

TABLETOP EXERCISE FOR SHORT WARNING NEAR EARTH OBJECT IMPACT EVENT

Summary Report for NASA HQ SMD Planetary Sciences Division NEO Program Office

August 19, 2013

EXECUTIVE SUMMARY

A table-top exercise was conducted at the Headquarters of the Federal Emergency Management Agency (FEMA) in Washington, D.C., on April 3, 2013. A primary goal of the exercise was to acquaint FEMA with the nature of an asteroid or comet impact and how a warning of an impact might evolve if the threatening object was detected a short time prior to possible impact.

The scenario selected was that a Near Earth Object¹ (NEO), an asteroid in this case, as large as 100 meters in diameter was discovered approximately one month before it might impact. The initial probability of impact was about 10%, or based on the initial tracking data, there was 90% likelihood that the object would not strike Earth. As more tracking data was obtained, the object's orbit was refined, resulting in certain impact being predicted two weeks prior to the projected impact date. At that time, the locations of possible impact points extended roughly from Pittsburg, PA, to the Atlantic Ocean off the coast of North Carolina, which included possible impact in the neighborhood of Washington, D.C. Final orbit measurements in the last two weeks placed the most likely impact as being in the Atlantic Ocean just off the Virginia/North Carolina coastline.

As the threat evolved, the exercise team provided estimates of the type of disaster that might result from the impact of an object this size and highlighted possible effects of an airburst, similar to that experienced in Chelyabinsk, Russia, and of a ground or ocean impact. The team also examined the possibility of launching a spacecraft to deflect or disrupt (fragment) the oncoming object and eventually concluded that it was simply not possible to fabricate and launch a spacecraft in the short time available, even if such a task was undertaken at the highest national priority.

Issues discussed during the exercise included:

- Public response to the predicted event and the uncertainty of the exact geographical area that would be affected by the impact, highlighting the need for a source of authoritative, trusted, and timely information on the threat and its evolution, and
- Potential that the impact or air blast would not be survivable within several kilometers of the event, and that a very large number of people might need to be evacuated away from a shoreline or ground impact location.

There were three main recommendations from the exercise:

¹ Near-Earth Objects (NEOs) are comets and asteroids that have been nudged by the gravitational attraction of nearby planets into orbits that allow them to enter the Earth's neighborhood.

1. Improve tools for communications on the nature and evolution of NEO threats to make it more clear to the public and decision makers how an actual threat might evolve. The communications tools should include an authoritative website that would explain orbit position uncertainty and other terms used in describing a threat, discuss options that are available for deflecting or disrupting a threatening object, and describe the nature of an impact disaster. This same website would be frequently updated with relevant information in the event of an actual impact warning.
2. Develop a national response plan outlining actions that should be taken to prepare a deflection or disruption mission/campaign and activate preparations for disaster mitigation. The plan would include links to international disaster mitigation organizations and space agencies that might be involved in a deflection/disruption campaign.
3. Explore establishment of a FEMA-led NEO Impact Working Group to guide the evolution of disaster response measures and provide recommendations on future exercises and specific warnings for this scenario. This group would:
 - a) Develop materials for an authoritative website on issues related to an impact warning and disaster
 - b) Develop and maintain a “Rolodex” of key players—a list of who has what capability to support key information requests, tools the science team community has to support information needs, etc.
 - c) Design and conduct two follow-on tabletop exercises. The first would exercise an actual message format via the National Warning Systems in order for all concerned to learn differences between a man-made object returning from earth orbit (routine, happens every day) and a NEO impact, which has a low probability of occurrence, but extremely high consequences based on size, compositions, velocity, etc. The second would involve the Federal Interagency (Whole of Government), perhaps using the Emergency Support Functions Leadership Group, and “role players” might be designated to actually exercise the national level decisions which may have to be made.

BACKGROUND

On February 15, 2013, the city of Chelyabinsk, Russia, experienced the effects of the entry into Earth's atmosphere of an asteroid estimated at 17 to 20 meters in diameter, where the overpressure from the entry and explosion of the object collapsed building walls, shattered windows, and reportedly injured over 1000 people. The asteroid that caused this destruction was not detected by any system prior to atmospheric entry.

On the same day as the Chelyabinsk event, the 40-meter diameter asteroid 2012 DA14 passed Earth, with a minimum close approach distance less than that of our geosynchronous satellites. That object had been discovered approximately one year before close approach.

Prior to even these two events, The Aerospace Corporation and NASA Headquarters had begun planning a tabletop exercise to acquaint the Federal Emergency Management Agency (FEMA) with the nature of an asteroid impact event and how such an event for a small asteroid might evolve if it is detected with only a short, several days to a few weeks, warning. The goal was to design a scenario that was possible, given today's asteroid discovery and tracking capabilities, and that highlighted how knowledge of such a threat might evolve over time and how such an entry and impact might affect people and property. The Statement of Work for the exercise is given in Attachment 1.

A team of experts in several key areas was assembled to design, develop details, and present the exercise. Key members of the exercise team were:

- William Ailor, The Aerospace Corporation: Project coordinator
- Dave Baiocchi, RAND Corporation: Public response and policy issues
- Mark Boslough, Sandia National Laboratories: Atmospheric and ground effects of asteroid entry and impact
- Nahum Melamed, The Aerospace Corporation: Asteroid deflection mission design
- Paul Miller, Lawrence Livermore National Laboratory (LLNL): Asteroid deflection payloads and effects of entry and impact on people and property
- Paul Chodas and Donald Yeomans, NASA Jet Propulsion Laboratory: Asteroid discovery and threat evolution

Key guidance and assistance in developing and presenting the details of the threat scenario were provided by

- Lindley Johnson, NASA, NEO Program Executive, Planetary Science Division
- Leviticus A. Lewis, Chief, Field Operations Branch, Operations Division, Response Directorate

Uma Bruegman of The Aerospace Corporation captured a record of the exercise activities. Attachment 2 provides a list of participants in the exercise.

EXERCISE SCENARIO

The exercise posed the scenario that an object originally estimated to be between 25 and 100 meters in diameter was discovered on April 1, 2013, with a predicted impact date of May 3, 2013. Figure 1 provides a calendar presenting the timeline for the exercise scenario. Initially, no information was available on the object's density, so it was assumed to have high iron content—a worst-case assumption since an iron meteorite was more likely to pass through the atmosphere and impact Earth.

The initial uncertainty of Earth impact was 1 in 10. Since it is not known at the initial point that the object will impact, a “?” was used on the possible impact date for the first inject (see Attachment 1). This symbol became an “X” after impact was certain.

Later in the exercise timeline characterization measurements found the object to be approximately 50 meters in diameter and it was determined to be on an orbital trajectory where it would enter at a ~20 degree angle on a ground path that passed over Washington, D.C. The object was predicted to impact ~100 km beyond the Delmarva Peninsula in the Atlantic Ocean, creating a tsunami on the east coast of the US and perhaps a small tsunami wave along the western coast of Europe.

Effects on the East Coast metropolitan areas of the US from the atmospheric shock wave from the entry and the tsunami wave and other effects from the ocean impact were modeled and the results were presented to the participants.

The exercise represented the passage of time and evolution in knowledge about the object from first discovery to impact. Participants in the exercise were provided “weekly” updates on the progression of the anticipated threat, with the information provided in each update representative of the increased understanding of the threat after a week’s effort in tracking, orbit refinement and object characterization. An overview of the information provided in each update is given below. Details are in the charts provided in Attachments 1 through 4.

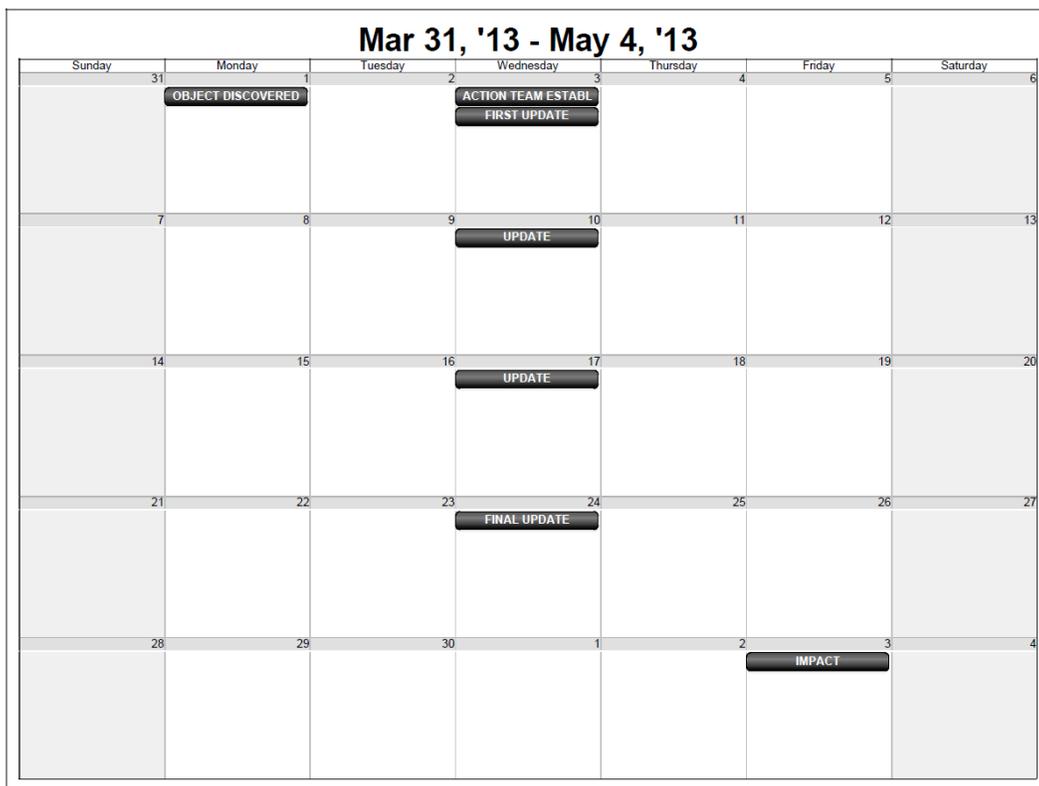


Figure 1. Exercise calendar.

First Update (Two days after discovery, ~4 weeks to impact)

Aerospace (Bill Ailor) introduced the exercise, noting that an object has been discovered that has a relatively high probability (1 in 10) of impacting Earth on May 3, 2013 and noting that this group has been called together to monitor the situation and, if necessary, recommend and execute actions to deflect or minimize the impact threat, to prepare the public for the event, and to mitigate the disaster that might follow an impact.

NASA (Lindley Johnson) provided first details on the object, which was discovered two days prior to the day of the exercise, which corresponded to approximately one month before very close approach to the Earth. The initial impact probability was 1/10 and first estimates of the size were between 25-100 meters. No information was yet available from which the material or composition of the asteroid might be estimated. As Fig. 2 shows, possible impact locations were along a path which included parts of Canada, the United States, and the Atlantic Ocean (the object would be approaching from the west). Each impact point was estimated by varying slightly the asteroid's orbit parameters and propagating the trajectory to either impact or Earth fly-by. The asteroid might eventually impact on only one of these red dots, and predictions of which points would have the highest probability for actual impact would be improved as more information from tracking resources became available. Should the object manage to pass through the atmosphere intact, its velocity at impact would be 19.8 km/sec. It would enter the atmosphere at a shallow angle, about 20 deg from the local horizontal.

As Fig. 3 shows, the threat was rated as a "3" on the Torino scale. Fig. 4 provides considerations used in that determination.

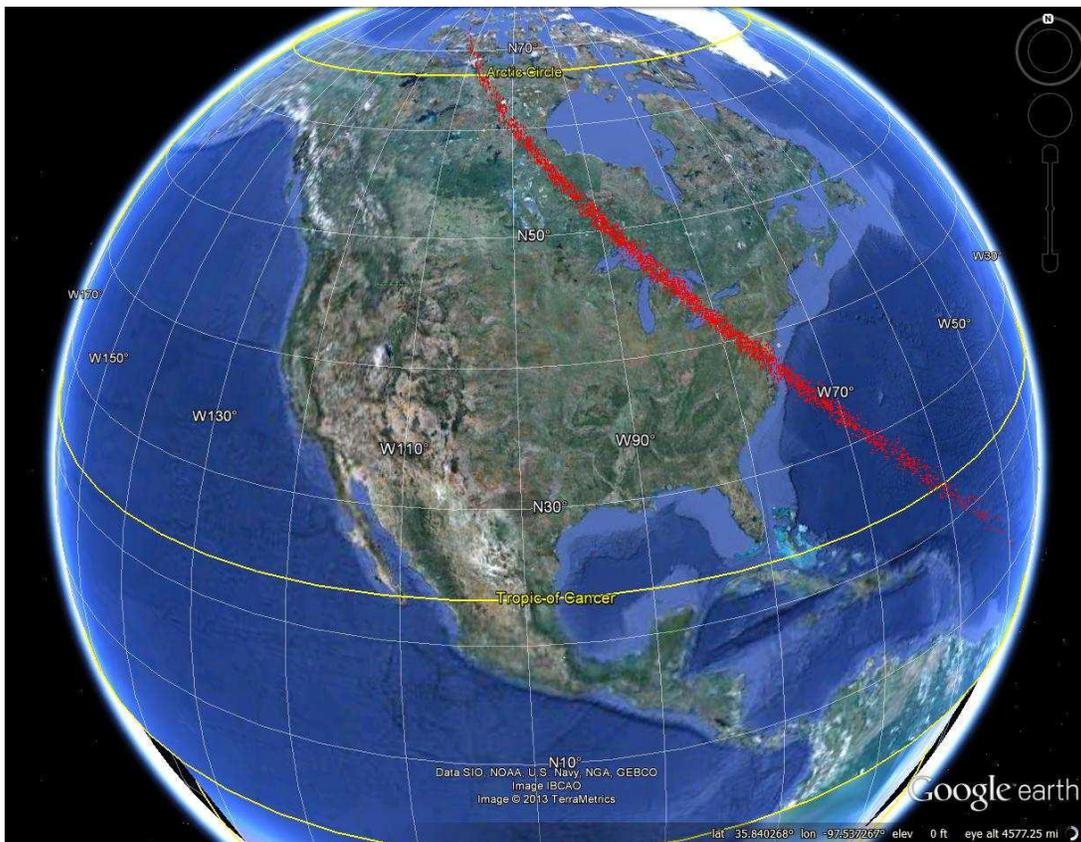


Figure 2. First predictions of possible impact points.

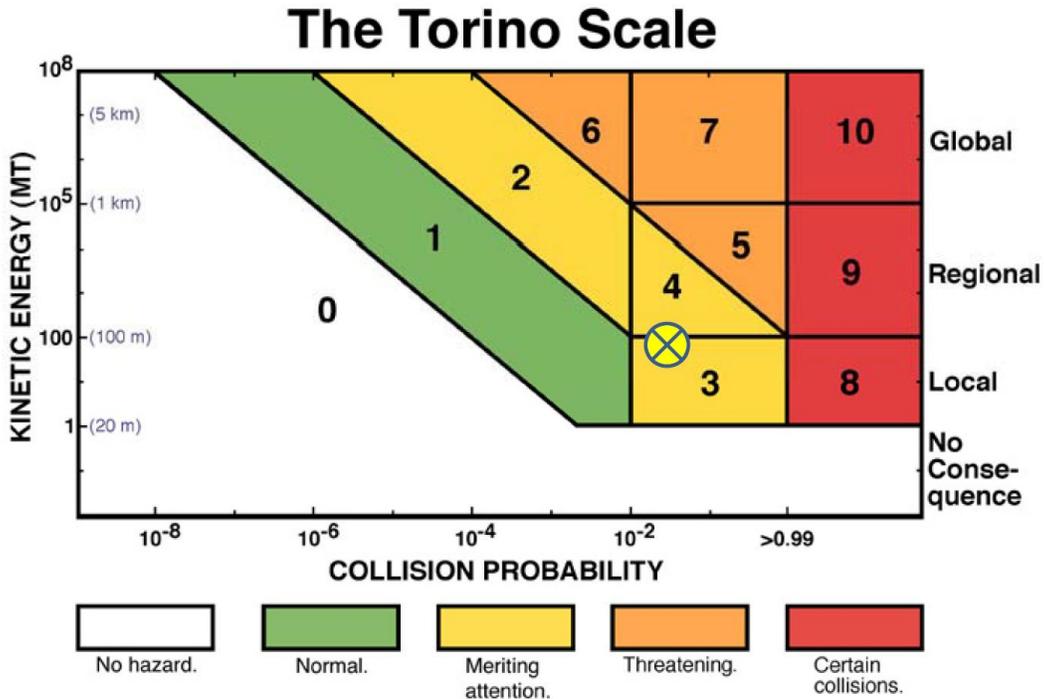


Figure 3. Assessment of threat on Torino scale (see Fig. 4 for clarification of rating system).

RAND (Dave Baiocchi) provided information on the early public knowledge of and reaction to the discovery, noting that all details known on the discovered object are generally posted on the open Internet very soon after discovery.

Sandia (Mark Boslough) gave information on potential shock wave, blast and impact effects that might be expected typical of information available on very short notice. He also described how effects and potential areas affected might vary with the size and composition of the asteroid and its entry angle.

Aerospace (Nahum Melamed) gave results of an initial look at deflection/mitigation mission options and discussed mission objectives and requirements. He found a total of three launch vehicles with the necessary capability on pads: one each in Russia, China, and the US. The next step was to see if there was a payload and payload bus (a launch stage with appropriate capabilities to deliver a payload designed to move or destroy a threatening object) that currently existed which could be utilized. He had found two possible mission timelines that could possibly reach the oncoming asteroid in time. The first required that the payload be launched within ten days of the current date and would reach the object in seven days (about 13 days before Earth impact); the second could be launched in 21 days and would require four days to reach the object. In the latter case, the encounter with the asteroid would occur five days prior to Earth impact. Investigation of options would move forward at the highest national priority.

Given that a mission might be possible, although unlikely given the time available, LLNL (Paul Miller) described the two mitigation options that might be used—deflection or dispersion. He concluded that the time after intercept was too short for an effective deflection option, and focused on dispersal—detonating a nuclear device in close proximity to the object, vaporizing, melting, and pulverizing the object. His modeling expected that some of the resulting debris cloud would miss Earth and the atmosphere would protect against smaller fragments less than 10 to 15 meters in diameter. Dr. Miller would be working with Dr. Melamed to see if a payload could be made ready in the available time.

No Hazard (White Zone)	0	The likelihood of a collision is zero, or is so low as to be effectively zero. Also applies to small objects such as meteors and bodies that burn up in the atmosphere as well as infrequent meteorite falls that rarely cause damage.
Normal (Green Zone)	1	A routine discovery in which a pass near the Earth is predicted that poses no unusual level of danger. Current calculations show the chance of collision is extremely unlikely with no cause for public attention or public concern. New telescopic observations very likely will lead to re-assignment to Level 0.
Meriting Attention by Astronomers (Yellow Zone)	2	A discovery, which may become routine with expanded searches, of an object making a somewhat close but not highly unusual pass near the Earth. While meriting attention by astronomers, there is no cause for public attention or public concern as an actual collision is very unlikely. New telescopic observations very likely will lead to re-assignment to Level 0.
	3	A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of localized destruction. Most likely, new telescopic observations will lead to re-assignment to Level 0. Attention by public and by public officials is merited if the encounter is less than a decade away.
	4	A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of regional devastation. Most likely, new telescopic observations will lead to re-assignment to Level 0. Attention by public and by public officials is merited if the encounter is less than a decade away.
Threatening (Orange Zone)	5	A close encounter posing a serious, but still uncertain threat of regional devastation. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than a decade away, governmental contingency planning may be warranted.
	6	A close encounter by a large object posing a serious but still uncertain threat of a global catastrophe. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than three decades away, governmental contingency planning may be warranted.
	7	A very close encounter by a large object, which if occurring this century, poses an unprecedented but still uncertain threat of a global catastrophe. For such a threat in this century, international contingency planning is warranted, especially to determine urgently and conclusively whether or not a collision will occur.
Certain Collisions (Red Zone)	8	A collision is certain, capable of causing localized destruction for an impact over land or possibly a tsunami if close offshore. Such events occur on average between once per 50 years and once per several 1000 years.
	9	A collision is certain, capable of causing unprecedented regional devastation for a land impact or the threat of a major tsunami for an ocean impact. Such events occur on average between once per 10,000 years and once per 100,000 years.
	10	A collision is certain, capable of causing global climatic catastrophe that may threaten the future of civilization as we know it, whether impacting land or ocean. Such events occur on average once per 100,000 years, or less often.

Figure 4. Considerations used to rate the potential hazard posed by an asteroid or comet on the Torino scale.

Second Update (~3 weeks to impact)

NASA (computed by Paul Chodas and briefed by Don Yeomans) reported that the impact likelihood has increased to 65% and showed the possible impact locations (Fig. 5). He noted that the ground path where impacts were possible still included Washington, D.C. and the Atlantic Ocean. The size of the object is now estimated to be between 45 and 60 meters in diameter. The threat was still rated as a “3” on the Torino scale, but as shown in Fig. 6 had moved to the right and down based on the increased probability of impact and decrease in the object’s estimated size.

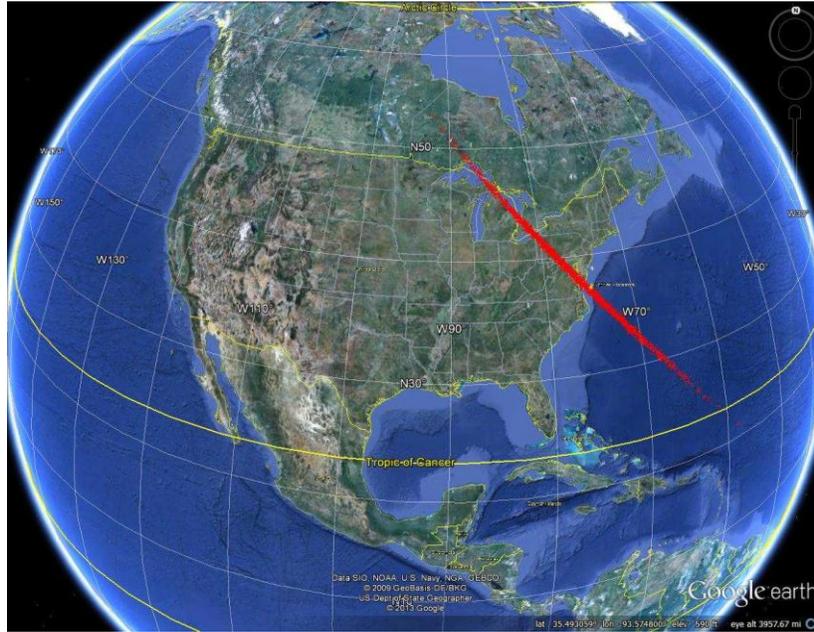


Figure 5. Possible impact locations at three weeks before possible impact based on best-available data.

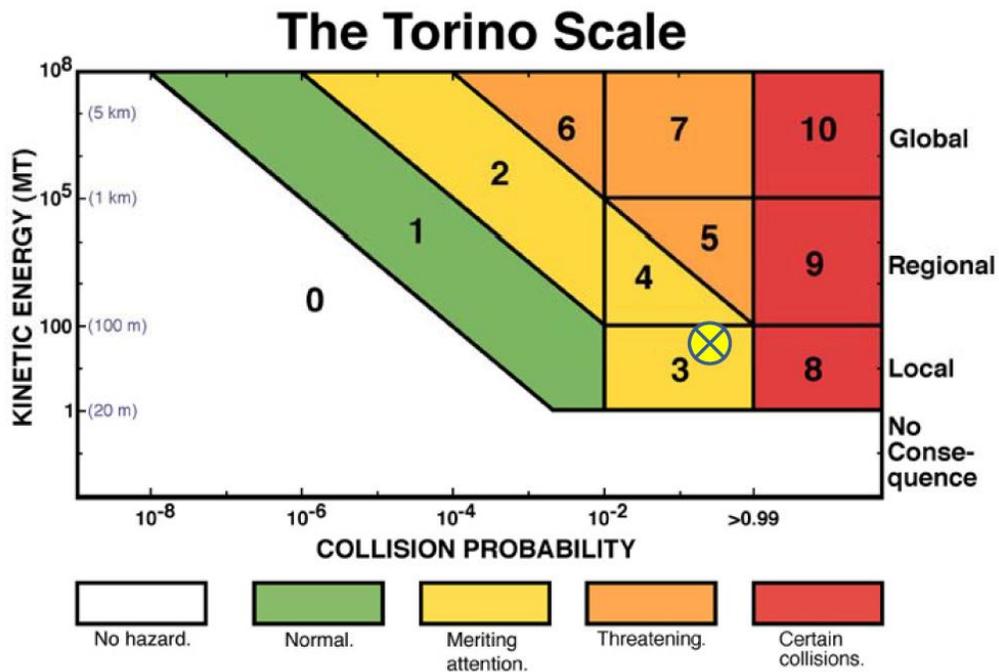


Figure 6. Torino scale at three weeks before possible impact

RAND (Dave Baiocchi) provided an update on the public response to date. During the exercise, FEMA noted that they, along with their NASA counterparts, would be actively working to report accurate and timely information to the public. Because of this action on FEMA's part, RAND reported that inaccurate videos on YouTube were largely being ignored by the media. Some people have started moving out of areas that are along the path of possible impacts. There are initial signs of shortages of gasoline, groceries and emergency supplies in the Northeast.

Sandia (Mark Boslough) provided more detail on the size of the potential blast and impact effects. He noted that the maximum projected size of the object and the entry conditions could cause an airburst overpressure equivalent to an explosion of 200-Mt of TNT.

Dr. Melamed reported that his team had eliminated the two foreign launch vehicles due to incompatibility with payload interface requirements. The team was now focused on using a Delta launch vehicle on the launch pad at Cape Canaveral Air Force Station. The team had also considered using an existing ICBM-class vehicle, but this was eliminated because these vehicles do not carry the targeting capability necessary for this mission. The team had found that there were no U.S. spacecraft available with the proper components or configuration for an intercept mission, but that the team would continue to work the issue. He noted that the launch must occur in 14 days, but it was clear that a spacecraft would need to be thrown together for this application and he rated the probability as much less than certain that an intercept and proper function of the explosive payload would occur as needed.

Dr. Miller reported on effects of a disaster of the predicted scale on critical infrastructure in the Capitol region. See his charts (Attachment 2) for details.

Third Update (~2 weeks to impact)

Dr. Chodas provided an update on the current impact possibilities, and noted that impact was now certain. The ground path where the impact might occur is shown in Fig. 7. As Fig. 8 shows, because of the now certain impact probability, the Torino scale shows the threat as an "8," with local consequences being the most likely.

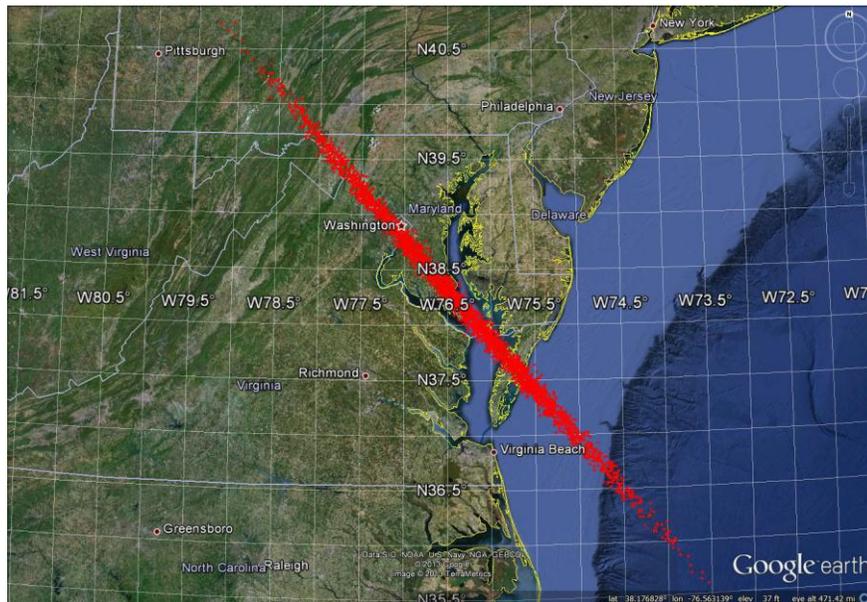


Figure 7. Possible impact locations at two weeks before impact based on best-available data.

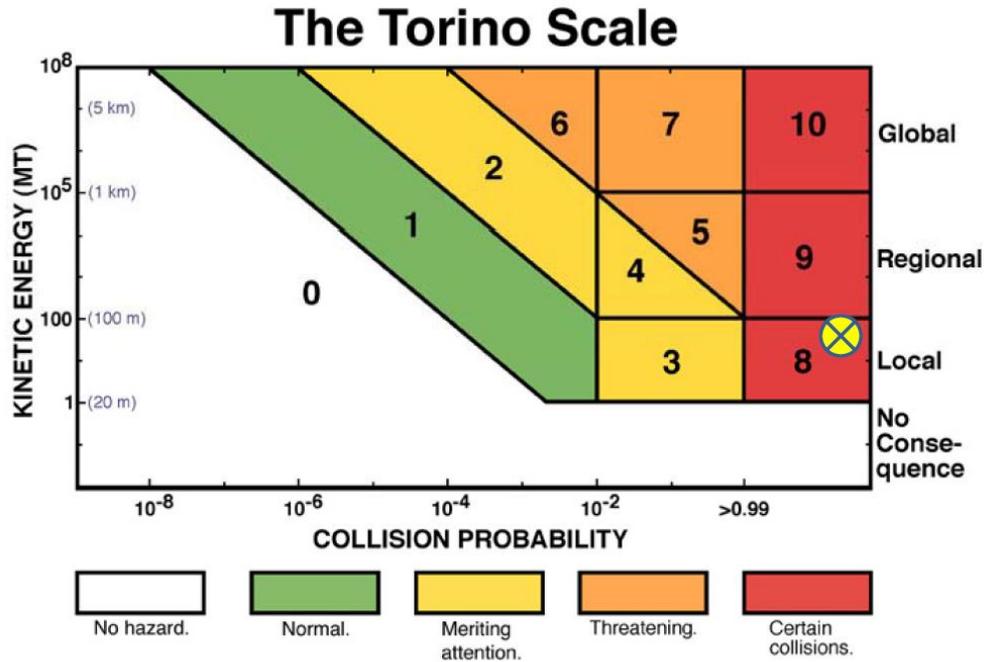


Figure 8. Torino scale at two weeks before impact

Dr. Baiocchi noted that people are moving west, away from areas where impact might be possible. Some have begun coalescing around nongovernmental organizations for basic necessities and comfort. Private sector logistics supply is tightening.

Dr. Melamed reported that his team had found that there is not enough time for tasks associated with space vehicle fabrication and launch vehicle and space vehicle integration, although a crash effort was being made to fabricate and launch in the short time remaining. Given the nature of this effort and the likelihood for mistakes, he gave his assessment that a successful mission was very unlikely and therefore asteroid impact was essentially certain.

Dr. Boslough used the new data on the size of the object to refine the consequences, estimating that a 50 meter diameter iron (worst case) asteroid would impact with an energy equivalent to a 10 Mt explosion, but he could not rule out the possibility of an airburst equivalent to 25 Mt. He predicted the event would cause total destruction over a radius of three miles from the impact point and that wood-frame buildings would collapse within 6.5 miles of the event. Should there be an airburst, for the worst case there would be total destruction within a radius of 6 miles of the event, with wood-frame buildings collapsed within 19 miles of the event. Windows would be shattered within 50 miles.

Dr. Miller updated information on critical infrastructures affected, assuming an impact in Cedarville State Forrest, located approximately 20 miles from Washington, D.C. Should this occur with no population evacuation or sheltering, he predicted 78,000 fatalities, 480,000 would suffer severe burns or injuries from broken windows, and over 5 million would receive first-degree burns if they were outside and exposed. He showed graphics of government buildings (prisons, post offices, FEMA Field Offices, law enforcement facilities), military facilities, communications facilities, ground transportation, energy, and water resources that would be affected (see Attachment 3).

Fourth Update (~8 days to impact)

Dr. Chodas provided the latest information on tracking the threat, stating that impact would most probably occur at 0800 EDT on May 3, 2013 on the Atlantic Seaboard off of Norfolk, Virginia. The

location of possible impact points has reduced to the area shown on Fig. 9. Given that the impact was likely to be in the ocean, the area affected by the resulting tsunami would extend up and down the East Coast, a regional consequence. As a result, the Torino Scale threat assessment was upgraded to “9” as shown in Fig. 10.

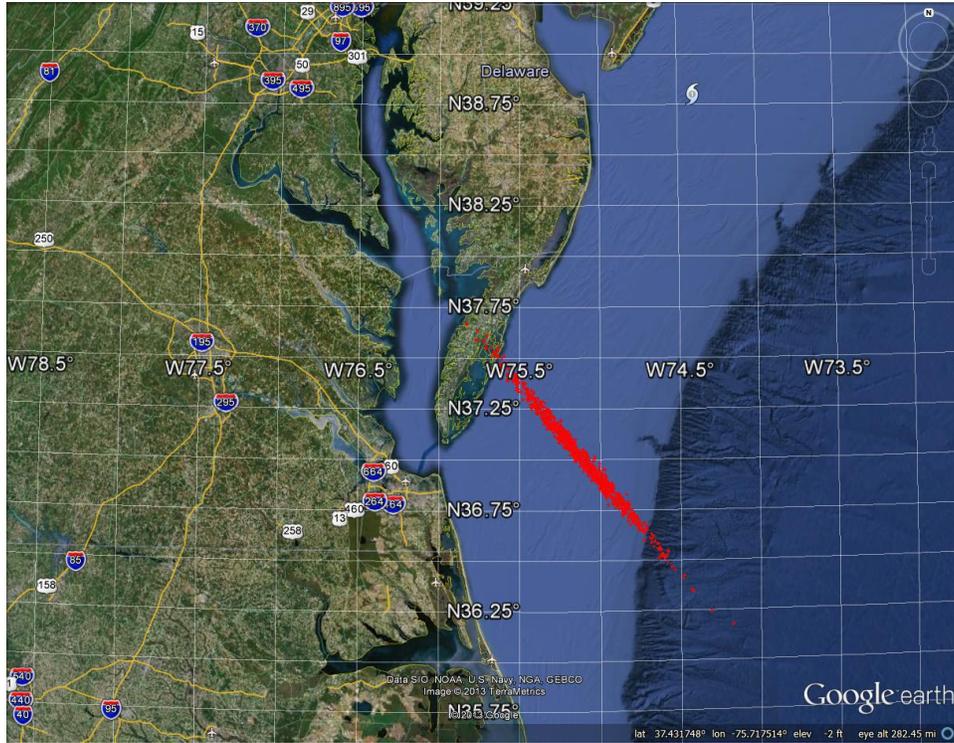


Figure 9. Possible impact locations at eight days before impact based on best-available data.

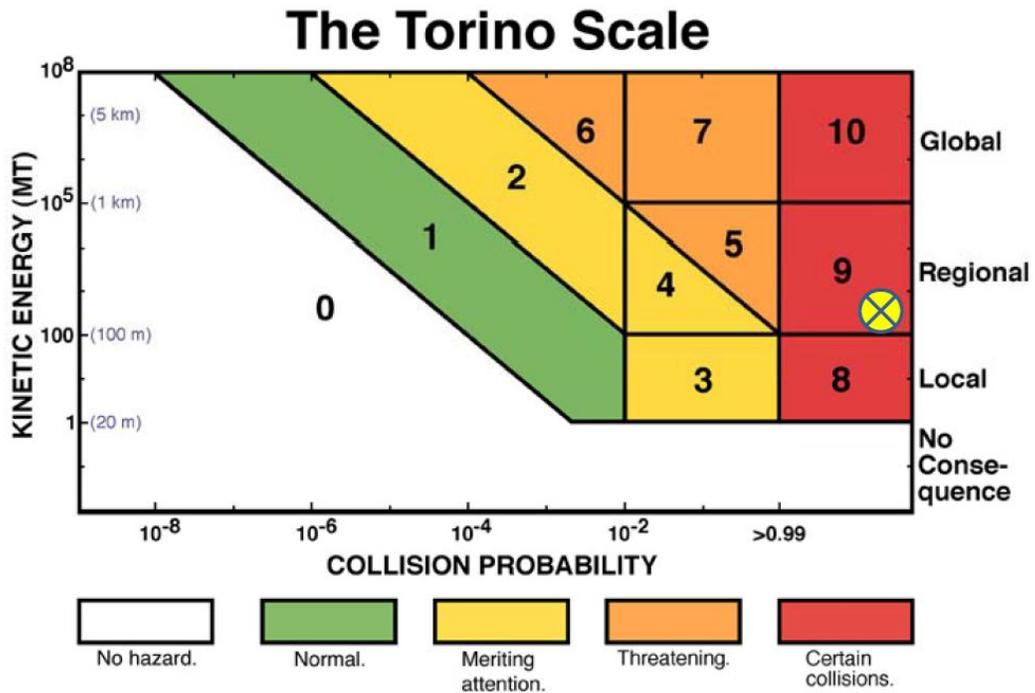


Figure 10. Torino scale at eight days before impact

Dr. Boslough provided possible areas that would be affected by tsunami extending from North Carolina to New York City, with the area at highest risk including the Southern tip of the Delmarva Peninsula.

Dr. Miller showed predictions of the progression of a tsunami wave from an impact location just past the Continental Shelf. He noted that a tsunami up to 15 meters high would impact a large area and inundate many coastal areas. Many areas will be totally destroyed and people will have very little to return to. He presented maps showing areas flooded and infrastructure affected (see Attachment 4).

Dr. Baiocchi reported that FEMA's action and accurate information updates (as demonstrated during the exercise) had tempered public response as to control panic and hysteria. However, bottlenecks were still developing along the major transportation corridors within in the Northeast. Portions of the transportation infrastructure (air, rail, etc) were shutting down due to the lack of personnel to run the facilities. There are shortages of gas, groceries, and emergency supplies in northeast coastal cities.

OBSERVATIONS AND RECOMMENDATIONS

The day after the tabletop exercise, the exercise team gathered to discuss observations and lessons learned from the exercise. Specific suggestions are collected below.

Communications with the public

- The public should be kept continuously informed with the best data available.
- The U.S. Government should prepare and deliver a daily press conference (before the evening news cycle) to provide an update with all known impact effects data and relief activities.
- An authoritative website that is updated as frequently as feasible should be maintained from the beginning.
- Effective and easy to understand visualizations should be provided to the public and the media.
- Graphics or animation showing how an impact threat might evolve and that presents and defines important terms should be developed.
- Technical terms such as “Monte Carlo” should be clearly defined (perhaps a web page should include technical terms and background information, or provide links to such information).
- Prudent to send out information and suggested pre-scripted messages to cultural and societal leaders (need to identify who these leaders are).
- The uncertainty and level of risk need to be made clear to the public and to decision makers using metrics and diagrams that can be readily understood by most citizens.
- The accuracy of the track and impact point should be communicated as they become available and evolve with time.
- The current scales that rate potential threats might be useful to experts, but were judged to be very difficult for the public to understand. A simpler system should be considered for informing the public.
- Consider developing an analog to NOAA’s “hurricane plot,” which is a risk visualization that most of the public understands (e.g., a plot that shows selected approach ground tracks as well as the possible impact points might help illustrate basic features of a threat and areas that would be affected).
- Discussions of damage and explosive potential should attempt to use language other than comparisons with nuclear weapon yields (e.g.: “number of Hiroshima devices) and avoid use of words like “kill zones.”
- Use of nuclear explosives will be a sensitive point with the public and international partners and must therefore be handled carefully and consistently.

Agency Involvement and Coordination

- Need to look for methods to increase accuracy and lead time of predictions. An appropriately located space-based system would greatly aid efforts in this area.
- The agencies required to lead the disaster preparation efforts should be identified well in advance of a threat.
- Disaster simulations conducted with states should include an asteroid impact disaster.
- There is a small possibility that an object of the size in the exercise could impact with no notice. In that case, FEMA would respond as it does in any disaster. An exercise for a no-warning event could be developed.
- FEMA supports the states in their response to disasters. In all cases the states will have the lead and plans will have to account for the differences in states authorities. For instance, evacuation order authority varies by localities and plans for large scale evacuations must account for this fact.
- Need to coordinate deflection response planning with other nations' space programs.
- What is the set of NGOs that could support training and decision making for an impact threat emergency?
- We need to develop tangible ways to continue to move forward and to maintain some level of momentum with impact emergency response planning.
- Emergency preparedness and response capabilities must be developed to answer general domestic and multinational asteroid threats.
- Multimedia graphics are needed showing scenario background and progress, predictions, affected areas, etc., for effective communication among the stakeholder organizations as well as the public at large (NASA has capabilities in this area).
- Utilizing international launch vehicle resources is unlikely for a domestic impact threat in the present mode of thinking and operation.
- Developing a complete remedy for all NEO threat situations is not realistic and the effort should be looked at from a risk reduction point of view.
- Developing mitigation for the set of objects that are or may become detectable will buy down a significant portion of the risk.

Information Enhancements

- Make information and descriptive material available on an authoritative website (e.g., info above).
- Provide better graphics illustrating relationship between approach directions, overpressure effects, and impact points.
- Develop a better description and illustration of how impact locations are developed.
- Consider developing something better than the Torino Scale for indicating to the public the level of risk.
- Provide information on the evolution of an impact threat and factors that affect uncertainty.
- Consider hurricane plot as example for representing possibilities.
- Provide a plot showing % of known objects vs. size and time; likelihood of impact by undetected object vs. size and time. We could show the nature of mitigation activities that might be necessary as more discovery and tracking resources come on line.
- Consider a paper on risk reduction—cost vs. level of risk reduction.

MOVING FORWARD

Post-exercise suggestions can be grouped into three key areas:

1. Improve communications

Supplement authoritative websites (e.g., <http://neo.jpl.nasa.gov>) with additional information that informs the public and decision makers on how an asteroid threat warning might evolve and criteria on which a decision to act might be based. The website should

- Define technical terms.
- Develop a framework for easy to understand graphics and illustrations that communicate risk.
- Describe how a threat might evolve.

2. Explore appropriate ways forward for planning response to potential NEO threats

Identify the most appropriate plan where the response of the United States to a serious asteroid impact threat would be addressed.

- Consider both protection of people and deflection/disruption of the threatening object.
- Assign responsibilities and response and communication protocols in the event of a serious warning or impact.
- Include the possibility of a threat/impact that does not directly affect the U.S.

3. Establish an authoritative interagency NEO emergency response team (NEO Working Group)

A working group of experts, probably including Federally Funded Research and Development Centers who have experts and tools in areas related to asteroid warning, deflection, and impact effects, should be established to support the development of a national plan and to develop materials and web pages for information. The group might be sponsored by FEMA and NASA (and possibly DoD), the main players in any impact mitigation exercise. The group would:

- Develop and maintain a “Rolodex” of key players--a list of who has what capability to support key information requests, tools the science team community has to support, etc.
- Develop and maintain a list of authorities worldwide that would be involved in providing accurate and authoritative information on an actual event. These individuals would be provided scripted information in the event of an actual threat.
- Develop and maintain list of existing tools and capabilities to support NEO disaster analysis
- Use the current Planetary Defense Conference as a way to keep informed on international developments.
- Meet semi-annually or at least yearly to review progress and recommend scenarios for FEMA.
- Work to be sure media and movies represent threat and mitigation accurately.
- Coordinate development of authoritative web page on planetary defense.
- Assess public opinion on NEO threat, possible deflection options.
- Develop and conduct a follow-on exercise with more detail and role playing that includes participation of other government agencies and perhaps lasting at least two work days. The exercise might include a no-warning scenario.

ATTENDEES

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