PDC2013
Flagstaff, AZ, USA
Abstract and Amplified Material

NEO Disaster Response and Recovery in the Context of Other Natural Hazards

Clark R. Chapman[1]
[1]*Southwest Research Institute., 1050 Walnut St. Suite 300, Boulder CO 80302, 303-546-9670, cchapman@boulder.swri.edu*

Keywords: *response, recovery, natural hazards, impact consequences*

ABSTRACT

The consequences of a NEO impact on the Earth, e.g. as reported by the Purdue impact calculator (http://www.purdue.edu/impactearth/), are not particularly dissimilar from those of more common, familiar natural disasters. Effects resemble those of an earthquake, tsunami, wildfire, landslide, volcanic eruption, windstorm, and other disasters. The scale of effects varies enormously, depending on the size of the impactor, but then many natural disasters can span the range from minimal damage to destruction across a region as large as a small country. An NEO impact may happen essentially without warning (as for an earthquake) or with appreciable warning (as for a hurricane). Thus much of the understanding of how to prepare for and respond to common natural disasters can be applied to an NEO impact.

There are differences, of course. Natural disasters generally can threaten only very small regions on the Earth (e.g. “tornado alley”, along coastlines, along continental plate boundaries), permitting cost-effective preventive measures (e.g. strengthening structures where earthquakes are likely to occur). NEO impacts can occur anywhere and, additionally because of their infrequency, years-in-advance NEO-specific measures would not be cost-effective. Because of the infrequency of NEO impacts, hence lack of familiarity, people may develop unrealistic fears (e.g. belief that there is deadly radioactivity) which they would not do in the case of a familiar disaster, so the behavior of victims may be less predictable for first responders. A final difference is that many disasters raise the possibility of another similar disaster occurring in the same location in the comparatively near future, whereas an NEO impact is a singular event; in the extremely unlikely case of another one happening shortly afterwards, it certainly wouldn’t happen in the same locality.

Despite these differences, we should expect that the response to an NEO disaster would be mounted by existing disaster response agencies in customary ways, which have a demonstrated degree of effectiveness (and also shortcomings and failures). By far the most likely NEO impact would be by a very small NEO; if it occurred in a populated locality, then it would be dealt with by local authorities in ways similar to responses to a building on fire, an airplane crash, or a tornado. Response to a much less likely large impact, e.g. by an impactor 100 m in diameter or larger, would probably resemble responses to major natural disasters, like the 2011 Japanese earthquake/tsunami or the 2004 Indian Ocean tsunami. Only if the impactor approached ~1 km diameter would the qualitative character of the consequences

enter wholly uncharted territory, requiring kinds of international responses never before experienced or even contemplated. (Of course such a giant impact would hopefully be prevented by a NEO deflection mission.)

The general form of response and recovery from natural disasters is applicable to most natural disasters and is summarized, for example, in Chapter 2 ("The Disaster Recovery Process") of the 2006 book "Holistic Disaster Recovery" produced by the Natural Hazards Center of the Univ. of Colorado. Many aspects of disaster recovery described in this document would apply to an NEO impact disaster. Of course, recovery involves re-establishing community infrastructure, but the primary issues involve *people*, including restoring their individual lives as well as restoring the social elements that sustain a community. Availability of financial resources to effect recovery is a major issue.

The major emergency-planning differences between a NEO impact and other natural hazards concern the discovery of the potential disaster, evolving predictions of the event, warnings and mitigation strategies, etc., all taking place *before* the impact. But once an impact happens, the widely adopted "all-hazards" approaches to response and recovery apply to the NEO disaster just as they do to any other natural disaster.

PRE-CONFERENCE AMPLIFICATION FOR MEMORY STICK

The 15 February 2013 asteroid impact and explosion in the atmosphere above Chelyabinsk, Russia, has heightened awareness of the importance of civil defense, emergency response, and evacuation as by far the most likely kind of mitigation we will need in future decades as we face the NEO impact hazard. It has always been the case, of course, that impacts by smaller bodies (larger than a threshold size for which the Earth's atmosphere provides adequate protection) are much more frequent than impacts by larger ones. Until now, of course, we were unaware of almost all impending impacts by small bodies because they were too small and faint to be found by search telescopes. We are on the verge of changing that, thanks to the 2008 TC3 event, which made us aware that different, inexpensive search protocols could, in fact, find "final plungers" hours to weeks before impact, permitting advance warnings. And the ATLAS project has been designed and funded, and it will soon be implemented to find an appreciable fraction of impactors several meters to several tens of meters in size before they hit (although not those coming from the general direction of the Sun). Another factor that has changed the odds towards dealing with smaller impacts has been the success of the Spaceguard Survey in finding 90% - 95% of >1 km impactors, and follow-up demonstration that none of them has more than a minuscule chance of striking Earth in the next century.

The size-frequency relation for NEOs is quite "steep" meaning that bodies only fractionally bigger than some size will strike much more often and, of course, the damaging energy released varies as the cube of impactor size. Thus it is very important to determine the lower threshold of impactor size that could be damaging. And civil defense officials must build in a conservative degree of prudence, to take into account uncertainties in estimates of impactor size and the natural variability in the range of damage that different bodies of identical size might inflict. (For example, the Carancas impact in Peru illustrated that even a very small, meter-scale body could, under special circumstances – in this case, perhaps body shape, strike the ground with much of its cosmic velocity intact.

In the 2003 NASA Science Definition Team (SDT) report, there was an explicit assumption that anything smaller than roughly 50 m in diameter would explode harmlessly in the upper atmosphere. Subsequently, there was discussion within the community about just what "harmless" meant, a re-examination of the literature extending back to Glasstone's 1960s studies of the effects of nuclear tests, and consideration of the appropriate range of uncertainties that emergency management officials should take. Still later, new studies of the physics of asteroid impacts in the atmosphere by Boslough, taking downward momentum into account (instead of assuming effects were like a static nuclear explosion with the same energy), suggested that the enormous damage of Tunguska in 1908 might have been due to an impact with an energy of just 3 to 5 MT, instead of the previously estimated 10 to 20 MT. That implied that impacts by smaller, more frequently impacting NEOs were more dangerous.

Chelyabinsk is a further warning that we should not ignore predicted impacts by bodies just 10 m in size, or smaller. As of this writing, the Chelyabinsk impactor is estimated to have been a rocky body about 15 to 20 m in diameter. It clearly was very dangerous, injuring more than 1,200 people (mostly by flying glass), sending some to the hospital with more serious injuries, causing structural damage to a few buildings, although apparently killilng nobody. It came in at an unusually low angle, less than 20 degrees, and thus exploded higher in the atmosphere and had less downward momentum than would a typical impact at 45 degrees. Obviously, people should be warned to stay away from windows and, probably evacuate from ground-zero, if an event like Chelyabinsk were predicted near a populated area in the future. And if a body were predicted to impact more vertically, than one could expect that an even smaller body could do equivalent damage. In all cases, the estimated size and mass of the predicted impactor would likely be uncertain and in most cases – when the albedo or diameter haven't even been measured (just the magnitude and maybe color) – the uncertainty in mass (hence energy) could be a factor of ten or more.

Thus I believe that it is now prudent for civil defense officials to issue warnings for some predicted impacts in populated places when the impactor is estimated to be larger than 5 m in diameter, and certainly to do so if larger than 10 m diameter (such events happen somewhere on land perhaps every couple of decades). Evacuation should be considered, if readily feasible, for impactors on land that are estimated to be roughly the size of Chelyabinsk and should be mandatory if estimated to be larger than 25 m. A predicted impact by a 45- or 50-m body, the previously estimated lower limit for damaging impact as of a decade ago, should now be considered to be a nearly certain major local disaster. While such a disaster on land is quite unlikely, perhaps ~5% chance this century, Chelyabinsk has shown us that what are estimated to be low probability events can indeed happen.

Chelyabinsk has also taught us several things about public perceptions of unlikely disasters. A concern about the impact hazard since the Snowmass conference of 1981 has been the possibility that a brilliant explosion in the skies might be misinterpreted by the public or by the military establishment of the affected country as a nuclear explosion and an act of war, possibly meriting counter-attack. Fortunately, despite its history of housing secret nuclear facilities in the Soviet era and at least one local nuclear disaster, the Chelyabinsk region responded to the February 15th event without evident fear of unusual repercussions: war did not ensue, there was no widespread fear of radiation, etc.

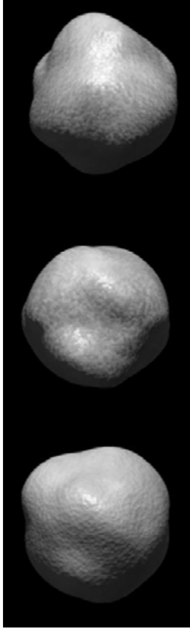
On the other hand, the unfamiliarity of the impact hazard did have other serious consequences in Chelyabinsk. Enormous explosions and intervals when there is a light in the sky much brighter than the Sun are very unusual, whether the cause is an asteroid impact or some kind of human/technological event. When the brilliant light outside was perceived by people inside buildings in Chelyabinsk, many rushed to the windows, unaware that a minute or two later a massive shock wave would shatter the windows. An analogous situation occurred during the 26 December 2004 Indian Ocean tsunami, which was a much rarer event in the Indian Ocean than in the Pacific. When waters suddenly receded prior to the cresting tsunami wave, people in some localities were attracted by stranded fish, flopping about on the seafloor that was normally below water…and ran to collect the fish, unaware of the impending on-rushing waters.

If there is ample time to warn people before an NEO impact, several unusual attributes should be mentioned. Of course, the possibility of a damaging shock wave arriving seconds to many minutes afterwards is a prime lesson from Chelyabinsk. These could knock down poorly constructed buildings and housing in underdeveloped localities, even though that was a rare outcome in Chelyabinsk. Beyond that, there will be rocks falling from the skies under the flight path and explosion. Being brighter than the Sun, the bolide should *not* be looked at directly or with binoculars, as as frequently cautioned before a solar eclipse. Because people may not understand, they should be alerted to the fact that an asteroid impact does not cause unusual radioactivity and that, unlike portrayals in movies, it is very unlikely to be accompanied by a follow-on impact near the same locality during subsequent minutes or years (nor will there be preceding bolides heralding the main event). Of course, an especially unlikely larger impact would have even more serious effects, to which emergency managers should be alerted by knowledgeable scientists (the populace itself would hopefully be evacuated, but some may be unable to leave and could suffer burns, bodily trauma, and other serious consequences).

What is the Smallest NEO that is Dangerous? [2008]

THEN THERE WAS CHELYABINSK

Model of 30 m NEA 1998 KY26 (radar)



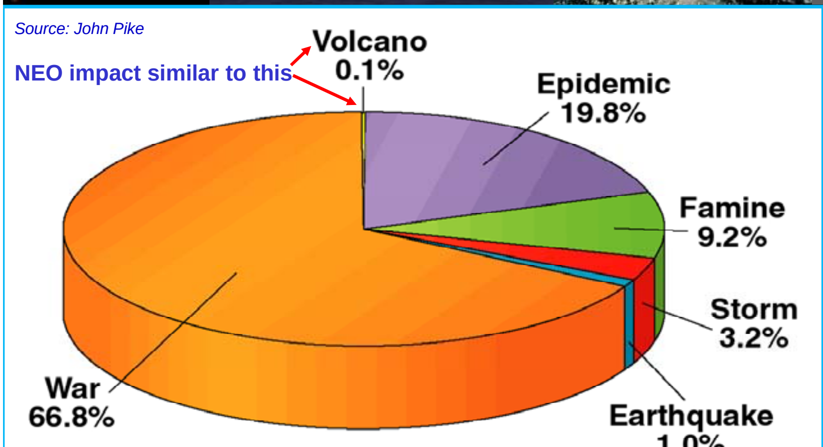
This will be a vital issue for decision-makers

- **2003 SDT report says the smallest truly dangerous non-metallic impactor is ~50 m diameter.**
- **Boslough** (2007)**: downward momentum from atmospheric blasts ➔ Tunguska caused by ~35 m (not 70 m) NEO.**
- **25 m NEOs impact ~10 times as often as 50 m NEOs, once per century.** (They may merit deflection, surely evacuation.) **A 10 m NEO strikes 1,000 times as often as a 100 m NEO.**
- **There are many uncertainties in how big/massive an NEO is and thus its likely damage…so a prudent emergency management official might choose to issue a warning to evacuate or shelter in place for even much smaller NEOs.**
  - **Anomalous 2007 impact explosion in Peru by ~1 m NEO.**
  - **Child may have been killed (indirectly) by ~10 m NEO impact above Indonesia on 8 Oct. 2009.**
- **Officials must make decisions and act prudently once the new surveys start discovering thousands of smaller NEOs and some appear (within uncertainties) likely to impact.**

What is the Smallest NEO that is Dangerous? [2013]

- **Chelyabinsk *was* dangerous, even though nobody was killed.**
- **It would have been even *more* dangerous if it hit at a steeper angle**
- **If a future impact is *predicted* to be as big as Chelyabinsk, uncertainties in mass, density, diameter, and albedo mean it *could* be 10 or 20 times as energetic, or something thought to be 10 or 20 times less energetic *could* be as damaging as Chelyabinsk**
- **Rare ones (metallic, aerodynamic shape) that are just meters in scale *could* hit at high velocity**
- **So: a prudent emergency manager would *warn* about any NEO estimated to be >5-to-10 m and *evacuate* if estimated to be >20 m.**

How Important is NEO Threat? We've Many Other Things to Worry About!



Mortality from Twentieth Century Catastrophes

The New York Times

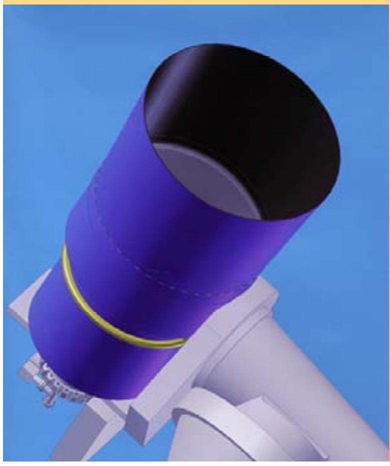
U.S. AND BRITISH TROOPS PUSH INTO IRAQ AS MISSILES STRIKE BAGHDAD COMPOUND

But Natural Hazards Command our Attention

- Consider the consequences of Katrina, the Japanese earthquake and tsunami, the Indian Ocean tsunami, storm Sandy…think back to what Vesuvius did to Pompeii.
- Consequences may involve mass mortality, but even lesser events can topple governments and change the way we think of ourselves in relation to nature.
- The impact hazard is commanding much attention lately…it is a very minor hazard compared with others, but it has the nearly unique trait that we can ***predict*** when and where an NEO might hit and we can warn people to get out of the way. In very rare cases that is not enough, but we can deflect the oncoming NEO so it does not hit.

ATLAS Telescopes Could Detect about Half of "Final Plungers"

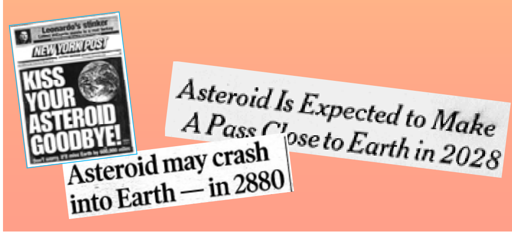
As search programs like ATLAS get underway, the number of NEO near-misses and actual strikes making news, meriting warnings, and many more tinier ones, will vastly increase.



- **The "Asteroid Terrestrial-impact Last Alert System"** (Univ. of Hawaii)
- **Two small telescopes would be designed to search for tiny asteroids as they get unusually bright during the last days and weeks before they hit.**
- **The 50% coming from roughly the direction of the Sun would <u>not</u> be detected.**
- **Late detection is much too late for deflection, but for these very small asteroids <u>warning</u> and <u>evacuation</u> would be made possible.**
- **NASA funded (inexpensive) and may be operational in 2015.**

Consequences from Small, Likely Impacts

OVER KASHMIR? OVER ISRAEL? HOW WOULD THE GENERALS RESPOND?



- **Damage & casualties are at most like a minor natural disaster (e.g. tornado, wildfire)**
- **Public and national over-reaction after 9/11 (**stock market, homeland security hysteria, Iraq war**) could be replicated by a modest but unexpected impact disaster…*but it didn't happen in Chelyabinsk*.**
- **An otherwise harmless but brilliant bolide (fireball) could be mistaken for an atomic attack, causing a dangerous response…but it d*idn't happen in Chelyabinsk.***
- **Even sensational journalism or a mistaken prediction about a possible future impact can be disruptive.**

Most Effects of a Modest NEO Impact are Familiar from other Natural Hazards

Meteorite punctured roof in Canon City, CO

- Shock wave, strong winds
- Falling rocks, like from cliffs or road-cuts, debris
- Seismic shaking
- Brilliant light and heat, maybe fire
- **So a NEO impact resembles, in some ways, an earthquake, a wildfire, a landslide, a volcanic eruption, or a windstorm.**

All effects happen nearly simultaneously and act synergistically. Nevertheless, normal emergency response measures should generally apply.