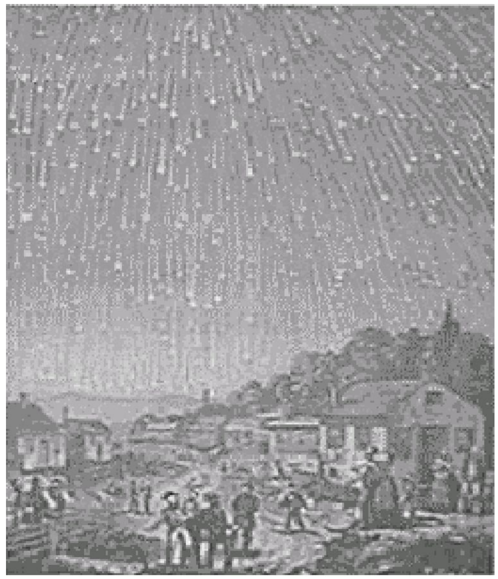

**THE SKY IS FALLING:**

Disaster Mitigation, Management, and Media regarding the Asteroid Hazard

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Faculty Advisor, Dr. Paul S. Hardersen

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## Abstract

From the dust grains that create “shooting stars” to the asteroid that wiped out the dinosaurs, the Earth orbits in a cosmic shooting gallery [Figure 1]. Scientists have begun to recognize the nature of these space born hazards and the impact that they have had on the history of this, and perhaps all, planets. In an attempt to quantify the actual danger to civilization and the planet, researchers have been searching the heavens for objects that are considered “Earth Approachers” – passing within or near the orbit of the Moon. As the number of potentially hazardous objects discovered increases, there has been a parallel increase in media and Hollywood interest. Consequently, the general public is progressively becoming more aware of this hazard from the skies. Unfortunately, depictions and reporting of these discoveries often do not accurately portray the hazard. This has lead to both public and policymaker confusion and, in some cases, a subsequent loss of scientific credibility. While the fault for this confusion is often blamed on both the media and the scientists, the core of this problem lies in a lack of clear and coherent policy. Part one of this paper will examine the hazard itself from the scientists’ investigations to the public’s perception of risk. As the prime creators of public perception, mass media is also investigated for their role as an educator and resource in the event of an actual hazard. Finally, the interaction between these often-competing forces and the asteroid hazard are examined through a series of case studies.

Asteroids are a natural hazard. While unique in origin, the manifestations of an impact can resemble other known Earth-based hazards including earthquakes, tsunamis, and nuclear explosions. By taking advantage of existing infrastructures and policies, asteroids can be planned for and managed in a similar manner as other natural hazards. Part two of this project examines the hazard from a disaster management perspective – looking at the relevant policies and programs that currently exist for other natural hazards. Effective disaster management plans can be implemented using existing resources to provide coordination between the media, the scientific community, and disaster relief agencies ultimately increasing public safety.

Finally, in part three, six specific expert recommendations for implementation are examined to provide a roadmap towards the establishment of a coherent asteroid hazard policy and disaster relief program.

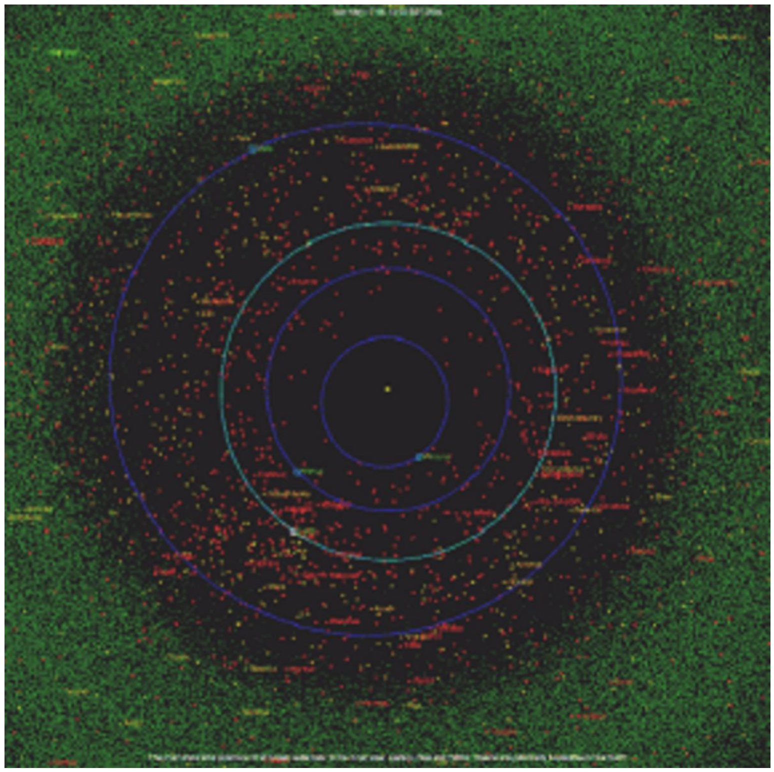

Figure 1: This map shows the position of all known asteroids (as of 2001).
Red and yellow objects are potentially hazardous to Earth.
The green dots represent asteroids that currently do not cross Earth's orbit.[1]

## PART I – The Asteroid Hazard and Public Safety

*And there shall be terrors and great signs shall there be from heaven.*[2]

*The Threat: Are you at risk?*

The last ten years have seen a growing awareness of the impact hazard, slowly passing from the fantasy realm towards a scientifically researchable public safety problem. While several policy-focusing events have helped to push this process forward, perhaps the most dramatic was on July 16, 1994, when 21 chunks of the fragmented Comet P/Shoemaker-Levy 9 plowed into the Jupiter, creating impact scars larger than our entire planet. Yet, even after that dramatic occurrence, acceptance that global geophysical events such as asteroid or comet impacts constitute normal if infrequent behavior, in geological terms, is still a struggle.[3] However, experts agree that an object from space will one day impact with Earth and while the odds are very slim that it will happen in any given year or century,[4] statistically, it is an eventual certainty. It could come next year, or not for a million years. Consequently, governments want to know whether, against the odds, our generation will need to prepare to defend the planet from this threat. Scientists have therefore shifted from an emphasis on understanding the probabilities to a straightforward program to find the potentially threatening asteroids and compute their orbits, one at a time, to see if any will hit Earth.[5]

At the request of the United States Congress, the National Aeronautics and Space Administration (NASA) has instituted a program to dramatically increase the detection rate of Earth-crossing objects known as the Spaceguard survey. The NASA Spaceguard survey is a ten-year program aimed at discovering 90% of the one kilometer or above sized Near Earth Objects (NEOs) by 2008. The one-kilometer size limit corresponds to the minimum mass (several tens of billions of tons) of an impacting body needed to produce global consequences (resulting in a ground burst explosion with energy in the vicinity of a million megatons of TNT).[6] As of July 11, 2004, 2921 NEOs have been discovered. 720 of these NEOs are asteroids with a diameter of approximately 1 kilometer or larger. Also, 616 of these NEOs have been classified as Potentially Hazardous Asteroids (PHAs).[7]

Of these, only 339 objects have good quality (well defined) orbits.[8] In these 2600 objects, there are 1171 Amor asteroids (Earth-approaching NEAs with orbits exterior to Earth's but interior to Mars'), 1226 Apollo asteroids (Earth-crossing NEAs with semi-major axes larger than Earth's), and 203 Aten asteroids (Earth-crossing NEOs with semi-major axes smaller than Earth's).[9]

Perhaps more worrisome than these km-scale ‘planet killers’ are larger meteoroids, from meters to hundreds of meters across, but which are more numerous and harder to track than those being searched for by the Spaceguard Survey. Impact rates and consequences vary enormously across this broad size range and due to varied compositions, but such objects share several general traits:

(a) Whether they explode in the atmosphere, on the ground, or in an ocean, they can have devastating consequences for people proximate to (or occasionally quite far from) the impact site;
(b) They are mostly too small to be readily detected or tracked by existing telescopic programs; and
(c) Their impacts are too infrequent to be witnessed and studied in detail by scientists, so their nature and effects are not yet well characterized. Yet, they are significantly more likely to happen than a km-scale impact.[10]
(d) It is estimated that there are perhaps 100,000 to 1,000,000 undiscovered asteroids on similar Earth crossing orbits.[11]

Thus scientific uncertainties are greatest for just those objects whose sizes and impact frequencies should be of greatest practical concern to public officials. The smallest NEO discovered before its closest approach to Earth was 2003 SQ222 (less than 30 meters in diameter) and is thought to be one of approximately 3,000 NEOs that pass closer than the Moon every year but are not detected.[12] Some of these objects don't miss. Nearly every year, objects pass thorough the atmosphere and reach the ground. In fact, within hours of 2003 SQ222's closest approach, a fireball streaked through the sky over India "turning night into day" injuring three people.[13] Two 11 pounds pieces were recovered from the impact site.[14]

While one might expect a stronger media interest in these actual impact events, of the 29 documented impacts that occurred between 1990 and 2000, over 90% happened in or over uninhabited parts of the world.[15] Since large parts of the world are uninhabited or sparsely populated, the odds are high that any impact will take place over or in a remote region. However, NEOs do not discriminate – by definition, all parts of the world are equally vulnerable to this hazard. It is only a matter of time before one of these smaller bodies impacts a major city causing extensive damage [Figure 2]. Currently, it is very unlikely that astronomers will discover a "small" (~200 m) impactor in advance.[16] Accordingly, it will also likely be impossible to issue any relevant public warning.[17] As stated best by 22-year NASA veteran and author James Oberg in his July 23, 1998 presentation at the United States Space Command's Futures Focus Day Symposium, "For a future asteroid impact, given our current level of insight into the situation in space, the expected warning time before impact will be zero. Well, say, five or six seconds, since there will be a bright flash that a few people will notice before being pulverized."[18]

Whether large or small, it is guaranteed that one-day astronomers will detect a NEO that is on a collision course with Earth and when it happens, it will be unprecedented. Worse yet, one day an unpredicted object will impact a major metropolitan area with no warning at all. This first impact crisis will confront governments, public safety organizations, and relief agencies with considerable social, technological, and managerial challenges[19] as there are no established policies in place, no chain of command, no hierarchy of responsibility - not even a set phone number to call in the event of a discovery. It is unlikely that any ad hoc organization created in the final moments of an unprecedented international disaster will be capable of adequately responding to the public safety crisis. Yet, with minimal expenditures towards training and organizational planning, the short-term toll of an impact disaster can be lessened while actual mitigation options are researched and implemented incrementally.

Figure 2: The destruction Template from the 1908 Tunguska event superimposed over London.[20]

Even a small impact, due to its random and "terrorizing" nature, will stir up public anxieties and likely to be blown out of proportion by the mass media. They will blame their governments, space agencies, and astronomers for failing to protect them from this cosmic disaster.[21] Many victims may well ask, "Why wasn't something done?"[22] While the public may give policymakers wider latitude with natural disasters, similar post-disaster pressure can be expected if negligence is suspected. After the disastrous earthquake in Bam, Iran, the mayor stated, "Despite several tremors and warning signs, the authorities did not issue warnings, did not make any preparations, and instead allowed 50,000 people to perish."[23] In most nations, it is unlikely that politicians would last long in the face of such perceived negligence.

As with any potential national hazard, "governments and other standard-setting organizations...must define a rational level of acceptable or tolerable risk"[24] for low probability/ high consequence events. One option would be to use the "Tolerability of Risk" (ToR) standpoint developed to assess nuclear reactor safety and serious, but rare, industrial accidents or environmental disasters. The concept is that if the risk is above some national limit (which depends, for example, on the likely number of fatalities), and therefore "intolerable", then changes are forced on the operator to make the probability of an accident per unit time less likely, and therefore the risk more tolerable.[25] In nuclear reactor design, the level of intolerability is set at one event per 100,000 years (per reactor), while the limit of tolerability is sometimes set as low as one event per 10 million years.[26] Viewed from this perspective, there is no question that the NEO hazard is significant, or, to put it another way: if NEOs were a business, they would not be allowed to operate! [27]

*A Brief Overview*

The English derivation of the word "disaster" is from the combination of the Latin terms "dis," meaning "evil" and "astro," meaning star -- or “bad star.”[28] This likely evolved from comets. Historically, comets have been interpreted, by the superstitious and/or uninformed, as bad omens or bad stars. In the *History of Nature*, first published in 77 AD, the passing of a comet was given responsibility for a host of dramatic world events.

> “A fearefull starre for the most part this Comet is, and not easily expiated: as it appeared by the late civile troubles when *Octavius* was Consull: as also a second time by the intestine warre of *Pompey* and *Cæsar*. And in our daies about the time that *Claudius Cæsar* was poysoned, and left the Empire to *Domitius Nero,* in the time of whose raigne and government, there was another in manner continually seene, and ever terrible.”[29]

The famous Bayeux Tapestry, which depicts Halley's comet on its 1066 return, again depicts comets as a bad omen for King Harold during the Battle of Hastings.[30] [Figure 3]


Figure 3: The Bayeax Tapestry[31] (Halley’s Comet Highlighted in Red)

Historical perceptions of danger from the sky have not always been based on the intangible. Dr. Jin Zhu at Beijing Astronomical Observatory has discovered at least 10 separate references to a devastating meteorite fall in 1490 AD at Qingyang, Shaanxi. All of these described “stone from sky like rain” or “stone rain countlessly” with three describing the size and extent of the damage saying “bigger ones in about 2-2.5 Kg, smaller ones about 1-1.5 Kg, killing tens of thousand people.”[32]

Until recently, nearly all of these dangers in/from the sky have been attributed to the gods or higher powers of the day. This “divine” connection has paralleled other disasters. For most of history, it was traditional to view certain sudden and extraordinary physical disturbances with marked negative effects as "Acts of God."[33] Whether it was volcanic eruptions, earthquakes, floods, or tsunamis, the source of the disaster agent was placed in the supernatural domain. With the spread of more secular and nonreligious ideologies, there was also a shift to substituting nature for the supernatural.[34] Hence the term ‘natural disaster.’ So earthquakes are now the result of plate dynamics and floods are the consequence of rainfall and drainage capabilities. In either case, the belief is that something external and beyond the control of the human victims is responsible for whatever negative happened.[35] Unfortunately, hazard mitigation measures are rarely adopted in communities where people define disasters as either “God’s will” or as inevitable natural occurrences.[36] In the hazard mitigation community, there is a third view.

Strictly speaking, there is no such thing as a natural disaster. There are only natural hazards, such as cyclones and earthquakes (and asteroids). The difference between a hazard and a disaster is an important one. A disaster takes place when a community is affected by a hazard (usually defined as an event that overwhelms that community’s capacity to cope).[37] It is misnomer to talk about natural disasters as if they exist outside the actions and decisions of human beings and societies. Allowing a high density population in flood plains, poor or non-enforced earthquake building codes, delaying evacuation from volcanic slopes, providing inadequate information or warnings about tsunamis, are far more important than the disaster agent itself in creating the casualties, property and economic losses, psychological stresses, and disruptions of everyday routines that are the essence of disasters.[38] If people are living in unprotected flood plains, in non-earthquake proof buildings in known seismic zones, or next to chemical plant complexes, they are creating the necessary conditions for a hazard to generate a disaster. In other words, the impact of the disaster is determined by the extent of a community's vulnerability to the hazard.[39] The human dimension of disasters is the result of the whole range of factors (economic, social, cultural, institutional, political, and even psychological) that shape people's lives and create the environment that they live in and their respective vulnerability.[40] However, for the asteroid hazard, this is not the case. All people living on planet Earth share a nearly equal risk of being affected by a NEO impact and even the smallest of objects that would survive through the atmosphere will overcome a community's ability to cope. For this hazard, disasters cannot be attributed to human choice, except perhaps, in the hesitance to take the hazard seriously.

Today, researchers have accepted that rocks from space can, and do, impact the Earth with potentially disastrous consequences. This was not true when the NASA Spaceguard Survey Report provided a quantitative estimate of the impact hazard and concluded that humans are as much at risk from impacts as from earthquakes and severe storms.[41] Some in the media even treated this original report with derision.[42] Even today, there is a "giggle factor" associated with claims that "the sky is falling."[43] Congressman Dana Rohrabacher (R-Calif), arguably one of the most influential members of the United States

Congress in matters affecting space and science, gave the keynote address at the 2004 Planetary Defense Conference comparing the general apathy about the impact hazard with public feelings about terrorism before the attacks of September 11, 2001.[44] He expressed his hope that it would not require a similar catastrophe to alert people to the need to take action to protect the planet from impacts.[45]

Currently there is no known way to definitively stop an asteroid or comet found to be on a direct collision course with Earth. Further, as stated above, smaller impact events will likely happen with little or no warning. Consequently, the best current option is to work concurrently to mitigate the hazard (long-term) and educate and equip disaster relief units to be both knowledgeable and prepared for the possibility, however unlikely (short-term). In the United States, a basic reality of the decentralized federal system is that much of the authority and capacity to cope with a threat is found at the state and local levels.[46] For instance, if a terrorist attack occurs, the "first responders" will necessarily be local fire, police and rescue personnel. If an impact were to occur, the first responders will likely not have the expertise and the wherewithal to cope effectively with the disasters that will accompany an impact. Funding for programs that help educate and equip first responders to be better able to react effectively to an impact disaster is critical because they (whether trained and equipped or not) will be on the front lines and the scientists, agencies, and search programs will, at least initially, be irrelevant.[47]

*Public Perception of Risk*

Risk communication plays a vital role in disaster reduction. Risk communication is the effort to convince people that a risk is real and describe what its characteristics are as well as providing information on what can be done about it.[48] However, effective risk communication alone, even if it is based on sound science, does not guarantee the most appropriate behavioral response. Risk perception is a major factor in this process.[49] Policymakers, public safety officials and the general public are poorly educated regarding the asteroid hazard and fill in their knowledge gaps with perceptions garnered from magazines, television and movies that are rarely accurate.

The terrorist attacks of September 11, 2001 have dramatically illustrated that public reactions to disasters vary enormously compared with the "objective" destruction, as measured by loss-of-life and property.[50] People in the United States are still reeling from terrorist attacks that killed 3000 people that still receive regular media attention (even over two years after the event), compared with the estimated 20,000 victims of the 2001 Bhuj earthquake in India[51] or the over 42,000 victims of the 2003 Bam earthquake in Iran[52], both of which barely registered in Western news media after the first day. Media coverage of anthrax attacks, which killed six people later in the autumn of 2001, overwhelmed efforts by the Centers for Disease Control to prevent (by publicizing vaccination programs for the susceptible) many of the over 30,000 deaths that would occur from the flu during the ensuing winter.[53] According to research in risk perception, a similarly exaggerated response may be expected from the public if even a small asteroid were to strike in the near future.[54]

Compounding the problem, communication between asteroid scientists and the public -- as mediated through science journalists -- has not been good.[55] Indeed, most people in the world remain wholly oblivious to the asteroid hazard and its potential manifestations. In the course of an impact prediction, concerns by an agitated public have been presented to national leaders, emergency management agencies, and military and space departments; few governments have anyone in authority that can answer such questions.[56] Without answers, the public will, again, return to perceptions. Brief "mass panic" in China in December 1989 was ascribed to a mistaken, nationally televised news story about an impending asteroid impact.[57]

The impact hazard involves its own peculiar suite of uncertainties. In some ways, asteroid impacts are more reliably predictable than any other natural disaster. Using orbital mechanics, it is possible to calculate precisely when and – to some extent - where an asteroid will hit, perhaps many years or decades in advance. But that is true only once its orbit has been precisely determined, which may take months or even many years after it is first discovered.[58] In the interim, an arcane suite of uncertainties clouds the reliability of predictions, and the ongoing highly technical work is difficult for science journalists to understand or translate to the public.[59] A public that does not understand the threat is unlikely to be motivated by a warning system in the event of an actual emergency. Public information and training is probably the most important area of disaster reduction[60] and, for the impact hazard, on of the primary tangible steps that can be started immediately. However, in the current world of terrorist threats, ongoing conflicts and diseases like AIDS and SARS, it will be difficult to convince the public that the risk of asteroid and cometary impacts is worth their attention. In fact, perhaps it is not.

*The Value of Warning*

The social purpose of NEO search programs is to "reduce dread."[61] Unfortunately, warning has little social value without an ability to mitigate.[62] In fact, false warnings can impose social costs that are not counterweighted by benefits of an informed public. For example, since the creation of the USGS Tsunami Warning System in the Pacific in 1948, Hawaii has experienced 20 warnings that have resulted in evacuations of coastal areas.[63] Of these 20 warnings, 15 have been considered "false" because no damaging tsunami ensued. A study conducted by the State of Hawaii after the May 1986 false alarm estimated the cost of lost business productivity to be between $30,000,000 and $40,000,000.[64] Even a minuscule reduction in global Gross Domestic Product (defined as the output of goods and services produced by labor and property globally) resulting from a false NEO alarm would swamp any direct benefits in public NEO hazard education.[65] In addition to the direct financial impact, false alarms also erode the credibility of an emergency management warning system[66] and the researchers behind it.

While the Spaceguard survey has been responsible for the discovery of an unprecedented number of NEOs, it has not reduced the actual risk to Earth at all. As David Tholen notes, "The risk to Earth is the same now as it was five years ago, and is the same as it will be five years from now. What changes (with additional object discoveries) is only our knowledge of the risk." [67] This distinction was echoed by Rusty Schweickart of the B612 Foundation, who wrote "Reducing risk could only result from changing the environment for the better... not simply knowing more about it. The risk can't have changed since we haven't done anything to reduce the incidence of asteroids hitting the Earth. Our actual risk didn't change... only the accuracy of our knowledge of it. [68] Statistically, there is a ten percent chance that another Tunguska-type event will happen this century, and several-tenths-of-a-percent chance of a giant tsunami-making impact.[69] Yet, for every such small-asteroid impact catastrophe, which might kill tens or hundreds of thousands of people, there are hundreds of more mundane but equally lethal natural disasters, like earthquakes, typhoons, and floods. The impact hazard must be considered in a context in which citizens of many nations are apprehensive about hazards associated with foods, disease, accidents, natural disasters, terrorism, and war. The ways that humans psychologically respond to such threats to their lives and well being, and the degrees to which they expect societal institutions (both governmental and private) to respond, are not directly proportional to actuarial percentages of the causes of human mortality nor to forecasts of likely economic consequences.[70] Concerns about particular hazards are often irrationally exaggerated or belittled, and they vary from year to year, affected by focusing events, media coverage, and hype.[71] It might be reassuring for the public to understand that most of the seemingly frightening hazards are actually unlikely to kill them (this list includes sharks, terrorists, airline crashes, and asteroids).[72]

On a tangible level, pinpointing the exact impact spot of a short-warning incoming NEO is difficult considering the host of variables such as composition, spin, and atmospheric interaction that can alter the impact zone and altitude. The effects of atmospheric interactions with the shape and composition of smaller impacting objects, including the important consideration of whether an object would fragment, are essentially unpredictable.[73] This would make it extremely difficult to pinpoint the actual impact site(s) until very soon before occurrence. It is doubtful that all of the relevant variables of an incoming NEO could be determined (and an exact impact location predicted) in time for the disaster management community to effect an evacuation. This underscores that simple orbital determination, while an important first step, is not enough to affect public safety. Until a mitigation option has been implemented, perhaps the only way to tangibly improve public safety is through the coordination and planning of relief efforts and by establishing NEO protocols for public communication and education.

*The Confusion and The Cost*

It is difficult to retain the interest of a media-based society in low probability events. Regarding the NEO impact hazard, this lack of public attention is, in part, the result of a never-ending stream of disaster reports that, upon further observation, turn out to be something that would have otherwise likely escaped public attention. "Of course, we want our response to the impact threat to be part of a serious, objective approach to a considered evaluation of what the threat is," explains Clark Chapman, a planetary scientist at the Southwest Research Institute, "So we don't like the irresponsible treatment of the threat by some individuals and some news media." [74] On the other hand, Chapman noted, "Any news is good news."[75]

However, the general public is not always rational when confronted with disparate reports regarding astronomical events. A relevant recent example was the passage of Comet Hale-Bopp. On November 14, 1996, an observer in Houston obtained electronic images through his telescope showing an alleged "mysterious Saturn-like object" following the comet and then speculated on a nationally syndicated radio show that it was an alien spacecraft. Despite the absurd nature of these claims, this story was picked up by several elements of the "mainstream" press resulting in astronomer, and Hale-Bopp co-discoverer, Alan Hale being bombarded throughout the following day by radio and television stations from around the country soliciting comments on the "mysterious spacecraft."[76] The "Saturn-like object" turned out to be a diffraction effect a bright 8thmagnitude star that the comet was located next to on the night in question. In an effort to redirect the flood of inquiries he was receiving, Hale posted this explanation, along with the appropriate photographs, on the Hale-Bopp Web Homepage. This explanation apparently generated an enormous amount of discussion on the Art Bell program and elsewhere, and led to a large amount of surprisingly vicious "hate mail."[77] I have included two examples below to show that some members of the public had no interest in scientifically credible explanations.

> "Methinks doth protest too much. . ." It's plain you went for the throat on this -- and the response is too coordinated and powerful -- moving to insult and discredit too quickly . . . you guys are acting as weird as that comet!
>
> “Art has integrity! If Art is withholding information, or denying it, believe that he has a very, very good reason for doing so! Trust him! He has the whole planet in mind and heart when making his decisions!”[78]

While the pseudo-scientific claims surrounding Comet Hale-Bopp are amusing, the fact that claims such as these receive such widespread acceptance among large segments of the general public is not something that scientists and rationalists should dismiss lightly.[79] This serves as a glaring example of the scientific illiteracy that pervades our society and that in the event of an actual impending impact, especially without an established credible source for NEO information, it will be impossible to stem the tide of false and inaccurate information that emerges from pseudo-scientific sources – information that may gain credibility by media exposure. In an actual impact scenario, however, lives will be on the line. With other natural disasters, whether the source or basis for an announcement was scientifically ‘legitimate’ or not, policymakers and the general public have often responded similarly to these pseudo-predictions.[80] Without a single established source for valid information, the public and media outlets may latch onto whatever information is available and the results for public safety could be disastrous.

Current unclear and inaccurate reporting on NEOs has already undermined the credibility and trust between scientists, the media, and the general public. Good media relations are rooted in trust. Like reputation, credibility is a fragile object and once lost, it is not easily regained.[81] Repeated "false" reports harm the publicly perceived credibility of scientists, decrease the apparent 'usefulness' of the NEO search project to lawmakers, and ultimately draw attention and resources away from a focus on public safety.

*The Information Chain*

If a 50-100 m object was found by any of the ongoing public or private observation programs, it would be uploaded to and announced by the Minor Planet Center (MPC) on the NEO Confirmation Page (NEOCP) with a rough orbital prediction to help follow-up observers find the object.[82] Initially, the approximate size of the object would be unknown. Under normal circumstances, the MPC would receive some follow-up observations during the following 24 hours and would revise the initial prediction published on the NEOCP (even though the orbit would still be somewhat speculative). At this point, institutions around the world including many amateur astronomers -- employed by no government or institution in their backyard endeavors – would help with the follow-up observations needed to pin down the newly discovered rock's actual trajectory.[83] Once three groups of observations are obtained, the MPC could reasonably calculate an initial orbit and would run the orbit forward for the Minor Planet Electronic Circular (MPEC) announcement of the observations, orbit, and ephemeris.[84] This first MPEC is usually issued when the MPC has three groups of observations. After another couple of days, however, there would be many additional observations and any inconsistencies would be uncovered defining the orbit even better. Within a few days, it should be pretty obvious if there is a significant impact probability.[85] Intuition would suggest that the impact probability increases progressively with every additional set of data, but this is not always the case mainly due to systematic observational errors. The evolution of impact probability during the first 100 days shows a rather erratic pattern though the situation has improved somewhat since 1997, however, since modern star catalogs based on Hipparcos results have smaller systematic errors: the 50% probability might be reached 4-5 weeks earlier."[86]

One certainty is that better information exchange and coordination among relevant entities (astronomers, fledgling NEO information organizations [e.g., the Spaceguard Foundation, the British NEO Information Center, and NASA's NEO Program Office], national and international disaster management agencies, etc.) might serve to prevent some official mistakes and miscommunications. [87] Even in the most disaster-prone country, lack of data is less often a problem than a plethora of conflicting data.[88] To address this issue, NASA recently announced a new web-based asteroid monitoring system, called Sentry, to help scientists better communicate with each other about the discoveries of new, potentially threatening asteroids and the follow-up observations that typically show those asteroids to be, in fact, no threat.[89] "Objects normally appear on the Risks Page because their orbits can bring them close to the Earth's orbit and the limited number of available observations do not yet allow their trajectories to be well-enough defined," said Donald Yeomans.[90] The Sentry system, managed by NASA's Jet Propulsion Laboratory (JPL), is similar to another online database, called NEODys, developed in recent years by asteroid experts in Italy. Researchers from the two systems are cooperating to cross-check results in an effort to make both systems more effective, Yeomans said.[91] In terms of speed, while a few years ago there were delays of several days while scientists compared their orbital predictions; today these predictions are created quickly and posted on the web by the JPL and Pisa teams. Because of this open sharing of information in a public forum, continuously monitored and followed up on by amateur astronomers from around the world, it is inconceivable that a potential impact could be kept secret. A real impact prediction, even at low probability, would be known all over the world in a matter of hours.[92] The unfortunate downside is that pseudo-scientific interpretations can be made and widely disseminated – often long before there is any credible orbital certainty.

*Forecasts, Impacts and Warnings*

In 1999, the NEO community developed the Torino scale [Figure 4]; a hazard index based on a zero to ten scale of rising threat-of-impact levels. The Torino scale was intended to improve definitions and communications between scientists, as well as their ability to communicate potential threats to the press and the public.[93] The Torino Scale ranks every NEO on a zero-to-ten basis, with zero representing the risk of impact being lower than that of a random unknown object hitting Earth in the same time frame. The Torino rankings were designed with the general public in mind, with higher values representing both a higher probability of impact and worse damage, but so far the Torino scale has been nearly nonexistent as far as the public is concerned.[94] While numerous researchers have critiqued the Torino scale and suggesting revisions, these critiques have focused on the scale's perceived technical weaknesses and neglected the central issue of its ability to inform the public in a satisfactory way.[95] Some say the Torino scale should be scrapped; mainly because it can be invoked from the early sighting of a new asteroid, with only scant data about the object's orbital path. "It's time we got rid of it," says Brian Marsden of the Harvard-Smithsonian Center for Astrophysics in Harvard, who says the public will not take the scale seriously if all it does is generate false alarms.[96] Perhaps the definitions of the Torino Scale could be tweaked behind-the-scenes without damaging either the consistency or credibility of the scale in its public presentation.[97]

| | |
|---|---|
| **EVENTS HAVING NO LIKELY CONSEQUENCES (white)** | |
| 0. | The likelihood of a collision is zero, or well below the chance that a random object of the same size will strike the Earth within the next few decades. This designation also applies to any small object that, in the event of a collision, is unlikely to reach the Earth's surface intact. |
| **EVENTS MERITING CAREFUL MONITORING (green)** | |
| 1. | The chance of collision is extremely unlikely, about the same as a random object of the same size striking the Earth within the next few decades. |
| **EVENTS MERITING CONCERN (yellow)** | |
| 2. | A somewhat close, but not unusual encounter. Collision is very unlikely. |
| 3. | A close encounter, with 1% or greater chance of a collision capable of causing localized destruction. |
| 4. | A close encounter, with 1% or greater chance of a collision capable of causing regional devastation. |
| **THREATENING EVENTS (orange)** | |
| 5. | A close encounter, with a significant threat of a collision capable of causing regional devastation. |
| 6. | A close encounter, with a significant threat of a collision capable of causing a global catastrophe. |
| 7. | A close encounter, with an extremely significant threat of a collision capable of causing a global catastrophe. |
| **CERTAIN COLLISIONS (red)** | |
| 8. | A collision capable of causing localized destruction. Such events occur somewhere on Earth between once per 50 years and once per 1000 years. |
| 9. | A collision capable of causing regional devastation. Such events occur between once per 1000 years and once per 100,000 years. |
| 10. | A collision capable of causing a global climatic catastrophe. Such events occur once per 100,000 years, or less often. |

Figure 4: The Torino Scale

By contrast, the Palermo Scale (PTS) was created for astronomers' use. It assigns zero to any object that has the same probability of hitting Earth in a given time period that a random object would. But it also assigns negative values to objects that pose less risk than random impacts.[98] The Palermo Scale is the base-10 logarithm of the *relative risk.*

$$PS = \log_{10} R.$$

The relative risk, R, is given by

$$R = P_I / (f_B \times DT),$$

where $P_I$ is the impact probability of the event in question and DT is the time until the potential event, measured in years.

The annual background impact frequency,

$$f_B = 0.03 \times E^{-4/5}$$

is the annual probability of an impact event with energy (E, in megatons of TNT) at least as large as the event in question.

The cumulative Palermo Scale value reflects the seriousness of the entirety of detected potential collision solutions. It is the base-10 logarithm of the sum of the individual relative risk values.[99]

$$PS_{cum} = \log_{10} (10^{PS1} + 10^{PS2} + 10^{PS3} + ...)$$

While providing more descriptive information to astronomers, the Palermo Scale does not necessarily provide more information to the general public in a ‘frame of reference’ that would be understandable. Some have argued that the Torino Scale would be more “elegant” if it were calculated more like the PTS.[100] In fact, there is a rough correlation between PTS values and Torino Scale values. The Torino Scale could be defined as PTS

+ 2.5 (rounded to the nearest integer, or 0 for negative values), and its values would usually not vary by one unit in the left part of the diagram, or in color in the right part.[101]

For a warning system or scale to be useful, it is imperative that early warning messages be understood by the people for whom they are issued[102] regardless of background. For local people, visualization and talk tend to be more important for analyzing and transmitting knowledge – (i.e. comparing is often more important than measuring); for educated and professional people, the written word is dominant and precise and quantifiable calculation confers weight and authority on information.[103] This distinction can be loosely compared with the goals of the Torino and Palermo scales respectively. The most appropriate means of gathering and disseminating early warning information must be carefully assessed and well defined within the disaster preparedness plan.

Similar to disaster mitigation vs. disaster relief efforts, there are two pieces of asteroid-related information that any scale needs to be able translate to the public. First, the public needs to know the odds of an actual impact (such as the Tornio or Palermo scales). Secondly, the public needs to know the extent of actual damage through a scale similar to the Richter scale. (i.e. if an impact destroyed a house, a neighborhood, Brooklyn, or New York State) There are no current scales for disseminating asteroid damage to the public beyond the rather non-specific descriptions given on levels 8-10 on the Torino Scale. After an impact has occurred, it is unlikely that the media or the public will be concerned with the probability that the impact might have occurred. Consequently, either another scale needs to be created for post-impact reporting or current scales need to be modified to translate more specific post-impact information to the public.

*Media and Asteroid News*

As the primary transmitters of pre and post impact information to the public, the media will be a crucial part of any NEO disaster management plan. It is important to realize that the media itself has an agenda that may or may not always be compatible with those of the science or disaster management community. Factors such as ratings and coverage costs play in to decisions on how and what to cover for a particular news program.[104] Before reaching the media, information is handled by a host of stakeholders, many of whom are influenced not by the objective news value of a given event but by political, professional, or commercial motives.[105] The media value of a particular crisis is subject to a number of filters or criteria that determines its "news value" relative to competing stories.[106] For example, it is unlikely that any NEO discovered on September 11, 2001 would have received the same sort of press coverage that some other NEOs have been given. Further, on both the local and national scale, electronic and print media are tuned to link audiences with advertisers. That is the ultimate goal of any media outlet. Sometimes, however, the business goals and/or political agendas of the informational and entertainment media -- whether print, TV, or internet -- often run counter to dispassionate purposes of educating and informing the public.[107]

By their nature, science and media have different pre-dispositions that tend to compound inaccuracies in information. For instance, conceptions of objectivity differ in the two worlds. Mass communication's emphasis is on fairness; almost always there is an assumption that there is a second or opposite side to a story. Science, conversely, stresses correctness, accuracy, validity and not balance, impartiality, or neutrality.[108]

Additionally, what is valued also differs in the two worlds. Timeliness is very important in the mass communication arena and thus a focus on the immediate. In contrast, in science, the significance of the information is much more valued. Related to this is that scientific information is never viewed (by scientists) as final or conclusive. Thus, scientists charge journalists with writing in ways as to imply more certainty than exists.[109] This is especially true with the asteroid hazard as information is constantly changing after an initial discovery and certainty is only developed over a lengthy period of time – one that happens on a time scale that would no longer make the story 'newsworthy' to the media reporting it.[110] Finally, scientists try and root what they report in the context of what others have earlier found using references, footnotes, bibliographies, reviews of literature, etc., to inform users of the link between the present and past. In the media, each story is discrete, unique, and isolated. Even if a paper ran a story on directly related research a few weeks earlier, the new story rarely refers to the previous story. The earlier research is not new and therefore, not news.[111] This is important to the asteroid hazard as retractions do not exist and are rather framed in the context of new news stories that often tend to discredit researchers for making bad predictions rather than the media outlets themselves for prematurely reporting a "non-story."

Reports of possible impacts by comets or asteroids are not exactly a new thing. Edmond Halley, long before the comet that bears his name made its first predicted return, suggested that a comet might eventually strike Earth with possibly devastating results. It wouldn't be surprising if, back in 1690, a few press reports blew Halley's warning way out of proportion, and astronomers worried that their credibility would be undermined as a result.[112] As asteroid detection programs improve and "near misses" are more frequently reported, the most likely aspect of the impact hazard that a public official will encounter is not the actual impact by a dangerous asteroid but (a) the prediction of a *possibility* of an impact or threatening near miss or (b) a serious mistake by professional scientists or, more probably, by the purveyors of scientific information in the media. In general, human foibles are more likely than a rare asteroid impact, but they can have *real* social and political consequences. [113]

Nonetheless, despite the chance for errors, asteroid watchers are committed to open sharing of results with the world.[114] Such openness is sometimes temporarily embarrassing as when the press play up a low probability prediction, but that is far better than trying to impose secrecy.[115] Jonathan Tate, founder and director of Spaceguard UK agrees that the unrealistic specter of doom dominates some stories. He says scientists are trapped: "Withhold information and we are accused of conspiracy. Release raw data as soon as possible and the media either add two and two to make five or accuse us of scare mongering." However, Tate said scientists who provide colorful quotes "are doing so to generate action by the government, action that is sorely lacking."[116]

For sure, even the most attentive readers may not explicitly remember all of the individual events of bad headlines about potential impacts, but repetition of such misunderstandings has a toll.[117] David Morrison (NASA/Ames Research Center) says that on the one hand, such reports do help raise public awareness of the issue, but they also have "demeaned the credibility of astronomers in the public's eye."[118] This is mainly due to the process of NEO orbit determination. It is the usual course of events for any potentially hazardous NEO that a warning is issued, only to be later dropped (not retracted) as the orbit is refined and the uncertainty ellipse shrinks to exclude the Earth.[119]

Because of this, it is doubtful that asteroid scares can ever be completely avoided, and "false" warning rates will, in all likelihood, surge upward with future expanded surveys. Society's response to these warnings (notwithstanding the scientific community's attempts to influence that response) may well determine the preferred scope of future NEO survey and/or mitigation efforts.[120]

*The Case Studies*

In an effort to examine the 'current state of affairs' with regard to asteroid hazard media reporting, this section will analyze several asteroids, their discovery, the dissemination of the information, the media and public response and the perceived 'results' of the event in terms of how, if at all, it affected policy, public opinion, public safety, and scientific credibility.

<u>1950DA – Armageddon 2880?</u>

"A kilometer-size asteroid, whose whereabouts have been unknown since just after its discovery 52 years ago, has suddenly reemerged as an object that may pose a significant threat to Earth in the distant future." Astronomers at Lowell Observatory rediscovered the object, known as 1950 DA, by accident on New Year's Eve 2000, and three months later a team of radar astronomers pinged it from Goldstone, California, and Arecibo, Puerto Rico. When orbital dynamicists combined the high-precision radar tracks with the half-century-long photographic record, they realized that 1950 DA will make three close brushes with Earth in the centuries ahead.[121] Integration of the orbit of asteroid (29075) 1950 DA, which is based on radar and optical measurements spanning 51 years, reveals a 20-minute interval in March 2880 when there could be a non-negligible probability of the

1-kilometer object colliding with Earth. Trajectory knowledge remains accurate until then because of extensive astrometric data and an inclined orbit geometry that reduces in-plane perturbations. The approach distance uncertainty in 2880 is primarily the result of uncertainty in the long-term magnitude of the Yarkovsky Effect (accelerations arising from thermal re-radiation of solar energy absorbed by the asteroid). Those accelerations depend on the spin axis, composition, and surface properties of the asteroid, so further refining the collision probability may be possible through direct inspection by a spacecraft.[122]

Inspired by the above information, the news media took this story and ran with it. In April 2002, headlines such as ‘Armageddon 2880?’ [123](ABC), ‘Space Menace Looms Centuries Away’ (CBS) [124] and ‘Asteroid could hit Earth’ (BBC) [125] began to circulate. Lead author Jon Giorgini of NASA's Jet Propulsion Laboratory explained that he isn't trying to sound a warning bell. Instead, he hoped to get researchers thinking about how to improve predictions of asteroid collisions — and how to prevent them. "It's so far in the future that it's nothing anyone should worry about now," he said. "But it illustrates the value of understanding things sooner rather than later."[126]

However, notes coauthor Steven R. Chesley of JPL’s NEO Program Office (JPL NEO), "The impact risk is not the story here, because we can say almost unequivocally that it's not going to hit Earth." The real story, he says, is how having such a precise orbit has allowed dynamicists to push the realm of impact prediction so far into the future. Typically impact probabilities can't be computed reliably for more than about 100 years in advance, beyond which gravitational perturbations and other forces make it impossible to predict an object's exact location. But, Giorgini notes, "Whenever we get radar data, it reduces orbital uncertainties and opens up a huge window into the future." His team's 900-year-long prognostication was able to include such subtle and esoteric effects as the Sun's mass loss and galactic tides.[127] For the purposes of this investigation, what is unique about this case is that an event 800 years in the future, with only a 1/300 chance of occurring, was not only considered newsworthy but worthy of 'Armageddon' in the headlines while the real story (of the extent and science behind the prediction) was barely reported.

1997XF11 – Apocalypse Could Be Just 30 Years Away

The special interest in this object began when International Astronomical Union Circular #6837 released by Brian Marsden on March 11, 1997 estimated a miss distance of only 50,000 km in its passage near Earth on October 26, 2028. Marsden wrote in the press information sheet referred to above that "recent orbit computations indicate it is virtually certain that it will pass within the Moon's distance of the Earth a little more than 30 years from now. The chance of an actual collision is small, but one is not entirely out of the question."[128]

The actual IAU Circular read:

> This object, discovered by J. V. Scotti in the course of the Spacewatch program at the University of Arizona on 1997 Dec. 6 (cf. MPEC 1997-Y11) and with H = 17.0 recognized as one of the 108 "potentially hazardous asteroids" (PHAs), has been under observation through 1998 Mar. 4, the latest data having been obtained by P. J. Shelus with the 0.76-m reflector at the McDonald Observatory. An orbit computation from the 88-day arc appears on MPEC 1998-E13 and MPC 31424. This nominal orbit indicates that the object will pass only 0.00031 AU from the earth on 2028 Oct. 26.73 UT! Error estimates suggest that passage within 0.002 AU is virtually certain, this figure being decidedly smaller than has been reliably predicted for generally fainter PHAs in the foreseeable future.

> The following ephemeris is given in the hope that further observations will allow refinement of the 2028 miss distance; physical observations would also presumably be useful. The object will next be at opposition in Feb. 2000 at V = 19.3. There will also be an approach to a distance of 0.065 AU on 2002 Oct. 31 (V = 13.7).[129]

The story was widely reported, with the following AP coverage: WASHINGTON (AP) – "An asteroid large enough to cause widespread destruction may be heading toward a 2028 collision with the Earth and will certainly pass closer to the planet than any such space object in modern times," astronomers said Wednesday. ``The chance of an actual collision is small, but one is not entirely out of the question," according to a notice filed by the International Astronomical Union.[130] ``It has enormous destructive potential," said Steven Maran of the American Astronomical Society, but he added it will take several more years of observations before experts are certain of its path. ``It scares me. It really does," said Jack G. Hills, an asteroid specialist at the Los Alamos National Laboratory. ``An object this big hitting the Earth has the potential of killing many, many people."[131] The *London Times* reported in a lead article by Nigel Hawes: "Apocalypse could be just 30 years away, astronomers said."[132] "They have identified an asteroid a mile across on a near-collision course with Earth. It is by far the most alarming object yet identified in the search for asteroids and comets with Armageddon potential."[133]

Following this announcement several astronomers searched older photographic records to try to locate previously unrecognized observations of 1997XF11. Eleanor Helin and her colleagues from JPL soon found images taken in 1990 that permitted calculation of an improved orbit. Based on this expanded observation set, Don Yeomans and Paul Chodas, both research scientists at the JPL NEO tracking office, recalculated the orbit and found that the 2028 close approach circumstances are: Time: 2028 Oct 26.26732 (06:24 UT) +/- 63 minutes; closest approach distance = 0.00638 AU = 954340 km +/- 0.00058 AU; relative velocity at closest approach = 13.914 km/s. This means that the asteroid will pass by the Earth at about twice the distance of the Moon, and that the probability of impact with Earth is effectively zero.[134]

Following this confirmation, the media stories took a different turn and the credibility finger pointing began. The media reported that the handful of false alarms, in which scientists said there was a remote threat that a particular asteroid would hit Earth in a certain year, have made headlines and frightened the public.[135] Within the scientific community, it continued. "A number of people in the NEO community have issue with the way Brian handles observations and orbital predictions," said Kelly Beatty, senior editor of *Sky & Telescope* magazine and a contributor to the development of the Torino Scale.[136] But Marsden says the announcement of XF11 was the very thing that brought out the additional data that eliminated the threat. In the end, he says, the publicity helped improve NEO research. To be sure, XF11 was a catalyst for scientific discourse that eventually contributed to the adoption of the very Torino Scale that Marsden criticizes. The publicity surrounding XF11, and the confusion generated in the scientist-journalist-public communication pipeline, were key events that encouraged the NEO community to support the adoption of the Torino Scale.[137]

Marsden says previous NEO announcements, regardless of their public effect, have increased awareness within the NEO community of the need to use all possible means to make additional calculations once an object has been discovered. "The public is more of a problem," Marsden says, "Because they have unfortunately received the message that astronomers make mistakes in their calculations (which is not true) and that they fight with each other (which is)."[138] This particular event highlights the need for a better and more effective mechanism for communication between the asteroid science community, the media, and the general public.

Summarizing the events, the AIAA released a position paper regarding the discovery of 1997XF11 illustrating six aspects of the asteroid impact hazard.

(1) When astronomers carry out searches, they typically find even threatening asteroids decades to centuries before their actual impact with the Earth. If it had turned out that XF11 posed a danger to Earth in 2028, we would have had three decades to deal with this threat.

(2) With a diameter of about a mile, XF11 is near the threshold for global disaster. The impact of an object this size with the Earth would release a million megatons of energy and would probably lead to the death of hundreds of millions of people.

(3) Most of the asteroids that could strike the Earth and cause a global catastrophe have not yet been found. For the year 2028 (or any other year) the chances of an unknown asteroid hitting the Earth are much greater than the chances of this particular asteroid hitting.

(4) If an unknown asteroid should hit us, we would likely have no warning at all. The first we would know of the danger is when we saw the flash of light and felt the ground shake.

(5) At the current rate of discovery, it will take more than a century to find 90% or more of the objects this large with Earth-crossing orbits.

(6) For better or for worse, the astronomers who carry out these searches and orbit calculations work in the public eye. The idea that a threatening asteroid could be kept secret (or that anyone would want to keep it secret) is ludicrous.[139]

1999AN10 – On Potential Collision Course with Earth, No One is Willing to Inform the Public

Dr. Andrea Milani at the University of Pisa placed his findings for asteroid 1999 AN10 on a personal webpage so that other astronomers could look at the data and confirm his findings before anything was announced publicly. In it, Milani explored many possible trajectories for the giant space rock over the coming decades. Within one of these trajectories, he says, there is a *remote* possibility that the asteroid will collide with Earth — depending on another near-Earth encounter 28 years from now.[140] "I have duplicated many of his findings," said Paul Chodas, "the one that he is proposing could result in an impact in 2039 is extremely difficult to match and I have tried it and I can't match it exactly. But I have no reason to doubt that his calculations are correct."[141] And thus began the saga of 1999 AN10, easily one of the most controversial and poorly-handled events in the history of asteroid science.

The story of this asteroid began when Andrea Milani and Steven R. Chesley put the following pre-publication paper on their personal webpage so that other scientists could review and attempt to duplicate and confirm their findings.

> CLOSE APPROACHES OF ASTEROID 1999 $AN_{10}$: RESONANT AND NON-RESONANT RETURNS May 12,1999.
>
> The Earth passes very close to the orbit of the asteroid 1999 $AN_{10}$ twice per year, but whether or not this asteroid can have a close approach depends upon the timing of its passage across the ecliptic plane. Among the possible orbits there are some with a close approach in 2027. The period of the asteroid may be perturbed in such a way that it returns to an approach to the Earth at either of the possible encounter points. We have developed a theory which successfully predicts the 25 possible such returns up to 2040. We have also identified 6 more close approaches resulting from the cascade of successive returns. Because of this extremely chaotic behaviour there is no way to predict all possible approaches for more than a few decades after any close encounter, but the orbit will remain dangerously close to the orbit of the Earth for about 600 years. [142]

Unfortunately, the webpage on which it was posted was not secure and was open to the general public. The webpage was found through 'pure coincidence' by Benny Peiser, of Liverpool John Moores University, which resulted in the following story being published on CCNet the following day:

> *ASTEROID 1999 AN10 ON POTENTIAL COLLISION COURSE WITH EARTH IN 2039 AND NOBODY SEEMS WILLING TO INFORM THE PUBLIC*
>
> Imagine a newly discovered asteroid, some one mile in diameter, is on a potential collision course with Earth in just 40 years - and no one is telling you about it. This is exactly what is happening with asteroid 1999 AN10. By pure coincidence, I have come across a research paper by Andrea Milani, Steven R. Chesley and Giovanni B. Valsecchi on the potential risk of 1999 AN10 hitting the Earth in forty years time. Yet instead of informing the interested public about their potentially explosive findings, the authors have hidden away their results on an obscure web page.[143]
>
> There is no reason whatsoever why the findings about 1999 AN10 should not be made available to the general public - unless the findings haven't been checked for general accuracy by other NEO researchers. If, however, no such independent assessment has taken place, the data should not be in the public domain in the first place. After all, NASA is threatening researchers with the withdrawal of funding if they dare to publish such sensitive information in any other form than in a peer reviewed medium. Obviously, one's own web site can hardly be considered a peer-reviewed journal. One therefore has to wonder why such relevant information is put into the public domain in such a weird and secretive way.[144]

Ironically, the Minor Planet Center had added 1999 AN10 to the list of "Potentially Hazardous Asteroids" on February 16, 1999, well before the Italian paper was posted on the Internet.[145] But apparently, even members of the asteroid community had not checked the established channels of communication. That day, the authors issued a formal letter of complaint to CCNet and Benny Peiser.

> Dear Benny- We strenuously object to your characterization of our actions regarding this paper, and to your attempts to sensationalize our work. This whole thing could have been explained easily if you had contacted one of us, but that apparently does not suit your purposes. Instead you released an uninformed report filled with speculation and innuendo.[146]

Soon, many in the asteroid community, including Richard Binzel, a professor of Earth, Atmospheric and Planetary Sciences at the Massachusetts Institute of Technology, Clark Chapman, and Michael Paine, Australian NEO researcher and advocate, were responding to this issue in defense of the authors.

> Richard Binzel wrote: "The authors are to be applauded for doing it right, that is, they are making sure their results are correct before making any public announcement, and they will provide their full analysis for scrutiny within the professional literature. The timescales involved require no immediate action, hence the weeks (or even months) required for the scientific review process to proceed is of no consequence. (*A lesson that Peiser apparently learned – see Asteroid 2004AS1*) Furthermore, there is no reason why this object should merit any extraordinary public attention as the probability falls below that for "undiscovered" objects out there."[147]

Media coverage of the event came in two waves and as two independent stories. On April 14, 1999 the *Boston Globe* reported that 'astronomers have found an asteroid that will come quite close to Earth in a few decades, and that even has a real but minuscule possibility of an impact.' They continued to say that 'This is only the second time in history - or perhaps the first time, depending on whose analysis of last year's discovery you believe - that an asteroid has been discovered that has a small but non-zero possibility of striking the Earth within a few decades.'[148] Nearly a month later, after the paper was formally published, a second wave of stories hit the media. Interestingly, the second round of stories was more sensational than the first, despite confirmation at the time of a zero impact probability. The AP wire reported that, 'in the cosmic equivalent of a bullet whizzing by Earth's ear, a half-mile-wide asteroid looks as if it will come closer to smashing into our planet than any other space rock astronomers have tracked.' "It is indeed very interesting," said Paul Chodas. "We're taking it very seriously."[149] For the purposes of this examination, asteroid 1999 AN10 first shows that proper channels are not always adhered to, even within the scientific community, potentially leading to rumor mongering and credibility loss. Secondly, this example shows that the media may treat an asteroid story inaccurately even after the determination of a safe orbit and even if there have been previous media reports.

2002EM7 – Whew! Stealth Asteroid Nearly Blindsides Earth

"Whew! Stealth asteroid nearly blindsides Earth," read the CNN headline for asteroid 2002 EM7.[150] Unfortunately, this headline showed a complete lack of understanding regarding NEO search methodology and practice. Public commentators suggested that the Spaceguard Survey is inadequate because asteroid 2002 EM7 emerged unseen from the direction of the Sun (called a "blind spot") and was found only after passing by the Earth.[151] The strategies controlling the telescopic asteroid surveys necessarily find asteroids retreating from the Earth about as often as coming toward the Earth.[152] Regarding this asteroid, Clark Chapman stated that 'the implied failure of the search strategy to see 2002 EM7 as it came from the direction of the Sun is poppycock. Such reports serve to augment public anxiety about asteroids.'[153]

2002 EM7 is about 70-m in diameter. Every year about 100 objects of this size pass by the Earth within this distance. Most are never seen. About 1 in every 10,000 hits the Earth. (Think of the Earth as a bulls-eye inside a target with a radius of the distance that 2002 EM7 missed us by. The Earth, with a radius of 6000 km, covers about 0.00016 of the area of that circle. Random tossing will hit the bulls-eye once every 6400 times.) You can expect an object this size to hit about once per century. An object about this size exploded above Tunguska, Siberia, in 1908, flattening trees within about 20 km of the impact site.[154]

Chapman further added that the role of the news media in handling the impact hazard has generally not improved as scientific knowledge about the impact hazard has become more robust.[155] In the case of 2002 EM7, however, it was not only mainstream media that presented this misrepresentation. The headline on Space.com read "Asteroid Buzzes Earth, Highlighting Cosmic Blind Spot." The article also stated that 'the event illustrates the potential of a surprise hit by an asteroid' and that 'no amount of searching, north or south, would have spotted 2002 EM7.'[156] Even established science writers, who have previously covered asteroid stories, may not have a complete or accurate understanding of the problem or unique circumstances surrounding an asteroid warning. When this happens, errors are compounded a thousand-fold as the information works its way through the public having originated from an established and credible source.

Lastly, there is an implied 'failure' to find the object, yet those in the scientific community know this is not correct. Yet, had this asteroid impacted the Earth, it would have done so with only the warning that military space assets are capable of giving. If that had happened, disaster managers would not have had a plan to turn to or experience to draw from. Despite this lack of preparedness, there was no public outcry about public safety after this event showing that, despite sensational headlines, public fear has not reached the point of public action. This also highlights a role for military involvement in NEO searches possessing both the manpower and resources necessary for a ‘last minute’ warning.

2002NT7 – The Most Threatening Object in the History of Asteroid Detection

> *“There have been "false alarm" stories in the past about threatening asteroids, some originating in poorly informed or misguided statements made by astronomers. The general pattern has been that a warning is issued and a day or two later retracted, reflecting either improved calculations or new data or both. It is entirely normal that a very low probability prediction of impact will go to zero as more information is processed. This is not a "failure" of the system, but rather the normal working of the Spaceguard Survey and supporting dynamical calculations. However, the press sometimes portrays this as a "mistake" by astronomers. Consequently, most of us prefer to see no press coverage of such low-probability predictions. It was in this spirit that no formal announcement was made concerning 2002 NT7, since new observations are accumulating and the whole situation is likely to resolve itself within a few days.”*[157]

Unfortunately, the media seems to have created the current flood of publicity surrounding NT7. Initial statements from the British press stated that 2002 NT7 was on a collision course with Earth with an impact predicted for February 1, 2019. The only qualification was that the prediction of an impact was still somewhat uncertain. There was no hint of the true situation, in which the probability of impact was at the 1-in-a-million level.[158]

It was first seen on the night of July 5, 2002 by the Lincoln NEA Research Program (LINEAR) automated sky survey program in New Mexico. Since then astronomers worldwide have been paying close attention to it, amassing almost 200 observations in a few weeks. Benny Peiser told BBC News Online that "this asteroid has now become the most threatening object in the short history of asteroid detection".[159] While technically true, the quote sounded ominous without the proper caveats, chiefly that "most threatening" was relative to other asteroids that also had very low odds of possible future impacts. Peiser's quote figured prominently at the top of the BBC story and was, it appears, excerpted to become the main theme of the Reuters and Sky News stories, as well as others that followed the next day in British newspapers.[160]

The reason for this bold statement is that astronomers rated the object with a score of 0.06 on the Palermo technical scale (Level 1 on the Torino scale), making NT7 the first object to be given a positive value. However, even if this particular object is a Palermo Scale 0.23, the first over the background, the chances that it would really smash us are 1/100,000 and observations are still preliminary. “This is reality. But Media don't go with reality, they go with fiction, especially in the summer.”[161]

As expected, however, additional observations quickly eliminated the possibility of an impact. The “all clear” for any impact in 2019 was released on July 26, 2002 and by August 1, 2002 (less than one month from discovery) continuing orbital improvements also eliminated a lower-probability impact in 2060. This progression of events reflects the normal working of the Spaceguard system. There is always an initial large uncertainty in the orbit of a newly discovered NEO, which is resolved as new observations are made.[162]

Donald Yeomans, manager of JPL NEO explained, "The goal, I suppose, is to be at the same time sober, informative but not too nerdy." Various BBC reporters from different wings of the organization called him that week. "Most of the six interviews I did with

BBC reporters Tuesday night began with their assumption that there would be a collision," Yeomans said. "One is then forced to back up and try to explain the real situation and the fact that there is not really a story here. They didn't wish to hear that."[163] Such failures are presumably due to a combination of the inarticulateness of researchers, the poor science and math education of the public, and inappropriate hyping and sloppy journalism by news media.[164] This time, however, under an agreed-upon policy of full disclosure, the blame for any misinformation sits mostly on the shoulders of the media, they say. “I think that in the end it comes down to the journalistic objectives, and, perhaps rarely, to journalistic integrity," said JPL’s Steve Chesley.[165]

Clark Chapman argued that the Torino Scale for impact risk seems to hold up well, and he suggested it should be used consistently in communicating with the public about new possibly-hazardous asteroids suggesting that astronomers should avoid references to the Palermo Scale - whose usage figured prominently in the reports about 2002 NT7. Some of those reports, Chapman says, were "confusing and inappropriate," since they stressed the fact that this was the first object ever to get a positive, greater-than-zero Palermo rating. Since the scale was barely a year old, he says, that's "like calling the Queens air crash last fall the worst transportation disaster of the century, when the century was barely a year old!"[166]

Scientists have started to understand that false alarms have harmed public perception of the search for NEOs and attempts at discovering the best mitigation techniques in case a crash would really happen.[167] There is wide divergence of opinion about what happened, much of it related to an apparent difference in press practices (and public expectations) in the United States and UK, the two countries in which most of the media stories originated. Simply put, the British press seems to be more prone to exaggerated headlines and lead-ins, sometimes combined with a dose of humor – and the British public understands this and does not expect a high level of technical accuracy from their press. Americans generally hold science reporters to a higher standard, although alternatively, the Brits might say that Americans lack a sense of perspective and perhaps also a sense of humor.[168]

2003QQ47 – Asteroid Update: End of World on Hold

"Asteroid update: End of world on hold" is how the CNN headline read. [169] The report continued to say that the newly discovered asteroid has zero chance of colliding with Earth in 11 years, although preliminary data had suggested such a doomsday scenario was possible, astronomers said this week. New data allowed a more refined projection of the orbit of the space rock, dubbed 2003 QQ47 -- ruling out more than a dozen possible strike dates, according to the NEO Information Center. Earlier this week, the U.K.-based asteroid-monitoring center posted a Web announcement stating that there was a remote chance the asteroid would hit our planet in 2014**,** possibly unleashing the energy equivalent of millions of nuclear bombs."[170]

Asteroid 2003 QQ47 was first observed on August 24, 2003 and given a one in 909,000 chance of impact on March 21, 2014. [171] "We have many asteroids that have residual risks," said Paul Chodas, "This particular one was of interest because it is fairly large, 1.3 kilometers [0.8 mile], and the predicted impact was only 10 years away. Combining those two factors, we raised it to some level of concern." The rock, first observed by LINEAR, was given a rare rating of one on the Torino Scale of asteroid and comet threats for the 2014 encounter. Additional observations allowed astronomers to plot the asteroid's orbital course more precisely the Torino rating was reduced to zero by JPL as well as the NEODyS asteroid-monitoring group in Italy.[172] By Tuesday evening (August 26, 2003), the risk for 2014 was eliminated. JPL said there was still a 1-in-2.2 million chance that an impact could occur sometime in the next century, but that is far below the "background risk" of a catastrophic collision in any given year.

Soon after, the UK NEO Information Center decided that this asteroid deserved special attention, and on September 2, 2003 they issued a press release calling attention to the danger of collision in 2014. Since the UK government supports the NEO Information Center, this quasi-official "prediction" was widely reported in the British press. While most stories correctly noted the very small odds of impact, they still treated this as a serious warning of a threat to Earth. The story was also reported in Europe, the United States, and Australia, but more moderately than in the UK. The result is another round of criticisms of astronomers, triggered by the NEO Information Center release (which they withdrew on September 3, 2003).[173] The reasoning behind the September 2, 2003 press release, over one week after the risk was reduced below the average background risk, is unknown. However, astronomers are so horrified by press scares over asteroids - including the recent furor over QQ47 that they are toning down the scale they use to rate the threat posed by asteroids in an attempt to discourage journalists from covering potential collisions.[174] While journalists insist they reported the information on QQ47 accurately, astronomers feel they were misrepresented. "That was certainly much ado about nothing," said Steve Chesley. "It was like a virus solely within the realm of the press."[175] This incident clearly illustrates the differing priorities of science and journalism. Further, it shows that stories are also generated from within the scientific community and officially released to the media. Without a specific set of criteria required before raising the Torino threat level, scientists will lack clarity when disseminating hazard information to the public. Perhaps MSNBC summed up the incident best by saying, "this week's alert followed the up-and-down course that is typical for observations of NEOs."[176]

<u>2004AS1 – A Killer Asteroid Didn't Collide with Earth Last Month…</u>

"A killer asteroid didn't collide with Earth last month. But panicky astronomers came mighty close to waking up President Bush with a nasty message that a collision was imminent." This was the headline of a *San Francisco Chronicle* article about 2004 AS1. The article continued saying, "During a scientific meeting on NEOs under way in Southern California this week, astronomers revealed that they seriously contemplated alerting top NASA officials -- and ultimately the White House -- to the possibility that a space rock was hours away from hitting Earth in mid-January. Late the night of January 14, 2004, Steve Chesley calculated about a 1-in-4 chance that the newfound asteroid was indeed about to slam into the Earth.[177]

The asteroid in question, bearing the temporary designation AL00667, had been discovered the previous night by LINEAR. Routine and largely automatic processing of these observations led to the posting (by the IAU-supported Minor Planet Center in Cambridge, Massachusetts) of an orbit that intersected the Earth within the next 36 hours.[178] Although the observations were limited and the orbit solution was highly non-unique, there initially appeared to be a distinct possibility, verified by orbital calculations carried out at the JPL NEO, of an impact in the northern hemisphere. Only a handful of astronomers (professional and amateur) were involved, and there were no scare stories in the press.[179]

Following is Clark Chapman's account of the events:

> "About 36 hours before President Bush's planned speech at NASA Headquarters on future American space policy, the LINEAR observatories in New Mexico routinely recorded four images of a moving object. Half a day later, on Tuesday, January 13, 2004, these data sets were sent (as part of the daily submission of data) to the Minor Planet Center in Cambridge, Massachusetts. Just before going to dinner, MPC researcher Tim Spahr ran the data through standard software to generate a nominal ephemeris for the new object. These are posted on the publicly accessible NEO Confirmation Page (NEOCP) so that amateur and professional asteroid astronomers around the world might be able to follow up on the LINEAR observations that night. It is through such follow-up astrometry that NEO orbits can be refined so that the object is not permanently lost. Spahr posted the ephemeris, based on LINEAR's four detections, on the NEOCP under the designation AL00667, along with ephemerides for several other recommended targets. Less than an hour later, a European amateur astronomer, Reiner Stoss, went to the NEOCP and noticed a curiosity: AL00667 was predicted to get 40 times brighter during just the next day, meaning that it was going to be six times closer to the Earth! He expressed his amazement on Yahoo's MPML (Minor Planet Mailing List) chatroom on the internet.
>
> "Professional asteroid researcher Alan Harris happened to be monitoring the chatroom and noticed the strange posting about a "bogie" (military slang for an unidentified, potentially enemy aircraft). Indeed, he found on the MPC's web site, with no comment at all, what he recognized to be an alarming prediction. He quickly calculated that an asteroid following this nominal ephemeris would strike the Earth just one day hence. He immediately alerted several of us, including NASA Ames Research Center's David Morrison (who chairs the IAU's Working Group on NEOs) and Don Yeomans (who heads JPL NEO). His message was sent at 5:09 pm (MST, used hereafter, is the time zone of LINEAR and of the amateur astronomer who later laid this bogey to rest).

"Yeomans and his associate Steve Chesley telephoned to the MPC to try to find out more about the asteroid from Spahr. Forty-five precious minutes had already elapsed since Harris' email, when all that Yeomans could report back to his colleagues was, "We've got a call into Tim Spahr to see if we can get the astrometry itself but Tim is not yet at home." About half-an-hour later, they reached Brian Marsden, director of the MPC, who was working late that evening. (Harris also alerted Marsden by email.) By policy, LINEAR and other single-night asteroid data (termed one-night-stands) are kept private by Marsden until they have been verified and linked with observations on other nights. But once contacted by Yeomans and Chesley, Marsden agreed to provide the data to the JPL researchers and did so about 20 minutes later; then, about 1 hour 45 minutes after being notified by Harris, they got to work trying to understand this anomalous asteroid. (Other asteroid orbit experts, in Arizona and Italy, later complained that they never had access to the data on AL00667.)

"The MPC faced the embarrassing fact that they had effectively made the first-ever prediction of a near-term asteroid impact without even realizing it themselves. Marsden hastily tried to fix the web page. Supported by no new observations, he posted a new, non-impacting (actually receding) trajectory, which was also consistent with the data. An hour later, Spahr -- having finished dinner, gone home, logged in and discovered what was happening, and raced back to the MPC -- replaced Marsden's post with yet another trajectory, once again showing the asteroid headed toward the Earth, but this time narrowly missing an impact. None of the later postings reflected new data: Spahr and Marsden were simply frantically trying to figure out for themselves what the data meant and what was politically correct to display on their web site. With hindsight, it is clear that the highest priority should be to search for "virtual impactors" -- that is, the subset of asteroid trajectories allowed by the uncertainties in the fit to the data that would result in an impact; if no asteroid is found in the patch of sky that meets these criteria, then there is no longer a threat of impact. The second priority should be to find the NEO, wherever it might be within the spread of uncertainty, so that it isn't lost. Another priority, of course, is not to confuse, mislead, or frighten people by leaving an effective impact prediction posted on the web site (without appropriate caveats, especially for non-experts who might suddenly be alerted to this web page's existence). With hindsight, we can surely imagine better solutions than any of those implemented on the NEOCP in unplanned crisis-mode that night. But the chief blameworthy error is lack of thorough planning by the NEO community for such a contingency, not in the spur-of-the-moment decisions actually made". [180]

A few very important details come from this account. First, and perhaps foremost, is that the object caught everyone completely off-guard. Secondly, no ephemeris data was known on the object. At the time it was posted to the Minor Planet Center's NEO Confirmation Page (NEOCP) with LINEAR discovery designation AL00667, this object was thought too small to be hazardous. As Spaceguard U.K. put it: "probably smaller than a bus, and would certainly never make it through the atmosphere to hit the ground." However, it turned out to be bigger than anyone had thought. JPL puts 2004 AS1's absolute magnitude at H=20.29, which by standard formula converts to a diameter of 230 to 520 meters/yards, with 295 as best guesstimate.[181] It is now known that it ultimately passed Earth on February 16, 2004 at just over 33 lunar distances (LD) and doesn't ever come closer than 8.56 LD.[182] Third, no mention was made of attempting to contact the military to confirm and follow-up on the sighting with space-based assets. Would it not be sensible to contact them before calling the President? Unfortunately, no established relationship or chain of contact exists between the scientists and the military. This situation illustrates clearly the importance and usefulness of establishing that link. Fourth, none of the later internet postings reflected new data. Yet, a decision was made regarding "what was politically correct to display on the MPC web site." In his account of the incident, Marden stated:

> "I quickly verified the complaint about the impact, computed several orbits myself that would have the object receding from the earth rather than approaching, supplied the observations to the NASA colleague so that he could do some independent orbit computations (which essentially agreed with those of the MPC), contacted a few potential observers in the United States, advised my MPC colleagues that "we had a problem", and replaced the offending nominal orbit by one that was less threatening. Of course, what we now urgently needed were follow-up observations."[183]

Importantly, with data from just four observations available, the uncertainties were large. There were many possible orbits the object could be on, and the majority of them did not threaten the Earth. How did the “problem orbit” become the first one of the possibilities posted? Why then, with no further information, was it then changed?

Events reached a crescendo when Steven Chesley, a researcher at NASA's Jet Propulsion Laboratory, looked at the available data and sent an e-mail saying the asteroid had a 25% chance of striking the Earth's Northern Hemisphere in a few days. It was then that astronomers Clark Chapman and David Morrison, chair of the International Astronomical Union's Working Group on NEOs, contemplated picking up the telephone to the White House.[184] "That would have jumped the gun before we knew much about the object," said Brian Marsden, of the Minor Planet Center. "I find it incredible that such action was contemplated on the basis of just four observations. That is just not enough to yield a sensible orbit. "There was no need to panic as it was obvious that the situation would have been resolved, one way or another, in another hour or two."

Fortunately for all concerned, shortly after the ominous Chesley e-mail, an amateur astronomer managed to dodge the clouds and take a picture of a blank patch of sky. This was significant because if 2004 AS1 really was going to hit the Earth, it would have been in the amateur's sights. The fact that it was absent meant the rock would not strike us. But Chapman says in his presentation that if it had been cloudy, and no more observations could have been obtained at the time, he would have raised the alarm. Marsden disagrees. "If it had been cloudy and the call had been made to the President it would have been disastrous." Many astronomers recognize that a false alarm could have brought ridicule on their profession. "They completely misread the situation," said Benny Peiser, "There was plenty of time to get other observers on the job."[185]

In a recent paper, Clark Chapman presented some relevant questions about this case.

> "What can we learn from this case? How could there have been an official, if unmonitored and obscure, posting by the MPC based on a calculation implying a major asteroid impact the following day, without the MPC even initially realizing it? How could the data, on which the calculation was based, be kept private so that many of the world's asteroid experts could not evaluate the situation, long after the threat was being debated in a public chatroom? How could the JPL Sentry system and the parallel NEODys system in Italy have failed to post the relevant information on their own official asteroid impact web sites? Why were the LINEAR data worse than usual for this particular "one-night-stand"? Were the computer programs used by the MPC and JPL that evening truly state-of-the-art and, if not, did that contribute to the scary predictions? How could one JPL expert calculate something like 1-chance-in-four of a near-term impact disaster, when in fact the asteroid never passed within millions of miles of our planet? Just how big was the nominally calculated impacting body, where would it have hit, and how much damage might it have caused? Did this event merit the unexpectedly high value of 3 on the Torino Scale (designed to educate the public about the seriousness of an impact prediction)? How did this potentially most dramatic of all asteroid impact predictions fail to be noticed by the news media? (Indeed, a search of CNN stories for the relevant dates indicated no stories regarding this asteroid.) How close did astronomers come to issuing another false alarm, this time with the potential for embarrassing not only NASA but the White House?[186]

David Morrison, Chair of the IAU working group on NEOs responded to these questions noting that the Spaceguard Survey was not designed to detect small asteroids a few days before collision. It does not have either the equipment or the resources to function as a warning system for imminent impacts. Its purpose is to carry out a long-term survey, with emphasis on discovering and calculating accurate orbits for asteroids larger than 1 km -- those with a possibility of triggering a global catastrophe if they collided with Earth. He continued by saying, “There should be planning at an international level of what action to take with respect to notifying governments and the public of a possible near-term impact.

This planning must recognize that it is likely that in all such cases new observations will quickly eliminate any possibility of impact rather than confirm it."[187] In this case, the asteroid would have impacted in 'a few days.' If hazard management needed to evacuate a large city, prepare for a possible tsunami, protect or preserve local infrastructure and house the public with only a 'few days' notice and no prior planning for this possibility, the results would have likely been disastrous.

2004FH – A Definite Miss

On March 18, 2004 at 5:08 PM EST a 25-m diameter space rock passed just 43,000 km from Earth - just beyond geostationary orbit. [Figure 5] It was the closest pass ever recorded. Yet, despite this record-breaking "close call," there was no slew of disaster and doom headlines. Rather, much to the credit of the scientists and media involved, the headlines were few and the reporting was not even remotely sensational. Searching every worldwide news agency, the 'scariest' headline was from the *India Times*, which read: 'Asteroid Too Close For Comfort'[188] – comparatively mild compared to previous headlines.

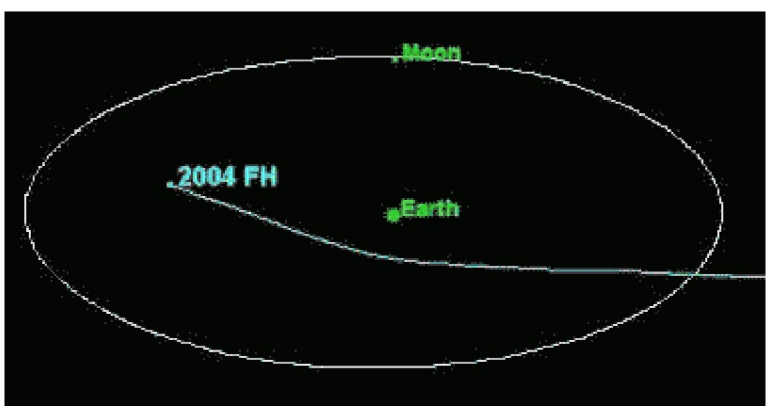


Figure 5: Asteroid 2004 FH passes about 43,000 km (26,500 miles) above the Earth's surface on March 18, 2004. Earth's gravity bends the trajectory of the asteroid by about 15 degrees. The asteroid crosses from one side of the Moon's orbit to the other in 31 hours.[189]

Three important points of note, however, can be drawn from this event. First, within the first few sentences of the network and web news reports was a version of the following:

> “The asteroid's close flyby, first spied late Monday, poses no risk, NASA astronomers stressed. "It's a guaranteed miss," said astronomer Paul Chodas.”[190]

The words ‘no risk’ and ‘guaranteed miss’ instantly turned 2004FH from a public safety news story to a news interest story. Without raising any alarms or causing panic, scientists still managed to increase public awareness, publicize their research, and promote the value of asteroid research and NEO watch programs. Secondly, neither the Torino nor Palermo scales were mentioned in any news reports or articles. If researchers and media want to educate the public on the hazard and provide a consistent method of NEO reporting, the Torino/Palermo scales will only be useful if the public understands their meaning. This can only be accomplished if both sides make an effort to include them (or any other decided upon scale) in every public report even if the value is zero. The third important point is that the rock was noticed at all. "The important thing is not that it's happening, but that we detected it," said Steve Chesley of the flyby.[191] Notably, the discovery of an asteroid of such a small size with existing capabilities implies that, though beyond the current 1-km mandate, asteroid search programs are robust enough to continue the effort on smaller scale (and higher probability) asteroids. Overall, considering how close this asteroid came and the muted media response, this incident seems to imply that either the media no longer believes that asteroids make sensational headlines or, perhaps, that communications between NEO researchers and the media may be improving.

*Problem Summary*

First, there are currently no established national or international policies for the communication and dissemination of asteroid hazard information. In lieu of established policy, communication to date has been an ad hoc mix of media, science, agency, and political sub-agendas. No official source for NEO information has emerged often resulting in unclear, confusing and occasionally, contradictory information presented to the public and to policymakers. Many believe that this has also damaged the credibility of the researchers, weakened media relations and actually reduced the safety of a public that has heard too many cries of wolf that the sky is falling.

Secondly, it is only a matter of time before a small NEO approaches unannounced and airbursts or impacts near a populated center causing massive damage and loss of life. Currently, most of the current work regarding NEOs is focused on observation, however, the smaller objects that are statistically more likely to strike are rarely observed and would likely impact unannounced. If that were to happen, relief and public safety agencies (not to mention governments and media) would be utterly unprepared. Thus, it makes sense to also prepare for this possibility from a hazard mitigation standpoint. Many of the possible manifestations of a smaller body impact resemble the potential damage from other natural hazards and, while there are aspects of the asteroid hazard that are unique, an investigation of existing resources and capabilities regarding other natural hazards provides a valid starting point and model.

## PART II – Resources and Capabilities

*There's a need for governmental policy makers to formulate a chain of responsibility for action in the event a threat to the Earth becomes known. "There isn't anybody to call. There is nobody there. There's nobody with authority and nobody with resources. We need to correct that."* [192]

*Similarities Between Natural Hazards*

While some aspects of the impact hazard (e.g., its predictability, variability in source composition, etc.) are unusual or unique, most destructive effects resemble those of tsunami, earthquakes, atomic bomb, volcanic explosions, sudden climate change, wildfires, etc.[193] Consequently, this section will examine other natural disasters and the protocols, policies and agencies that exist for them in hopes of extrapolation to the NEO case.

In the cases of a short warning hazardous NEO discovery, there are ample analogs with other disasters in terms of mobilizing warning and recovery efforts. The locations likely to be affected should be known nearly as reliably as other predictable disasters (such as hurricanes or earthquake-generated tsunami) in which case evacuation procedures could be implemented. However, because of fairly large error margins, the evacuation area would need to be significantly larger than any known analog. In addition, impacts can occur at any location on Earth and may not necessarily be near the restricted localities where natural or weather-related disasters are common and emergency warning-and-response procedures are well practiced. Further, there may be significant differences from historical experience in the associated post impact disasters. An impact-generated tsunami might have different characteristics (e.g. wave frequency, direction of propagation) from previously experienced tsunami because of the location and manner (asteroid impact) in which it was generated.[194] [195]

Most social scientists interested in disaster research do not use a typology of different agents or classes of physical agents but take a generic approach to the problem.[196] The agent-specific approach assumes that each type of hazardous agent (e.g., a volcanic eruption, nuclear radiation fallout, asteroid impact) or classes of agents (e.g., the source being in the natural or in the technological sphere) have certain distinctive characteristics that have consequences for mitigation and relief efforts.[197] The generic approach assumes that there are more individual and organizational behavioral similarities than differences across all disaster occasions.[198] For many human and organizational problems in disaster management, the specific agent causing the disaster does not matter. Whether the emergency task is warning, evacuation, sheltering, feeding, search and rescue, disposition of the dead, mobilization of resources, communication flow, inter-organizational coordination, public information, etc., the same general activities have to be undertaken irrespective of the specific agent in the situation.[199] Additionally, the general kinds of bureaucratic arguments advanced for a physical solution to potential disaster problems, the social sources of support, and resistances in the governmental and private sector to such measures, population views of the legitimacy and acceptability of the planning suggested, and willingness to put preventive measures on a political agenda, also show considerable similarities irrespective of the particular disaster agent involved.[200] In the United States, many agencies already have existing plans or procedures that could prove useful, if coordinated, in mitigation of the impact hazard.

In the event of an impact disaster, the problem of an unprepared disaster management plan will be exacerbated by an uninformed public. In developing a method for accurate and open sharing of information with the public, the established disaster management community has unparalleled experience.[201] The public considers the National Oceanic and Atmospheric Administration (NOAA) and the United States Geological Survey (USGS) as having credibility regarding hurricane warnings and earthquake advisories, respectively.[202] With respect to sources of information, people judge risk communicators on the basis of such traits as their perceived competence, objectivity, consistency, honesty, and trustworthiness.[203] To date, a publicly credible source for communicating impact information has yet to emerge. For any communication plan to be effective, it is vital that disaster managers and journalists interact regularly, before a disaster occurs, to educate each other to lay the groundwork for effective working relationships in the aftermath of a disaster.[204] By becoming more familiar with each other's work, disaster managers, scientists, and journalists can join forces to ensure an appropriate message reaches audiences when it is needed allowing for accurate, effective and widespread dissemination.[205]

*Existent Capabilities*

In the development of an asteroid hazard response plan, it is both economical and responsible to survey the current resources that could be used to assist the overall effort to increase public safety. This section will provide a brief look at some existing hazard related agencies – from both the risk mitigation and disaster response perspectives – and draw some preliminary analogies to the asteroid hazard.

National Aeronautics and Space Administration (NASA)

The stated purpose of the NASA NEO Program is to coordinate NASA-sponsored efforts to detect, track and characterize potentially hazardous asteroids and comets that could approach the Earth.[206] Their NEO Program is focused on observation and the Congressionally mandated goal of locating at least 90 percent of the estimated 1,000 asteroids and comets that approach the Earth and are larger than one kilometer (about 2/3-mile) in diameter by the end of the next decade.[207]

Whether NASA's mandate will extend to smaller diameter NEOs is still undecided. On February 11, 2004, Representative Dana Rohrabacher, (CA) introduced the "George R. Brown Near-Earth Object Survey Act" in the House of Representatives. The purpose of the bill is to provide for "a NEO survey program to detect, track, catalogue, and characterize certain NEOs and comets."[208] This bill calls on NASA to plan, develop, and implement a NEO Survey program to detect, track, catalogue, and characterize the physical characteristics of NEOs and comets equal to or greater than 100 meters in diameter in order to assess the threat of such NEOs in striking the Earth. Notably, this bill allocates $20 million for each of the fiscal years 2005 and 2006. In order to spend these funds, they would have to be appropriated to NASA in a separate set of actions from the House and Senate neither of which have acted on this legislation.[209] However, Dr. Ed Weiler, NASA Associate Administrator for Space Science, stated that it is premature to consider an extension of the current national program to include a complete search for smaller-sized NEOs." Weiler also stated that NASA did not feel they "should play a role in any follow-on search and cataloging effort unless that effort needs to be specifically space-based in nature."[210] While space based observatories would increase detection rates and provide longer impact warning times, there are no current plans to fund such a satellite.

The NEO program office is also currently responsible for “managing the detection and cataloging of Near-Earth objects” and “facilitating communications between the astronomical community and the public should any potentially hazardous objects be discovered.”[211] To accomplish this coordination and communication with the astronomical community, NASA co-funds the Minor Planet Center (MPC) where many international observatories and amateur astronomers can upload their observational data. With respect to public communication in the event of a hazardous NEO discovery, however, specific protocols have not been established and partnerships with other federal agencies with existent capabilities have not been defined for this purpose. By leveraging other federal agencies that have an established infrastructure and experience with other natural hazards, communication, mitigation and recovery protocols can be developed and implemented thereby increasing public safety at relatively low cost.

<u>The National Oceanic and Atmospheric Administration (NOAA)</u>

Providing the infrastructure that makes weather reporting and warnings possible, NOAA is responsible for the space assets that allow for tracking and real-time information gathering. There are facets of NOAA’s operations and protocols that can be translated into the asteroid hazard mitigation scenario. For example, when reporting on incoming hurricanes, NOAA utilizes satellite imagery and relatively long lead times from the birth of the storm till landfall. While the exact area of landfall can shift until the final moments, an area of damage is estimated and evacuated prior to the storm’s arrival.[212]

The infrastructure to track a potential disaster and relay real-time information to public safety officials, decision makers and relief workers in the area would be invaluable to any post impact relief effort.

Further, the public already knows and trusts NOAA (and the associated National Weather Service (NWS) as a source for credible and accurate disaster information. This was accomplished by establishing a single source to disseminate information to media and the public. A key step astronomers must take to minimize media frenzy over false positives is to organize a similar central information source, similar (for example) to the National Hurricane Center. The role of this center will be to convey, with a single authoritative voice, the consensus findings of international experts regarding whether any asteroid close encounter merits public or governmental concern.[213] Continuing with the present situation of multiple information sources serves only to erode the credibility of professional astronomers.[214] In the event of an impact, far more than credibility would be at stake. Rather than fund a completely new and unknown organization to accomplish this task, it makes far more sense to utilize what is already established.

Another relevant similarity is the establishment of a relative ‘scale’ to inform the public how a storm will affect their community. To transmitting information to the general public about an incoming hurricane, a standard scale was established to give the relative size, strength, and damage potential of a storm. This scale, known as the Saffir-Simpson [Figure 6] scale, has become common knowledge in the United States – especially along costal areas.[215]

**Saffir-Simpson Hurricane Scale**

| Scale Number (Category) | Sustained Winds (MPH) | Types of Damage | Hurricanes |
|---|---|---|---|
| 1 | 74-95 | **Minimal:** *Damage primarily to shrubbery, trees, foliage and unanchored mobile homes. No real damage to other structures.* | *Irene, 1999* |
| 2 | 96-110 | **Moderate:** *Some trees blown down. Major damage to exposed mobile homes. Some damage to roofing materials, windows and doors.* | *Georges, 1998*<br>*Floyd, 1999* |
| 3 | 111-130 | **Extensive:** *Large trees blown down. Mobile homes destroyed. Some structural damage to roofing materials of buildings. Some structural damage to small buildings.* | *Betsy, 1965*<br>*Alicia, 1983* |
| 4 | 131-155 | **Extreme:** *Trees blown down. Complete destruction of mobile homes. Extensive damage to roofing materials, windows and doors. Complete failure of roofs on many small residences.* | *Andrew, 1992* |
| 5 | >155 | **Catastrophic:** *Complete failure of roofs on many residences and industrial buildings. Extensive damage to windows and doors. Some complete building failure.* | *Camille, 1969* |

*NOTE: Damage can vary greatly and may not apply to all areas, such as Hawaii.*

Figure 6: The Saffir-Simpson Hurricane Scale[216]

While this scale does not account for all possible variability in a hurricane, it does provide the public with a relative scale that is easily understandable and memorable. The Torino Scale for asteroid events, while similar in form, provides only a little of the same type of information related to size, strength, and damage potential.

NOAA's experience with both long and short lead-time events and public dissemination of real-time disaster information provides a reasonable model for handling typical asteroid discovery information and the types of public warning systems that will be understood and remembered. For asteroid hazard mitigation, an approach that focuses on both the long term (NOAA) and the immediate (NWS) is required.

The National Weather Service (NWS)

The first and perhaps most common source of public information is the NWS. The NWS provides weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean areas, for the protection of life and property and the enhancement of the national economy.[217] The NWS is the sole United States official voice for issuing warnings and information during life threatening weather situations.[218] This is accomplished through two means, NOAA Weather Radio (NWR) and the Emergency Managers Weather Information Network (EMWIN).

To keep the public informed, NOAA and the NWS have established a constant 'weather' band known as NWR. NWR is the prime alerting and critical information delivery system of the NWS and broadcasts warnings, watches, forecasts, and other hazard information 24 hours a day.[219] NWR has the means to distribute a warning within minutes to the general public in a targeted area. While there might not be time to evacuate an area, if a smaller NEO was discovered on the way in by (for example) a military satellite, there might be time to send an a warning to the community to take shelter. Importantly, there might not be time for conformation, explanations or the establishment of protocols. If advanced organizational planning is not done, any potential to save lives will be lost in the bureaucratic shuffle.

EMWIN is a system that transmits live weather information to computers across the United States and over most of the Pacific Ocean. The National Weather Service gathers live weather and emergency information from sources across the globe and the EMWIN system broadcasts that data via satellite, radio, and the Internet.[220] Computers can use the satellite downlink to access a stream of real-time weather information from NOAA's Geostationary Operational Environmental Satellites, GOES-8 and GOES-10.[221] Emergency management groups and municipal agencies retrieve the EMWIN data from satellite and retransmit it through local radio frequencies. Anyone within a 40-50 mile range of the transmission signal can access that data via computer.[222] In some small island countries, it is the most reliable way to get forecasts and warnings.[223]

Finally, the NWS has historically received readings from a network of amateur meteorologists that provide rain gauge and local weather information to a central hub. This is, in fact, quite similar (in principle) to the MPC acquiring reports from amateur astronomers to help with orbital calculations and discoveries. NWS data and products form a national information database and infrastructure that can be used by other governmental agencies, the private sector, the public, and the global community.[224] If the United States wanted to establish a national NEO watch center to coordinate observations (and supplement the work of the overburdened MPC), the NWS can provide a proven effective model.

<u>The United States Geological Survey (USGS)</u>

The USGS shares hazard research and warning responsibilities for tsunamis, earthquakes, volcanoes, landslides, and other natural Earth-based phenomenon. As with NOAA, one important duty of USGS is the preparation and dissemination of accurate information to emergency relief officials and the general public. Again, while not specifically mandated to handle a NEO impact threat, the USGS does have mandated responsibilities in areas that could be produced as a secondary result of an impact.

Under the Stafford Act (Public Law 93-288), the USGS has the responsibility to issue timely warnings of potential volcanic disasters to civil authorities and affected communities.[225] The strategy the USGS uses to provide volcano warnings in the United States also involves a series of alert levels that correspond to increasing levels of volcanic activity. As a volcano becomes increasingly active, a correspondingly higher alert level is declared. This alert level ranking thus offers the public and civil authorities a framework they can use to gauge and coordinate their response to a developing volcano emergency.[226] The USGS is also responsible for providing information about earthquakes to government agencies and the public. Information about earthquakes is used in many ways, including the response to felt earthquakes by the public, by Federal, State, and local government agencies, and by private organizations.[227] With a successful and effective system for disseminating this type of information for other natural disasters, it would be pointless to develop an entirely new system specifically tailored to NEOs when the scope of the existent system could be widened to include NEOs with some training at relatively minor expense.

Because public safety is involved, the USGS stated policy is to promote the rapid release of accurate, consistent, and understandable estimates of earthquake size.[228] In the event of a NEO impact, it will be important that emergency relief and public safety workers have accurate and consistent information regarding the extent of damage and possible secondary effects. If emergency workers have never heard of the Tornio scale, it is unlikely they will understand the type of damage to expect from an eight.

Similar to the current state of affairs regarding the Torino and Palermo scales, the USGS also has two scales that it uses to express the dangers from earthquakes. The severity of an earthquake can be expressed in terms of both intensity and magnitude. However, the two terms are quite different, and they are often confused.[229] Magnitude is calculated (and disseminated) through the use of the Richter Scale. This is a 1-10 scale derived from the logarithm of the amplitude of waves recorded by seismographs. (Appendix A) Adjustments are included in the magnitude formula to compensate for the variation in the distance between the various seismographs and the epicenter of the earthquakes.[230]

The effect of an earthquake on the Earth's surface is the intensity. The intensity scale consists of a series of certain key responses such as people awakening, movement of furniture, damage to chimneys, and finally--total destruction. Although numerous intensity scales have been developed over the last several hundred years to evaluate the effects of earthquakes, the one currently used in the United States is the Modified Mercalli (MM) Intensity Scale. (Appendix A) It was developed in 1931 by the American seismologists Harry Wood and Frank Neumann and based on the scale invented by Giuseppe Mercalli in 1902. This scale, composed of 12 levels of intensity that range from imperceptible shaking to catastrophic destruction, is designated by Roman numerals. It does not have a mathematical basis; instead, it is an arbitrary ranking based on observed effects.[231]

This is analagous to the current NEO scenario in that there are two scales that are used, one that provides a scientific understanding of the earthquake and one which provides a more general scale in terms that the public can relate to in terms of actual effects. However, in the earthquake case, it is the scientific scale (Richter) that has permeated both the media and general public and has become the scale that most people are familiar with. Consistent use of a single scale by the media has resulted, in the United States, in a wide public understanding of the meaning of this scale. Public understanding and adoption of a NEO scale, such as the Torino Scale, will only occur if it is consistently invoked by the media when reporting on a NEO.

Finally, in addition to its history of effective and accurate dissemination of disaster and hazard information, the USGS also is home to an astrogeology research program. The stated mission of the USGS Astrogeology Research Program is to establish and maintain geoscientific and technical expertise in planetary science and remote sensing to perform the following tasks:

- Scientifically study and map extraterrestrial bodies,
- Plan and conduct planetary exploration missions, and
- Explore and develop new technologies in data processing and analysis, archiving, and distribution.[232]

In the event of a short-term incoming NEO scenario, one of the most important questions that will need to be addressed is the composition of the incoming body itself. As the sole United States federal astrogeology program, it is likely that this cadre of experts may be turned to for answers. Currently, accurate compositions (determined through visible and near-infrared (VNIR) spectroscopy) have been established for less than 1% of known NEO's.[233] Funding observers to establish a database of compositional information for all

PHAs identified in the Spaceguard Survey, in terms of public safety, could be one of the most important tasks this program could undertake. Currently, there are no plans for this.

The Federal Emergency Management Agency (FEMA)

FEMA is an independent federal agency with ~2,500 full-time employees stationed in Washington, D.C., and across the country, and nearly 4,000 standby disaster assistance employees to help out after a disaster.[234] FEMA's mission is to reduce the loss of life and property and protect the nation's critical infrastructure from all types of hazards, through a comprehensive emergency management program of risk reduction, preparedness, response, and recovery.[235]


Figure 7: FEMA Disaster States of Involvement[236]

Importantly, FEMA does not respond to every disaster that occurs in the United States FEMA responds when a disaster overwhelms a state's resources and is requested by a state governor. Federal disaster declarations are made by the President, and allow the federal government to pay for disaster recovery. Disaster assistance comes from a special fund set up by Congress under the Stafford Act. FEMA also uses a percentage of disaster assistance money to fund hazard mitigation projects in communities devastated by disasters. While the definition for the acronym ECA (Earth Crossing Asteroid) is defined within the FEMA preparedness appendix, no mention of mitigation, education, or risk reduction information appears within the public literature. However, when an impact occurs, FEMA will be a central player in national disaster relief efforts providing experience, resources and manpower.

United States Department of Defense (DoD)

As part of their duties to the nation, the DoD maintains a program of space surveillance that detects energetic upper atmospheric airbursts caused by NEOs. There are roughly 30 airbursts every year that typically release ~1 kiloton TNT equivalent energy and are caused by objects primarily in the 1-10 m size range.[237] The DoD does not publicly support any programs that specifically address collisions from objects from space with the Earth[238] though Brigadier General Simon Worden testified to Congress that there is at least one satellite in orbit that can track objects in space - "better than ground-based systems."[239] However, he continues that even in the defense community, the issue is not seriously considered."[240] "We are making progress with the NEO hazard issue, but there is still a giggle factor within the Pentagon," he said. "DoD may have interest in developing dual-use technology but not in assuming responsibility for NEOs.[241]

With superior in-space tracking ability, it might seem logical that the military would be more involved in this effort, however, these sensors are used for vital early warning purposes and data sharing is difficult because thier detailed performance is classified.[242]

In recent years, the DoD has been working to provide extracts of this data to nations potentially under missile attack with cooperative programs known as "Shared Early Warning" and some data about asteroid strikes have also been released to the scientific community.[243] Unfortunately, it typically takes several weeks for this data to be released. In an emergency, this would be far too late.

One option under consideration is for the DoD to assume the role of collecting available data and assessing what, if any, threat might exist from possible NEO collisions of all sizes. DoD has already studied what a military-based NEO warning center might look like through adding people (fewer than 10) to current early warning centers and support staffs within Cheyenne Mountain to form the basis of a Natural Impact Warning Clearinghouse.[244] While DoD has been asked to assist NEO search efforts, the DoD has not been assigned tasks, nor has any item relating to NEOs been included in military operational requirements.[245] This does not mean other groups, in particular the international scientific community, should not continue their independent efforts.[246] Such an activity from the DoD would seem to overlap, if not duplicate, the work of the International Astronomical Union (IAU) Minor Planet Center (MPC), JPL NEO, and University of Pisa NEODyS program, which among themselves have almost 10 full-time employees. NEODyS and the JPL NEO Program currently watch hundreds of NEOs and the under-funded IAU MPC is already on overload from keeping track of 50,000 fully cataloged comets and asteroids, plus several hundred thousand partially cataloged objects.[247] Beyond consistent funding, it is unclear what a United States based military program would accomplish in this area that is not already being done.

Air Force officials indicate that senior decision-makers do not consider the finite probability of future impact events as a threat that warrants funding.[248] Consequently, the senior official at the Planetary Sciences Office and program managers at the Air Force Office of Scientific Research (AFOSR) stated that senior management within their organizations wished to move away from the phrase "NEO threat."[249] Thus, Air Force NEO programs are not justified based on a NEO-Earth impact threat, but are rather justified on obtaining better broad-based and deep space situational awareness capabilities to detect, identify and track unnatural, possibly hostile space objects, such as adversaries' potential "super black" systems in space.[250]

United Nations and Multi-national Perspectives

Over 320 different observatories located in some 35 different countries are involved in making astrometric observations of NEOs.[251] More than 70 percent of them are owned and operated by amateur astronomers with fourteen of these observing programs [Figure 8] being collectively responsible for around 88 percent of observations[252] and NEO discoveries. [Figure 9] This section will examine some of the international NEO work currently underway as well as multinational perspectives on disaster management.

| Program | Number | Telescope | P.I. |
|---|---|---|---|
| LINEAR | 725 277 | 1.0-m GEODSS | G. H. Stokes |
| Spacewatch | 126 143 | 0.91-m reflector | R. S. McMillan |
| LONEOS | 103 493 | 0.59-m Schmidt | E. L. G. Bowell |
| NEAT | 43 333 | 1.0-m GEODSS | E. F. Helin |
| Xinglong | 35 240 | 0.60-m Schmidt | J. Zhu |
| ESO | 33 744 | 1.0-m Schmidt | E. W. Elst, C.-I. Lagerkvist |
| ODAS | 27 742 | 0.90-m Schmidt | A. Maury, G. Hahn |
| Klet | 19 764 | 0.57-m reflector | J. Tichá |
| Catalina | 17 792 | 0.41-m Schmidt | S. M. Larson |
| Oizumi | 13 929 | 0.25-m reflector | T. Kobayashi |
| Visnjan | 13 295 | 0.41-m reflector | K. Korlevic |
| Ondrejov | 10 300 | 0.65-m reflector | P. Pravec |
| Woomera | 8 843 | 0.30-m reflector | F. B. Zoltowski |
| Prescott | 7 659 | 0.46-m reflector | P. Comba |

**Figure 8: Leading Observing Programs**[253]

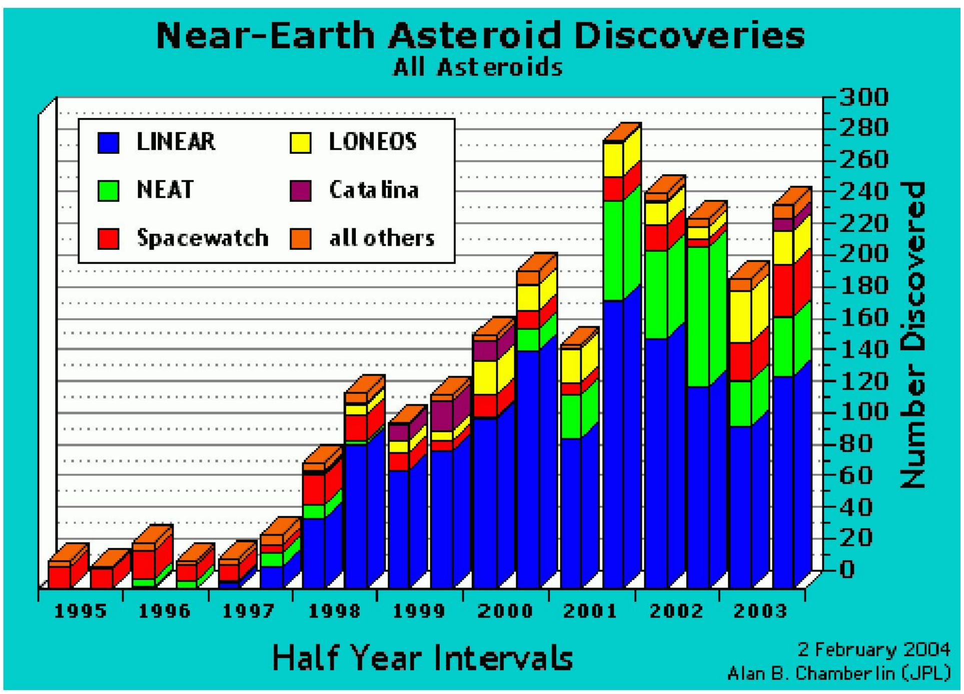


**Figure 9: NEA's Discovered by Site**[254]

**International Astronomical Union / Minor Planet Center**

The Minor Planet Center (MPC) operates at the Smithsonian Astrophysical Observatory (SAO), under the auspices of Division III (Commission 20) of the International Astronomical Union (IAU). The MPC is responsible for the collection, verification and dissemination of astrometric observations and orbits for minor planets and comets, via the *Minor Planet Circulars* (issued monthly) and the *Minor Planet Electronic Circulars* (issued as necessary).[255] The MPC is perhaps the closest thing to an internationally accepted clearinghouse for NEO information. The MPC is a nonprofit organization, with principal funding coming from subscriptions to various services, as well as support from NASA and SAO.[256] However, funding for the MPC has regularly been reduced and subscription rates for MPC services are down with the availability of electronic data. Discoveries are far outpacing the ability for data to be processed in a single location (at current funding levels) causing the MPC to often become "overwhelmed."[257] While some have called for a distribution of responsibility between different NEO centers, others believe that since the MPC already has the expertise, links and credibility, distributing the data collection and dissemination process would only produce practical and organizational complications.[258] NEO Discovery rates are unlikely to fall in the near-term. An official international clearinghouse for data (for observers) would reduce confusion, conserve resources and reduce duplication of effort. The innate uncertainty attached to early NEO discoveries makes this information nearly useless to media and the general public and should perhaps be limited to registered observation programs. (who would be free to contact the media individually, if desired, to eliminate any calls of 'cover-up' while retaining the integrity and respectability of the source)

**Spaceguard UK**

Spaceguard UK was established in early 1997 to pursue the following aims:

1. To promote and encourage British activities involving discovery and follow-up observations of NEOs.
2. To promote the study of the physical and dynamic properties of asteroids and comets, with particular emphasis on NEOs.
3. To promote the establishment of an international, ground based surveillance network (the Spaceguard Project) for the discovery, observation, and follow-up study of NEOs.
4. To provide a national United Kingdom information service to raise public awareness of the NEO threat, and technology available to predict and avoid dangerous impacts.[259]

A number of well-publicized meetings have been precipitated by the activities of Spaceguard UK, taking the subject of Planetary Defense from the realm of a handful of experts to the corridors of the House of Commons and the British media. Spaceguard UK is acknowledged as the prime UK non-governmental organization concerned with Planetary Defense and the impact.[260] The 2000 report of the British government's Task Force on Potentially Hazardous Near Earth Objects was published in September 2000 and makes 14 recommendations for government action and all recommendations were accepted by the minister, Lord Sainsbury.[261] However, the Under Secretary of State for science and technology decided in 2000 that the United Kingdom will not fund additional studies into the threat from NEOs or planetary defense matters over and above the UK national contribution to ESA.[262] On 11 September 2003 Lord Sainsbury announced in the House of Lords that all 14 recommendations had been implemented. In reality, nine of the recommendations have not seen any action at all and only one has actually been implemented.[263] Several ministers' comments have suggested that it is unlikely that the situation will change in the near future.

**Russia**

Russian NEO search efforts are hampered by a severe lack of funding, a lag in technology and limited interaction and peer review with the outside community. Consequently, Russian NEO research has focused on short-term practical responses using available technology in the event of a confirmed incoming. At the 1996 Space Protection of the Earth Conference, held in Snezhinsk (Chelyabinsk-70), Russia, representatives of Russian aerospace industry (Lavochkin, Khrunichev, and Makeyav) described comprehensive proposals to deal with the impact hazard, collectively called "Space Shield."[264] These proposals were exclusively designed for the short-range interception of incoming NEOs and advocated development of a space-based optical detection system with a range of 10-20 million kilometers to provide 4-7 days warning, coupled with multi-layered space-launched and ground-based interceptor missiles with kinetic-energy or nuclear warheads.[265] David Morrison, the only United States scientist to attend, stated that these proposals implicitly or explicitly the basics of NEO defense: the importance of carrying out a Spaceguard type search, the advantages of ground-based over space-based searches, the expectation of long warning times, the advantages of intercepting at very great range from the Earth, the advantages of deflection over disruption, the dangers of maintaining a large fleet of rocket interceptors on the pad, etc.[266]

In the event that any of these “basics of NEO defense” turn out to not apply to an incoming NEO, it might be comforting to have another option. Vadim Simonenko, deputy head of the Russian Institute of Technical Physics, addressed this saying, “We have a completely different attitude in this country to the impacts of Tunguska class bodies. Such an impact (in a populated area) would be an awful event. To prevent this, it is necessary to develop short-time-observation ability and an alert system (more probably with space-based telescopes and radio telescopes) and to develop an in space ready-for-interception system capable of dispersing similar small bodies."[267] Unfortunately, this type of planetary defense system could not only be used for NEO defense, but also as a military weapon capable of causing the destruction of entire countries and regions.[268] In fact, statistically, it is more likely to do so.[269]

**United Nations (UN) and Disaster Risk Reduction**

While limited tangible progress has been made, the international nature of the NEO hazard has been recognized politically. A December 03, 2003 General Assembly document stated that the almost complete lack of defined governmental responsibilities and the complete lack of coordination of policies at the international level is counterproductive to the goal of finding a rational response for the potential NEO threat.[270] To help remedy this, the UN has held a series of international workshops encouraging scientific cooperation facilitated by the International Council for Science (ICSU) and the IAU to be complemented by parallel policy cooperation through the UN Organization for Economic Cooperation and Development.[271] Ultimately, however, the UN has taken the position that international cooperation on the NEO hazard is constrained without improved coordination at the national and regional levels.[272]

Through the efforts of the United Nations system, disaster risk reduction has become a growing issue of policy concern and, as in the United States, the focus leans towards the social rather than technical aspects of risk reduction. The multi-hazard Disaster Risk Reduction *Mainstreaming Framework* was created through the United Nations as a functional way to build collaboration between stakeholders in order to reduce the impact of natural disasters by integrating disaster risk reduction measures into development policies.[273] While recognizing the need for technical and scientifically-based approaches to risk reduction often associated with the natural hazards discipline, this framework lays responsibility for reducing the impact of disasters on policy-makers, communities, non-governmental organizations, and the private sector and designed as a measurement tool for establishing political commitment and community participation around disaster risk reduction, and as an aid to strategic planning.[274] Like risk, the capacity to mitigate is socially structured. Vulnerability and mitigation are two sides of the same coin. Disaster losses are a function of the ability to mitigate, and conversely, failure to mitigate means that sooner or later losses that could have been avoided will occur.[275] This is true of all nations with respect to the asteroid hazard, however, since asteroids are non-discriminatory in choosing a target, it is important to consider the coping capacity of developing nations. A country, such as Bangladesh, has lost more lives in a single major catastrophe, a typhoon, than many European societies have experienced in their entire histories.[276] However, mitigation efforts (such as building reinforcement, the building of dikes, etc.) are expensive endeavors. In developing countries, the process has been reinforced by recognition that national development can be seriously hindered by a major disaster. In some cases, the material losses can be up to five or more percent of the yearly gross national product.[277] The effects of a NEO impact in a developing nation would be catastrophic and potentially unrecoverable. Currently, even issuing impact warnings in the developing world would be difficult if not impossible.[278]

# PART III - Options and Conclusions

*"Earth's history is filled with unanticipated catastrophes and their disastrous consequences. With appropriate planning, the human toll could be lessened."* [279]

*Three Mitigation Modes*

One day a NEO will impact a populated area. Without the ability to destroy or otherwise redirect an incoming impacting body, it is certain to happen – it is just a matter of time. Consequently, while rare, NEOs are a legitimate addition to the list of possible civil disasters.[280] The paramount issue in a hazard management strategy is the prevention of loss of life. Early detection and characterization (of structure, spin, composition, etc) of potentially hazardous NEOs is an important first step to quantify the risk Earth faces. However, if an impact occurs, plans must exist to minimize the mortality and economic destruction and, in extreme cases, to preserve civilization and the human species. While this generation may not face an incoming threat, there are things that can be done today to help insure a safer tomorrow.

Mitigation of the NEO impact hazard can take three forms. The preferred but most technically challenging (and expensive) option is to develop a means to deflect the threatening NEO, changing its orbit so that it will miss Earth.[281] Alternatively, we can continue to search the skies to find any possible hazardous NEOs, determine their compositions, structures and orbits and prepare the public (through education, warning systems, etc) as well as possible. Least desirable, but perhaps most likely, would be to hope for the best and deal with the aftermath of an impact should one occur in the same way we recover from earthquakes or other natural disasters.[282] At minimum, a chain of command and responsibility should be established that uses, where possible, existent governmental resources and experience while reducing duplication of effort.

*Six Steps Towards a Safer Future*

At the 2004 AIAA Planetary Defense Conference, a position paper was drafted that recommended six steps that can be accomplished today, at minimal expense, to improve the current situation.[283] Each of these steps will be examined and expanded upon below.

> 1. **Find (or create) an organizational/governmental home within the United States government for the planetary defense issue.** This interagency office should establish a formal protocol for disseminating information regarding NEOs when the probability of impacting Earth exceeds specified thresholds.[284]

This point was addressed in Morrison et al. "Dealing With The Impact Hazard" that explained planning for adaptation entails establishing a chain of responsibility prior to the materialization of an emergency.[285] In it, a hypothetical NEO emergency organizational plan, using the United States government, was used as an example. In the executive branch, the National Science and Technology Council (NSTC) (part of the White House Office of Science and Technology Policy) seems to have natural purview over the impact hazard.[286] The NSTC is tasked with establishing clear national goals for Federal science and technology investments and preparing research and development strategies that are coordinated across Federal agencies.[287] The formal assignment of the NEO impact hazard to an NSTC committee would be accomplished by drafting a Presidential Decision Directive (PDD/NSTC) or Presidential Review Directive (PRD/NSTC) and little else would need to be done until there is confirmed warning of a threat.[288] In the unlikely event of a short lead-time NEO Threat, the PDD can be issued as a joint National Security Council NSC/NSTC document, for which there is precedent in the National

Space Policy of September 19, 1996 (PDD/NSTC 8 and PDD/NSC 49).[289] By simply preparing the documents that establish the organizational chain of command and assign responsibilities for response and/or recovery tasks, there would be far less confusion in the event of an actual NEO disaster.

2. **Extend the *Spaceguard Survey,* currently focused on finding and cataloging 1-km-class objects and larger, to include finding and cataloging 100-m-class NEOs and larger.** These smaller objects pose a significant portion of the impact hazard. This task can be accomplished by relatively inexpensive telescopic and/or spacecraft systems; however, a substantial increase in the funding base beyond the current level of NASA funding (~$4.0 million per year) is required. This funding must be maintained into the future to watch for long-period comets and rogue asteroids. [290]

This point is covered in detail in the 2003 NASA "Study to Determine the Feasibility of Extending the Search for NEOs to Smaller Limiting Diameters."[291] Results of that study show that extending the survey is both technically feasible and financially worthwhile through a cost/benefit analysis. According to their cost/benefit assessment, the benefits associated with eliminating these risks justify substantial investment in PHA search and mitigation systems.[292] Importantly, to actually reduce the risk of PHA damage, investments must also be made in mitigation system research and field-testing. Without the proven ability to deflect, destroy, divert or otherwise protect the Earth's surface from an impact, all an enhanced search system is accomplishing is better quantifying the existent risk. Plans are already on the drawing board for the Large-aperture Synoptic Survey Telescope (LSST), a dedicated, large telescope 20 feet [6.9 meters] across, with a wide field, that would able to survey the entire night sky every few weeks. The LSST would be able to detect NEOs down to 300 meters in size, as well as potentially find 100,000 supernova and Kuiper Belt objects all at a cost of $125-150 million. [293]

3. **Conduct mission design studies and flight tests to characterize requirements for short-, medium-, and long-range missions to eventually demonstrate the ability to move an asteroid.** These studies would compare current capabilities with mission requirements and help to identify and prioritize technology research and development goals.[294]

As stated before, simply discovering the orbits of existing NEOs does little to reduce but quantify the existent risk for Earth. Without the ability to move and/or deflect a NEO, simple knowledge of its ephemeris does little more that provide a timeline for the implementation of other "on the ground" mitigation options or the preparation of relief efforts. It is important that mission design studies include an examination of political and policy-level decisions and decision timelines for various deflection scenarios (short-term, long-term, nuclear, non-nuclear), potential public and government concerns and responses to a potential threat and subsequent deflection effort, and management of a deflection effort in the face of public expectations and uncertainty.[295]

4. **Develop and fund ground-based techniques (including planetary radar) as well as missions to several asteroids to gather information that contributes to designing deflection missions.** Critical information includes object sizes and dynamics, object types (e.g., binary), characteristics of surface and sub-surface materials, responses to explosive forces, and characteristics relating to attaching a spacecraft or other large structures to NEOs. [296]

While finding and tracking orbits is the necessary first step, no mitigation strategies can be developed without compositional and structural knowledge of the specific body. (A solid iron body would need to be handled far differently than a rubble pile of chondritic material) While funding a space mission to every NEO is cost prohibitive, compositional information is also obtainable through ground based VNIR spectroscopy. Funding should be made available to at least characterize those objects listed as potentially hazardous.

5. **Increase public awareness of and appreciation for the NEO threat. Bring evidence of previous NEO impacts to the attention of the public to increase awareness that impacts do happen and that the possibility of future impacts should not be ignored.** Build public and political support for increased funding for planetary defense related research of the type recommended above.[297]

As discussed previously, public perception of risk is not based on facts or statistics, but rather by an emotional response to a perceived hazard. Overall, two specific factors were noted: First, accurate public education about the asteroid hazard is nearly non-existent. Pseudo-scientific portrayals of the asteroid hazard through Hollywood and even less reputable sources have lead to confusion and perpetuated the "giggle factor." Second, faced with repeated false alarms and inaccurate news reporting (to the fault of both the scientists and the media) has created a "yawn factor" and lulled the public into a false sense of security. In the event of a crisis, no single credible source for public information exists and there are no guidelines or restrictions governing the reporting of NEO information. Increasing awareness will only be successful if coupled with an education campaign designed to dispel myths and provide information in a consistent, clear, and uniform way. In the event of an impact, this will be even more important for disaster warning and recovery efforts.

6. **Include NEO impacts as possible disaster scenarios for disaster recovery and relief agencies.** Assess what lessons can be learned

> from major disasters that would apply to NEO impact disasters to help disaster relief agencies develop responses to possible emergencies of this type. [298]

To date, the NEO community has not made much effort to enter into dialogue with government agencies that deal with security and recovery issues. [299] The NEO science community needs consider the societal context of NEO searches and mitigation as ultimately, these other considerations play a critical role in determining what priority will be placed on protecting our planet from cosmic impacts.[300] Determining the compositional history of the solar system, while important and interesting, is unlikely to warrant the same level of funding as a project described as one that will save lives.

Additionally, the NEO community should engage other professionals with greater experience in disaster mitigation and national security. Technology and experience gained in other large-scale disasters will most likely form the foundation of how these impact events will be managed and classified. Given the size and energy of the projectile, the estimated area of damage, and whether impact effects might be localized or global in nature, relief agencies can begin to build basic disaster response scenarios, anticipate public health concerns, and formulate questions today rather than during the crisis itself. Planning and preparedness for one disaster may have unforeseen beneficial effects for another. This idea is not new as similar coordinated preparations are underway to deal with the possibility of a terrorist attack. Studies have identified a number of areas that can be enhanced by decades of research in traditional disaster areas[301] such as wildfires, arson, accidental explosions and bombs, floods and dam sabotage, chemical spills and chemical attacks, epidemics, etc.[302] Using many of the same analogues, asteroid preparation and mitigation efforts could be significantly advanced and integrated into current disaster management schemes.

From a disaster preparation standpoint, there are many specific questions that must be assigned to and resolved by relevant agencies. These are well described in a Garshnek et.al. article in *Space Policy* and summarized below:

**Evacuation plans**: evacuation of the immediate impact area and regions of danger around Ground Zero will be of critical importance. This activity may be as large and as complex as evacuation of an entire continent. Which nations will open their doors? How much time is needed to carry this out? What authorities will make these decisions? What national/international policies would need to be in place? [303]

**Water insecurities**: Wells and water pipes will most likely be damaged in areas affected by impact shock. Re-digging wells and surveys of water quality and quantity will need to be done. Surface water, rivers, streams will most likely be contaminated (therefore uncontaminated ground water must be reached). Who will do this and how will it happen?[304]

**Food stores and food production capabilities**: If an impact causing a catastrophe of global proportions threatens the world food supply, the following questions would need to be answered: What types of food should be stored? How much food? Where should it be stored? Who would be the authority ensuring the population receives the food it needs? If we are threatened with an "impact winter" and cannot grow food naturally on the surface, what types of artificial means might be employed to produce food in enclosed spaces? Do we currently have the adequate technology to grow food this way or do we need to expand development of this capability? Could we do this on a large scale if necessary?[305]

**Public education and the media**: What role can the media play in educating the public as to what to expect should a large impact event be foreseen? How should the media work with scientists, civil defense coordinators, government, etc. to work with the public and assist them in preparing to survive?[306] How do we get the public to discern important factual information and react appropriately? How can communication between scientists and media be improved to increase public credibility?

**International cooperation**: International cooperation, coordination, and consistent involvement will play a key role. If a nation or even an entire continent is to be evacuated, how can other nations prepare to help accommodate displaced persons and populations? How will these displaced people be fed, sheltered, and medically cared for? What policies would need to be in place to ensure mobilization of international assistance for such a unique event?[307] How would such things be funded? Who will provide security?

**Tsunami preparedness**: With the impact tsunami hazard in mind, what steps can be taken in the pre-disaster phase to diminish the consequences of an impact generated tsunami?[308]

**Survival technologies**: What types of technologies could assist the affected populations in surviving an impact disaster? For example:

- How robust are our global satellite communications technologies? In which impact scenarios will they not be operational? How might they be used to communicate essential public information to individuals as well as serve central command and control centers? Do we have contingency plans in place to ensure communication satellite operations during local and global impact disasters?
- How reliable will our energy sources be during local or global impact disasters? In which scenarios will hydroelectric power, nuclear power, solar energy, and fossil fuel work well? In which scenarios will these energy sources become non-operational? What sources of power might be useful during impact winter and can we produce them on a large enough scale to accommodate energy needs?[309]
- Do we have technologies in place, or can we develop technologies that can mitigate the effects of wide-spread acid rain, water acidification, or counter the source of impact winter (i.e. shorten impact winter by ridding the atmosphere of suspended particulate matter)?[310]

These are but a few examples of the types of disaster management preparation that would benefit from proactive policy development and funding to ensure the best possible outcomes rather than rely on an ad hoc development scheme that will inevitably be fraught with holes, inefficiency, and problems that could have been avoided.

Rocks from space hit Earth all the time and some, if the size, speed and angle are just right, pass through the atmosphere and hit the ground. This has always happened and it always will. It is only a matter of time before one makes it through to impact or explode near a populated area. Even the smallest of these is capable of the devastation caused by the Hiroshima atomic bomb; the biggest could kill every living thing on the entire planet. While search programs continue to find the large PHAs, smaller (statistically more likely) objects are likely to arrive and impact with little or no warning and when this happens, it will be an unparalleled disaster relief effort. Researchers and the media have a poor relationship that has exacerbated public confusion regarding the hazard, reduced the credibility of both and created a political “giggle factor” that makes NEO projects difficult to fund. This is mainly the result of insufficient or non-existent protocols. Further, in the event of an actual emergency, there are no plans, no chain of command and no assigned responsibilities. Admittedly, the odds of an impact in any given generation are small. Politicians can do nothing and be reasonably assured that they will not be remembered by history for negligent inaction that lead to the death of millions. Then again, by implementing the six steps listed above (many of which can be started with resources that already exist), they will be starting a process that will endure into the future and ultimately save lives and perhaps, one day, the planet.

# Appendix A – The Richter and Mercelli Earthquake Scales

## The Richter Scale

| Magnitude | Earthquake Effects | Estimated Number Each Year |
|---|---|---|
| 2.5 or less | Usually not felt, but can be recorded by seismograph. | 900,000 |
| 2.5 to 5.4 | Often felt, but only causes minor damage. | 30,000 |
| 5.5 to 6.0 | Slight damage to buildings and other structures. | 500 |
| 6.1 to 6.9 | May cause a lot of damage in very populated areas. | 100 |
| 7.0 to 7.9 | Major earthquake. Serious damage. | 20 |
| 8.0 or greater | Great earthquake. Can totally destroy communities near the epicenter. | One every 5 to 10 years |

## Modified Mercalli Intensity Scale

| Mercalli Intensity (at epicenter) | Magnitude | Witness Observations |
|---|---|---|
| I | 1 to 2 | Felt by very few people; barely noticeable. |
| II | 2 to 3 | Felt by a few people, especially on upper floors. |
| III | 3 to 4 | Noticeable indoors, especially on upperfloors, but may not be recognized as an earthquake. |
| IV | 4 | Felt by many indoors, few outdoors. May feel like heavy truck passing by. |
| V | 4 to 5 | Felt by almost everyone, some people awakened. Small objects moved. Trees and poles may shake. |
| VI | 5 to 6 | Felt by everyone. Difficult to stand. Some heavy furniture moved, some plaster falls. Chimneys may be slightly damaged. |
| VII | 6 | Slight to moderate damage in well built, ordinary structures. Considerable damage to poorly built structures. Some walls may fall. |
| VIII | 6 to 7 | Little damage in specially built structures. Considerable damage to ordinary buildings, severe damage to poorly built structures. Some walls collapse. |
| IX | 7 | Considerable damage to specially built structures, buildings shifted off foundations. Ground cracked noticeably. Wholesale destruction. Landslides. |
| X | 7 to 8 | Most masonry and frame structures and their foundations destroyed. Ground badly cracked. Landslides. Wholesale destruction. |
| XI | 8 | Total damage. Few, if any, structures standing. Bridges destroyed. Wide cracks in ground. Waves seen on ground. |
| XII | 8 or greater | Total damage. Waves seen on ground. Objects thrown up into air. |

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