughly 120 meters in size.

Based on the BOSSSA data used to update ground-based observations of the asteroid from October 2019 until this month, the Jet Propulsion Laboratory's Center for Near Earth Object Studies (CNEOS) has narrowed down the area of impact to a region roughly 40 kilometers (25 miles) long by 20 kilometers (13 miles) wide, stretching across the greater North Los Angeles area (see below). The impact region is highlighted by the red dots in this depiction, each a possible impact point. Since the asteroid has again moved into the glare of the Sun and can no longer be observed by ground-based optical telescopes, further improvements on these predictions will not be possible until roughly a month before impact, when the asteroid approaches within range of the Arecibo planetary radar.



This message is released as part of an exercise in a fictional scenario.

EXERCISE – EXERCISE – EXERCISE

EXERCISE – EXERCISE – EXERCISE

This message is released as part of an exercise in a fictional scenario.

To support impact disaster planning, experts across the country are refining their models of the characteristics and effects of an impact of an object the size and type of 2016 TTX. Experts say an object of the size and composition of 2016 TTX could break up and explode as it streaks through the atmosphere, but a few large fragments would likely survive and impact the ground. However, they calculate that the explosion (called an airburst) will release as much as 50 Megatons of TNT equivalent energy. The resulting air-blast will likely cause total destruction within a 10-kilometer (7 mile) radius and produce major damage over a 25-kilometer (16 mile) radius from the center of the ground-point of the blast.

During the few weeks before impact, 2016 TTX will be approaching Earth from the direction of the Sun, so ground-based optical telescopes will not be able to observe it. However, radio telescopes equipped with radar transmitters will be able to observe the object, and the radar observations should be able to collect enough data on the asteroid to produce an image of it, finalize its orbital path, and precisely measure its size, shape, and body dynamics.

Because the impact will occur in the United States, NASA's Planetary Defense Coordination Office (PDCO), which is a member of the IAWN, has the lead on providing any current information on 2016 TTX as it becomes available. The U.S. Federal Emergency Management Agency's (FEMA's) National Response Coordination Center (NRCC) is working with FEMA Region 9, headquartered in Pasadena, California, to prepare for a certain large-scale catastrophic event.

This message is released as part of an exercise in a fictional scenario.

EXERCISE – EXERCISE – EXERCISE

APPENDIX C. Presentation Charts

3rd Annual FEMA-NASA Near Earth Object Impact Table Top Exercise

The Aerospace Corporation
October 25, 2016

Agenda, October 25

TIME	SPEAKER	TOPIC
0800	Welcome (Bill Ailor, Aerospace)	Introductions
0805	Lindley Johnson (NASA)	NASA's Planetary Defense Coordination Office and NASA's program addressing the NEO hazard
0820	L.A. Lewis (FEMA)	Introduction to the exercise, goals, expectations
0900	Bill Ailor (Aerospace)	Introduce team. Describe exercise flow
0910	Paul Chodas (JPL)	Overview of threat described in press release provided with read-ahead material
0925	Donovan Mathias (NASA-Ames)	Possible impact areas
0930	BREAK	
1000	Paul Chodas (JPL)	2nd Inject
1015	Nahum Melamed (Aerospace)	Deflection possibilities
1020	Mark Boslough (Sandia)	First-look charts on physical effects of entry of observed object
1035	Paul Miller (LLNL)	Tsunami
1045	Barbara Jennings (Sandia)	Tsunami effects
1050	Donovan Mathias (NASA-Ames)	Risk Assessment, Population affected
1100	Group Discussions	
1200	LUNCH	
1245	Group Feedback	
1330	Paul Chodas	Final Inject
1345	Mark Boslough	Physical effects in predicted impact area
1355	Donovan Mathias	Population displaced
1405	Barbara Jennings	Infrastructure affected
1415	BREAK	
1445	Group Discussions	
1545	Group Feedback	
1630	EXERCISE ENDS	

Wednesday, October 26: Hot Debrief & Lessons Learned. 9:00 AM Same Room. Check in at 8:30 AM

william.h.ailor@aero.org

Planetary Defense Coordination Office (PDCO)

Lindley Johnson
Program Executive / Planetary Defense Officer
Science Mission Directorate
NASA HQ
October 25, 2016

Planetary Defense Coordination Office

This new office was recently established at NASA HQ to coordinate planetary defense related activities across NASA, and coordinate both US interagency and international efforts and projects to address and plan response to the asteroid impact hazard.

Planetary Defense Coordination Office Mission Statement:

Lead national and international efforts to:

- Detect any potential for significant impact of planet Earth by natural objects
- Appraise the range of potential effects by any possible impact
- Develop strategies to mitigate impact effects on human welfare

Planetary Defense Coordination Office

The PDCO is responsible to:

- Ensure early detection of potentially hazardous objects (PHOs) – asteroids and comets whose orbits are predicted to bring them within 0.05 AU of Earth's orbit - and characterize PHOs of size large enough to affect Earth's surface to provide warning of potential impact effects if not deflected or mitigated
- Provide timely and accurate communications about PHOs and any potential impact
- Lead research into potential asteroid deflection and impact mitigation technologies and techniques
- Provide lead coordination role in U.S. Gov't planning for response to an actual impact threat (*e.g.,* planetary science and deep space mission expertise for Federal Emergency Response Team).

The PDCO:

- Manages NASA's Near-Earth Object Observations Program to obtain best data available
- Coordinates NEO observation efforts conducted at ground-based observatories sponsored by the National Science Foundation and space situational awareness facilities of the USAF
- Participates in federal agency exercises to plan and develop appropriate impact response
- Conducts collaborative research on mitigation techniques with interagency and international partners

5

NASA's NEO Search Program

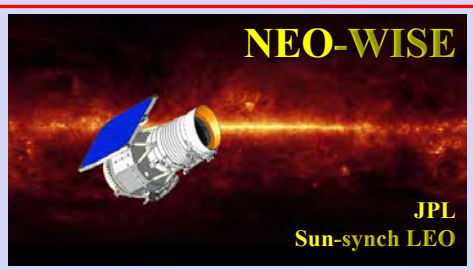
(Current Survey Systems)

Minor Planet Center (MPC)
- IAU sanctioned
- Int'l observation database
- Initial orbit determination

http://minorplanetcenter.net/

Center for NEO Studies @ JPL
- Program coordination
- Precision orbit determination
- Automated SENTRY

http://neo.jpl.nasa.gov/



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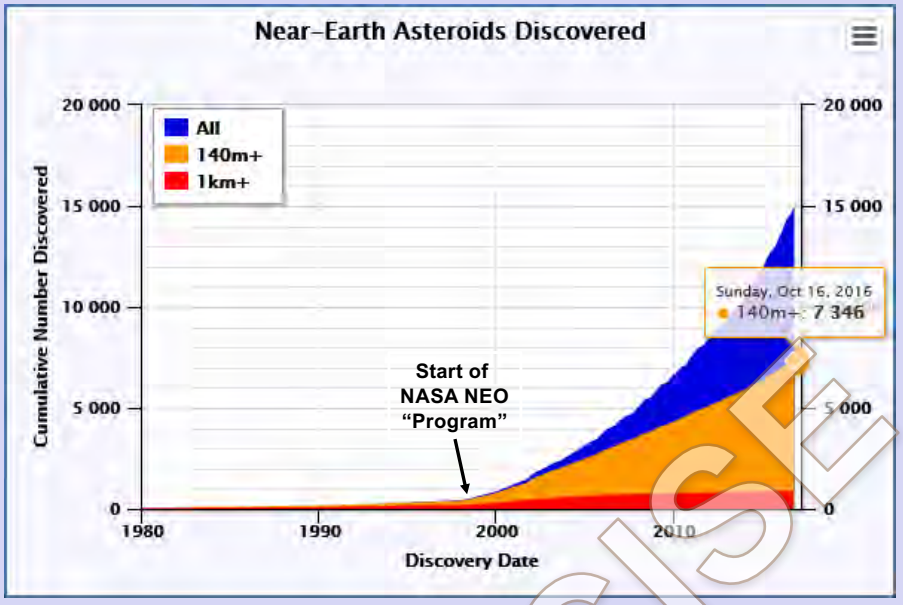
Known Near Earth Asteroid Population



As of 10/16/2016
15,008

Also 107 comets

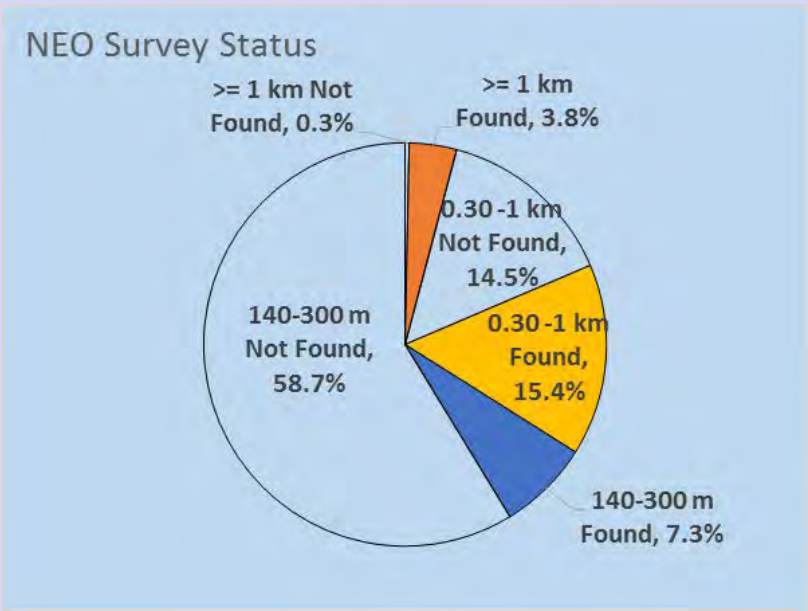
1740 Potentially Hazardous Asteroids
Come within 5 million miles of Earth's orbit

875 >1km
157 PHAs

7

Near Earth Asteroid Survey Status

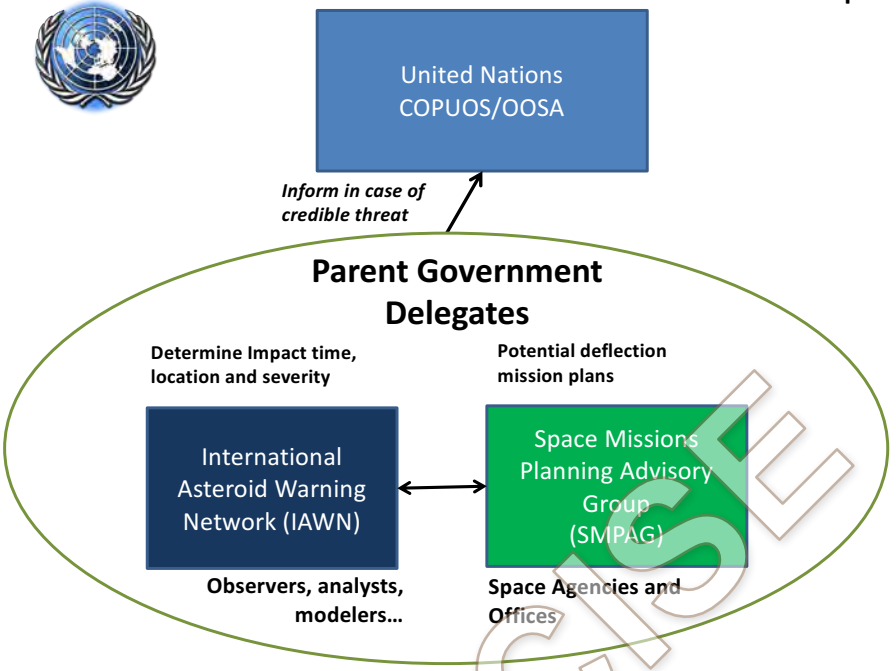
If Population >= 140 meters in estimated size is ~ 25,500 = 100%



8

UN Office of Outer Space Affairs
Committee on Peaceful Uses of Outer Space

Overview for NEO Threat Response



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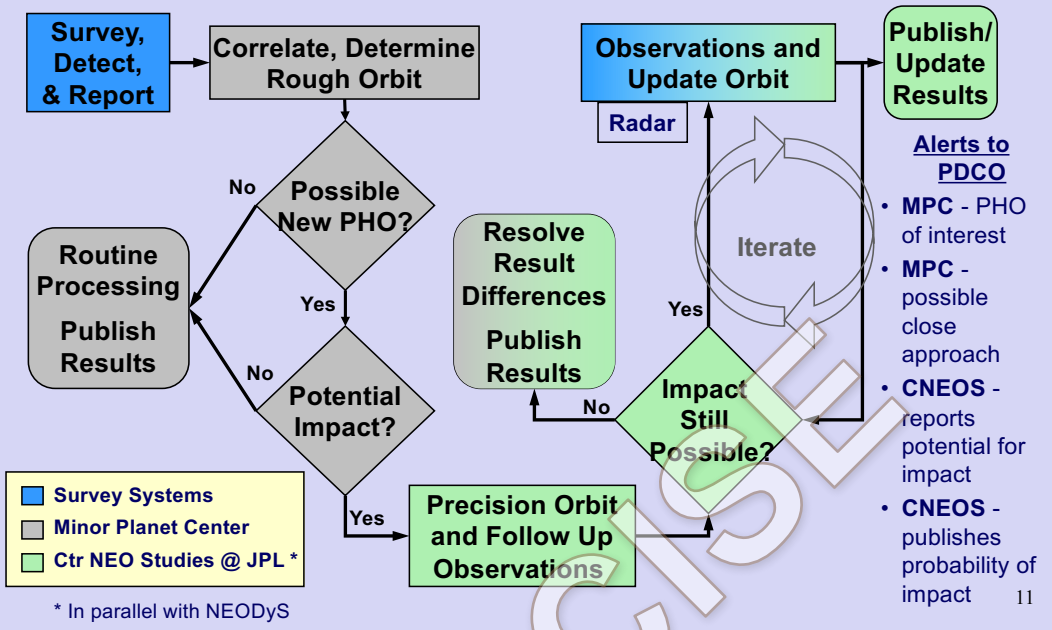
Planetary Defense Coordination Office

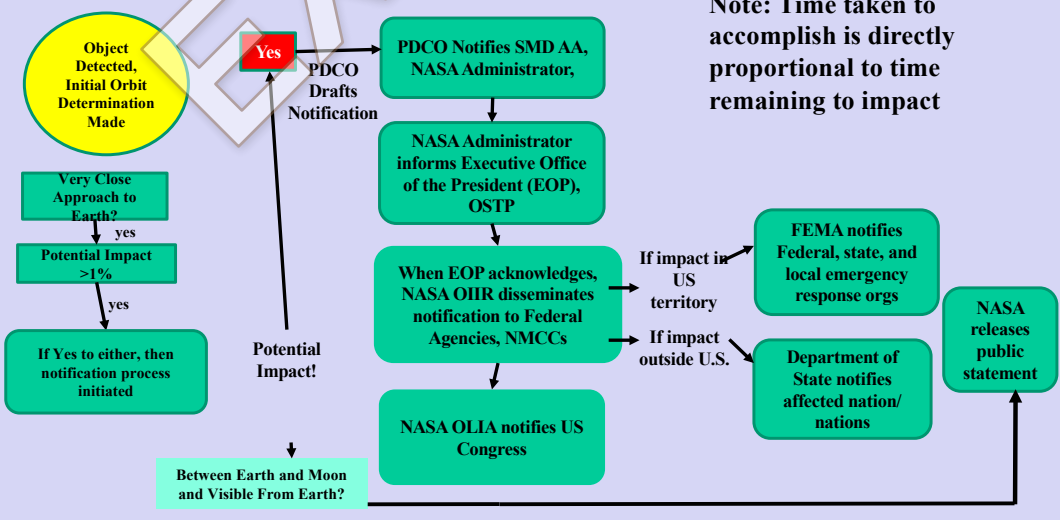
Rapid Notification Process

10

NEOO Survey and Alert Process



Planetary Defense Coordination Office Potential Impact Notification Process



3rd Annual FEMA-NASA Near Earth Object Impact Table Top Exercise

October 25, 2016

FEMA

FEMA/NASA Third Near Earth Object Impact Tabletop Exercise October 25-26 2016, The Aerospace Corporation, El Segundo, CA

Overview

- NASA HQ SMD Planetary Sciences Division, Planetary Defense Coordination Office has partnered with the FEMA Response Directorate in a series of tabletop exercises discussing the impact of a NEO in the United States.
- FEMA and NASA have been cooperating since June 2010 on developing procedures for this scenario as required by Congress.
- Emphasis on previous exercises was to provide a basic overview of this scenario to FEMA executives, ESFLG and LNO Action officers. This exercise will emphasize interactions with the FEMA Regional staff and interaction with state, local, tribal emergency management officials.
- Purpose of exercise is to assess leadership reactions, information requirements and responses to a hypothetical prediction of a potentially hazardous object (PHO) impact with Earth in a short time.

15

Overview

- Joint efforts include formation of the Planetary Impact Emergency Response Working Group (PIERWG), cooperation on the OSTP sponsored National Preparedness Science and Technology Task Force-Space Hazard Review Team and the Interagency Working Group For Detecting and Mitigating the Impact of Earth Bound Near Earth Objects (DAMIEN). The DAMIEN Working Group is currently developing a National Strategy and Action Plan for this scenario.
- Lessons learned from the previous tabletops and this tabletop in particular due to the invited members of state and local emergency management agencies would be used to inform the national strategy and action plans being developed by the FEMA-NASA PIERWG and the DAMIEN Working Group.

16

FEMA-NASA 3rd NEO TTX

- **Critical Considerations in Response and Recovery for State and Local Officials**
  - Notifications
  - Prioritization
  - Public nonobservance of Instructions
  - Situational Awareness
  - Social Media
  - Limited Deployment Capability(Federal State Local Emergency Responders
  - Weather
  - Continuity (City-County-State Governments)
  - Access to Scene
  - Debris Management
  - Public Information to Relocated Individuals, Households and Host Communities
  - Economic Impacts

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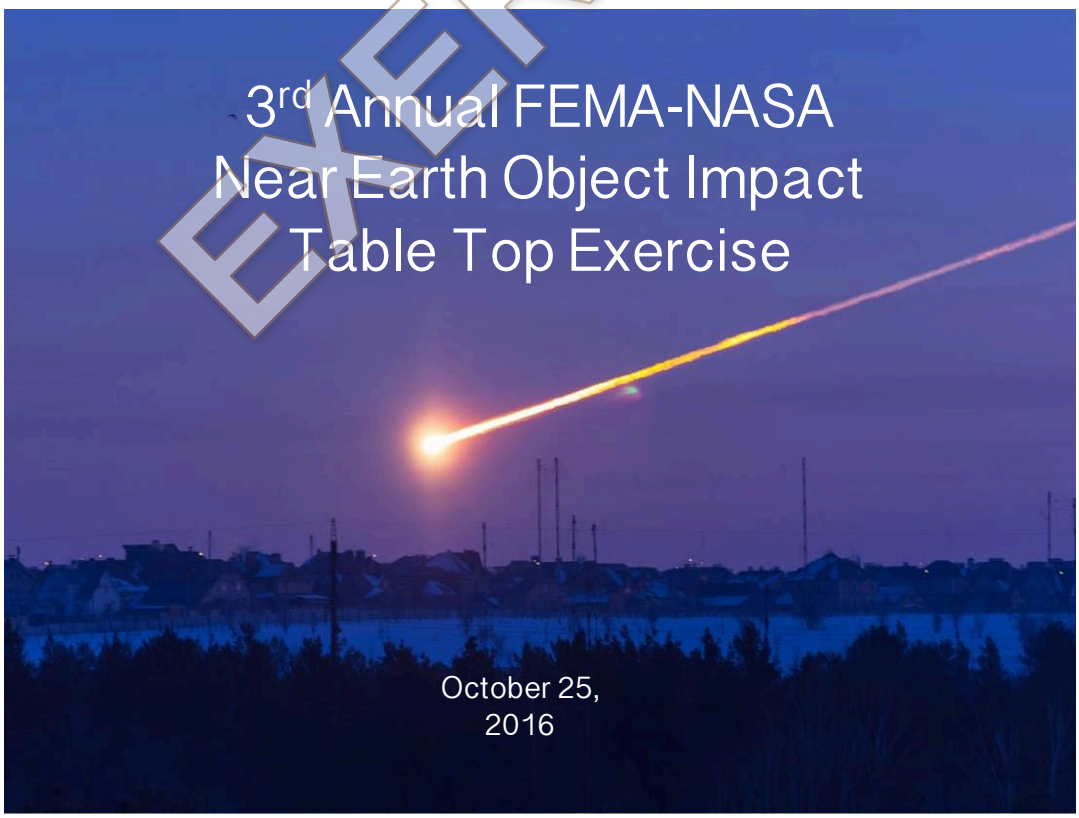
FEMA-NASA 3rd NEO TTX

- **Critical Considerations (continued)**
  - Insurance
  - Emphasis on Local Primacy in Recovery
  - Permanent Relocation
  - Interstate/Intrastate Coordination
  - Operating in the Damaged Zone
  - Devastated Infrastructure
  - Coordination of Programs and Services
  - Public and Private Capability

18

FEMA-NASA 3rd NEO TTX

- **Key Issues for Coordinated Federal Decision-making**
  - Public Information and Warning
  - National Insurance Policy
  - Disposition of the Severe Damage Zone
  - Sheltering
  - Emphasis on Local Primacy in Recovery
  - Permanent Relocation
  - Interstate/Intrastate Coordination
  - Operating in the Damaged Zone
  - Devastated Infrastructure
  - Coordination of Programs and Services
  - Public and Private Capability



Agenda, October 25

TIME	SPEAKER	TOPIC
0800	Welcome (Bill Ailor, Aerospace)	Introductions
0805	Lindley Johnson (NASA)	NASA's Planetary Defense Coordination Office and NASA's program addressing the NEO hazard
0820	L.A. Lewis (FEMA)	Introduction to the exercise, goals, expectations
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1630	EXERCISE ENDS	

Wednesday, October 26: Hot Debrief & Lessons Learned. 9:00 AM Same Room. Check in at 8:30 AM

Primary Team Members

NAME	ORGANIZATION
Bill Ailor*+	The Aerospace Corporation
Linda Billings	NASA HQ
Mark Boslough*	Sandia National Laboratories
Craig Burkhard	NASA Ames Research Center
Paul Chodas*	NASA Jet Propulsion Laboratory
Souheil Ezzedine	Lawrence Livermore National Laboratory
Victoria Friedensen	NASA HQ
Barbara Jennings*	Sandia National Laboratories
Lindley Johnson*	NASA HQ
L.A. Lewis*	FEMA HQ
Donovan Mathias*	NASA Ames Research Center
Nahum Melamed	The Aerospace Corporation
Paul Miller*	Lawrence Livermore National Laboratory
Jan Osburg	The RAND Corporation
Megan Bruck Syal	Lawrence Livermore National Laboratory

*Presenter *+Organizer

Exercise Flow

- Threat used is feasible and realistic, but not necessarily representative of real threat
  - *Warning time could be much longer or shorter, or in some cases there would be no warning*
  - *Object could be larger (more warning likely), or smaller (could be no warning; e.g., Chelyabinsk, Tunguska)*
  - *Consequences could range from none (ocean impact of relatively small object) to local/regional disaster of type that might result from scenario described in this exercise*
- Information on threat will be presented as it might be for a real threat
- Presentations will provide basic details on information available and potential consequences; questions invited
- L.A. Lewis will lead exercise participants in discussions of preparations, etc.
- Participants will provide feedback on recommendations at end of discussion period
- Experts available to answer questions

william.h.ailor@aero.org

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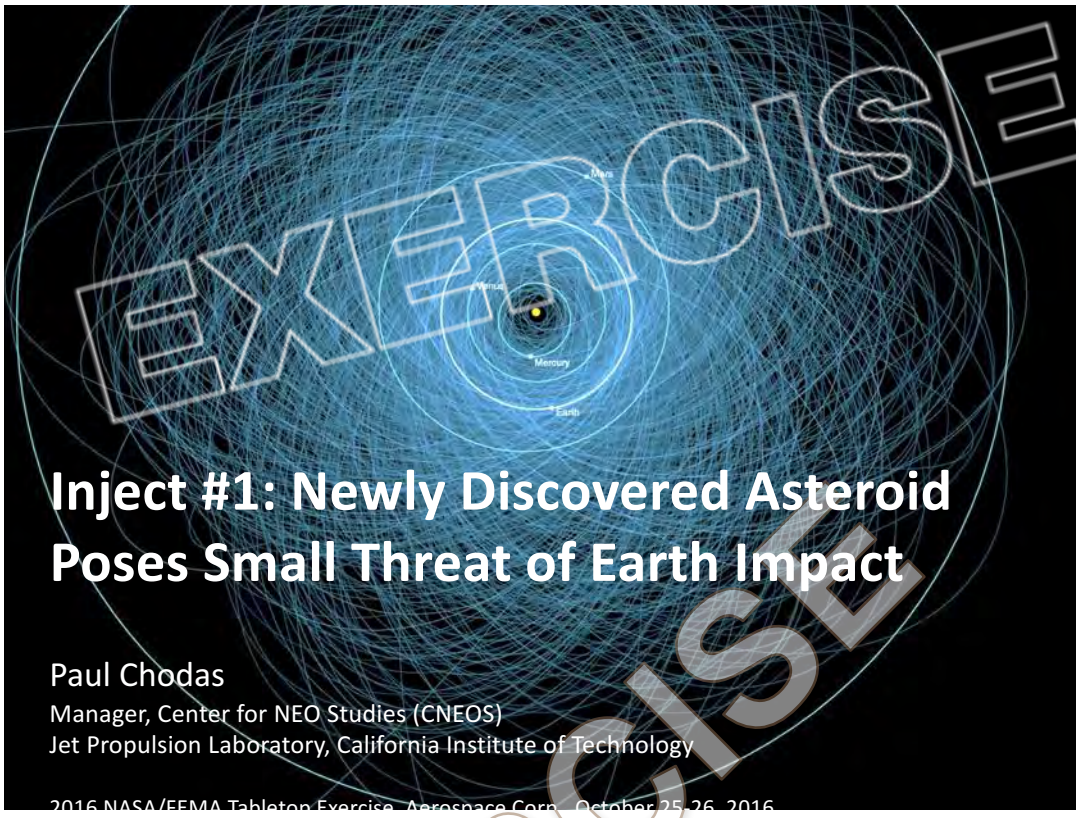
Assuring Mission Success

Inject #1:
October 25, 2016
~4 Years Before Possible Impact

Paul Chodas, JPL



Inject #1: Newly Discovered Asteroid Poses Small Threat of Earth Impact

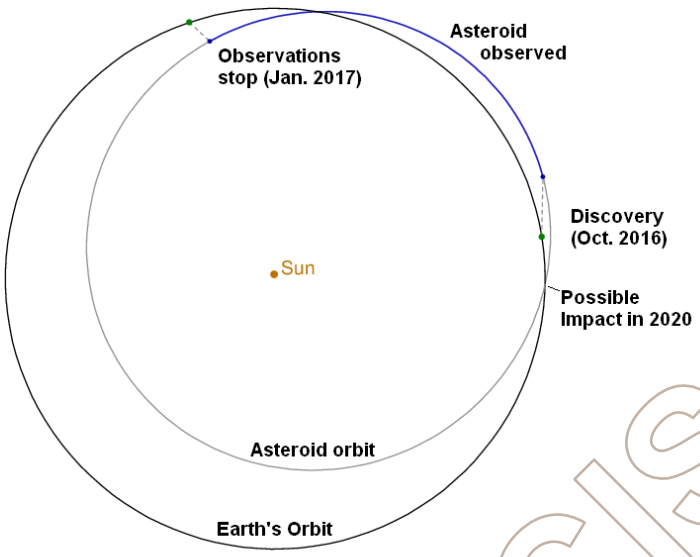
Paul Chodas
Manager, Center for NEO Studies (CNEOS)
Jet Propulsion Laboratory, California Institute of Technology

2016 NASA/FEMA Tabletop Exercise, Aerospace Corp., October 25-26, 2016

Asteroid "2016 TTX"

- **Asteroid Discovered** on Oct. 1, 2016 by the Catalina Sky Survey, near Tucson
- Followed up and confirmed by dozens of observatories around the world
- Approximate orbit and rough size known within a day:
  - Asteroid orbits the Sun once every 295 days or so (it orbits faster than our planet)
  - Orbit comes close to Earth ➔ **Potentially Hazardous Asteroid (PHA)**
  - Asteroid size, based on its brightness: **100 to 300 meters (300 to 1000 feet)**
- Within a couple days, IAWN detects a small chance of impact on **Sep. 20, 2020**
- As asteroid is tracked, its chance of impact rises: **0.1%** on Oct. 7, **1%** on Oct. 13
- Even though orbital motion is very predictable, the data don't reveal exactly where the asteroid is and exactly how fast its going, so we can't be sure exactly where the asteroid will be when the Earth crosses its orbit on Sep. 20, 2020
- Predicting an asteroid impact is a little like predicting a crash on two intersecting race tracks, while we're in one racecar observing the other car

Orbit of 2016 TTX



Asteroid orbits Sun mostly inside Earth's orbit

Orbit period: 295 d

After the asteroid orbits almost 5 times, and Earth almost 4 times, they will come very close on Sep. 20, 2020

Size: 100 – 300 m

EXERCISE ONLY!!

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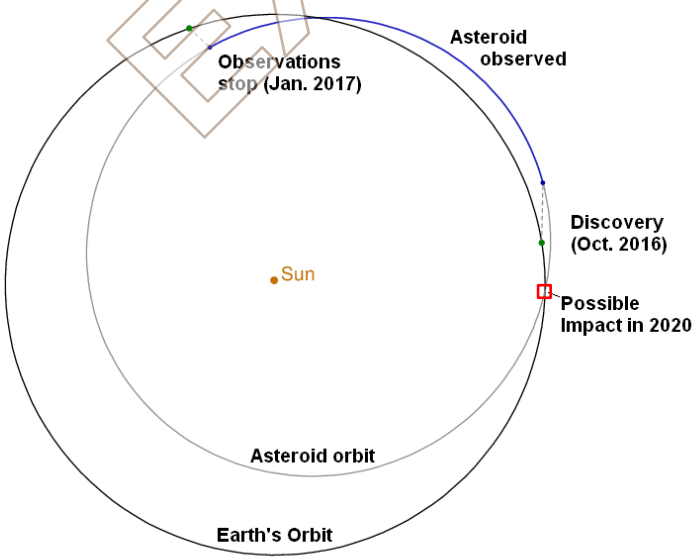
Orbit of 2016 TTX



Asteroid orbits Sun mostly inside Earth's orbit

Orbit period: 295 d

After the asteroid orbits almost 5 times, and Earth almost 4 times, they will come very close on Sep. 20, 2020

Size: 100 – 300 m

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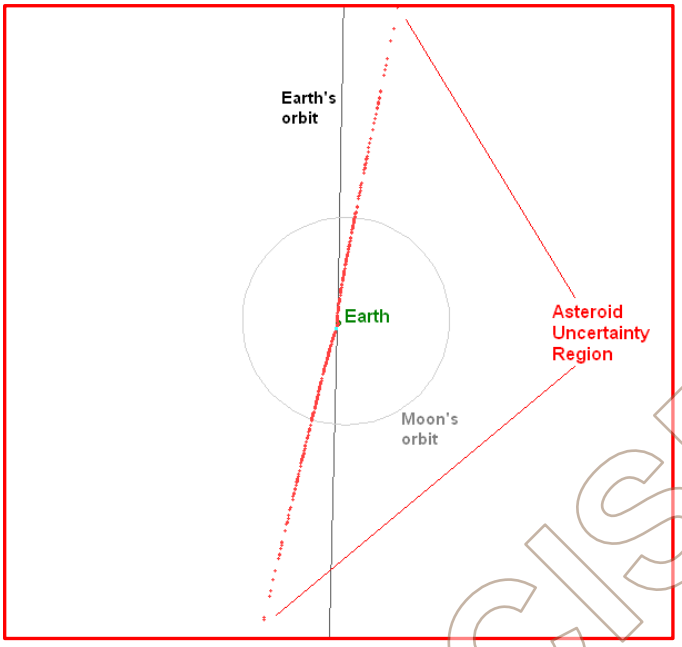
Position Uncertainty on Sep. 20, 2020



Uncertainty region (red dots) aligns with asteroid's orbit about Sun

2 million km long on Oct. 24, 2016

Region will shrink as more observations are made

Region shrinks within itself: as data is added, parts of the region are eliminated

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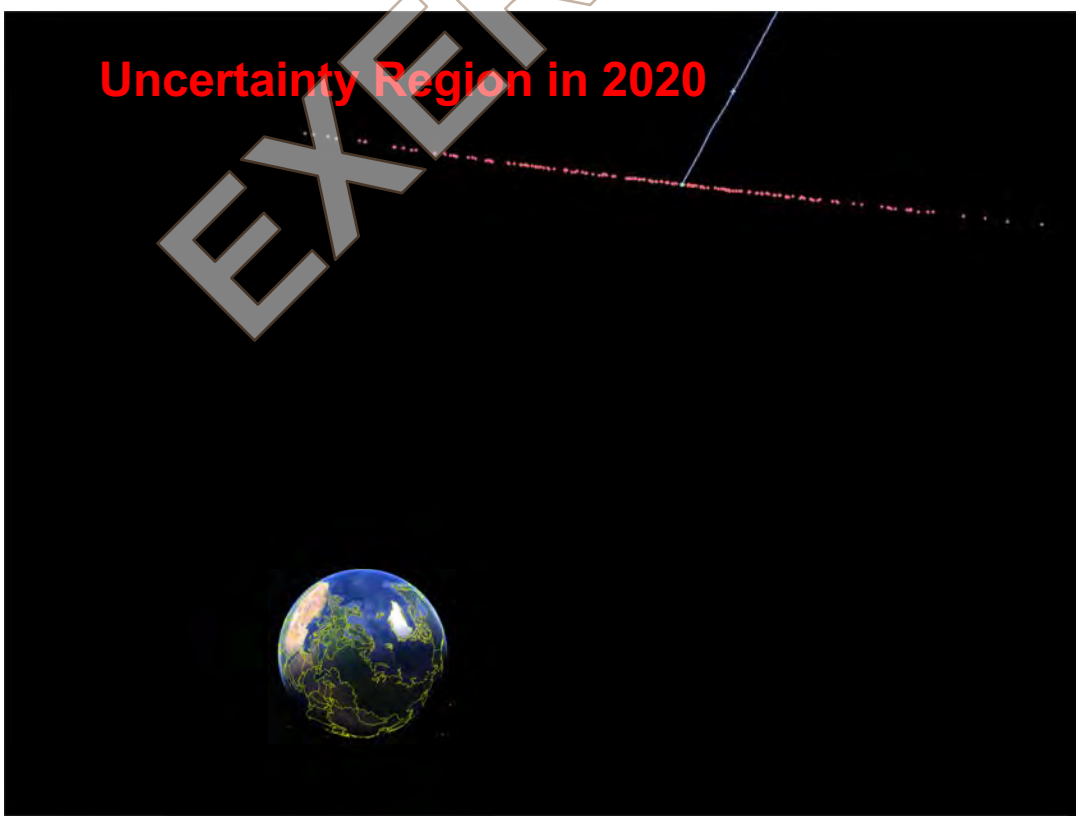
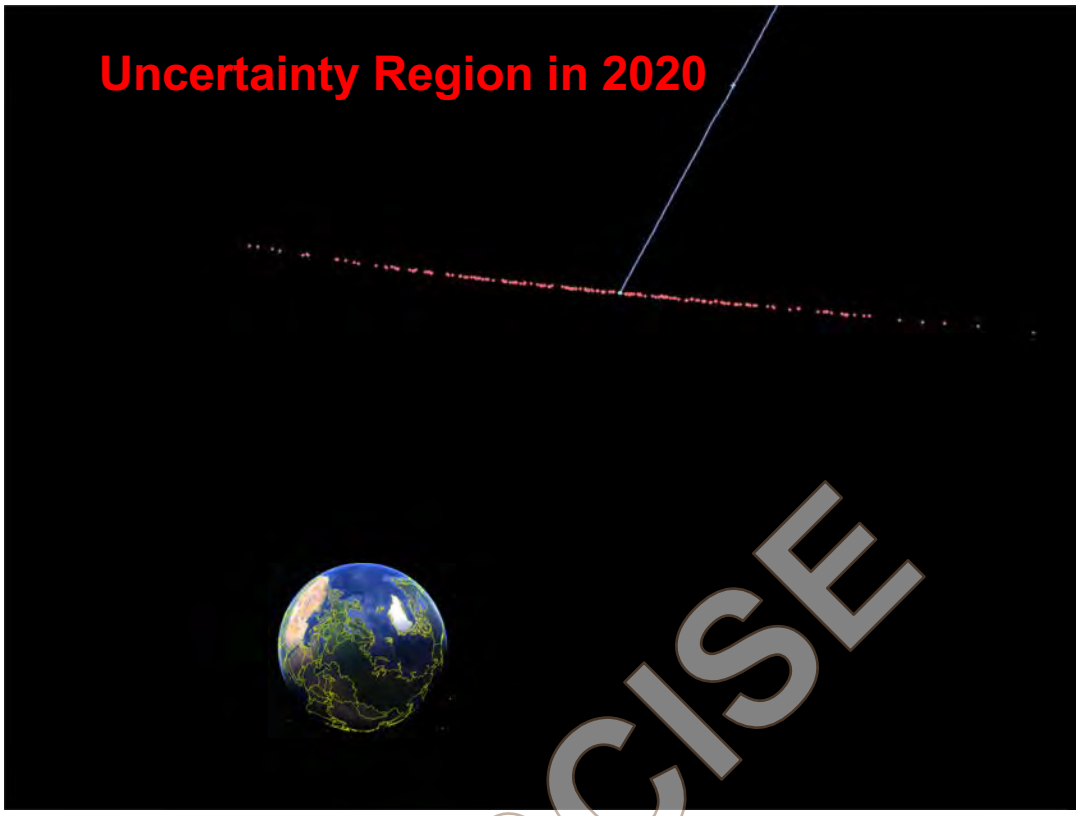
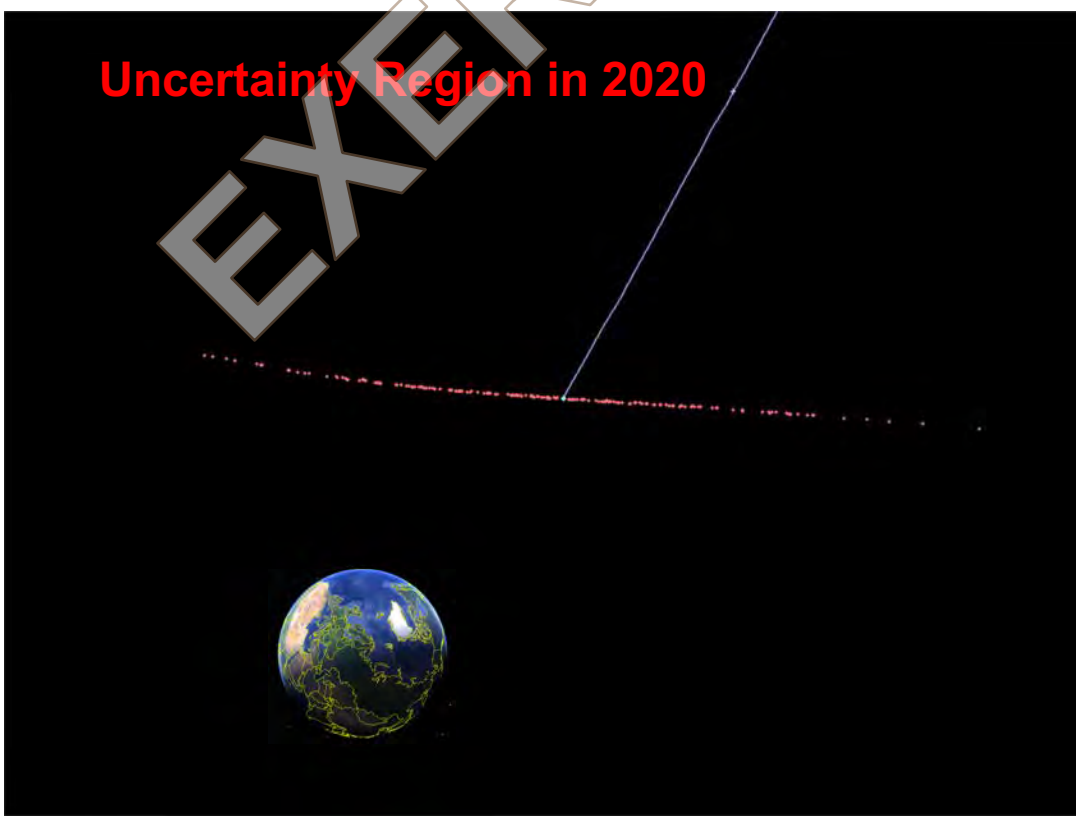
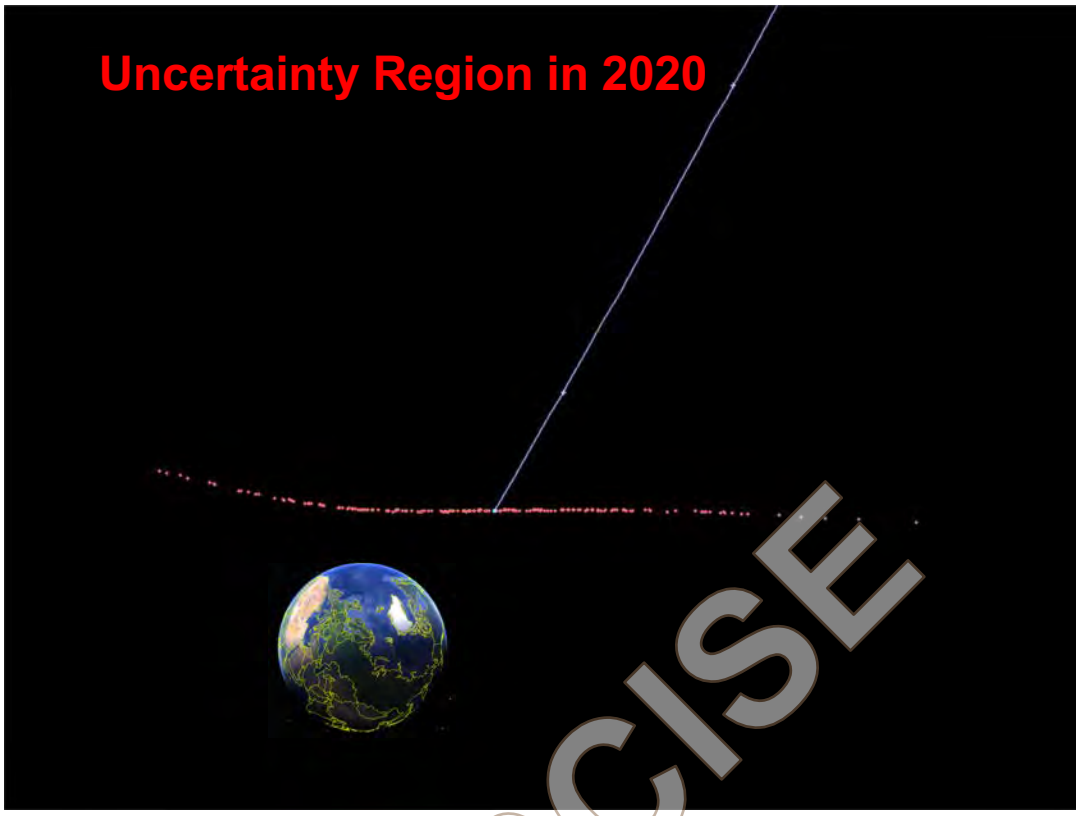
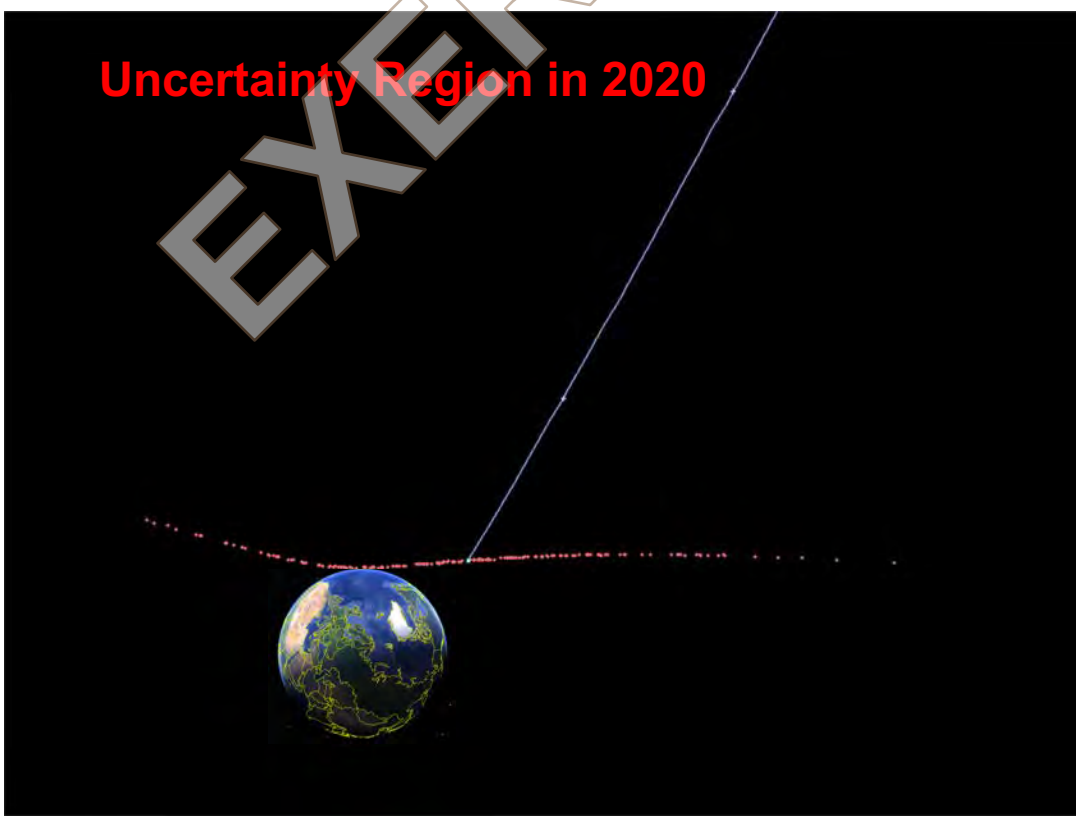
Uncertainty Region in 2020











2016 TTX: Risk Corridor

EXERCISE ONLY!!

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Risk Corridor

- If the Earth slices through the uncertainty region when it passes through the orbit intersection point, this produces a long narrow **risk corridor** on the Earth's surface
- The risk corridor extends more than halfway around the world
- If the asteroid impacts the Earth, it will impact somewhere along the risk corridor, not off it, even as more observations are added
- When enough observations are added, either:
  - The uncertainty region no longer intersects Earth (impact is not possible), or
  - Risk corridor shortens into an **impact footprint** located somewhere along the corridor

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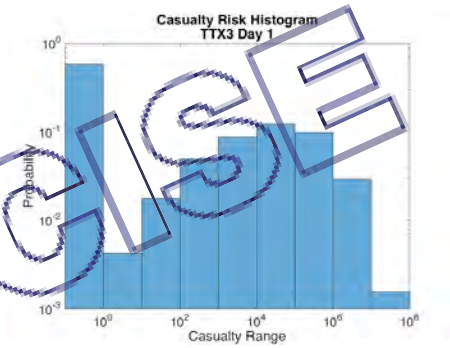
TTX#3 Probabilistic Asteroid Impact Risk Assessment

Donovan Mathias, Lorien Wheeler
Engineering Risk Assessment Team
Asteroid Threat Assessment Project
NASA Ames Research Center

TTX3, Pasadena, CA
October 24, 2016

Inject 1 Risk Assessment

- Small percentage chance of Earth being hit.
- If impact does occur, based on the location and compositional uncertainty, the accompanying plot shows the range of possible casualty outcomes.
- Following chart shows swath of *possible* damage.
  - Yellow represents window breakage and minor structural damage potential.
  - Green represents significant structural damage.
  - Red represents potential for total devastation.
  - Only one impact could happen (not bulldozer path).



Histogram of possible casualty outcomes conditioned on impact occurrence.

Inject 1 Hazard Zones

Window breakage, minor structural damage (1-4 psi)
Moderate to severe structural damage (4-10 psi)
Complete devastation (10+ psi)

Inject 1 Worst Case Close-ups

Western CONUS hazard zones

Eastern CONUS hazard zones

Window breakage, minor structural damage (1-4 psi)
Moderate to severe structural damage (4-10 psi)
Complete devastation (10+ psi)

At this point (4 years to possible impact)…

- IAWN has issued an alert, resulting in press release provided in read-ahead
  - *Object detected October 1, 2016*
  - *On Oct 25, 2016, object has 2% probability of striking Earth on September 20, 2020*
  - *If it were to strike, impact would be at some point on the threat corridor shown by Paul Chodas*
- Meeting of Space Mission Planning Advisory Group (SMPAG) called to initiate and coordinate planning for mitigation
  - *UN-endorsed, currently existing*
  - *Members are world's national space agencies and offices*
- Options to be considered
  - *Flyby of asteroid to collect data on size, characteristics, improve orbit prediction*
  - *Possible methods and missions to deflect object if probability of impact increases*
- Disaster response agencies notified

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Inject #2, Nov. 25, 2017: Asteroid Headed for Impact in Southern California Region

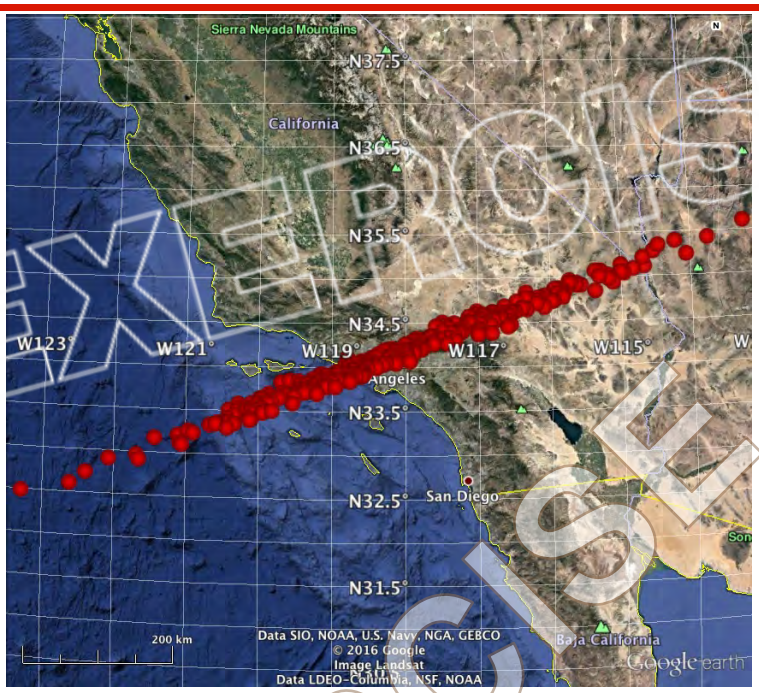
Paul Chodas
Manager, Center for NEO Studies (CNEOS)
Jet Propulsion Laboratory, California Institute of Technology

2016 NASA/FEMA Tabletop Exercise, Aerospace Corp., October 25-26, 2016

Impact Now Certain in Southern California

- Based on hundreds of tracking observations, orbit experts agree that asteroid 2016 TTX **will impact** in the Southern California region on **September 20, 2020**
- The predicted impact region is about 800 kilometers (500 miles) long, roughly centered on the city of Los Angeles
  - It's equally likely the impact could occur in the ocean or on land
- Asteroid has moved into the glare of the Sun and can no longer be observed; further updates on the impact region will not be possible until the asteroid re-emerges two years from now
- The asteroid is size uncertain: it is roughly 100 to 250 meters (300 to 800 feet) across; the composition is believed to be stony, possibly metal-rich
- A space mission to gather more information about the asteroid is under development; it would be launched in March 2019, about 20 months from now, and reach the asteroid 11 months later
- Feasibility of deflecting the asteroid off its collision course is being investigated

Inject #2: Predicted Impact Region, November 25, 2017



EXERCISE ONLY!!

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Assuring Mission Success

Deflection Possibilities

Nahum Melamed
The Aerospace Corporation

TTX#3 Scenario

- Asteroid size and density drive deflection requirements
- Two deflection techniques explored
  - *High energy kinetic Impact*
  - *Nuclear standoff detonation*
- Kinetic impact deflection requires multiple launches
- Nuclear standoff deflection possible, but requires large yield
- No suitable launch and payload assets available
- Conclusion: No deflection capability available in time to avert impact

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AEROSPACE

Inject 2

Physical Effects Briefing

Nov. 25, 2017
TTX3

Mark Boslough
Sandia National Labs
Albuquerque, NM

Bill Fogleman, GRIT – Mapping

Sandia s a mu t program laboratory operated by Sand a Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE AC04 94AL85000.

Sandia National Laboratories

This is what we know:

Entry speed: 13 ± 0.4 km/s (~29,000 mph)

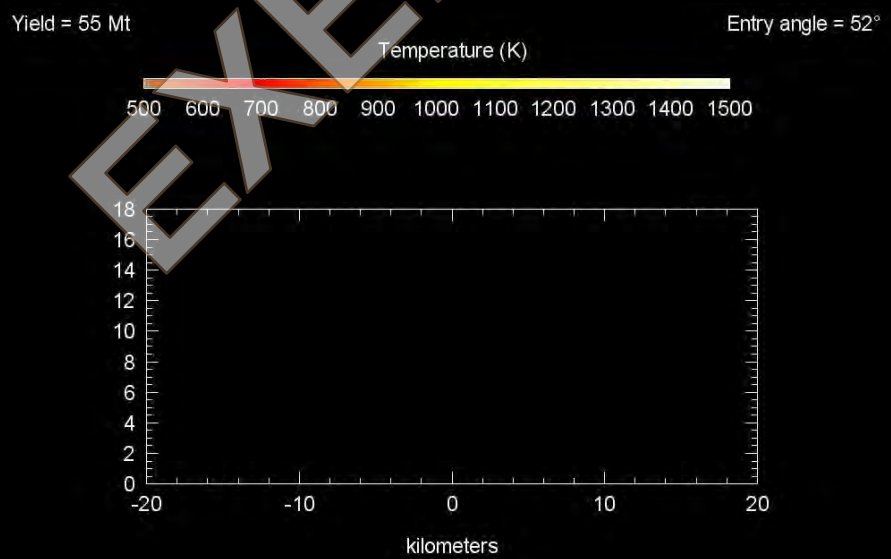
Size: as large as 300 meters diameter

Composition: Stone, density as high as 2.9 g/cm^3

~55 Megaton impact cannot be ruled out

Probability of impact = 100%

51



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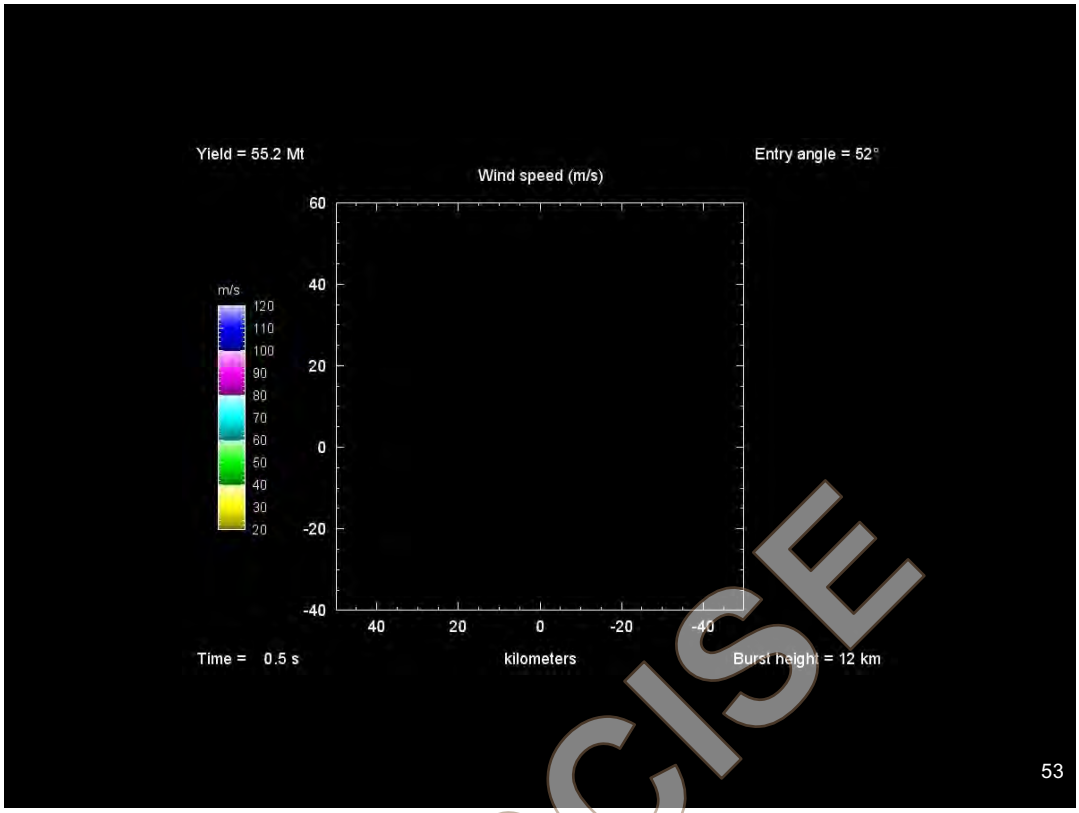

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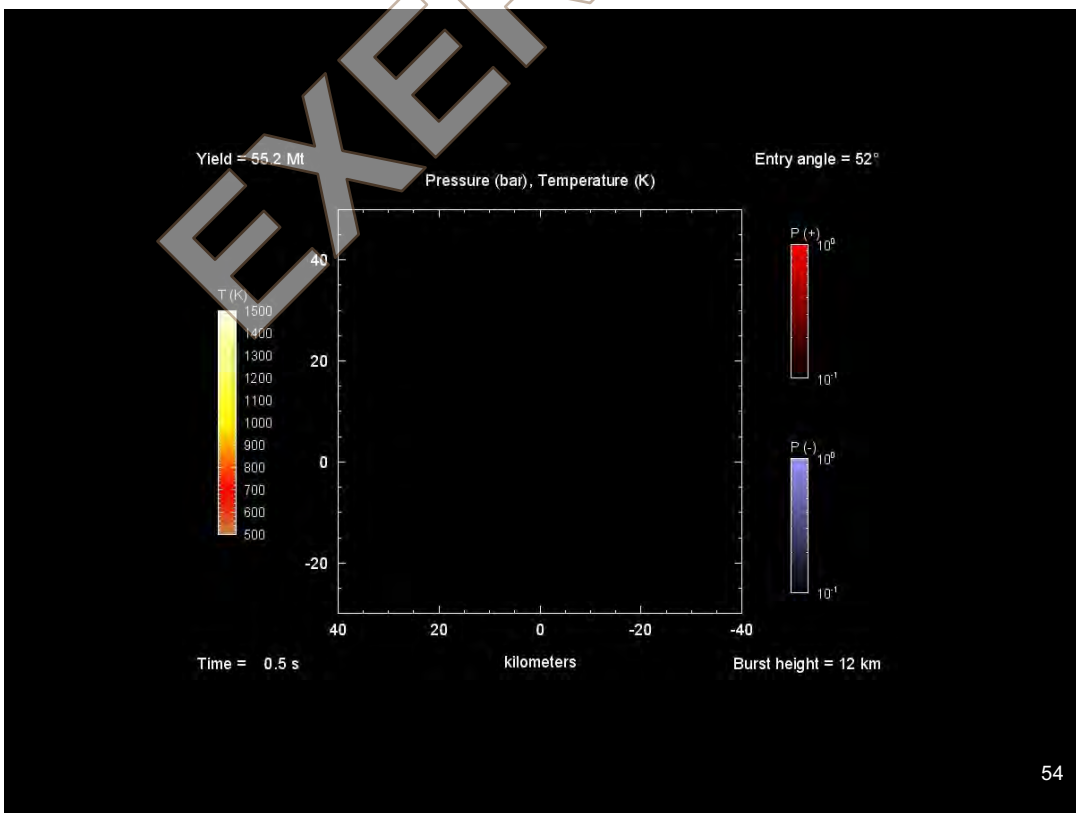

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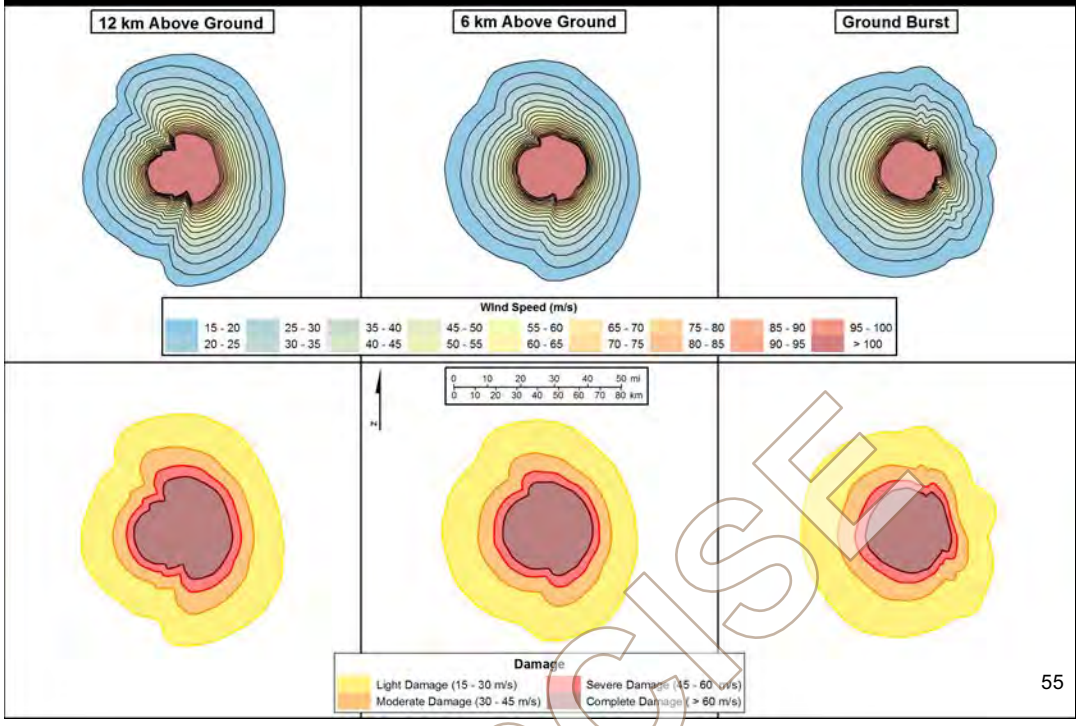
Comparison of damage vs. height of burst



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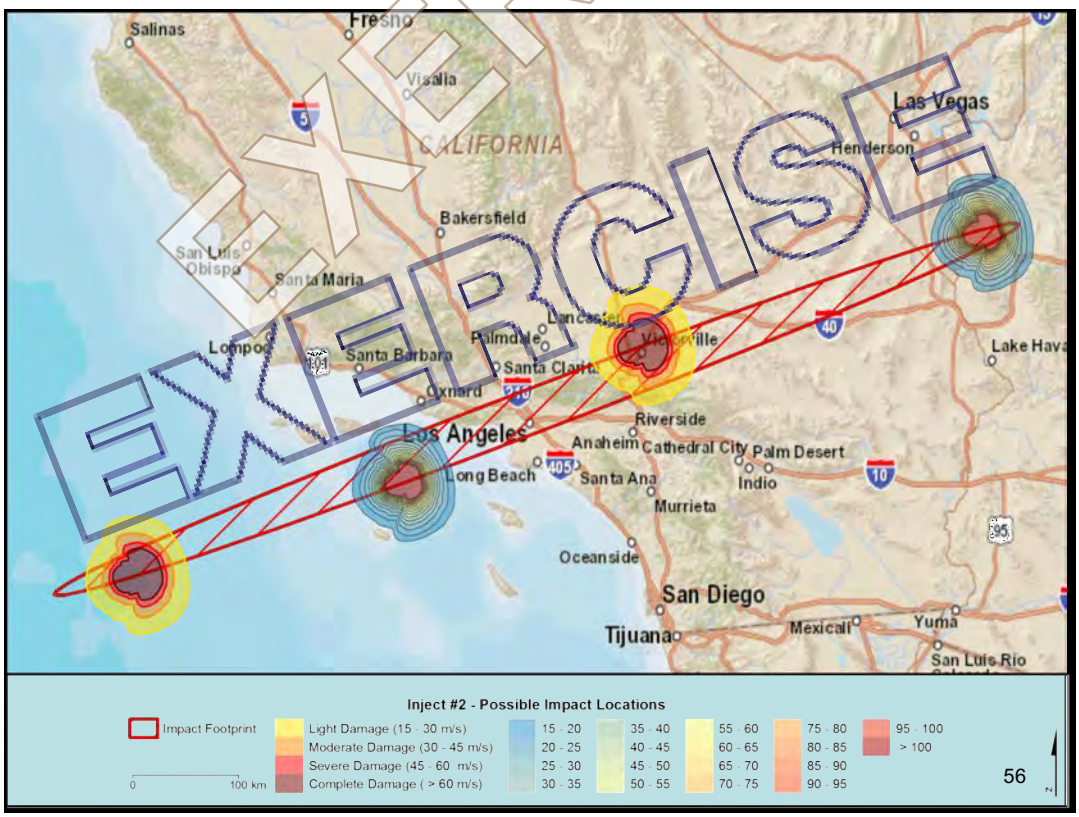

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Simulations of water impacts in support of TTX3 (2016 FEMA Tabletop exercise)

Souheil Ezzedine, Megan Bruck Syal, and Paul Miller, LLNL

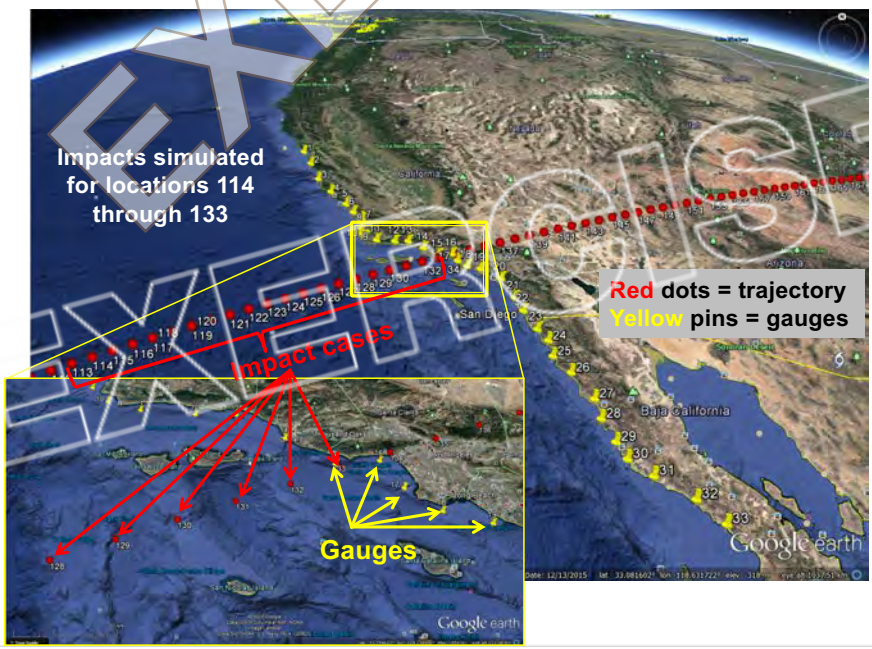
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

LLNL-PRES-705579

Lawrence Livermore National Laboratory

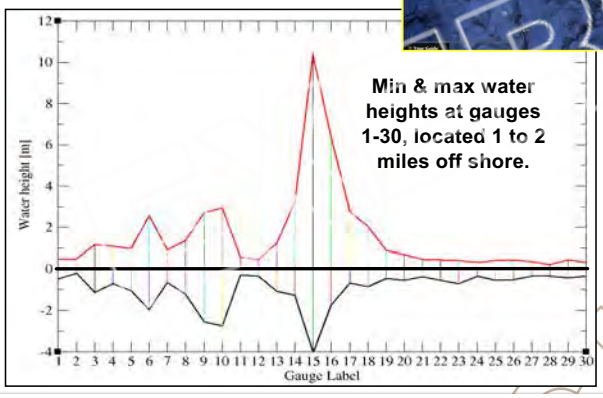
flooding

Water impacts of 300-m and 120-m asteroids were modeled



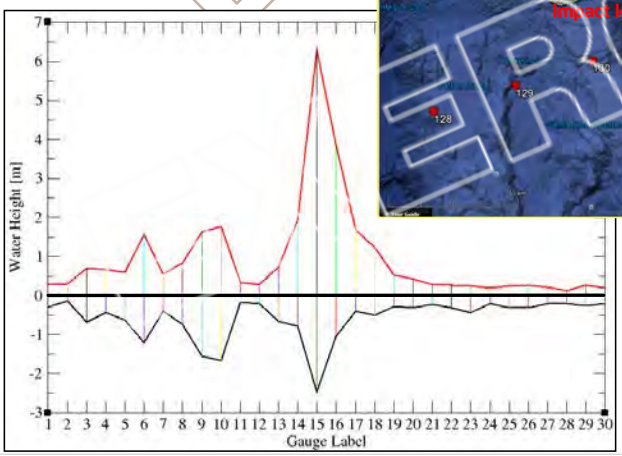
flooding

A 300-m asteroid could produce maximum local wave heights of 10 meters



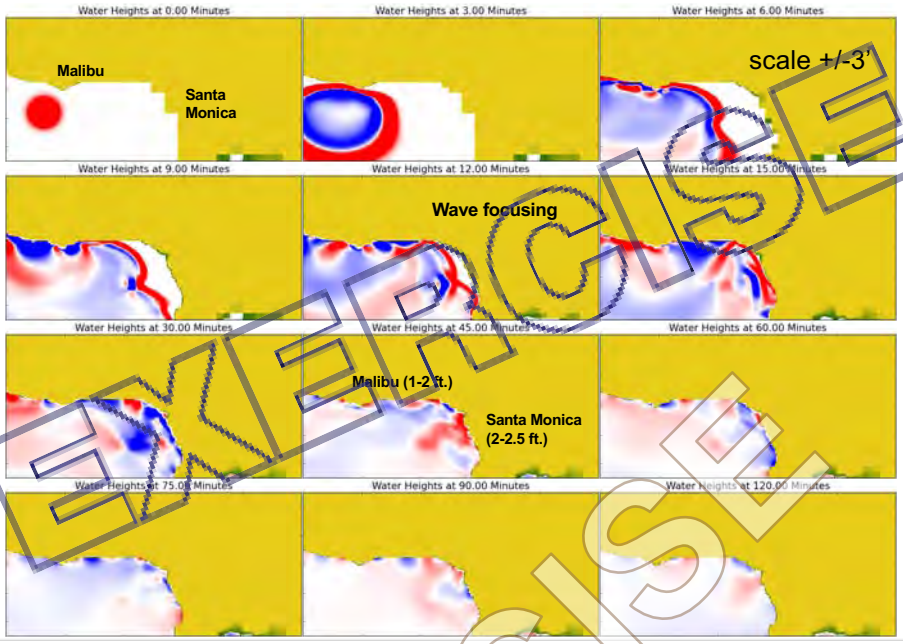
flooding

A 120-m asteroid could produce maximum local wave heights up to 6 meters



flooding

Flood heights from 300-m object could approach 3 feet



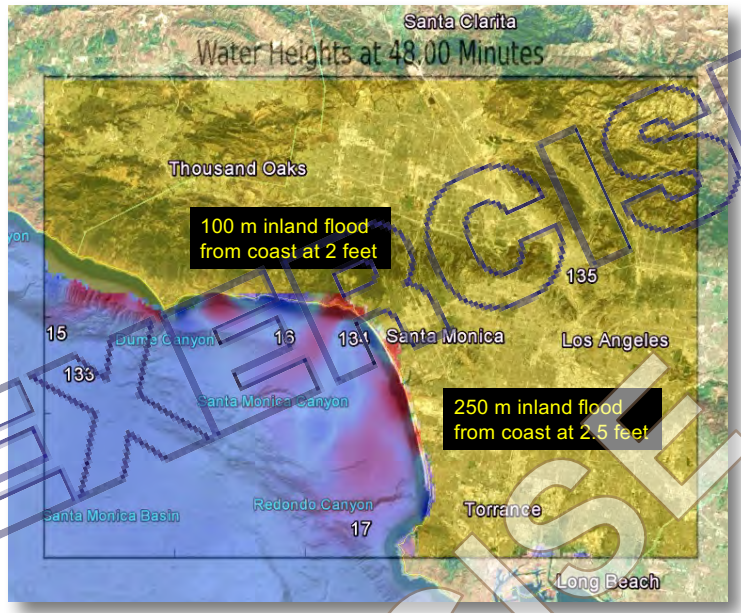
flooding

Flood heights from a 120-m object are up to 1.5 feet

Malibu area has the moderate water heights (0.5-1 feet) with ~45m inland flood over long time of exposure compared to Santa Monica (1-1.5 feet) ~75m inland, but short time of residence. Water waves recede in 45 minutes from impact.

flooding

Flooding could extend 100 to 250 meters inland



flooding

Summary of flooding modeling

- Several asteroid impact sites were simulated to assess line of sight exposure and water-wave focusing effects
- 300-m asteroid has more effect than 120-m asteroid
- Coastal areas could expect wave heights of up to 10 meters (32 feet)
- Worst-case floods approach 3 feet locally
- Affected areas: from Oxnard to San Clemente with varying degrees of coastal flooding only
- Most affected areas: Malibu through Santa Monica – Malibu has more maximum exposure time than Santa Monica (a couple hours)

Exceptional service in the national interest

Sandia National Laboratories

At Risk Critical Infrastructure
October 25-26, 2016

Barbara Jennings, PhD

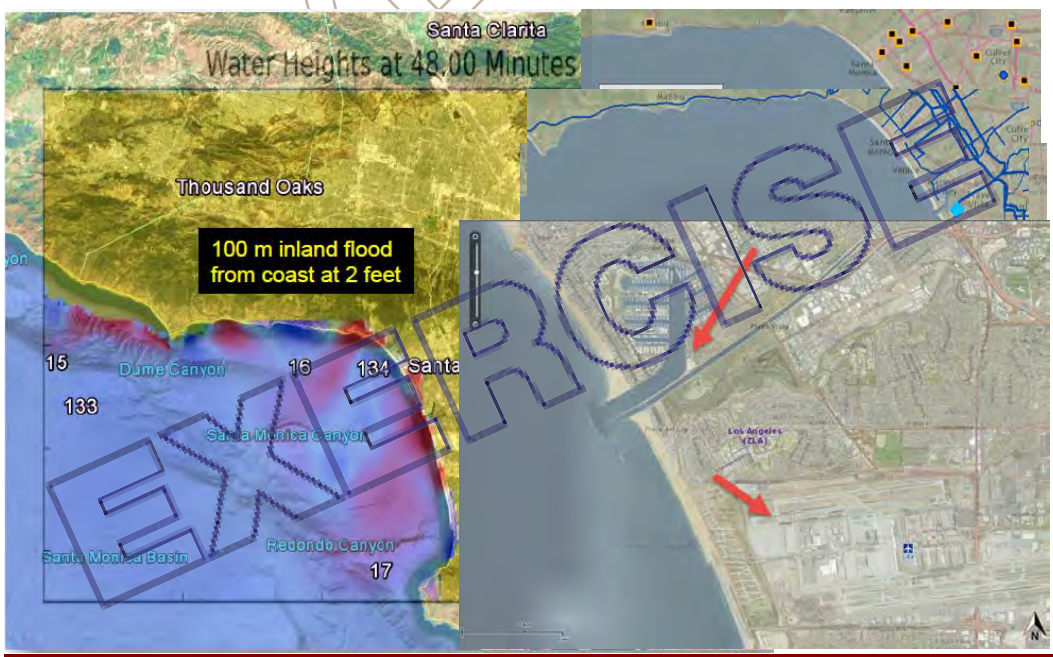
Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY | NNSA

Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2011-XXXXP

Tsunami Inundation Possible

Sandia National Laboratories



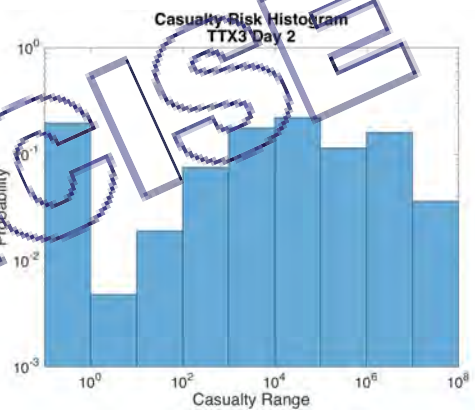
TTX#3 Probabilistic Asteroid Impact Risk Assessment

Donovan Mathias, Lorien Wheeler
Engineering Risk Assessment Team
Asteroid Threat Assessment Project
NASA Ames Research Center

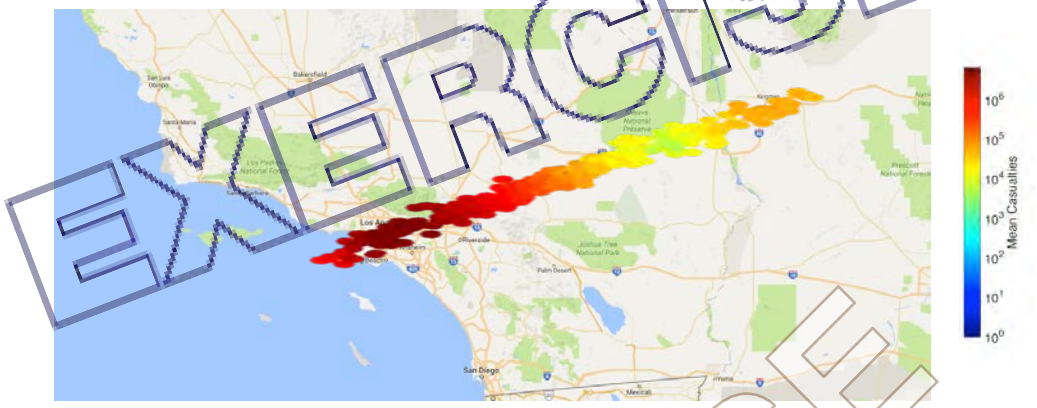
TTX3, Pasadena, CA
October 24, 2016

Inject 2 Risk Assessment

- Earth strike is confirmed.
- Large uncertainty still exists for object size and composition.
- Consequence estimates:
  - 20% chance of no casualties
  - 75% chance of >1,000 casualties
  - 25% chance of > 1,000,000 casualties

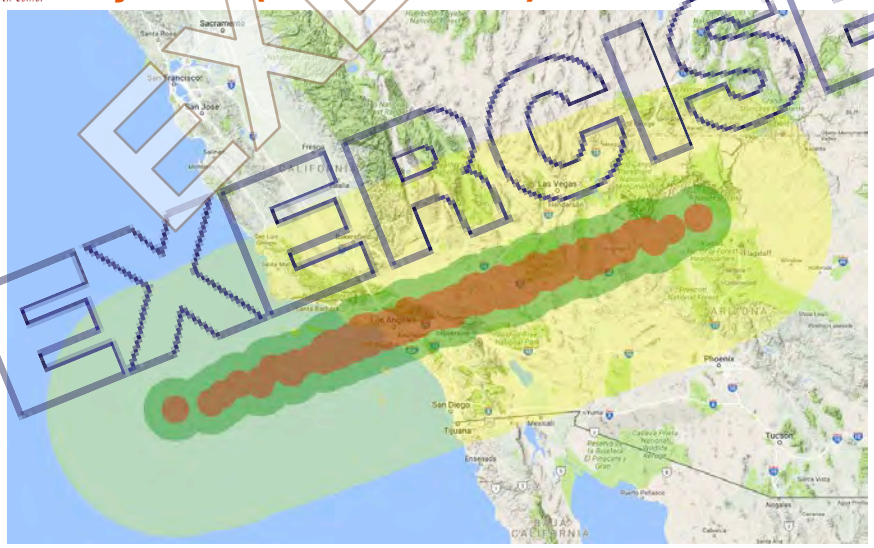


Inject 2 Expected Casualties



- Each circle represent the expected (average) casualties associated with impact at its location.
- Only one actual impact will occur.
- Ocean impacts include tsunami and airburst damage potential.

Inject 2 (Worst Case) Hazard Zones



Window breakage, minor structural damage (1-4 psi)
Moderate to severe structural damage (4-10 psi)
Complete devastation (10+ psi)

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Exercise Group Discussion (Feedback after Lunch)

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Exercise Group Feedback

Agenda, October 25

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william.h.ailor@aero.org

AEROSPACE

Inject #3, Mar. 10, 2020: Asteroid Will Impact in Greater Los Angeles Area

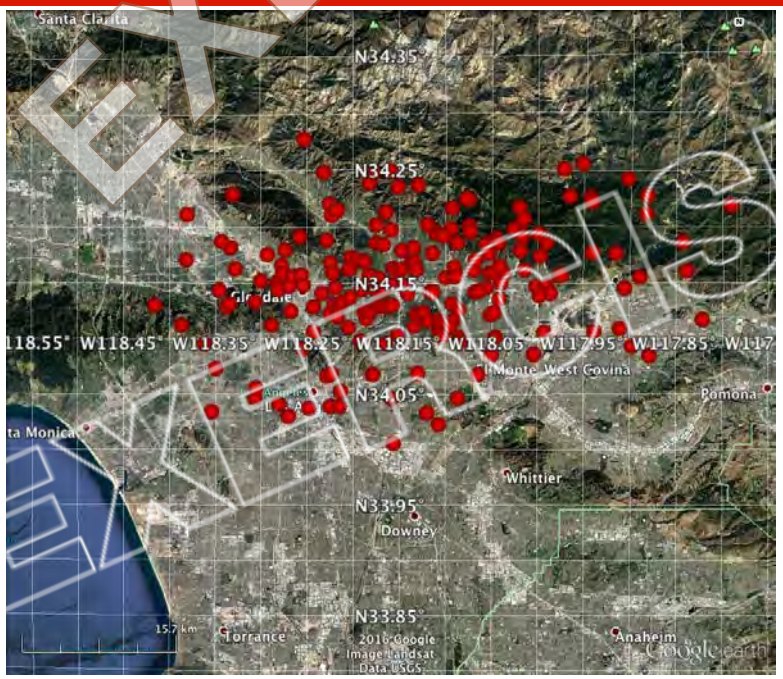
Paul Chodas
Manager, Center for NEO Studies (CNEOS)
Jet Propulsion Laboratory, California Institute of Technology

Aerospace Corp., October 25-26, 2016

Impact Will Occur in Northern Los Angeles

- Based on hundreds of tracking observations of asteroid 2016 TTX, along with data provided by a spacecraft flyby, orbit experts have narrowed down the predicted impact region to the Northern Los Angeles area
- The predicted impact region is roughly 40 by 20 kilometers (25 by 13 miles)
- The asteroid has now moved into the glare of the Sun and can no longer be observed by Earth-based telescopes
- Further refinements on the predicted impact region will not be possible until the asteroid approaches within range of the Arecibo radar facility roughly one month before impact
- Images and other data collected from the flyby on February 18 give astronomers a much better idea of the true size of the asteroid: roughly 100 to 120 meters (300 to 400 feet) across
- The flyby also confirmed that this asteroid is stony, and metal-rich composition

Inject #3: Predicted Impact Region, March 10, 2020



EXERCISE ONLY!!

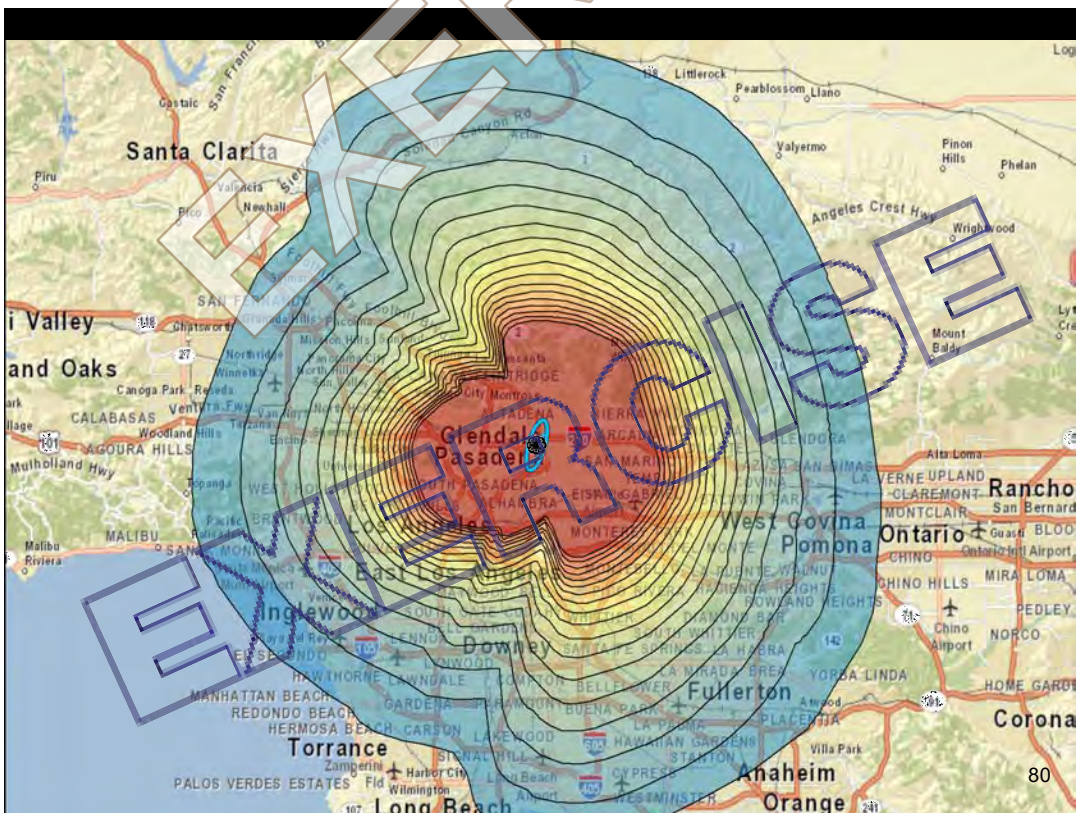
Inject 3

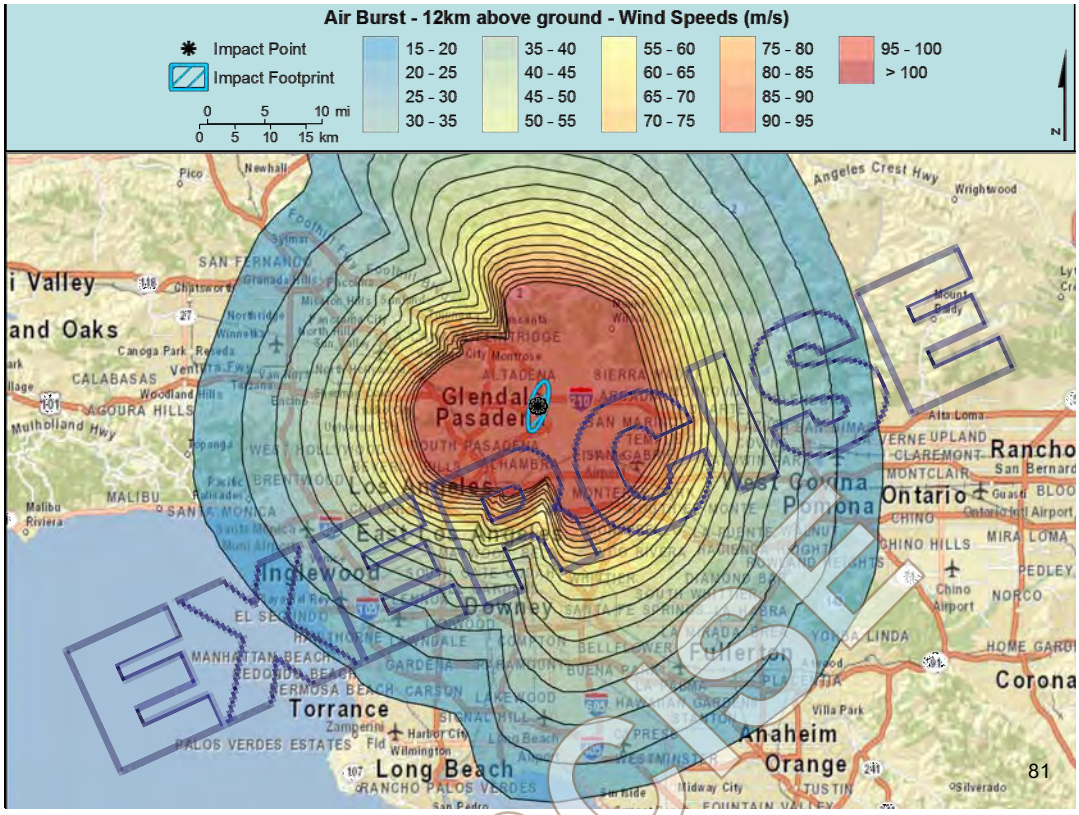
Physical Effects Briefing

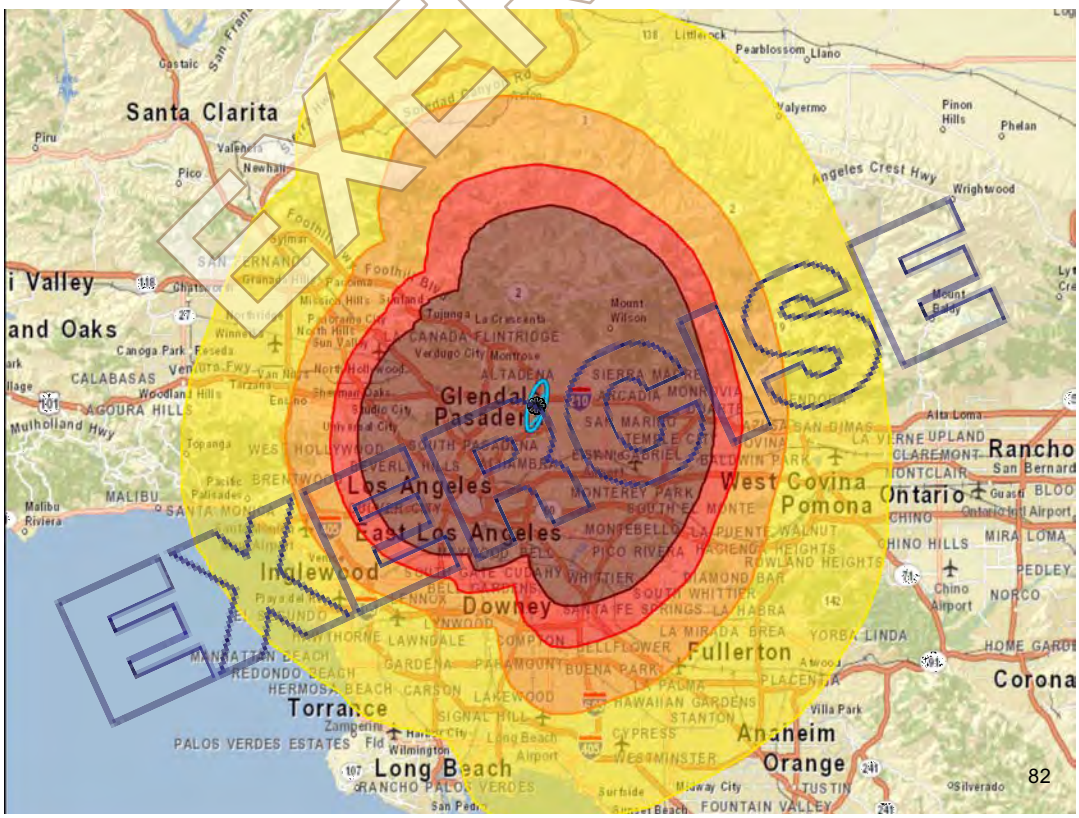
Mark Boslough
Sandia National Labs
Albuquerque, NM

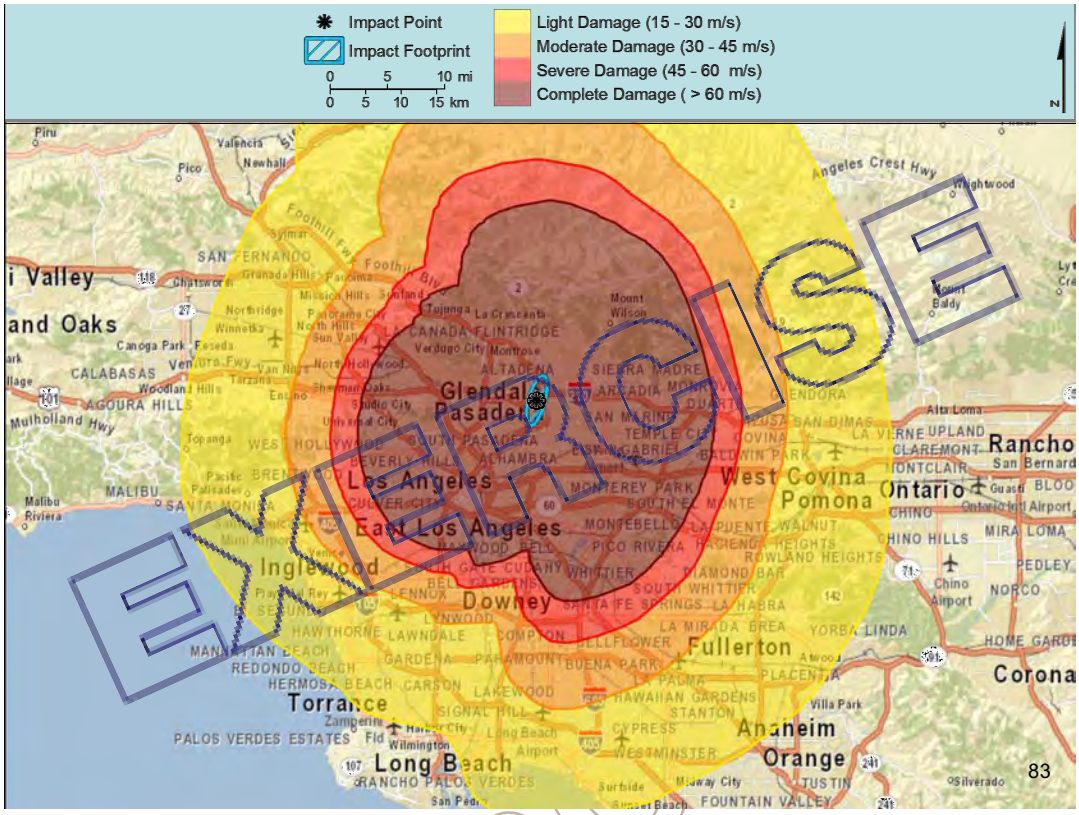
Bill Fogleman, GRIT – Mapping

Sandia s a mu t program laboratory operated by Sand a Corporation, a Lockheed Martin Company,
for the United States Department of Energy under contract DE AC04 94AL85000.








Impact Point
Impact Footprint
0 5 10 mi
0 5 10 15 km
Light Damage (15 - 30 m/s)
Moderate Damage (30 - 45 m/s)
Severe Damage (45 - 60 m/s)
Complete Damage (> 60 m/s)
N
EXERCISE
Glendale
Pasadena
Los Angeles
East Los Angeles
Inglewood
Downey
Torrance
Long Beach
West Covina
Pomona
Ontario
Rancho
Fullerton
Anaheim
Orange
Corona
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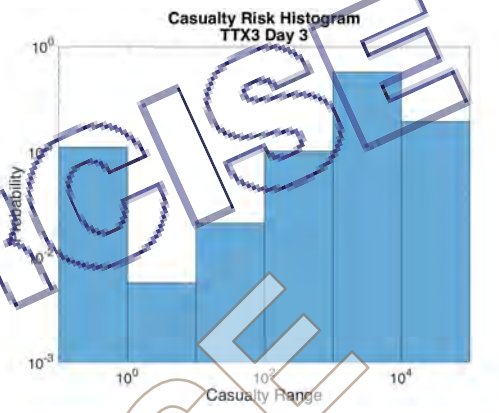
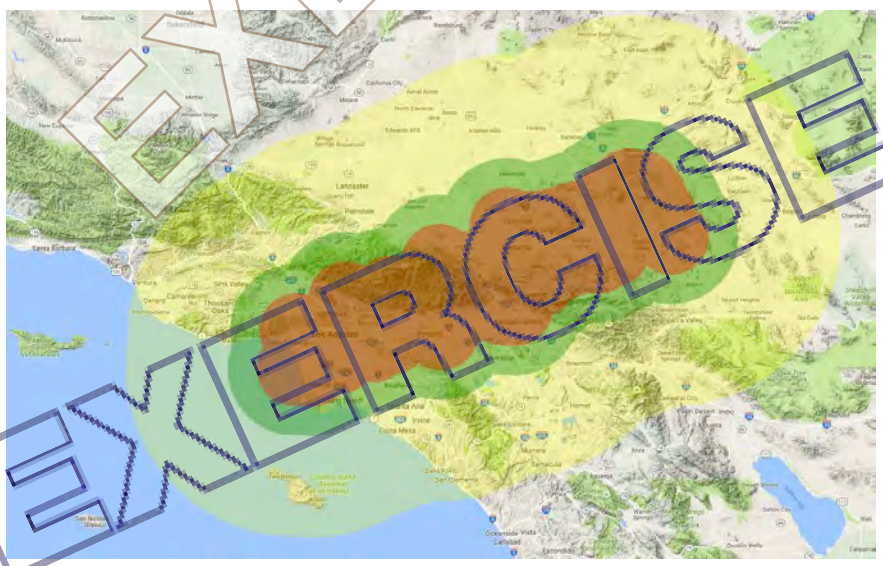
NASA
TTX#3 Probabilistic Asteroid Impact Risk Assessment
Donovan Mathias, Lorien Wheeler
Engineering Risk Assessment Team
Asteroid Threat Assessment Project
NASA Ames Research Center
TTX3, Pasadena, CA
October 24, 2016

Inject 3 Risk Assessment

- Location of impact refined.
- Diameter confirmed 90-150m, 120m most probable.
- Stony composition.
- Consequence estimates:
  - 10% chance of no casualties
  - 75% chance of >1,000 casualties
  - 20% chance of > 10,000 casualties



Inject 3 Worst Case Hazard Zones



Window breakage, minor structural damage (1-4 psi)
Moderate to severe structural damage (4-10 psi)
Complete devastation (10+ psi)

Inject 3 Median Hazard Zones

Window breakage, minor structural damage (1-4 psi)
Moderate to severe structural damage (4-10 psi)
Complete devastation (10+ psi)—*None present in median case*.

Exceptional service in the national interest

Sandia National Laboratories

2016 FEMA Tabletop Exercise TTX3
At Risk Critical Infrastructure
October 25-26, 2016

Barbara Jennings, PhD
Sandia National Laboratories

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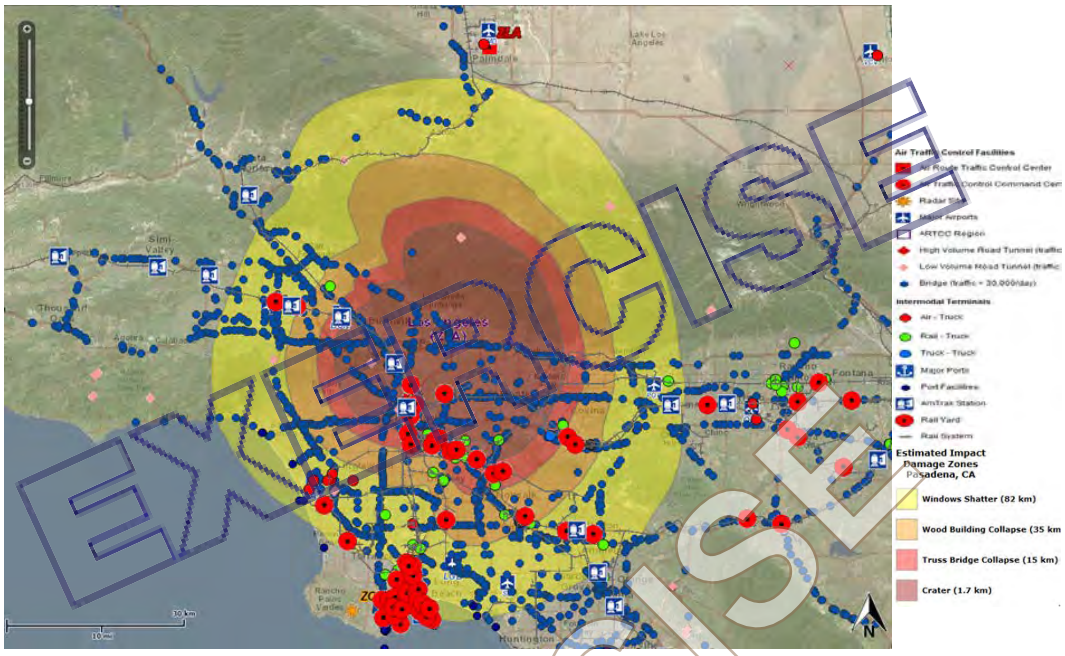
Disruption to Transportation

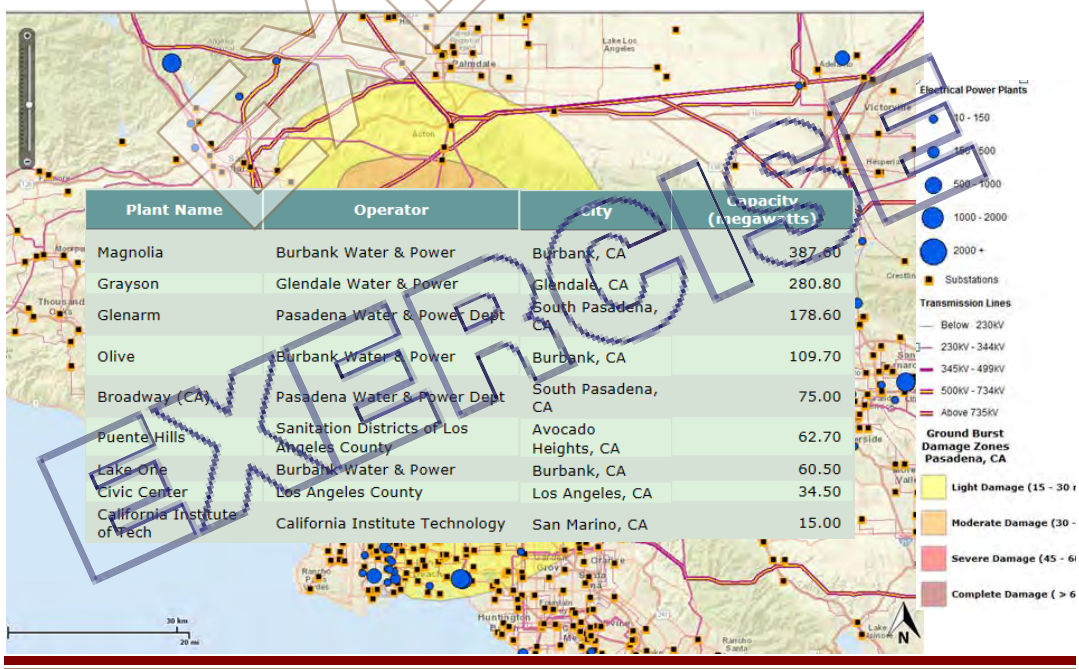
Sandia National Laboratories



Electrical Infrastructure At Risk

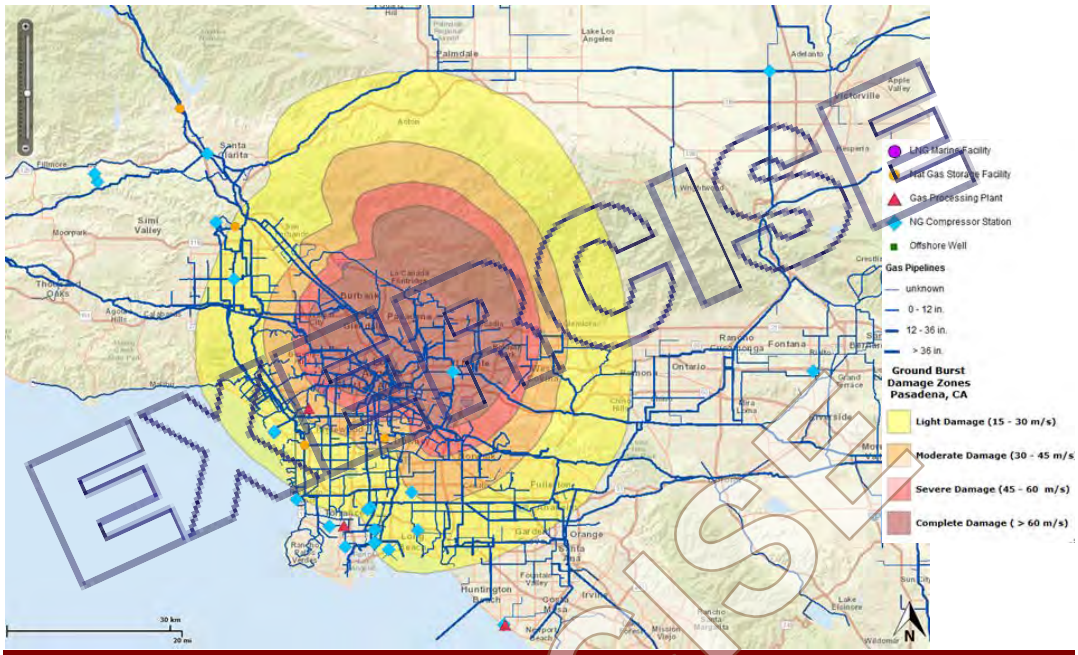
Sandia National Laboratories

Plant Name	Operator	City	Capacity (megawatts)
Magnolia	Burbank Water & Power	Burbank, CA	387.60
Grayson	Glendale Water & Power	Glendale, CA	280.80
Glenarm	Pasadena Water & Power Dept	South Pasadena, CA	178.60
Olive	Burbank Water & Power	Burbank, CA	109.70
Broadway (CA)	Pasadena Water & Power Dept	South Pasadena, CA	75.00
Puente Hills	Sanitation Districts of Los Angeles County	Avocado Heights, CA	62.70
Lake One	Burbank Water & Power	Burbank, CA	60.50
Civic Center	Los Angeles County	Los Angeles, CA	34.50
California Institute of Tech	California Institute Technology	San Marino, CA	15.00



Natural Gas Infrastructure At Risk

Sandia National Laboratories



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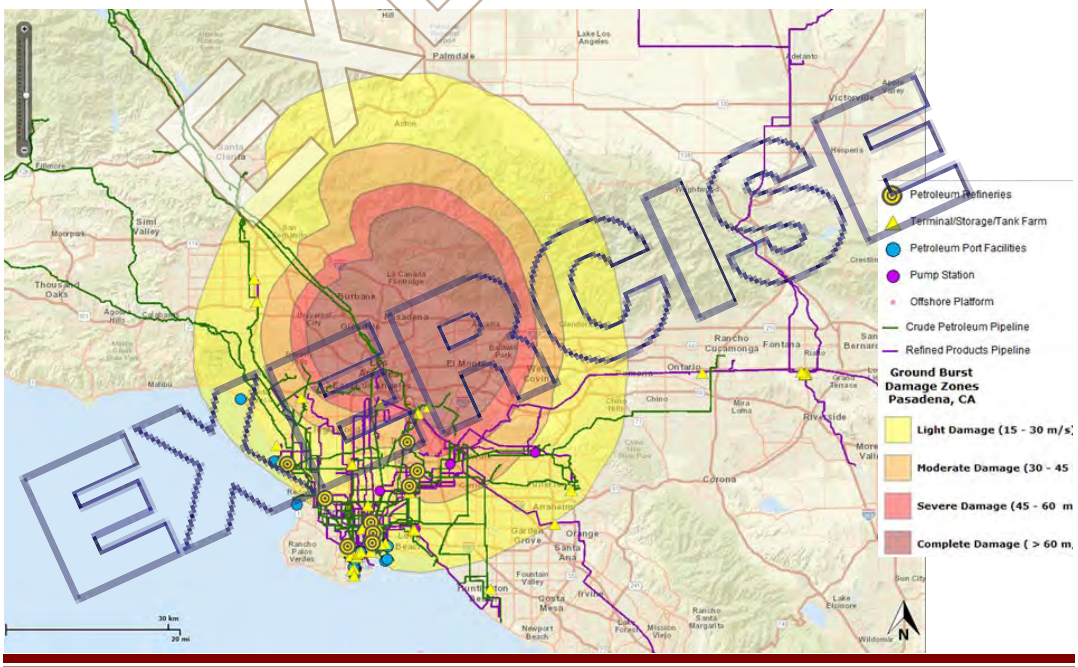
Petroleum Resources at Risk

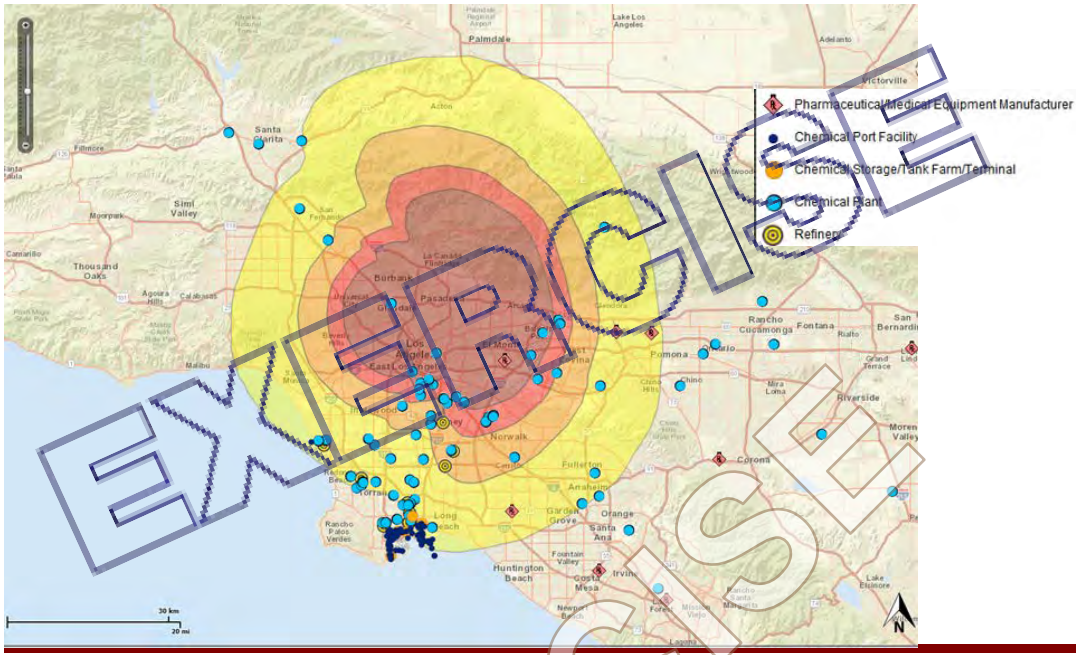
Sandia National Laboratories



92

Petro Chemical Facilities at Risk

Sandia National Laboratories



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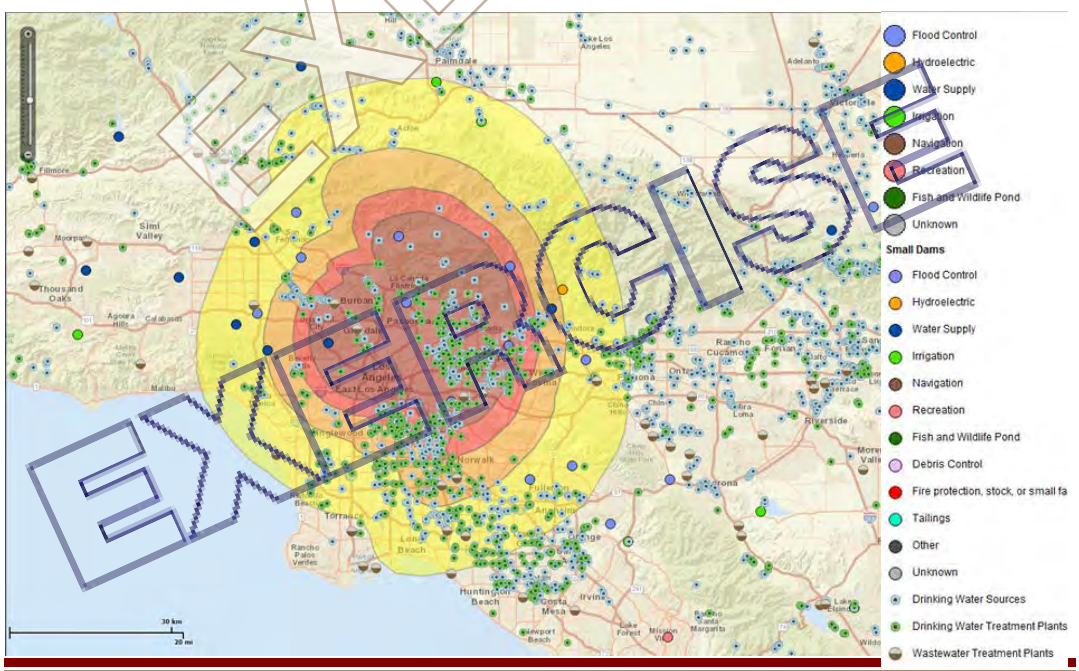
Water, Waste Water & Dams

Sandia National Laboratories



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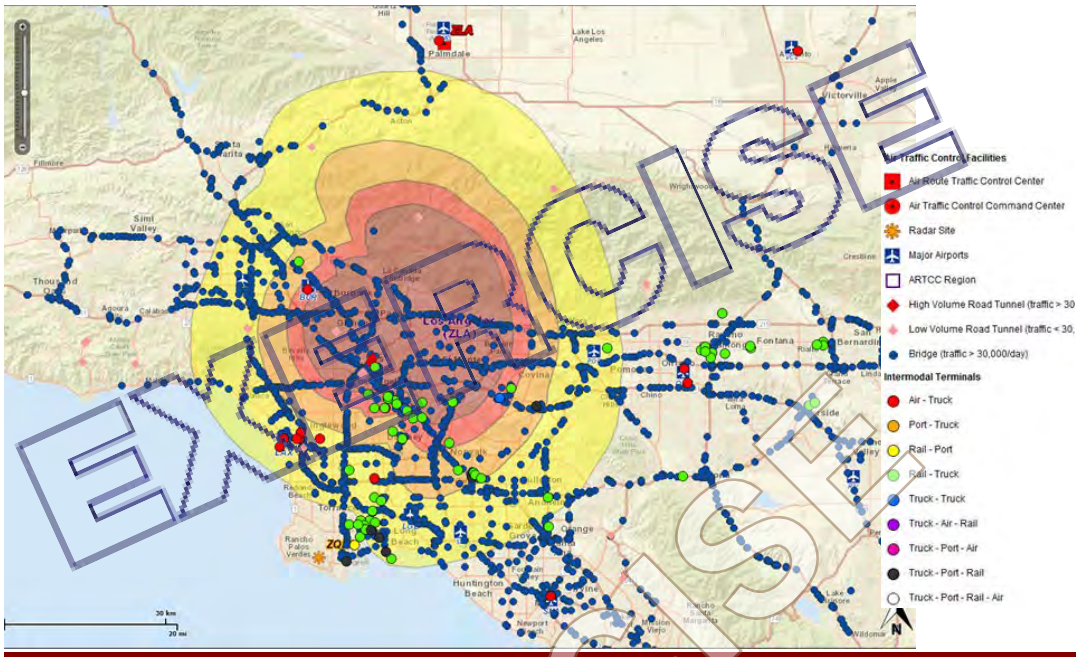
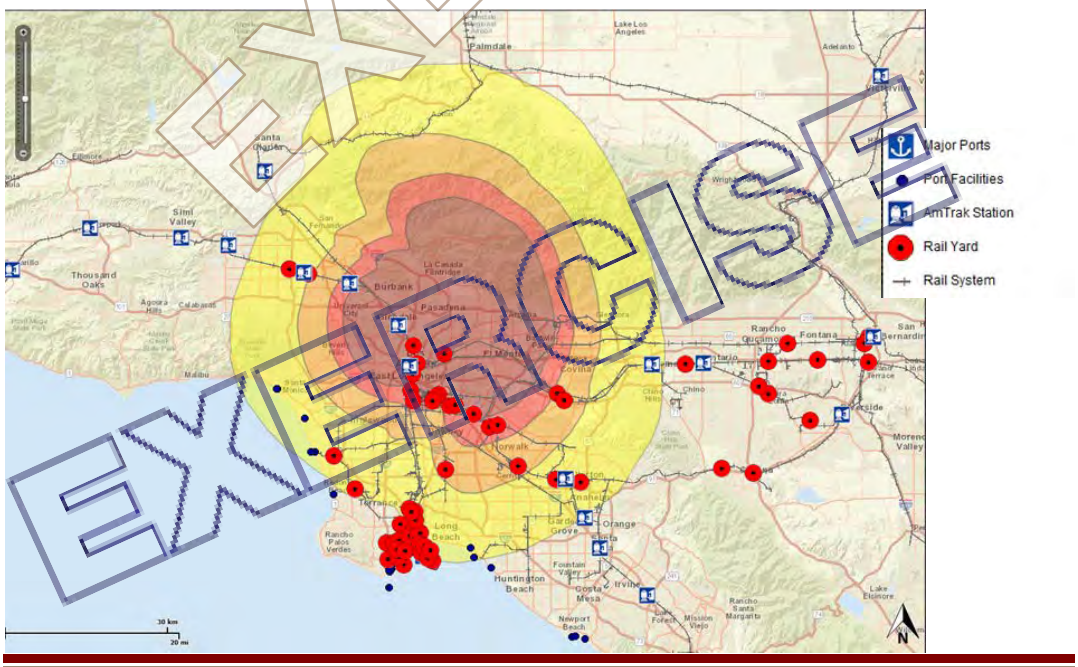
Transportation Services at Risk

Sandia National Laboratories



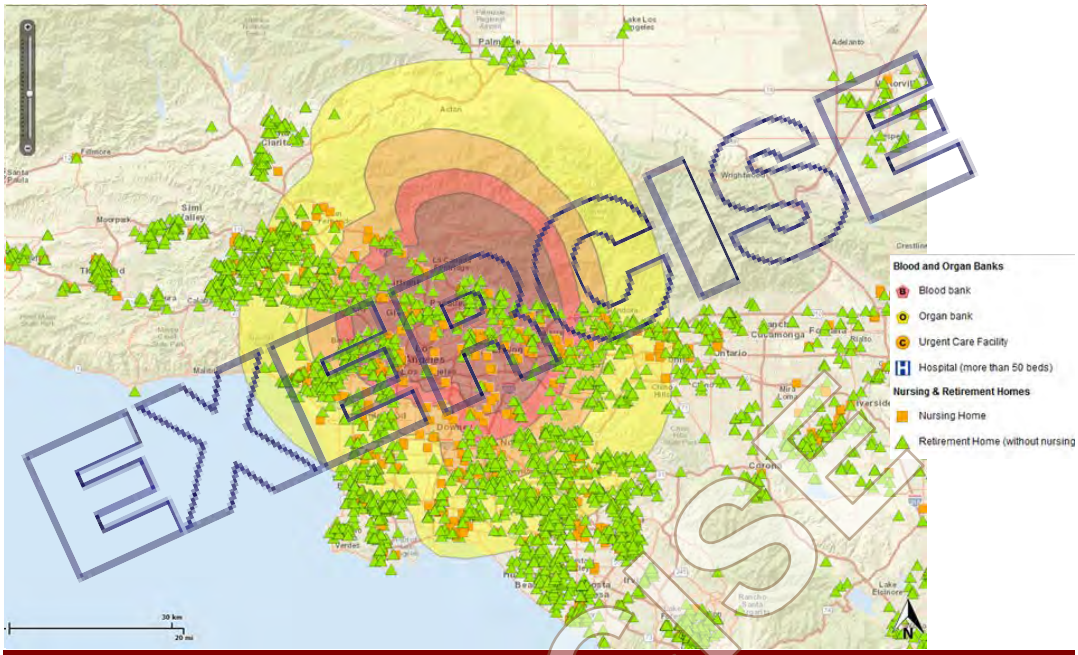
Ports and Rail at Risk

Sandia National Laboratories



At Risk Community Health & Retirement

Sandia National Laboratories



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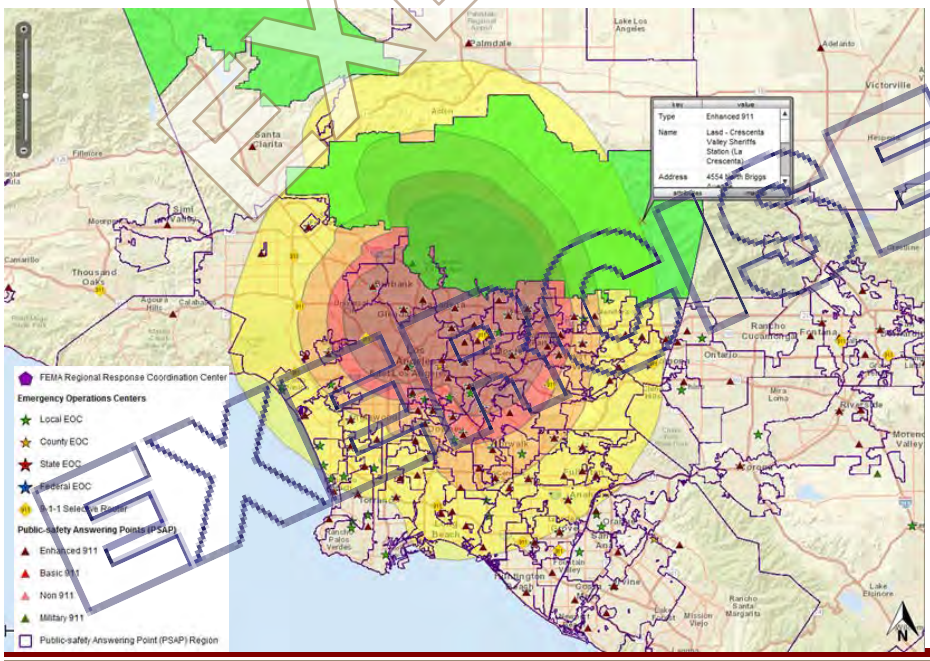
Emergency Responders FEMA & 911

Sandia National Laboratories



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william.h.ailor@aero.org

AEROSPACE

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AEROSPACE

Exercise Group Discussion & Feedback

william.h.ailor@aero.org

AEROSPACE

Final Prediction: September 18, 2020 (2 Days to Impact)

Radar observations begin ~22 days before impact

Impact in Pasadena, CA, just south of Rose Bowl

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APPENDIX D: FEMA-NASA Public Affairs Follow-Up Exercise

After briefly discussing the immense public relations challenges that would likely arise in the event of a predicted asteroid impact, attendees at the October 2016, NASA-FEMA Tabletop Exercise recommended conducting a follow-up exercise specifically for representatives from NASA Office of Communications and FEMA Office of External Affairs to discuss these challenges in further detail.

This follow-up exercise, which used the same scenario as was used in the October exercise, was conducted on December 7, 2016, at NASA Headquarters. The objective was to educate the agencies' professional communications and engagement staff on the asteroid hazard, provide a basis for discussion, and to solicit feedback on proposed communication and engagement best practices and other recommendations.

Summary

The exercise's discussion themes included determining roles and responsibilities, agency processes, and joint messaging. Specific topics of discussion included:

- Ensuring effective communication channels with all NASA and FEMA stakeholders.
- Understanding current engagement strategies and outreach mechanisms.
- Ensuring the accuracy, timeliness, and understandability of joint messaging for such an event.
- Building awareness and confidence in NASA's Planetary Defense Coordination Office (PDCO) in advance of an impact, to ensure that the general public trusts information and life/safety guidance distributed.

Recommendations

Attendees recommended the following actions to strengthen the working relationship between NASA Office of Communications and FEMA Office of External Affairs, and to increase awareness of the asteroid hazard:

- Share pertinent strategy, policy, and procedure documents between the agencies.
- Draft a document of asteroid hazard facts that could be used to answer anticipated frequently asked questions or as responses to queries in the event of a short-notice or no-notice impact and prepare other informational products, such as videos.
- Consider conducting a tabletop exercise for other internal or external stakeholder groups.
- Build public/stakeholder recognition of the asteroid hazard and of the roles that NASA's PDCO and FEMA's Response Division would play in this high risk/low probability event using social media and other outreach channels.

- **NASA-FEMA TTX #3 Public Affairs Follow-Up Exercise Attendees**
-
- DC Agle, Media Relations, JPL
- Joshua Batkin, Director, Office of External Affairs, FEMA
- Linda Billings, Consultant, PDCO, NASA
- Dwayne Brown, Senior PAO, Science Mission Directorate (SMD), NASA

- Lauren Butler, Strategic Communications, FEMA
- Laurie Cantillo, Lead Communications Specialist, SMD, NASA
- Laura Cirillo, Congressional Affairs, FEMA
- Casey Deshong, Region IX External Affairs, FEMA
- Frank Ferreira, Intergovernmental Affairs, FEMA
- Victoria Friedensen, Program Executive, PDCO, NASA
- Gloria Huang, Digital Communications, FEMA
- Bob Jacobs, Acting Associate Administrator, Office of Communications, NASA
- Lindley Johnson, Planetary Defense Officer, NASA
- Nancy Jones, Office of Communications, Goddard
- Tara Kane, Staff Assistant, Operations Division, FEMA
- L.A. Lewis, Chief, National Response Coordination Branch, Operations Division, FEMA
- Eileen Lainez, Deputy Director, Public Affairs, FEMA
- Rafael Lemaitre, Director, Public Affairs, FEMA
- Daniel Llargues, Public Affairs, FEMA
- Alexa Lopez, Press Secretary, FEMA
- Veronica McGregor, Manager, News and Social Media, JPL
- Ryan Streeter, Intergovernmental Affairs, FEMA
- Stephanie Tennyson, Deputy Director, Office of External Affairs, FEMA
- Michelle Thaller, Deputy Director, Science Communication, NASA
- Ali Travis, Director, Strategic Communications, FEMA
- Hannah Vick, Acting Director, Disaster Operations, FEMA
- Melissa Wiehenstroer, Presidential Management Fellow, PDCO, NASA