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NEO IMPACT SCENARIOS

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ABSTRACT

Several of this Conference's baseline scenarios involve NEOs, with specified physical characteristics, predicted to strike Earth at a specified future time. They offer opportunities for aerospace engineers to design successful deflection missions to very specific constraints. These scenarios serve as the foundation for some of this conference's papers.

Here I step back and examine a broader range of implications of these scenarios; I also describe some different, but plausible or even much more likely, scenarios that astronomers, engineers, policy makers, and public officials should be prepared to deal with. The impact hazard so far has been essentially theoretical, with no consequential physical impacts (except for fireballs, meteorites, and, of course, Tunguska) during the 20th century. The same will likely be true for this century. But the impact threat is not, therefore, only a very low-probability or far-distant-future issue; it has ongoing practical implications.

To prepare for the unlikely discovery of an actual threatening NEO, the purpose of Spaceguard and the raison d'etre for designing mitigation, the world's "sentry" system must be reliably prepared to deal with events that are unexpected, indeed unprecedented. In particular, astronomical observing techniques, reporting procedures, the sifting of data and posting of ephemerides by the Minor Planet Center (MPC), the independent calculations of impact probabilities by Sentry and NEODys, and the process of public announcement of a potential impact...all must avoid missing the very unlikely signal, should one manifest itself. Yet the chance of an unprecedented real event happening is much smaller than that an error has occurred. So very careful judgements must be made, and quickly. For even though a predicted impact is likely to be decades away, rapid, reliable decisions are required to follow-up an NEO while it is still near the Earth, and to provide the fast-paced news media with accurate information to avoid hype.

Some impact scenarios have substantial implications for the further design and operation of detection and warning systems as well as for disaster planners and crisis mitigation. For instance, if a real impact were predicted, plans for evacuating ground zero might be needed, even as efforts to divert the NEO were underway.

One scenario actually played out just last month (13-14 January 2004). For nine hours, experts felt there was a credible chance (perhaps 1% to 25%) that a mini-Tunguska (or even Tunguska-scale) impact might occur the very next evening (just after President Bush's space policy speech), or at least during the next few days. The real object (much larger and farther away) missed the Earth by millions of km several weeks later. But the MPC posted on its Confirmation Page a nominal orbit, fitting undersampled LINEAR data, that actually impacted the Earth. Six hours later, some experts still thought that it might hit. Finally, amateur astronomer Brian Warner, with clear skies, found that the "virtual impactor" did not exist, so impact was ruled out. Had he been clouded out, when should a report have gone out, and with what consequences?

INTRODUCTION

Asteroid impacts into our planet are, fortunately, very rare. As a result, however, we lack previous experience in dealing with this threat. We must think in abstract terms about how to address any of the wide range of possible contingencies. Much of the advance planning being reported at this conference concerns the technical, engineering aspects of how to effectively divert an asteroid from impact, should one ever be found to be on a threatening course. But a full, end-to-end systems approach[1] is necessary to thoroughly evaluate how to move from the initial, necessarily imprecise telescopic observations of a potentially threatening object to the final stages of implementing a deflection mission or, if that is impractical or fails, dealing with the aftermath of a never-before-experienced kind of calamity.

Any asteroid (or cometary) impact scenario involves several crucial phases, long before any overt mitigation is called for. Telescopic identification of a potential impactor and predicting whether and where it might hit is a much more complex process than is generally realized, involving ever-changing estimates of impact probabilities; in unfavorable cases, it could take years between identification of an object and a certain prediction of impact. Concurrent with the astronomical research, appropriate notice must be given to the public and government officials; since they are not well prepared to relate to the kinds of probabilities and uncertainties that are inherent in this topic, and the threatened impact may be very frightening, the communications process requires careful advance planning. Even after an impact is confidently predicted, there are many things that must be done before mankind simply (a) mounts a deflection mission or (b) evacuates ground-zero and takes other on-the-ground disaster mitigation measures. To prepare for a deflection mission, the best possible assessment of the nature of the impacting body -- and its likely physical response to proposed approaches to deflection -- must be made, if time is available (see papers in the abstracts and book emanating from the September 2002 Workshop on Scientific Requirements for Mitigation of Hazardous Comets and Asteroids[2,3]). To prepare for on-the-ground mitigation, better understanding of the location of impact and probable direct destruction and environmental consequences[4] will have to be achieved than we can confidently calculate today. In short, a lot of scientific research will be needed. There are other, less concrete attributes of a never-before-experienced impact that are wholly unique to this hazard involving psychology, sociology, and international politics. For instance, people will respond psychologically in unexpected ways to this unique threatened (or actual) disaster, so traditional on-the-ground measures taken toward disaster mitigation or after-the-fact relief must be modified or augmented to address such differences.

My purpose here is not to treat thoroughly all of these intermediate steps and associated issues. I wish to emphasize some elements of impact scenarios that have been thought about less than others, but which deserve serious attention. In particular, I address auxiliary issues related to the four Defined Threat (DEFT) scenarios[5] that were prepared to focus thinking and research in advance of this conference. And I will discuss what are certainly the most likely impact scenarios -- not represented by any DEFT scenario -- to be faced by the public, government officials, and the scientific community: various near-term crises, occasioned by most-probably mistaken or hyped reports of predicted impacts or "near misses" by small asteroids[6,7]. As it happens, we have a particularly cogent example, which took place out of the public limelight just last month, but -- in some ways -- seemed for a few hours, to some of the world's Near Earth Asteroid (NEA) experts, to be the most significant potential impact possibility ever identified by the Spaceguard Survey. The potential impact, with an estimated probability as high as 25% of happening within the ensuing few days, did not happen, of course. But the event illustrates the kinds of issues that may well confront us again in the near future.

AUXILIARY ISSUES CONCERNING THE DEFT SCENARIOS

Of the four scenarios offered for analysis prior to this conference, one (Aramis) attempts to simulate an aspect likely to pertain to almost any impact scenario -- changing (generally improving) knowledge about the impacting body and the circumstances of impact with time. In this hypothetical case, knowledge is sporadically improved -- from groundbased observations -- over a seven-year period after discovery. It is then anticipated that a precursor space mission would be launched to better define the nature of the body, well before the predicted impact, which is specified as occurring about 27 years after discovery of the body in photographic images obtained years earlier. In this case, the body is initially estimated to be 1.5 km in diameter, and thus is large enough to threaten civilization. Beyond the physical science and engineering issues, which are modeled in the scenario or which are to be examined based on the scenario, there are many pertinent issues involving public notification, development of an international response to the threat, and so on.

For instance, recent experience with impact scares[8] already reveals banner-headline treatment of predictions of even *very small* chances of a decades-hence impact by a body this size. In this scenario, it is artificially specified that the impact location (Indian Ocean) is approximately known within weeks of the discovery, but this is extremely unlikely. Whether discovery of a potentially hazardous NEA is through the protocol of the Spaceguard Survey, or in this irregular (but possible) fashion through examination of older photographic plates, a major issue concerns *who* will inform *what* officials and news media about the impact threat? At the moment, there still exists only a few disconnected elements of what should become established protocol for handling such a case. The International Astronomical Union (IAU) has a procedure for rapidly verifying the legitimacy of an impact prediction, but there is no official *receiver* of such a prediction, either in the United States or internationally. NASA's Near Earth Object (NEO) Program Office at the Jet Propulsion Laboratory (JPL), as one of the IAU prediction checkers, would be obligated to inform appropriate officials in the Office of Space Science at NASA Headquarters. But how such information gets disseminated among potentially relevant agencies (the White House, National Security Agency, Dept. of Homeland Security, Federal Emergency Management Agency, the Dept. of Defense, etc.) has never been specified[1]. The same lack of planning for such a contingency pertains to other nations and to the United Nations.

One can anticipate, during the period of months and years during which the rather sparse and noisy astronomical data about the object begin to crystallize, that there will be technical arguments about what is really known about the object and political arguments about what should be done about it. It might stabilize such disputes to have anticipated their nature and thought about procedures for resolving them. No doubt, the world's full arsenal of astronomical capabilities would be devoted to learning more about the object and it is plausible to imagine that a precursor mission to investigate the body might be launched very quickly. So the timeline for learning about the body might be compressed compared with the Aramis scenario. But, perhaps enhanced by widespread anxiety about the threat, serious issues could arise even during this reconnaissance phase, long before any explicit mitigation activity were initiated. For instance, how could the nation or nations implementing the precursor space mission convince doubters that the mission would not modify the trajectory of the asteroid in some fashion that would move the ground-zero point closer to another nation? Schweickart[9] has addressed an analogous issue that arises during any low-thrust deflection operation.

One can imagine that much more serious issues may arise during the design and execution of a deflection mission. They might even shape the nature of such a mission as strongly as engineering considerations. In a climate of fear, one might expect major international concerns, for example, about the use of nuclear power or indeed nuclear weapons in a deflection mission. Depending upon how long in advance a deflection scenario happens, there may need to be concurrent development of preparation for an impact disaster, which would be of a wholly unprecedented scale. For instance, with a worldwide climate disaster the most probable environmental outcome that would cause mass casualties[4,10], how many years before impact should measures commence to store up food supplies in order to protect against a failure of the deflection mission? In other DEFT scenarios (e.g. D'Artagnan and especially Porthos), the possibilities for successful deflection are compromised by the short warning time, and even more weight must be given to planning for mass evacuations and other steps to mitigate casualties, as well as for post-disaster relief efforts. Although such issues have been considered[11], much more advance consideration is warranted, given the fact that there is absolutely no precedent for a natural disaster with the features of an asteroid/comet impact.

SHORT-TERM IMPACT SCARES: THE CASE OF AL00667

In my OECD case studies report[6], I presented as one of six representative scenarios (Case F) what has already been, and will continue to be, the most likely way in which the impact hazard comes to the attention of the public and public officials. I generically call the case "Prediction (or Media Report) of Near-Term Impact Possibility". As asteroid detection programs improve and "near misses" are more frequently reported, the most likely public manifestation of the impact hazard 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 news media. In general, human foibles are more likely than a rare asteroid impact, but they can have *real* social and political consequences.

Since the infamous case of 1997 XF11 in March 1998[8], there have been more than half-a-dozen other cases of predictions of impact possibilities that have received considerable press attention. Steps have been taken, after most of these events, to correct procedures to lessen chances for future errors, misinterpretations, or misreporting. But nature continues to surprise us and reveal new, unexpected examples of how Spaceguard observations of NEAs can evade our protocols and result in yet another media event. The general point is that we must broaden our horizons about ways in which our data, analyses, and communications might result in cries of "Wolf!" that tend to discredit the public's appreciation of the impact hazard and the Spaceguard Survey. At the same time, we must be very careful that we do not thereby screen out that highly improbable signal of an actual impending impact that is the *raison d'etre* for the whole effort.

Just last month (January 2004) perhaps the most surprising impact prediction ever came and went, this time out of the view of the round-the-clock news media. It illustrates how an impact prediction came very close to having major repercussions, even though -- with hindsight -- nothing was ever, in reality, threatening to impact. It is a story of success in that the impact prediction was nullified in record time, less than half-a-day, but the success was accomplished through a set of *ad hoc*, unofficial, and often unfunded activities and relationships, although assisted in major ways by the official infrastructure, such as it exists (the LINEAR Project, the IAU Minor Planet Center, and the NASA NEO Program Office).

About 36 hours before President Bush's planned speech at NASA Headquarters on future American space policy, the Lincoln Near Earth Asteroid Research (LINEAR) observatories in New Mexico routinely recorded four images of a moving object. Half a day later, on Tuesday, January 13th, these data 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 LINEAR's 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, on the MPC's web site, with no comment at all, was what Harris 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 JPL's Don Yeomans (who heads NASA's NEO Program Office). 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 shortly after the 15 minute telephone call ended; 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 -- 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 what is effectively an 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.

By mid-evening, there was a loose, international network of dozens of amateur and professional asteroid astronomers, and their confidants, trying to get a grip on the situation. They were communicating in diverse one-on-one and multiparty conversations -- in person, over the phone, via email, and on chatroom postings. Harris later estimated that he received over 200 email messages on this topic within just 9 hours. People hastily concocted numerous theories about what might be really happening. Were the data artifacts or a geostationary satellite? Was this a test or a hacker's hoax? With just four LINEAR data points to work with, obtaining a definitive answer was inherently difficult.

Efforts by the MPC to alert potential observers, and discussions on the MPML, were met with reports of cloudy weather throughout most of Europe and the United States. One English amateur astronomer, made aware by the MPML postings, observed the originally predicted position with his telescope around local midnight and reported finding nothing. To experts back in the U.S., however, it wasn't clear how definitive his search had been (his telescope could barely reveal objects as faint as AL00667). Several additional negative reports, of uncertain quality, came in later to the MPC, but most of these were unknown to other asteroid experts working the problem that evening. Finally, much later in the night, the LINEAR observatory itself, through partial clouds, obtained additional images of the wayward asteroid. But they were not analyzed until the following morning, and posted on the MPC website just a few hours before the President was scheduled to speak.

As Tuesday evening progressed, there was a consensus that the situation had to be taken seriously. To be sure, many LINEAR postings, at this unrefined stage of analysis, eventually prove not to be real NEO's (most turn out to be main-belt asteroids) -- but over half *are* real. Several scientists independently calculated that the would-be impactor was big, around 30 m across. I suggested to several colleagues, via email and phone, that even though an impact still seemed improbable, the facts were serious enough to start planning for what an announcement might say if one proved necessary.

Meanwhile, Chesley, an asteroid orbit expert, had begun a hasty but quantitative analysis of the four LINEAR data points. Working with Spahr who ran MPC software Chesley wasn't deeply familiar with, Chesley began calculating a range of possible trajectories. He was aware that the typical uncertainties of LINEAR positional measurements were quite large, owing to the fact that LINEAR's purpose is to discover previously unknown asteroids and their positions just well enough to be followed up by others with equipment better suited to measuring precise positions. He analyzed over 800 slightly different fits to the data, encompassing the likely range of uncertainty. To his astonishment, fully 40% of the test-trajectories were virtual impactors: they impacted the Earth within the next several days. Many of the rest that missed nevertheless passed uncomfortably close to the Earth. Chesley was aware that the data could conceivably be consistent with some very different trajectories, but only if the positions were somehow askew by an unexpectedly large amount. He wrote an ominous message to the same list that Harris had initially notified about the bogey, estimating perhaps a 25% chance of impact by a 30 m body, within the next few days. He expressed confidence that the chances of impact were at least 10%, and that it would occur in the Earth's northern, most populated, hemisphere.

Impact by a 30 m body would be 1 or 2 Megatons, which might be deadly and damaging immediately below the blast, and could conceivably trigger an inappropriate military "response". (If, as was distinctly possible, the asteroid were darker and larger than usual, and/or the effects greater than expected, the force of its impact could even match or exceed the great 15 Mt Tunguska event of 1908.) With hindsight, it was realized that there is little consensus on how much damage a 30 m impactor might cause. A recent report[12] assumes that impacts over land of this magnitude are harmless, whereas several publications[4,6] predict appreciable damage and perhaps some deaths. Perhaps what is most relevant in this story is what we were *thinking* that evening. A mid-evening email from Harris is illustrative: "An airburst that size would cause some ground damage maybe, certainly enough to frighten and maybe injure some folks."

One chance in four?! If Chesley weren't mistaken, there was a fair chance of the largest cosmic impact in a century happening tomorrow night...or at least within the next few days. My general take on the news was that there almost certainly was an error: it is far more likely that somebody had goofed than that nature had truly dealt us such an improbable hand of cards. But the crisis was real and it had to be taken seriously. There were good reasons to announce the threat to responsible officials, and to the public, without delay. Yet there were also good reasons to wait a little longer. We didn't have to wait for long.

At just about the same time that Chesley was sending out his ominous message, Harris received an email message, on a totally different topic, from Brian Warner, an amateur astronomer, with a 20-inch aperture telescope at 7,000 feet on the Palmer Divide, just north of Colorado Springs. Harris and Warner were collaborating on a project to measure lightcurves of small solar system objects. Warner's message to Harris mentioned that he had just gotten some good data on an unusual, faint comet. Harris immediately realized that: (a) Warner is up observing, (b) hence his skies must be clear, (c) he had just observed a comet roughly as bright as the threatening asteroid, and (d) Warner is an exceptionally experienced observer. So Harris thanked him, in a return email message, and then urged him to try to find AL00667. Warner was closing up his telescope, but happened to catch Harris's message before going to bed. Harris in turn asked Chesley to calculate a reasonable boundary for the patch of sky that Warner should search. Chesley encountered obstacles and couldn't provide the information until about 1:20 a.m., but Warner managed a good search anyway. By 1:35 a.m., Warner reported that no object was there. That was good enough for Chesley and Harris who announced "that settles it" and headed off to sleep.

Therefore, instead of waking up to headlines and TV news specials of an asteroid strike about to happen in the next day or two, life went on as usual around the world. The White House issued a press release in advance of the President's talk and later he spoke about his ideas for NASA. Election campaigns and the war in Iraq continued. People went to work or school in cities and towns around the globe. But the heavens remained benevolent. On the MPC web site, the improved -- and vastly changed -- estimates of AL00667's size and trajectory were posted, and it was given an official designation, 2004 AS1, after the following night's confirming observations from the Czech Republic. This much larger, much more distant NEO passed closest to Earth in mid-February, missing it by many millions of km.

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 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? How close did astronomers come to issuing another false alarm, this time with the potential for embarrassing not only NASA but the White House? What things went wrong, and what things went right during the evening of January 13? Finally, what can be learned from the events so that a more reliable treatment and analysis of Spaceguard Survey data can be accomplished next time?

I will not delve into these questions in depth here, although I have submitted a follow-up article for publication elsewhere on such matters. But they are the kind of issues that the NEO hazard community should be evaluating *before* further unanticipated scares happen. Let me note several relevant aspects of this particular event. First, Spaceguard and the existing infrastructure (MPC, IAU Working Group on NEOs, NASA NEO Program Office) were never designed to find small asteroids on their final plunge. In reality, the chances are remote that they will do so. So it makes no sense, at least until a system like that recommended by the NEO Science Definition Team[12] is operational, to beef up procedures for handling such situations. Yet this recent event illustrates that there must be advance planning of protocols to handle situations beyond the nominal scope of Spaceguard. It is just not acceptable to ignore the implications of data that experts judge to be genuinely threatening, even if -- in some "meta" or Bayesian sense -- one could judge that the impact was far less probable than Chesley's analysis was suggesting.

In fact, the LINEAR data were *not* erroneous. Due to unlucky attributes of the scant data and the resulting fits to the data by standard orbit-fitting algorithms, the probability was indeed appreciable that an impact would happen. In this case, the much more probable reality -- that the asteroid was much farther away -- happened to fall in the wings of the errors. With hindsight, one can see that the residuals for the Earth-impacting trajectory were actually considerably smaller than the typical uncertainties of LINEAR data, and that could have been an early clue that the fit was artificially forcing AL00667 closer to the Earth than it really was. As it turned out, the LINEAR data were actually noisier than normal for this object, due to poor conditions and the object's faintness. So the evening's excitement was not the result of some simple, technical mistake. Instead, it illustrates a generic problem associated with trying to understand noisy, undersampled positional data taken over a short duration in time -- typical attributes of preliminary data on new NEAs.

Many communications links were broken. Indeed, they had never been set up. Most communications the evening of January 13th were informal ones among *ad hoc* groups of people. While speedy treatment of NEA observations is important, both to inform observers so they can make follow-up observations and to prevent media hype while uncertainties remain, it was never contemplated that there might be any practical situation involving a very near-term impact. The MPC is not staffed 7 days a week, or 24 hours a day. If AL00667 had happened on a weekend, or even just later that night, many asteroid experts would not have been readily available. IAU procedures are not designed to provide reliable checking of predictions in such a short time. Much information that could have been analyzed or considered by other asteroid experts (e.g. the one-night-stand positions, or notices received of negative observations of the virtual impactor patch of sky) simply remained in the MPC and was not available. NEO Program Office staffers very plausibly had an obligation to inform NASA Headquarters about the prospects, even though they knew they had only partial information; and NASA might have notified the White House, under the circumstances. But although Yeomans had the home telephone number of the cognizant NASA Headquarters official, no pre-planned criteria existed to specify under what circumstances notification should be made. Had Brian Warner's skies been cloudy, several of us would have urged that a public announcement be issued later that night or first thing the next morning (we were unaware that the MPC had solid negative observations, if in fact the negative observations were reliable). But there was a potential lose-lose situation: the NEO community would certainly have been criticized for raising an alarm when the asteroid failed to hit, yet failure to announce the impact possibility, followed by an actual impact, would have been scandalous. We should understand such trade-offs in advance, and not try to analyze them late at night in a crisis atmosphere.

There will never be another event exactly like AL00667. Nor just like 1997 XF11, nor any of the other scares or media events during the last few years. But there will be more surprises, and lessons can be learned if people try to empathize with the players, and the incomplete and changing state of information they faced, as the evening of January 13th progressed. An inherent attribute of the NEO hazard is that many of its aspects are like a very fuzzy picture very slowly coming into focus. Decisions must be made, and actions taken, before the picture is sharp. Since nature, fortunately, gives us few chances to practice handling asteroid impacts, it is important that we begin to deliberately plan for the wide variety of scenarios, one of which might some day suddenly become manifest.

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