THE ASTEROID/COMET IMPACT HAZARD

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Abstract

An impact by an asteroid or comet larger than 1 km in diameter (30,000 Megaton energy) occurs about every 100,000 years, or 1 chance in a thousand per century. Objects of this size could cause serious regional disasters (e.g. tsunami) and objects only slightly larger would have global environmental consequences (e.g. severe ozone loss, injections of water and dust into the stratosphere, wildfires) that might threaten the future of civilization as we know it. (Smaller impacts can create damage similar to other major natural disasters, but they probably account for <0.1% of such disasters.) This "impact threat" was virtually unknown until the past two decades.

This Case Study reviews the history of how this "new" hazard came to be "discovered" by the scientific community and about how knowledge of the hazard has spread to the general public in the last few years. I also review the modest efforts by the Congress, other U.S. governmental agencies, and other international groups (national, international, military, and private) to deal with the impact hazard. The unusual nature of the hazard (enormous consequence, extremely low probability of occurring in our lifetimes) has presented difficulties in getting it considered along with other natural hazards and by agencies with responsibility for mitigation. It now appears likely that the discovery rate of Earth-approaching objects will increase dramatically in the next decade, raising one practical issue that has not been addressed: how to communicate with officials and the public concerning discoveries of objects that may impact the Earth in the near future.

Introduction

The Earth is subjected to a continuing "celestial rain" of cosmic debris. Nearly all of it is fine dust or larger objects that mostly burn up in the atmosphere and is of little consequence to our environment. Occasional larger (or stronger) objects survive to be found on the ground and are known as meteorites. Every couple years a meteorite causes damage, penetrates a roof, strikes a car, or is otherwise a nuisance, but such events are newsworthy only because of their rarity and unusual nature. Yet the power-law that describes the size distribution of cosmic debris has no large-size cut-off. Very rarely (every few 100,000 years or so, or 1 chance in several thousand during a human lifetime) a comet or asteroid more than a mile in diameter strikes the earth with serious global environmental consequences that could conceivably threaten civilization as we know it. Even more rarely (every 100 million years or so) a cosmic projectile 5 to 10 miles across strikes, with consequences so terrible that most species (including the dinosaurs 65 million years ago) are threatened with extinction. It is plausible that an even larger object, perhaps 25 miles across or larger will strike the Earth during our Sun's lifetime with the possibility of virtually sterilizing the surface of our planet.

This "impact hazard" by near-Earth objects (NEOs) is strikingly different from most natural hazards in two ways: (1) the potential consequences of a major impact exceed any other known natural hazard, and (2) the probability of a major impact occurring in a politically relevant timescale (say, during our lifetimes) is extremely low. It is interesting, however, that multiplying the probability of a major impact by its consequences yields an annualized death rate similar to that of some of the traditional natural hazards being discussed in this Workshop (hundreds of deaths per year worldwide, see Morrison *et al.*, 1994).

Another interesting feature of this hazard, in the context of "prediction", is that this hazard is evolving from one that was almost unknown two decades ago (hence a serious impact would certainly not have been predicted) to one in which 80-90% of the risk could, within two more decades, be predicted so exactly that mitigation measures within our technological capability could approach 100% effectiveness. Within the remaining 10-20%, the prediction would either be too late to mount more than partial countermeasures or there might (if a comet were suddenly to appear from the direction of the Sun) be a wholly unforecast "act of God".

In this case study, I outline the history of how this hazard was "discovered" by scientists. Then I delve more deeply into the recent history of how the world's political entities became aware of the impact hazard and what is, and is not, being done about the problem. Finally, I address some of the policy issues that are emerging.

I should note briefly my own background and point-of-view about this issue. I am an astronomer and geoscientist by training and have long had a professional interest in both small planetary bodies (asteroids and comets) and in impact cratering of planetary surfaces. I am not, however, among the small group of astronomers who are engaged in constructing telescopes to search the heavens for threatening objects. Although, as a scientist, I have served on policy advisory committees, my own participation in policy-making process has been rudimentary (I was a member of the Pima County, Arizona, Planning and Zoning Commission and chaired the committee that drafted the county grading ordinance.) My view of how society should deal with the impact hazard has been shaped by the literature of risk perception in which it is argued that there is no single objective way for society to assess the relative importance of the hazards we face.

However, as a scientist, I believe that an important input to political evaluation of this hazard is the concrete scientific information we have learned about the hazard (about the frequency of impacts, about the consequences of those impacts, about the technological issues of how we find potential impactors and what we might do about them) so that policy makers are aware of and have access to factual knowledge (and associated error bars) about the hazard. As a citizen, my personal belief is that the impact hazard is important enough to merit further study and analysis and that it is worth the cost to augment the search for potential impactors (although certainly *not* worth advance preparation of on-the-launch-pad defensive measures). But I also believe that some other natural hazards -- and *many* other, mostly medical and accidental, hazards -- deserve more urgent attention than the impact hazard.

At the present time, there is minimal funding of work on the hazard, although there are fledgling attempts in several countries, and by several international organizations (including the U.N.) to take the impact hazard into account. I am not aware that FEMA or the "hazards community" (i.e. the subscribers to *The Natural Hazards Observer*) has taken serious interest in this particular hazard, despite very widespread media attention given to it in recent years, especially in the spring of 1997. There are important policy issues that must be addressed -- in particular, how the scientific community appropriately advises officials and the public about the chances of an impact occurring shortly after discovery of a potentially threatening body, but before it can be proved that the object will not hit.

Discovery of the Impact Hazard

Comets have been perceived as threatening objects since antiquity. But the scientific concept that they are physically solid bodies (which would be potentially dangerous if they were to impact) was not proposed and widely accepted until the mid-20th century when Whipple (1951) proposed the "dirty snowball" model for comets. The greater danger (probably) is posed by asteroids, and the first asteroid discovered to be in an orbit that crosses the Earth's orbit around the Sun ("Earth-crossing asteroid") was not discovered until 1932. Soon thereafter, a Harvard astronomer, Fletcher Watson (1941), wrote cogent sentences about the dangerous prospects of such an asteroid (a few miles wide) crashing into the Earth. With hindsight, the literature tells us that some other important scientists also forecast both the enormity as well as the rarity of a potential impact. Such eminent pre-Space-Age researchers included Ralph Baldwin (1949) and Ernst Öpik (1957).

From at least the 1950's through the 1970's there were also (we now recognize) prescient remarks (again by Öpik, but also many others including one of the founders of planetary science, Nobel laureate Harold Urey [1973]) about the possibility that mass extinctions of species in the geological record might be explained by impacts of large asteroids or comets. Other astronomical ideas (e.g. nearby supernovae explosions) competed with traditional speculations of paleontologists (e.g. that early mammals ate dinosaur eggs) as alternatives to the impact idea, and the astronomical hypotheses -- in particular -- were ignored and not further developed.

In the late 1960's (Kleiman, 1968), an M.I.T. space systems engineering class was presented with the problem of what would they do if an Earth-approaching asteroid (they chose Icarus) were found to be on a collision course with Earth. Their conclusions, published as "Project Icarus" (*loc cit.*), represent the first serious consideration of what human society might do if confronted with this threat. Yet, in a political and cultural context, the M.I.T. study was conducted in a vacuum and led nowhere. During the 1970's, several science fiction novels were published with asteroid/comet impact as a central theme. Some were of limited circulation but at least two were by world-renowned science fiction writers: "Rendezvous with Rama" (Arthur C. Clarke) and "Lucifer's Hammer" (J. Pournelle and L. Niven). There was also the 1979 grade C movie "Meteor".

Perhaps (or perhaps not) these antecedents led to the sudden convergence around 1980, on several fronts, of the idea that asteroids and comets might pose a significant hazard to humanity. The fundamental scientific context was the "Golden Age" of space exploration, commencing with the Ranger and Mariner investigations of the Moon, Mercury, and Venus, and the Apollo explorations of the surface of the Moon. The early Mariners showed that Mars and Mercury are also cratered worlds, and the moon rocks returned by Apollo astronauts provided radiometric calibration of the ages of geological units on the surface of the Moon. The research of Eugene Shoemaker (cf. 1963) and others, substantially motivated by the dawning of the Space Age and the Apollo program, finally settled a long-standing debate about the origin of various "crypto-volcanic" craters on the Earth -- Meteor Crater in Arizona, and others, were shown to be impact craters.

By 1980, telescopic observational programs (chiefly by Helin and Shoemaker, 1979) to survey Earth-approaching or Earth-crossing objects, as well as continuing exploration of the planets (e.g. Voyager's imaging of the surfaces of the four large moons of Jupiter, three of which showed cratered surfaces and the other extraordinarily active volcanism that erases any impact craters almost immediately after they are formed) provided an overwhelming planetary science context for understanding that the Earth, too, is living in a cosmic "shooting gallery".

I have not been able to definitively pin down all of the antecedents to the critical July 1981 Snowmass, Colorado, workshop on the impacts of asteroids and comets, chaired by Gene Shoemaker (I was a member). One important influence was that Tom Gehrels, of the University of Arizona, had been promoting the construction of a telescope (now called "Spacewatch") to search for Earth-crossing asteroids. Gehrels had been the leading scientist surveying the properties of asteroids since the late 1950's, and he became more interested in the near-Earth asteroid population by the late 1970's (he had organized a scientific conference concerning Eros in the mid-70's, cf. special Eros issue of *Icarus*, Vol. 28, No. 1, May 1976).

In June 1980, the NASA Advisory Council (composed of high-level outside advisors to the space agency) held one of its annual retreats ("New Directions Symposium") on Martha's Vineyard, providing a forum for NASA's management to step back from the day-to-day programs and find a "vision" to define and support its future programs. These officials, thinkers, and technologists proposed several future themes for NASA. One subpanel, including the late Barney Oliver (vice-president of Hewlett-Packard), proposed a theme of investigating the potential hazard to the Earth posed by asteroids and comets.

An outgrowth of that summer meeting was the convening, by NASA, of the Snowmass "Spacewatch Workshop" the following summer, organized by NASA Planetary Astronomy program head Bill Brunk and chaired by Gene Shoemaker. I was asked to participate, in part because of my then-recent role, as a member of COMPLEX (Committee on Planetary and Lunar Exploration), helping to formulate the National Research Council's report on the next decade's strategy for investigating small bodies (comets and asteroids).

In the meantime, Luis and Walter Alvarez and their collaborators, had discovered the infamous iridium layer at Gubbio, Italy, and had developed the idea that a 6-mile-wide asteroid crashed to Earth 65 million years ago, causing the mass extinctions that define the Cretaceous-Tertiary (K/T) boundary, most famously exemplified by the demise of the dinosaurs. Their epochal paper in *Science* (Alvarez *et al.*, 1980) had appeared by the time of the Snowmass meeting, and the Alvarez team was represented at the Shoemaker meeting by Frank Asaro. But the history of the Alvarez hypothesis (e.g. see Alvarez, 1997) suggests that they looked to the evidence from planetary science only *after* developing the core idea; I know of no evidence that the Alvarezes' work on the Gubbio mystery informed the NASA study that led to the Shoemaker meeting.

So, following the confluence of various scientific threads, by summer of 1981 a representative group of scientists and technologists was assembled, including military experts (e.g. Gen. Theodore Taylor), astronomers (e.g. Tom Gehrels), geoscientists (e.g. David Roddy), aerospace engineers (e.g. Alan Friedlander), and others (e.g. Barney Oliver) to discuss and debate the proposition that human civilization was at risk from comets and asteroids and that there might be something that could be done about it. During the Spacewatch Workshop, I participated in a core sub-group that defined the magnitude of the hazard in terms that could be compared with other natural hazards. Nothing was fundamentally different from the original insights of Fletcher, Baldwin, and Öpik nor from the more thoroughly developed later analysis by Chapman & Morrison (1994), which was based on the preliminary thinking at Snowmass: there is a small, but non-zero, risk of a civilization-threatening impact happening that is much smaller than the K/T boundary impact 65 million years ago but far larger than the 1908 Tunguska impact (which *could* have killed millions had it unluckily struck in the center of a city, but in fact only killed a couple of people at most). Preliminary thinking about how to discover potential impactors (Tom Gehrels presented the Spacewatch concept) and about how to destroy a potential impactor, if found, (by nuclear explosives launched to rendezvous with the object) were all discussed at Snowmass.

NASA intended to release a report of the Snowmass findings, but that never happened. In fact, a 90-page draft report was written by the members of the Workshop during the months following the meeting. Important philosophical issues were raised and debated during the writing of the report. For example, George Wetherill, of the Carnegie Institution, expressed deep concern about the potential destablizing influence on the Cold War political climate by advocacy of using nuclear weapons in space for destroying or deflecting threatening asteroids. This was one factor among many leading to some delay in issuing the report.

The report was, in fact, never released. Several years ago, I interviewed Gene Shoemaker, some committee members, and the cognizant NASA official (Bill Brunk), and concluded that the chief reason the report was never completed and released was due to Gene Shoemaker's overcommittment (a characteristic of this exceptionally talented scientist, who tragically died in July 1997) -- he simply never finished it -- and *not* due to any reluctance on NASA's part, perhaps due to the controversial nature of the proposed mitigation measures. (The latter hypothesis had been suggested by some.) Shoemaker's scientific conclusions about the frequency of impacts of objects of various sizes, developed for the Snowmass meeting, were eventually published in an important review article in (Shoemaker, 1983). Copies of the draft report *were* circulated to participants of at least one of the major meetings of the early 1990's, and thus it entered into discussion at that time.

The increasing rate of discovery of NEA's by the search teams led by Shoemaker and by Helin (whose collaboration ended around 1982), soon to be joined by Gehrels' Spacewatch telescope, created a general awareness within the planetary science community by the late 1980's that the Earth is subject to potentially dangerous impacts from asteroids and comets. Two major interdisciplinary meetings about the Alvarez hypothesis concerning the K/T boundary (the Snowbird conferences of 1981 [Silver & Schultz, 1982] and 1988 [Sharpton & Ward, 1990]) helped generate a consensus among most non-paleontologist scientists that an impact was responsible for the K/T mass extinctions. Shortly thereafter, the "smoking gun" was discovered: the immense Chicxulub crater in the northern Yucatan (first recognized as a geophysical anomaly in the 1950's by Mexican oil-exploration geologists, proposed as an impact crater in the early 1980's (see *Sky & Telescope*, March 1982, pp. 249-250), and finally recognized for its significance by the geological community following publication of the paper by Hildebrand *et al.* [1991]).

Despite continuing hold-outs -- generally paleontologists unwilling to admit to such a haphazard explanation for one of the major revolutions in the evolution of species on our planet -- there is widespread acceptance of the hypothesis that the impact of a 6 to 10 mile wide asteroid in the Yucatan 65 million years ago rendered dinosaurs extinct and led to the evolutionary burst of mammals and the eventual emergence of homo sapiens. That a hazard might still exist is a logical consequence, since 65 million years ago is quite recent in geological history, long since the early epochs of higher impact rates in the solar system. Indeed, the statistical assessment of the near-Earth population of asteroids and comets was robust by 1990, and not very different from preliminary assessments decades earlier.

Recognition of a modern-day hazard, as distinct from the role of impacts in Earth history, took a little longer to develop. In spring 1988, Morrison and I submitted an abstract on the impact hazard to the 2nd Snowbird Conference, but it was initially rejected. Reasons for rejection included concerns that discussion of the modern impact hazard would distort the hoped-for rational discussions of the K/T boundary and other revolutions in the evolution of life. We appealed, on the grounds that the possibility of a modern-day catastrophe needed to be appreciated by just the interdisciplinary scientists who would be present at Snowbird, and that the topic needed to be brought into the scientific mainstream. We were finally given poster space, but not a slot on the oral program.

In 1989, a small asteroid (later named Ascelpius) was discovered to have made a "close" (by astronomical standards) pass by Earth and, due to an exaggerated and somewhat incorrect NASA press release[1], led to headlines around the world as well as a presentation by myself at the Meteoritical Society meeting that summer (Chapman *et al.*, 1989). Later the same year, the book *Cosmic Catastrophes* by myself and Morrison was published (Chapman and Morrison, 1989), leading to further public discussion of the issue. We were invited to contribute to a Hazards session at the December 1989 American Geophysical Union meeting in San Francisco. Thus, by the end of 1989, the "impact hazard" had entered the scientific literature, if only as abstracts for several meetings. It would be two more years before a technical article on the hazard appeared in the peer-reviewed literature (Ahrens & Harris, 1992).

Public, Political, Military, and International Developments (1989 - 1993)

It took a while for the idea of a contemporary hazard to reach the public and political leaders. A chapter written primarily by myself in the trade book *Cosmic Catastrophes* (Chapman & Morrison, 1989) was a critical influence. Our book dealt with a wide range of catastrophes, ranging from the ozone hole to the death of the Sun. In the final chapter of our book, "Chapter 19: Threat from the Skies: Will a Comet Strike?", we told the story of the Snowmass meeting and outlined the principal conclusions of the unpublished Shoemaker report. (Joint work on this chapter with my co-author David Morrison eventually led to a technical article on the impact hazard. Originally conceived as a piece for *Scientific American*, we decided that the topic needed to be addressed in the peer-reviewed literature, so we redirected the article toward *Science*. *Science* chose, for reasons that were never satisfactorily explained to us, not even to send the paper out for review, so we sent it instead to *Nature*, which published it in early 1994 [Chapman & Morrison, 1994].)

Congressional interest. A few months after publication of our book (and attendant modest, but nonetheless national, media coverage), my co-author, David Morrison, was invited to discuss the topic by the Space Caucus of the U.S. House of Representatives. On June 26, 1989, he met with about 25 congressional staffers, including Terry Dawson, who -- as staffer for the House Committee on Science,

[1] The press release said that it was a "near miss" in the sense that only a matter of timing had prevented a collision -- that, if the asteroid had arrived six hours earlier, a collision would have ensued. In fact, the asteroid's orbit does *not* exactly intersect the Earth's orbit. Many asteroids pass much closer to the Earth and go undetected. With the recent increased discovery rate, some of these are now being found, sometimes *after* closest approach. None of them were "near misses" by the standards of anything resembling common parlance, although their observed proximity is unusual by historical standards.

Technology, and Space working for the Committee's Chairman, Rep. George Brown -- played a pivotal role in keeping the topic before the Congress until the Republican take-over of the House in 1995.

Perhaps inspired by the low-key national discussion of this issue, the American Institute of Aeronautics and Astronautics (AIAA, the chief professional society of aerospace engineers) drafted a white paper recommending enhanced efforts to detect and calculate the orbits of potentially threatening bodies. Their lobbying efforts in the Congress were favorably received, resulting in draft language added by Dawson, at Brown's request, to NASA's 1991 authorization bill (dated September 26, 1990):

"The Committee believes that it is imperative that the detection rate of Earth-orbit-crossing asteroids must be increased substantially, and that the means to destroy or alter the orbits of asteroids when they threaten collision should be defined and agreed upon internationally. The chances of Earth being struck by a large asteroid are extremely small, but since the consequences of such a collision are extremely large, the Committee believes that it is only prudent to assess the nature of the threat and prepare to deal with it. We have the technology to detect such asteroids and to prevent their collision with the Earth. The Committee therefore directs that NASA undertake two workshop studies. The first would define a program for dramatically increasing the detection rate of Earth-orbit-crossing asteroids; this study should address the costs, schedule, technology, and equipment required for precise definition of the orbits of such bodies. The second study would define systems and technologies to alter the orbits of such asteroids or to destroy them if they should pose a danger to life on Earth. The Committee recommends international participation in these studies and suggests that they be conducted within a year of the passage of this legislation."

NASA Workshops and Studies. NASA's response was, and -- at least until recently -- has remained, decidedly low-key, responding to the Congressional interest in a minimally adequate way. Three actions taken in 1990, by the NASA official appointed to handle the matter (the late Jürgen Rahe) were (a) to ask me to chair an international scientific conference on Earth-approaching bodies (held in San Juan Capistrano, CA, in July 1991), (b) to appoint David Morrison to chair what became known as the Spaceguard Survey Committee to study the possibilities for detecting dangerous asteroids and comets, and (c) to appoint John Rather to chair what became known as the Interception Workshop to investigate what could be done, technologically, should an object be found to be on a collision course with Earth.

The international conference was covered by the national network news, beginning a level of interest by the media in the impact hazard that has continued to rise through March/April 1997, when most networks (Fox, NBC, ABC, PBS) aired special documentaries or, in the case of NBC, an expensive, heavily-promoted fictional miniseries, on the topic. The Spaceguard Committee largely repeated the analysis of the Snowmass meeting, adding technical details about how to efficiently search for near-Earth objects, and proposed a global network of six 2.5-m telescopes, costing $50 million, that would find about 3/4ths of the dangerous objects (90% of the Earth-crossing asteroids larger than 1 km diameter) during the course of 25 years, at an annual operations cost of about $10 million. Many of the remaining 1/4 of the threatening objects (long period comets entering the inner solar system for the first time) were found to be *much* more difficult to detect. The Committee made the argument that it would be significant to identify most of the potentially hazardous objects; if, as expected, none of them were found to be on a near-term collision course, then the hazard would be reduced by a factor of 4. The report was published, in limited numbers, in early 1992 (Morrison, 1992).

The follow-on Interception Workshop was held in early 1992, following completion of the work of the Spaceguard Survey group, at Los Alamos National Laboratory. This meeting had a powerful impact on the subsequent political debate, so I will briefly outline its salient features. Strategic Defense Initiative (SDI) proponent Edward Teller and his disciple, Lowell Wood, were prominent participants of the meeting. By keeping the press away from the meeting, organizers only fueled the media's skepticism of what happened behind the closed doors. As it was, many of the Department of Energy researchers who had been recently introduced to the question of how to deflect asteroids, were provided with a technically flawed analysis by Wood *et al.* (1990) arguing that there is great danger from very small asteroids that impact frequently, which in fact burn up in the Earth's atmosphere and never pose a danger to anyone on the ground. Therefore, many of the analyses readied for presentation at Los Alamos concerned application of Strategic Defense Initiative ("Star Wars") technology originally intended to shoot down enemy missiles.

Astronomers in the audience, including Morrison and myself, tried to explain that the small objects posed no significant hazard, and that it was the large (>1.5 km diameter) objects that were of concern. Indeed, schemes *were* discussed at the Detection Workshop that would mitigate impact of the larger ones, including stand-off detonation of a neutron bomb, but also including outlandish "blue sky" ideas involving anti-matter and other notions more appropriate for science fiction novels. I, in particular, asked that my name be omitted as a co-author of the Interception Workshop report (Rather, Rahe & Canavan, 1992), although I assented to having my doubts and critique appear in an appendix of a more complete "Proceedings".

Having been deliberately excluded, the media were interested in finding out what really happened at the Interception Workshop. Subsequent investigative reporting by the *San Jose Mercury-News*, an op-ed piece in the *New York Times* by physicist Robert Park (Park, 1992), and pieces in such trade magazines as *Aviation Week* enhanced public skepticism about whether the ex-Cold Warriors were looking for anything under the sun to justify continuation of SDI. There was also concern about the self-interested motives of some astronomers interested in getting funding for their telescopes. Simultaneously, debate on national radio talk shows and regular news media commentaries played into the "giggle factor" that inevitably accompanied this difficult-to-relate-to "Chicken Little" hazard.

At least partly because of the giggle factor and the controversies surrounding Edward Teller's program -- which included practicing by actually deflecting an NEO with a bomb (Teller's word was "experimentation") -- NASA would have little or nothing to do with the topic. NASA met its responsibility by providing brief, watered-down reports on the work of the two committees to the Congress in spring 1993. But it printed only a minimal number of copies of the reports and issued no press releases. Wesley Huntress, who was in charge of NASA's Solar System Exploration Division and had become Associate Administrator for Space Science by the time he testified to the House Committee on Space on March 24, 1993, was particularly uninterested in doing more than he had to about the hazard issue. NASA had issued a proposal opportunity in 1992, with a reported $1.5 million of available research funds diverted from elsewhere, to enhance the detection programs already in place; but the funds had shrunk to less than $500K by the time funding was allocated in 1993. Despite the tone of Huntress' testimony (he described the modest efforts that had just received enhanced funding), NASA effectively gave a negative response to the Congressional call for a two-decade-long program involving the construction of several large telescopes.

Civilian vs. military debates. Another important outgrowth of public discussion of the Los Alamos meeting was that Carl Sagan developed an interest in the topic. His passionate, politically oriented perspective, was articulated in his inimitable way in articles he wrote for scholarly publications (c.f. Sagan 1992) as well as for the large-circulation Sunday supplement, *Parade*. It was one of several major topics that Sagan then pursued until his untimely death in late 1996. Sagan was interested in, and acknowledged, the serious danger posed by impacts in the scheme of human and planetary evolution. But he was deeply disturbed by the prospects that discussion of asteroid diversion might undermine international treaties that, in his view, prohibited the use of nuclear weapons in space under any circumstance. He even mused that scientists shouldn't even try to *find* NEA's, because of the potentially dangerous response of the military should one be found. Most disturbing of all, to Sagan, was the possibility that development of a technology to divert asteroids away from Earth could be used by a "madman" to divert asteroids to crash *into* the Earth (Sagan & Ostro, 1994). Sagan contributed to a technical analysis of this "deflection dilemma" (Harris *et al.*, 1994), based on his debate with Edward Teller at the January 1993 Tucson meeting "Hazards due to Comets and Asteroids".

The Los Alamos meeting was a public relations debacle for technologists from Los Alamos, Livermore, and the general military/DOE communities. (For instance, the *Wall Street Journal* headlined a post-Los Alamos story: "Never mind the peace dividend, the killer asteroids are coming!") During the subsequent two-and-a-half years, there were several attempts to improve communication between the "deflection community" and the generally academic astronomers and geophysicists investigating asteroids and environmental consequences. Col. Pete Worden, of SDI, then the Air Force Space Command, and now Deputy for Battlespace Dominance at the Pentagon, organized a retreat at Erice, Sicily, in May 1993, which also -- for the first time -- had significant representation from the space policy community (chiefly American, but also international). Among the participants were John Pike (Federation of American Scientists), Bob Park (American Institute of Physics), and American [George Washington?] University space policy analyst John Logsdon. Morrison and Teller (1994) even collaborated on a joint chapter for the "Hazards" volume. (As of this writing, the proceedings of the Erice meeting have still not been published.)

Another meeting of the two communities was held in May 1994 at the Air Force Space Command in Colorado Springs, spearheaded by AFSC Chief Scientist John Darrah (SAIC, 1994). While those discussions led to some cooperative arrangements involving telescopes and instrumentation, the two groups began moving apart shortly afterwards.

International interest. There has been a strong international component to early public discussion of the impact hazard, which is appropriate for a hazard that is indiscriminate when it comes to national boundaries. Even in the 1980's, there were modest telescopic search programs for NEO's underway in Australia and France. Jürgen Rahe, appointed by NASA to lead its response to the 1991 mandate from Congress, insisted that the Spaceguard Survey Committee have international representation. Indeed, probably the greatest interest in the impact threat has been expressed by Russians, from both its astronomical and military communities, even though in the post-Soviet era, they have less capability to address the problem. Russian interest is undoubtedly enhanced by the fact that the largest terrestrial impact in recorded history took place early this century in Siberia, and one of the largest subsequent impacts also occurred in Russia (Sikhote-Alin, 1947). An international conference was organized in late 1991 by astronomers in St. Petersburg just weeks after the city's name-change from Leningrad. There has also been considerable interest in Italy, which has an active group of asteroid researchers; it is only coincidental that in 1973 Arthur C. Clarke wrote a fictionalized account of a major impact occurring in northern Italy, which led -- in his story -- to the creation of a "Spaceguard Survey," whence the name of NASA's survey committee. The International Astronomical Union established a Working Group on Near Earth Objects in 1991, with Andrea Carusi (Instituto Astrofisica Spaziale, Rome) as Chair; he later became a major player in developing European awareness of the impact hazard.

In spring 1994, in cooperation with the Explorer's Club of New York, an international workshop was organized by the United Nations and held in the U.N. building in New York (the proceedings have just been published, in mid-1997, by the New York Academy of Sciences [Remo, 1997]). Although it was a minor activity, by U.N. standards, it led to modest actions within the U.N., including reconsideration of some elements of U.N. space policy.

Media and public opinion. A final arena of increasing awareness is the general public. Virtually nobody, outside of the few scientists involved, was aware of the impact hazard until 1989. Publicity that attended the publication of our book (e.g. Rush Limbaugh expressed great interest in his radio talk shows) and the "near-miss" by Ascelpius began an ever-increasing interest on the part of the media. One of the early media mishaps occurred following our AGU talk and associated AGU press conference in December

1989, when a mistranslation of a wire service story by the New China News Agency led to the false announcement of an imminent asteroidal impact into China; although the story was withdrawn some hours later, it already had led the national evening news telecasts in China, causing panic in some quarters, according to American press accounts. The "giggle factor" was already active when Vice President Quayle -- who had been the butt of derision by the media -- publicly expressed concern about the impact hazard during a speech at the national meeting of the AIAA. After columnists poked fun at him, Quayle is said to have become angry at Pete Worden, then serving on the staff of the National Space Council headed by Quayle, who arranged his AIAA speech.

The first general treatment of the impact hazard by the American news media accompanied the international scientific conference held in San Juan Capistrano in July 1991. Stories were broadcast on the evening newscasts by most networks, and accounts appeared in national news magazines. Press coverage reached a new level in autumn 1992 (including a cover story in *Newsweek* ["Doomsday Science", issue of Nov. 23, 1992]) connected with the mistaken announcement of a century-in-the-future impact by Comet Swift-Tuttle. It was about this time that Paul Slovic (Univ. of Oregon), a leader in the field of risk perception, conducted his first poll concerning the impact hazard. As he reported, in early 1993 (see Morrison, Chapman & Slovic, 1994), only 25% of the public had heard of the impact hazard, at this point; respondents were fairly respectful of the scientific community's statement of "facts" about the impact hazard, but decidedly cautious about plans (particularly military ideas) to do anything about it.

By July 1994, the impact hazard was a topic of curiosity and was finally being debated in the technical literature, considered by policy analysts and governmental bodies, and being used as a justification for modest funding by both astronomers and by technologists in governmental labs. But the topic might have languished there were it not for the remarkable arrival of Comet Shoemaker-Levy 9.

Post Shoemaker-Levy 9 Developments

The entirely serendipitous early-1993 discovery of Comet Shoemaker-Levy 9 orbiting Jupiter, by Gene and Carolyn Shoemaker and David Levy (cf. Shoemaker & Shoemaker, 1995), and the comet's subsequent spectacular crash into Jupiter in July 1994 -- capturing banner headlines around the world for a week -- finally changed the impact hazard from a theoretical curiosity into a very distinct possibility in the public mind. Far from being an historical or paleontological event, the impacts were witnessed in real time by amateur astronomers and by the public, tuned in to the newly popular World Wide Web that was used to distribute telescopic images from such remote sites as the South Pole and the Hubble Space Telescope. And the resulting black spots in Jupiter's atmosphere, as large as the entire planet Earth, provided dramatic evidence of the potential harm that could be done if such an impact were to strike the Earth (cf. Chapman, 1995). While Jupiter is hit much more often than the Earth is, the implications nevertheless became palpable.

Scientific developments. The modest incremental funding of telescopic search programs by NASA has, so far, yielded minimal scientific advances directly related to the impact hazard. (The search programs continue to find objects of theoretical interest to asteroid researchers, dynamical astronomers, and so on, such as the discovery of a small asteroid in a "horseshoe orbit" connected with the Earth.) E. Helin has moved her observing program from Palomar Observatory to Hawaii (where joint cooperation with the Air Force has put into operation the NEAT telescope, which is finding many Earth-approaching asteroids). The LONEOS telescope, being developed at Lowell Observatory by E. Bowell (and the late E. Shoemaker), will probably not be fully operational for at least a year.

Perhaps the major scientific contribution directly related to the impact hazard in the last couple of years is the definitive evaluation of potential environmental consequences of impacts (Toon *et al.*, 1997).

Congressional activities. Before the impacts even concluded, the Congress asked NASA to establish a new committee -- "Near-Earth Objects Survey Working Group", chaired by Gene Shoemaker -- to evaluate how the most dangerous asteroids might be found. The request was for an implementation plan. Once again, Gene Shoemaker's overcommittments in the post-comet-crash months were a major factor leading to a delay (nearly a year) in the group's report (Shoemaker *et al.*, 1995). By that time, public fascination with Shoemaker-Levy 9 had waned. More important, the Republicans were now in charge of the Congress; although there have been no notable partisan differences on this issue, key individuals, such as Rep. Brown's staffer Terry Dawson, were no longer there. Therefore, the Shoemaker committee's conclusions (that a 10-year program costing less than $50 million could discover 2/3rds of the threatening objects) languished until at least 1997, when some renewed interest began surfacing in Congress.

NASA activities. During the last few years, NASA has gradually expanded its interest -- if not direct funding for search activities -- in the threat from NEO's. A long-planned spacecraft investigation of the large, Earth-approaching asteroid Eros -- the Near-Earth Asteroid Rendezvous mission -- has been touted significantly in terms of helping to better evaluate the impact hazard. Eros has recently been shown to have a roughly 50% chance of ending its existence by crashing into the Earth, although this is likely to be many millions of years from now and cannot possibly happen in the near future.

NASA has once again, under direction from Administrator Dan Goldin, reconsidered its basic goals. Following discovery of possible fossil life in a Martian meteorite and other related discoveries, the concept of "Origins" as a major focus of NASA's explorations has emerged. At a recent (May 1997) meeting of NASA managers and advisors in Breckenridge, Colorado, the concept of "Destiny" has been added to "Origins", with the potential impact by a comet or asteroid high on the list as an element of the prospective destiny of mankind. The close approach of Comet Hyakutake in early 1996 and the even more spectacular apparition of Comet Hale-Bopp in spring 1997 has heightened the interest of the space agency in this issue. Hale-Bopp, which came nowhere near Earth, nevertheless *did* penetrate within the Earth's mean distance from the sun; had it struck, it would have been vastly more devastating than even the K/T boundary impact.

Military programs. Edward Teller has backed away from his advocacy of "experimentation" in the near future. In a lesser way, however, the proposed Clementine 2 space mission (a follow-on to the first SDIO-initiated Clementine mission), would perform actual cratering experiments on a target asteroid. Besides scientific interest in such experiments, there is little doubt that the promoters of the project also see it as the first step in developing the logistics to "deal with" a dangerous asteroid, as well as to begin direct assessment of the physical properties of objects that would be required before a deflection system could be reliably implemented.

In other respects, there has been continued interest on the part of the American military about developing a "planetary defense" program to deal with the threat. For example, an Air Force study resulted in the October 1996 publication of a report ("Planetary Defense: Catastrophic Health Insurance for Planet Earth", Urias *et al.* 1996) that advocates deployment of a planetary defense system by the Department of Defense. It would consist of "a detection subsystem, command, control, communications, computer, and intelligence (C4I) subsystem and a mitigation subsystem." I am not up-to-date concerning specific DoD programmatic initiatives in this area.

International developments. At a September 1995 meeting in Vulcano, Italy, of the International Astronomical Union's NEO committee, it was decided to create an international "Spaceguard Foundation" to solicit funding from various sources and to coordinate international efforts in mounting a detection program similar to that advocated by the Morrison and Shoemaker committees. In March 1996, with Andrea Carusi as President, the Foundation was incorporated in Italy and began several efforts.

One of Carusi's enterprises, initiated prior to formation of the Foundation, was to arrange for the Parliamentary Assembly of the Council of Europe to pass a resolution, on March 20, 1996, on "the detection of asteroids and comets potentially dangerous to humankind." The resolution urges the governments of member states and the European Space Agency to support international programs that would inventory NEO's larger than 0.5 km in size and contribute to international efforts to evaluate and deal with potential impacts.

National affiliates of the Spaceguard Foundation have been founded in Japan, the U.K., and Germany. Meanwhile, Australia has backed away from its once significant role in detection of NEO's. Spaceguard Foundation Vice President Duncan Steel's observation effort was closed down within the last year, although international pressure may yet reverse that action.

A series of American-Russian bilateral meetings, held in the once-secret Soviet city of Chelyabinsk-70 and at Livermore, California, primarily engaged the military community, although there were a few representatives from the civilian/academic community. In late 1996, Vadim Simonenko, of the Russian Federal Nuclear Center, established a private "Space Shield Foundation" in Russia to promote international programs on hazard analysis, identification of NEO's, and planetary protection.

The impact hazard continues to be used as an excuse for other political issues, for example control of nuclear weapons. On April 17, 1996, for instance, *The New York Times* reported (under the headline "Chinese seek atom option to fend off asteroids") that Chinese government officials were opposing nuclear weapons test bans because of their potentially utility against asteroids.

Public interest and media coverage. About ten trade books on the topic of the impact hazard have appeared in the last two years, mostly by reputable authors. However, several feature a neo-catastrophist perspective popular in Great Britain, which holds that the Earth is in a much more precarious state than is generally accepted in the scientific community (the books are reviewed by D. Morrison at: http://ccf.arc.nasa.gov/sst/book_review.html). Articles about the impact hazard have appeared in national magazines; a recent, and particularly accurate and well-written, article is by Ferris (1997).

In the spring of 1997, there was unprecedented television coverage of the impact hazard, including a widely promoted but inaccurate and poorly received NBC miniseries, entitled "Asteroid". Higher quality documentaries were broadcast on several networks, including rebroadcast of a 1995 PBS "Nova" program on the topic. Perhaps the best of the series was a National Geographic Special, featuring Gene and Carolyn Shoemaker. A 1996 film production on the impact hazard, primarily featuring the 1995 Vulcano meeting, by the National Film Board of Canada has been receiving critical acclaim. There are rumors of major Hollywood disaster movies in the works.

Analysis

The impact hazard raises a variety of issues involving the interface between scientists and public policy. Some of them are similar to issues presented by other natural hazards, although the specifics are often different because of the unusual character of the impact hazard. The previous section has described the 17-year history during which the impact hazard went from being a science fiction tale to a documented element of our reality, to which the public has been widely exposed. However, very little has been accomplished in integrating this topic into the existing private and governmental structures that deal with natural hazards and their mitigation.

Although I am a principal in this topic, I can count on the fingers of one hand the number of inquiries that I have dealt with from entities involved in hazard mitigation and analysis. In the early

1990's, I did receive an inquiry about the impact hazard from a German insurance consortium (Münchener Rückversigherungs-Ges.) that deals with analysis of natural hazards. I also had one telephone call from a FEMA official. Late last year, I learned that the American Geophysical Union had a committee making recommendations about hazards and was able, at the last minute, to get language into the adopted resolution that included the impact hazard.

There are significant NEO issues that the hazard community must face. One concerns the elements of predictability, and how predictions can be communicated effectively to relevant officials and to the public. At the moment, more than 90% of asteroids large enough to potentially threaten civilization have not been discovered; in addition, virtually all comets that might strike the Earth have not been discovered. Should the Spaceguard Survey be undertaken, that situation would change over the next two decades to one in which *most* of the potential impactors will have been surveyed and it will have been reliably determined whether or not (almost certainly not, but if so, then when and where) they will impact Earth during the next century. Even if the Spaceguard Survey is not formally undertaken, the rapid advance in astronomical instrumentation -- including that available to amateur astronomers -- combined with the augmented interest in this topic is likely to accomplish the Survey's objectives in the next 50 years.

During this time of augmented discovery, there will be *many* "false alarms". This is because the process that discovers a new Earth-crossing object takes a significant period of time before the orbit can be reliably determined to be on a collision course or not. Even though the odds are strongly against the possibility that even *one* such object will be found to be in an orbit that will actually strike Earth within the next century (less than one chance in a thousand), *many* will certainly be found that will, for a period of time, have the Earth within error-bars of a collision for months or even for a year or two. This is an inevitable consequence of the time baseline required for obtaining position measurements that can accurately specify an orbit. Yet approximate orbits, with large error bars that might well include the Earth, can be derived almost immediately.

Some thought has been given by astronomers, including Ted Bowell at Lowell Observatory, Don Yeomans at J.P.L., and Brian Marsden of the IAU Circulars bureau in Cambridge, Mass., to the problem of how to narrow the uncertainties following a discovery. Richard Binzel, of M.I.T., has proposed a simple numerical scale -- analogous to the Richter scale -- whereby astronomers would classify an object as to the likelihood of it posing a major danger (Binzel, 1997). (The scale is a function of both orbital uncertainty and size [equivalently kinetic energy of impact] of the object.) Despite some discussion of these issues, however, they have not been adopted and would not, in all probability, be used for detections that are made in forthcoming years.

Although the 1994 announcement that Comet Swift-Tuttle might impact Earth a century later was based on a mistaken analysis (one might generously call it a "crude" analysis: see discussion of this episode by Steel, 1995), the higher rates of detection will certainly yield many more "near misses" and potential future impactors than we have seen in the past. Because of competition among different observing programs, it is plausible based on past experience to expect announcements to be made to the press that are poorly qualified. And then, of course, the media often mis-report even accurately qualified scientific announcements (a recent example was a report on CNN in the last week of July 1997 that an asteroid 3/5ths of a miles across would "destroy the Earth" -- I have checked into it, and it resulted from oversimplification of a longer, more accurate CNN story based on a scientifically factual press release by E. Helin).

I know of no efforts, even at a preliminary level, to establish formal communications links between potential discoverers of NEO's (professional and amateur astronomers in the U.S., Japan, France, Russia, and other countries, as well as Air Force and other military detection programs) and public and military officials who might be called on to respond to potentially threatening impacts. Fortunately, it is much more likely that a threatening object will be found decades or centuries before impact than that it will be found hours or weeks before impact. But, especially if the size is poorly constrained or if exaggerated attention is given to small objects, imminent impacts could well find themselves thrust into the laps of unprepared high government officials. The fall of Skylab, and more recent (1996) crash of a Russian Mars probe in the southern hemisphere, are reminders that even minuscule debris from space can create a sensation. It is reliably known that the White House was alerted in 1994 when a rather modest sized impact (10's to 100's of kilotons) was detected by downward-looking surveillance satellites (this is the event described technically by McCord *et al*., 1995). Exploding meteors, with yields approaching a megaton, enter the upper atmosphere rather frequently, and are very spectacular even if they do little or no damage on the ground.

It is quite possible that there *already* have been significant tsunamis in Earth history caused by impacts into the ocean, but whose causes have been unrecognized. From data given by Toon *et al.* (1997), it seems plausible that every thousand years, or so, an impact (probably by an iron projectile with kinetic energy of about a megaton) would cause a tsunami equivalent to the biggest tsunamis recorded during the 20th century. It is distinctly possible that warnings of impact-caused tsunamis could be prepared, but the infrastructure for doing so is now lacking. (It must be realized that impact is a very minor contributor to normal tidal waves, but the very biggest ones on a time scale of centuries will be disproportionately caused by impacts.)

Despite the fact that we have been in an International Decade of scientific research on natural hazards, I am also aware of no integration of the impact hazard into those research programs. Indeed, as a "case study" of how research on the impact hazard has fared, I should note that I myself have never received any funding (other than payment of consulting services for advising several committees) for explicit studies of the impact hazard. As far as I can tell, except for the telescopic search efforts, there has been no formal funding by any federal agency for research on the impact hazard (as distinct from allied topics, like analysis of the K/T boundary, research on the Shoemaker-Levy 9 comet crash, or spacecraft studies of asteroids). As I understand it, what little research has been done has either been funded by modest in-house discretionary funds, has been done "on the side," or resulted from bits and pieces of funding by miscellaneous grants that were awarded for more general research. This is probably why the literature is thin in terms of the numbers of professional papers published in the refereed literature, as distinct from brief conference reports or white papers.

Therefore, it is mostly for the future to tell us whether NASA, the National Science Foundation, the Department of Energy, elements of the DoD, FEMA, or other entities will fund a research program on this topic. In the absence of such programs, it is expected that telescopic searches will go on, but relatively little else will be done about the resulting environmental consequences, methods of mitigating impacts, and ways for society's institutions to appropriately deal with news that a particular NEO discovery has been made. In particular, the detailed technical question about how to make impact predictions will remain a topic for occasional cocktail-party speculation by a few astronomers rather than being addressed in a thorough fashion, despite the inevitability that it will sooner or later (most likely sooner) become an issue of major public attention.

The dominant reasons why the impact hazard has failed to become incorporated into the natural hazard policy arena are, in summary: the newness with which the hazard has been recognized; the extremely unusual nature of the hazard (extremely high consequence, extremely low probability); the wide gap between the community knowledgeable about the hazard (planetary scientists) and the natural hazards community and associated public officials; the fact that in an era of budget-cutting, federal agencies are loathe to begin new research programs; the controversial issues related to mitigation (i.e. diverting an incoming object with nuclear explosives); and self-interested motives on the part of both astronomers and ex-Cold Warriors that have distorted the projects that have been proposed for funding.

The larger issue raised by the impact hazard is the level at which governments should, or should not, do anything about it. Several years ago, *Fortune* magazine published a cost/benefit analysis demonstrating that it was worth spending hundreds of millions of dollars a year on planetary defense. Some advocates of planetary defense within the DoE community have argued, in effect, that billions should be spent annually. However, based on nothing more than the low probability (often incorrectly translated into being equivalent to a long waiting time until the next event happens) of a major impact, an argument can be made that no public funds should be expended on this unlikely hazard and that such funds should instead be spent on other hazards that *certainly* will happen (even if with more modest consequences) during the next years.

Currently, what public debate has ensued concerning these questions has been conducted either by technical people primarily engaged in other activities or in the media. Since there has been an inadequate base of research on many of the fundamental questions, it is understandable that there has been no formal analysis by an advisory body (like the National Academy of Sciences) or by governmental policy-makers about how to handle this threat. It seems to me that, at the very least, a conscious decision should be made by society about whether to deal with the impact hazard or not.

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APPENDIX: NEO HAZARD CHRONOLOGY

(abstracted from a chronology developed by David Morrison)

1758	Recovery of Comet Halley confirms that comets have periodic orbits
1801	Piazzi discovers first asteroid (Ceres)
1803	French Academy concludes that meteorites have extraterrestrial origin
1898	Witt discovers asteroid Eros (Earth approaching but not Earth crossing)
1906	Barringer drills unsuccessfully for meteorite at Meteor Crater
1908	Tunguska event: 15 megaton airburst in Siberia flattens 2000 sq km
1932	Reinmuth discovers Apollo, first Earth-crossing asteroid
1947	Sikhote-Aline iron meteorite falls in Siberia
1950	Whipple proposes that comets have solid nuclei (dirty snowball model)
1951	Opik calculates impact probability for Earth-crossing asteroids
1960	Shoemaker completes detailed geological study of Meteor Crater
1965	Mariner 4 discovers that martian surface is heavily cratered
1969	MIT class studies asteroid defense (*Project Icarus*) Dating of Apollo lunar samples establishes terrestrial impact rate
1971	Gehrels organizes first major international meeting on asteroids
1972	Teton event: potential impactor skips off atmosphere USAF surveillance satellites begin to observe atmospheric impacts
1973	Urey suggests possible impact contribution to extinctions Shoemaker and Helin begin Palomar photographic survey (PCAS) Clarke coins term "Spaceguard" in novel *Rendezvous with Rama*
1977	Niven and Pournelle portray comet impacts in novel *Lucifer's Hammer*
1979	Alvarez team identifies extraterrestrial iridium in K-T boundary layer Voyager discovers that heavy cratering extends to outer solar system Film *Meteor* depicts joint US/USSR defense against asteroid impact
1980	Alvarez team publishes proposal of impact cause for K-T mass extinction NASA Advisory Council recommends study of impact hazard
1981	NASA sponsors Snowmass Workshop on the impact hazard First Snowbird conference: Interdisciplinary meeting on the K-T boundary Penfield and Camargo propose large impact structure in Yucatan
1982	Shoemakers begin separate Palomar sky survey (PACS)
1983	Shoemaker publishes standard Earth-impact average flux curve TTAPS authors propose concept of nuclear winter

1984	Gehrels discovers first NEO with new automated Spacewatch system
1985	Chicago University team identifies global wildfires at K-T boundary
	Time publishes cover story on impact extinction of dinosaurs
1986	Flotilla of international spacecraft investigate Comet Halley
1988	Second Snowbird conference: Global Catastrophes and Earth History
1989	Chapman and Morrison publish book *Cosmic Catastrophes*
	Spacewatch discovers asteroid Ascelpius passing much closer than Moon
1990	Hildebrand proposes Chicxulub in Yucatan as K-T impact crater site
	Melosh suggests heat from backfalling ejecta caused K-T firestorm
	AIAA issues position paper urging program to detect NEOs
	US Congress requests NASA to study NEO hazard, surveys, and defense
	Clube and Napier publish book *The Cosmic Winter*
1991	Chapman organizes first international NEO scientific meeting
	NASA establishes NEO working groups chaired by Morrison and Rather
	International Astronomical Union establishes NEO Working Group
	First Russian meeting on the NEO hazard is held in St Petersburg
	DoD approves Clementine mission to orbit Moon and fly by Geographos
1992	Tunguska impactor is identified as asteroidal, not cometary
	NASA releases report from Spaceguard Survey Working Group
	DoE and NASA sponsor NEO interception workshop at Los Alamos
	Ahrens and Harris publish technical paper on asteroid deflection
	Public concern is aroused over possible Swift-Tuttle impact in 2126
	Sagan discusses impact hazard in article in *Parade Magazine*
	Newsweek publishes cover story on impact hazard
	Fortune publishes cost analysis of impact risk
	Slovic conducts first public opinion poll on impact hazard
1993	Gehrels hosts major international impact hazard meeting in Tucson
	Shoemakers and Levy discover Comet S-L 9 at Palomar
	Impact of S-L 9 with Jupiter is predicted for July 1994
	Los Alamos releases NEO Interception Workshop Report
	US Congress holds hearings on NEO hazard and defenses
	Worden organizes Erice international conference on impacts
	The Economist publishes cover story on the impact hazard
	Clarke's novel *Hammer of God* deals with defense against NEO impact
	NASA approves Near Earth Asteroid Rendezvous mission to Eros
1994	Chapman and Morrison publish technical analysis of impact hazard
	Hills and Goda publish analysis of impact tsunami hazard
	Clementine spacecraft is launched but fails before reaching Geographos
	Largest Earth atmospheric impact (50-100 KT) observed from space
	Time publishes cover story on S-L 9 and impact hazard issues
	Astronomers mount unprecedented effort as Comet S-L 9 impacts Jupiter
	US Congress asks NASA for plan to discover all large NEOs in 10 years
	NASA and US Air Force begin consultation on joint NEO surveys
	NASA appoints NEO Science Working Group chaired by Shoemaker
	Russians host impact defense conference (SPE-94) at Chelyabinsk-70
	Spacewatch discovers closest NEO (1994XM, 105,000 km from Earth)
	Shoemaker terminates his Palomar NEO survey (PCAS) after 22 years
	USAF proposes NEO defense role for military in *Spacecast 2000 Report*
	Sagan's book *Pale Blue Dot* includes extensive impact hazard discussions
1995	Gehrels publishes 1300-pg multi-author technical book on impact hazard
	AIAA issues second position paper calling for action on NEO defense

Internet Web page on *Asteroid and Comet Impact Hazard* established
The Planetary Society begins publication of quarterly *NEO News*
Shoemaker Spaceguard report submitted to NASA & US Congress
Livermore Lab hosts conference on asteroid defense issues
UN sponsors asteroid meeting in New York
Internat'l Astronomical Union sponsors Spaceguard Workshop in Vulcano
Steel publishes book *Rogue Asteroids and Doomsday Comets*
NOVA broadcasts TV documentary *Doomsday Asteroid*

1996 Australian government terminates NEO photographic search program
Helin terminates Palomar photographic survey (PCAS)
Spaceguard Foundation formed in Europe to promote NEO surveys
Parliamentary Council of Europe endorses NEO Spaceguard concept
NASA and USAF begin Near Earth Asteroid Tracking program in Maui
NASA launches NEAR space mission to asteroid Eros
DoD obtains funding for Clementine 2 mission to intercept two NEOs
Science conference on 1908 Tunguska impact held in Bologna
Russians host impact defense conference (SPE-96) at Chelyabinsk-70
Comet Hyakutake passes within 15 million km of Earth
Lewis publishes book *Rain of Iron and Ice*
Verschuur publishes book *Impact: The Threat of Comets and Asteroids*
US cable TV broadcasts documentary *On a Collision Course with Earth*

1997 NASA NEAR spacecraft flys past asteroid Mathilde
US Congress proposes that NASA triple its NEO research program
NASA and USAF agree to collaborate on Clementine 2 mission
Toon et al. publish detailed analysis of environmental effects of impacts
Comet Hale-Bopp brightest in decades, widely observed
Newsweek cover story on Hale-Bopp includes NEO hazard discussion
US cable TV broadcasts documentary *Three Minutes to Impact*
NBC broadcasts National Geographic Special
NBC broadcasts miniseries *Asteroid* in which impact wipes out Dallas
Businessman Jim Benson offers award for amateur discoveries of NEO's