LEGAL ISSUES RAISED BY THE DETECTION OF NEAR-EARTH OBJECTS

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Abstract

The mainstream scientific community has begun to take seriously the possibility of an asteroid or comet colliding with Earth and causing widespread death and destruction. An asteroid whose orbit around the Sun crosses Earth's orbit is called an "Earth-crossing asteroid" (ECA) or an "Apollo asteroid," and a comet whose orbit crosses Earth's orbit is called an "Earth-crossing comet" (ECC); both ECAs and ECCs are collectively referred to as near-Earth objects (NEOs). If an NEO crosses Earth's orbit at the same time Earth is at that position, there will be a collision. Credible scientific evidence exists to support the theory that such events have happened at various times in Earth's past, with the larger NEOs causing mass extinctions of plant and animal life. Such an event happening now could seriously affect human life and society, even if the NEO were not large enough to cause a mass extinction. During the 1980s, the mainstream scientific community came to accept the fact that NEOs pose a remote but potentially substantial threat to Earth. Scientists now call for a systematic international Spaceguard Survey of the sky to identify any NEOs which may pose a threat to Earth. Such a detection effort would require international coordination and cooperation of a high degree, but would pose no significant legal questions. If an NEO were found to pose a threat to Earth, efforts would then turn to remedial measures, which would pose some significant legal questions. This paper is addressed only to the detection efforts which would take place under the Spaceguard Survey, and not to any remedial efforts.

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I. Introduction - The Geological, Historical, and Astronomical Evidence

"Impacts by Earth-approaching asteroids and comets pose a significant hazard to life and property. Although the annual probablility of the Earth being struck by a large asteroid or comet is extremely small, the consequences of such a collision are so catastrophic that it is prudent to assess the nature of the threat and to prepare to deal with it. The first step in any program for the prevention or mitigation of impact catastrophies must involve a comprehensive search for Earth-crossing asteroids and comets and a detailed analysis of their orbits. At the request of the U.S. Congress, NASA has carried out a preliminary study to define a program for dramatically increasing the detection rate of Earth-crossing objects...." [1]

A. Very Recent History

On March 23, 1989, an asteroid one-fifth to one-half mile in diameter crossed Earth's orbit within 400,000 miles of Earth's position at that moment. While this might seem to be a large distance to most people, in terms of time the asteroid was a mere *six hours* from the Earth. Had the Earth been six hours slower or the asteroid been six hours faster, and the two bodies collided, the impact would have been equivalent to the explosion of 1000 to 2500 one-megaton hydrogen bombs, according to scientists. [2] On land, it would have left a crater 5 to 10 miles wide and a mile deep; at sea, it would have created enormous tidal waves. [3] In January 1991, an asteroid 30 feet in diameter passed within 106,000 miles of Earth. Had that object collided with Earth, it would have created a crater 300 feet wide and 100 feet deep. [4] While this smaller asteroid would have affected a much smaller area, its impact would still have been devestating to life within that area.

B. The KT Boundary Event

Scientists have found geological evidence of more than 100 large objects hitting Earth. [5] One of them, estimated to have been about 6 miles in diameter, is believed to have struck the Yucatan peninsula of Mexico 65 million years ago, causing the extinction of over 50 percent of all species on Earth, including all of the dinosaurs; this is the so-called "KT boundary" event, ending the Cretaceous period and beginning the Tertiary period. [6] Such a 6-mile-diameter asteroid hitting Earth today would threaten all life and civilization, as it would have the force of a 100 million-megaton explosion, which is 10,000 times what the combined nuclear arsenals of the United States and the Soviet Union could have produced at the end of the Cold War period. [7]

Ronald Prinn of the Massachusetts Institute of Technology demonstrated through use of computer simulation the devastation which would be caused by a 6-mile-diameter asteroid:

> As the asteroid passed through the atmosphere, a shock wave created intense heat, igniting forests and grasslands for thousands of miles around the impact site. The sudden atmospheric heating also formed nitric oxides, which later produced acid rain. As the resulting dust and soot turned day into darkest night, the earth was defoliated, and photosynthesis ceased on most of the planet. For perhaps as long as a year the planet froze, until the clouds cleared and the carbon dioxide released by the vaporization of terrestrial rocks led to global warming. [8]

The question now, said Prinn, was not how the dinosaurs died, but how any other life was able to survive. [9] Fortunately, scientists believe that objects as large as 6 miles in diameter colllide with Earth only once every 50 to 100 milion years or so. [10]

C. The 1908 Tunguska Event

The most recent event of a near-Earth-object actually colliding with the Earth occurred in 1908, when on June 30th a small comet composed of ice and rock, now estimated by scientists to have been about 180 to 300 feet in diameter, entered the Earth's atmosphere and exploded at about 20,000 feet over a remote region of Siberia near the Tunguska River. [11] Apparently, as far as is known, no one was present at the site under the explosion and there were no fatalities, but the effects were still noticable over distance and time; as Chapman and Morrison describe:

> There was only one literate witness, a trader at a post about 70 miles away, and the explosion even at that distance was sufficient to knock him off his chair. But the blast wave was large enough to be detected by instruments all over the world, and the shattered forest had still not recovered when Soviet scientific expeditions surveyed the area 20 years later. [12]

The blast is now believed to have been at least 12 megatons, based on meteorological baragraph recordings in England, and possibly as high as 20 megatons, based on the radius of destruction. [13] The region of the taiga forest affected by the explosion, 2000 square kilometers, would have encompassed an area as large as New York City:

> Siberian forest trees were mostly knocked to the ground out to distances of about 20 km from the endpoint of the fireball trajectory, and some were snapped off or knocked over at distances as great as 40 km. Circumstantial evidence suggests that fires were ignited up to 15 km from the endpoint by the intense burst of radiant energy. The combined effects were similar to those expected from a nuclear detonation at a similar altitude, except, of course, that there were no accompanying bursts of neutrons or gamma rays nor any lingering radioactivity. Should a Tunguska-like event happen over a densely populated area today, the resulting airburst would be like that of a 10- to 20-megaton bomb: buildings would be flattened over an area 20 km in radius, and exposed flammable materials would be ignited near the center of the devastated region. [14]

D. The Arizona Meteor Crater

The Tunguska object did not produce an impact crater, since it exploded far above the Earth's surface, but many other NEO's which have collided with Earth have produced impact craters. The most famous is the Arizona Meteor Crater, "the best example on our planet of a relatively fresh impact crater similar to the features that are found in such abundance on the Moon, Mercury, and Mars." [15] The Arizona Crater is shaped like a bowl, about 4000 feet in diameter and 600 feet deep. It was formed about 50,000 years ago when a nickel-iron alloy meteor, estimated to have been about 200 feet in diameter with a mass of several million tons, struck the ground. [16] The resulting explosion is estimated to have been from 10 to 20 megatons. [17] Although the Meteor Crater is surrounded by an extensive ejecta blanket (indigenous soil and rock as well as fragments of the original meteor thrown out from the impact site by force of the impact), the meteor itself was destroyed upon impact. [18]

All in all, approximately 130 impact craters have been identified on Earth on land, ranging in size up to the 124 mile diameter Chicxulub crater on the Yucatan peninsula, believed to be the KT boundary object, and ranging in age from relatively young in geological time, such as the 50,000 year-old Arizona Crater, to about 2 billion years old. [19] Other land impact craters may not yet have been discovered, due to effects of erosion and other geological processes, and any objects which impacted in the Earth's oceans obviously would be very difficult to find and study, if in fact they survived the impact in the first place.

II. Response of the Scientific Community

Much of the initial response of the scientific community to the possibility of impact catastrophes, long a popular subject in science-fiction, was directed toward simply refuting the psuedo-science of sensationalists such as Immanuel Velikovsky. [20] It was the work of competent scientists, such as Luis W. Alvarez and his son, Walter Alvarez, which led the way to the current views of scientists on impact catastrophes on Earth.

Luis Alvarez, a Nobel-Prize-winning physicist, and his son Walter, a well-known Professor of Geology at Berkeley, began research in the late 1970s which led to the now-accepted theory among most scientists that the Cretaceous period, the third and last of the periods of the Mesozoic Era, the era in which dinosaurs were the dominant life forms, was ended by the effects caused by the impact of an asteroid or comet at least six miles in diameter. [21] It was the publication of a paper by the Alvarezes in 1980 in *Science* magazine which marks an historic turning point in the attitude of the general scientific community toward the study of such impact catastrophes on Earth; before the 1980s, geology textbooks did not even discuss the possibility of such events, and traditionally-trained geologists usually considered such possibilities psuedo-science, such as proffered by Velikovsky. [22] By the end of the 1980s, much research had been done by scientists which supported the Alvarez impact hypothesis concerning the KT boundary event. [23]

The first organized consideraton of the current threat to Earth posed by the implications of the Alvarez research was in June 1980, when NASA sponsored a week-long seminar at Woods Hole, Massachusetts, on new directions and goals for the agency. [24] Many topics were discussed with no relationship to impacts by asteroids or comets, but one subgroup did consider the threat and concluded that it should be taken seriously. This subgroup, which included Luis Alvarez, NASA Administrator Robert Frosch, and other noted space scientists and engineers, proposed a "Project Spacewatch" to address the threat:

> The idea was to build optical and radar telescopes capable of discovering the potentially threatening asteroids and comets, and then - in the unlikely event that one should be found to be on an eventual collision course with Earth - to undertake a rendezvous space mission to "give the object the proper nudge," perhaps by exploding a bomb alongside it. [25]

In July 1981, NASA followed up the "Spacewatch" idea by conducting a workshop, through the NASA-Jet Propulsion Laboratory, at Snowmass, Colorado, entitled "Collision of Asteroids and Comets with the Earth: Physical and Human Consequences." [26] The Workshop was attended by scientists and engineers from a wide range of relevant disciplines, who explored the Spacewatch idea in more detail than had been done the previous year at the more broadly-oriented Woods Hole seminar. [27] Although in September 1981 the NASA-JPL workshop produced a 100-page draft report, this report was never released; much later, in 1989, Chapman and Morrison included a summary of the main conclusions of the workshop report in their book, *Cosmic Catastrophes*, and also presented these results at the American Geophysical Union Natural Hazards Symposium. [28] After discussing the historical and geological evidence of asteroid and comet impacts, the effects of such impacts, and the probability of impacts of various-sized objects, the draft workshop report concluded that "a dedicated telescope could detect many of the most hazardous near-Earth asteroids in a 10-year program and that larger efforts - well within technological capabilities and practical cost limits - could discover even more of them, could track their trajectories, and could 'ameliorate' a potential catastrophe, if an object were discovered to be on a collision course." [29]

In 1990, the American Institute of Aeronautics and Astronautics published a position paper entitled *Dealing with the Threat of an Asteroid Striking the Earth*. [30] Noting in its introduction the passage of the March 23, 1989 asteroid, now named "Apollo Asteroid 1989 FC" by scientists, through Earth's orbit only 6 hours after Earth had been at that same point, the paper warned that:

> Had it struck the Earth, the energy released would have been equivalent to that of 1000 to 2500 megatons of TNT (or 1000-2500 one-megaton hydrogen bombs). In an area of high population density such as the northeast corridor of the U.S., Los Angeles, or Tokyo, millions of people would have died instantly. [31]

The AIAA paper, which originated in the AIAA Space Systems Technical Committee and was approved by the AIAA Board of Directors, went on to recap briefly some of the history of the discovery of the Apollo asteroids which cross Earth's orbit as well as briefly discuss their threat to Earth, including the assessment by some scientists that the risk to any single human of being killed by an asteroid is comparable to that of being killed on an airplane trip. [32] The paper's recommendations included "that a systematic and open program be established to detect and define the orbits of Earth-crossing asteroids with a precision which will permit the prediction of impacts with some confidence," and "that a study also be performed to define systems which can deflect or destroy, or significantly alter the orbits of, asteroids predicted to impact the Earth." [33]

The AIAA took its recommendations to Congress, specifically, the House Committee on Science, Space and Technology. This led to the Committee's findings:

> 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 the Earth being struck by a large asteroid are extremely small, but since the consequences of such a collision are extremely large, the Committee believes 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 would 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. [34]

Pursuant to this mandate, NASA organized the NASA International Near-Earth-Object Detection Workshop in spring 1991, which held an International Conference on Near-Earth Asteroids, June 30-July 3, 1991, at the San Juan Capistrano Research Institute in California. Subsequent meetings were held September 24-25, 1991, at the NASA-Ames Research Center, and on November 5, 1991, in Palo Alto, California. [35] Other asteroid-related events in 1991 were a meeting in St. Petersburg, Russia, October 9th-10th, on the "Asteroid

Hazard," and a resolution endorsing international searches for near-Earth objects (NEOs) passed by the General Assembly of the International Astronautical Union (IAU), in August in Buenos Aires, Argentina (see below). [36]

III. The Spaceguard Survey Report

The *Spaceguard Survey* report of the NASA International Near-Earth-Object Detection Workshop is one of the products mandated by Congress. A second workshop examined the question of altering asteroid orbits. Detailed examination of the issues raised by this second workshop is beyond the scope of this paper, which is addressed to the detection function and its legal aspects; also, the report of the second workshop has not been released at the time of this writing.

The Detection Workshop determined that the greatest danger is posed by NEOs with diameters of more than 1 km:

> The greatest risk from cosmic impacts is associated with objects large enough to disturb the Earth's climate on a global scale by injecting large quantities of dust into the stratosphere. Such an event would depress temperatures around the globe, leading to massive loss of food crops and possible breakdown of society.... The possibility of such a global catastrophe is beyond question, but determining the threshold impactor size to trigger such an event is more difficult. Various studies have suggested that the minimum mass impacting body to produce such global consequences is several tens of billions of tons, resulting in a groundburst explosion with energy approaching a million megatons of TNT. The corresponding threshold diameter for Earth-crossing asteroids or comets is between 1 and 2 km. Smaller objects (down to tens of meters diameter) can cause severe local damage but pose no global threat. [37]

Impacts from such more than 1 km objects occur on the average of from "once to several times" each million years and "are qualitatively as well as quantitatively different from any other natural disasters in that their consequences are global, affecting the entire planet." [38] Of the total population of NEOs, about 90 percent are near-Earth asteroids or short-period comets, while the remaining 10 percent are intermediate- or long-period comets with orbital periods of more than 20 years. [39]

The Workshop defined a survey or search strategy with the objective of finding "most of the larger and potentially hazardous NEOs (not necessarily when they are near the Earth)," calculating their long-term orbital trajectories, and identifying "any that may impact the Earth over the next several centuries." [40] Any NEOs which appeared to be on Earth-impact trajectories would not threaten Earth for "at least several decades," giving sufficient time to take corrective action. [41] The Workshop also stated, however, that it was not discussing either a short-range search or a quick-response defense system:

> The chance that a near-Earth asteroid will be discovered less than a few years before impact is vanishingly small. The nature of the NEO orbits allows us to carry out a deliberate, comprehensive survey with ample time to react if any threatening NEO is found. In contrast, however, the warning time for impact from a long-period comet might be as short as a few months, requiring a different class of response. [42]

As for the current state of knowledge about the NEO threat, the Workshop concluded that "(n)o object now known has an orbit that will lead to a collision with our planet during the next few centuries, and the vast majority of the newly discovered asteroids and comets will also be found to pose no near-term danger." [43]

The Workshop recommended a survey consisting of "a coordinated international network of specialized ground-based telescopes for discovery, confirmation, and follow-up observations," involving both the northern and southern hemispheres. [44] The technology for such a survey has already been developed and demonstrated by the University of Arizona. [45] The Workshop's conclusion was that the survey should focus on detecting objects larger than about 1 km in diameter:

> The international survey program described in this report can be thought of as a modest investment to provide insurance for our planet against the ultimate catastrophe. The probability of a major impact during the next century is very small, but the consequences of such an impact, especially if the object is larger than about 1 km diameter, are sufficiently terrible to warrant serious consideration. The Spaceguard Survey is an essential step toward a program of risk reduction that can reduce the risk of an unforeseen cosmic impact by more than 75 percent over the next 25 years. [46]

IV. Legal Aspects of Near-Earth Asteroid Detection Efforts

The major legal consideration of the NEO survey discussed and recomended by the Workshop is international cooperation. Apart from informal efforts consisting of personal links between scientists in various countries, organized efforts have been in progress for several years, the most prominant of which is the International Near-Earth Asteroid Survey (INAS), which has increased cooperation among observatories in 17 countries. [47] The Workshop recommends an immediate expansion of this effort before the full network of survey telescopes becomes operational. [48]

A successful international survey program would need to be "arranged on an inter-governmental level," according to the Workshop:

> To ensure stability of operations, the NEO survey program needs to be run by international agreement, with reliable funding committed for the full duration of the program by each nation involved. [49]

In August 1991, the XXIst General Assembly of the International Astronomical Union passed a resolution recognizing the threat posed by NEOs and the need to learn more about them. The resolution called for the establishment of an ad hoc Joint Working Group on NEOs with the following mandate: (1) Assess and quantify the potential threat, in close interaction with other specialists in these fields; (2) Stimulate the pooling of all appropriate resources in support of relevant national and international programs; (3) Act as an international focal point and contribute to the scientific evaluation, and; (4) Report back to the XXIInd General Assembly of the IAU in 1994 for possible further action. [50]

The *Spaceguard Survey* has a similarity to the NASA Search for Extraterrestrial Intelligence (SETI) program, now renamed the High Resolution Microwave Survey for domestic political reasons. But while it is not clear whether the discovery of intelligent life beyond Earth orbit would pose any type of threat to Earth (and good argument exists to the contrary), the discovery of an NEO on a collision course with Earth would evoke the most basic duty of any government to its people, namely, the protection of those people from violent death. In this respect the Spaceguard Survey is very evocative of the weather prediction activities of the National Oceanic and Atmospheric Administration (NOAA) of the United States Department of Commerce. NOAA's ability to predict violent weather phenomena, such as hurricanes, tornadoes, and severe snow- and rainstorms directly affects lives and property. The same is true for the forest fire prediction and suppression efforts of the United States Forest Service and the nascent Earthquake prediction efforts of the United States Geological Survey. While NASA has not heretofore been thought of as providing such lifesaving services, other than through activities such as the development and launching of meterological satillites (which are operated by NOAA or by foreign countries), NASA's role in the *Spaceguard Survey* clearly will go beyond the realm of pure scientific study and into the lifesaving function if an NEO is found to be on a collision course with Earth.

Regarding the major treaties on outer space activities, only the 1967 Outer Space Treaty has any relevance to the detection efforts of the *Spaceguard Survey*, and then only generally and by way of evocation. For example:

<u>Article I</u>: "The exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind....

"There shall be freedom of scientific investigation in outer space, including the Moon and other celestial bodies, and States shall facilitate and encourage international co-operation in such investigation."

<u>Article III</u>: "States Parties to the Treaty shall carry on activities in the exploration and use of outer space, including the Moon and other celestial bodies, in accordance with international law, including the Charter of the United Nations, in the interest of maintaining international peace and security and promoting international cooperation and understanding."

<u>Article V</u>: "....States Parties to the Treaty shall immediately inform the other States Parties to the Treaty or the Secretary-General of the United Nations of any phenomena they discover in outer space, including the Moon and other celestial bodies, which could constitute a danger to the life or health of astronauts."

<u>Article IX</u>: "....States Parties to the Treaty shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose...."

It is obvious that the drafters of the Outer Space Treaty, though quite prescient in many other ways, were not thinking about NEOs and their danger to Earth, although the quoted provisions of Articles V and IX do come suggestively close (for example, just change the word "astronauts" at the end of Article V to "residents of the Earth"!). Since the detection phase of the evolving NEO response plan, which has been well-stated by the Workshop in the *Spaceguard Survey*, does not involve launching any objects into outer space, but only studying certain of the smaller celestial bodies from the Earth, the Treaty provides only the most general guidance.

Regarding the second phase of the NEO response plan, the deflection of any NEO which is determined to be on a collision trajectory with Earth, the Outer Space Treaty, as well as several of the other space treaties, has much that must be considered in planing and executing such a response. These considerations, however, are beyond the scope of this paper, and the deflection phase has yet to be stated publicly in any coherent and rational manner at the time of this writing.

V. Conclusion

The *Spaceguard Survey* presents no legal problems which need to be remedied. A formal agreement among the individual scientists and institutions conducting the survey should be executed, however. This agreement could be similar to the two-page SETI "Declaration of Principles Concerning Activities Following the Detection of Extraterrestrial Intelligence," which sets forth "a series of guidelines for individuals or organizations, national or international, engaged in carrying out radio searches for extraterrestrial intelligence." [51]

Footnotes

1. *The Spaceguard Survey: Report of the NASA International Near-Earth Object Detection Workshop* (Morrison, ed.), January 25, 1992, at p. v (hereinafter *Spaceguard Survey*). See also a shorter version prepared by Dr. Morrison for the 43rd Congress of the International Astronautical Federation at: Morrison, *An International Program To Protect the Earth from Impact Catastrophe: Initial Steps* (IAA-92-0226, 1992).

2. AIAA, *Dealing with the Threat of an Asteroid Striking the Earth*, at 1 (April 1990). Press reports at the time reported that the impact would have been in the range of 20,000 megatons. *See* Leary, "Unseen Asteroid Comes Near Earth," *New York Times*, April 20, 1989, at A1, col. 1; and Johnson, "Scientists Try to Handicap the Odds of a Great Celestial Smashup," *New York Times*, April 23, 1989, at sec. 4, p. 7, col. 1.

3. *Id.*

4. Wilford, "Astronomers Duck as a Tiny Asteroid Passes," *New York Times*, January 25, 1991, at A12, col. 1.

5. Verschuur, "This Target Earth," *Air & Space*, October/November 1991, at 88, 89; and Leary, *supra* note 2.

6. Verschuur, *id.* at 88.

7. *Id.* at 89-90.

8. *Id.* at 89.

9. *Id.*

10. Chapman and Morrison, *Cosmic Catastrophes*, at 77 (1989).

11. *Id.* at 4, 19. The *Spaceguard Survey* estimates that the object was only about 60 meters in diameter. *Spaceguard Survey*, *supra* note 1, at 8.

12. Chapman and Morrison, *supra* note 10, at 4. Due to the remoteness of the Tunguska regon as well as the political upheaval in Russia accompanying the First World War and the subsequent revolution and civil war, the Tunguska event was not investigated scientifically until 1927 and 1929. *Id.* at 13.

13. *Spaceguard Survey, supra* note 1, at 8, 9.

14. *Id.* at 9 (also see photo and diagram on page 8).

15. Chapman and Morrison, *supra* note 10, at 14. This crater is sometimes called the Barringer Crater, after the geologist who first studied it scientifically and whose descendants still own it. *Id.* at 16.

16. *Id.* at 18.

17. *Spaceguard Survey, supra* note 1, at 2.

18. Chapman and Morrison, *supra* note 10, at 20, 21.

19. *Spaceguard Survey, supra* note 1, at 4; and Verschuur, *supra* note 5, at 89.

20. Velikovsky published several books, beginning in the 1950s, arguing that celestial objects struck Earth, but he was not a competent scientist and did not base his theory of planetary collisions on new evidence from geology or astronomy. Chapman and Morrison, *supra* note 10, at 186 and Chapter 13 generally.

21. Chapman and Morrison, *supra* note 10, at 82, 86, and Chapter 6 generally. A comet would have had to have been larger than an asteroid to produce the same effect. *Id.* at 86.

22. *Id.* at 82, 87.

23. *Id.* at 87 (see the discussion at 88-93).

24. Chapman and Morrison, *supra* note 10, at 276.

25. *Id.*

26. *Spaceguard Survey, supra* note 1, at 1; and Chapman and Morrison, *supra* note 10, at 277

27. Chapman and Morrison, *supra* note 10, at 277.

28. *Spaceguard Survey, supra* note 1, at 1; and Chapman and Morrison, *supra* note 10, at 277-280, for a discussion of the workshop conclusions. Chapman and Morrison state in their book that while some of the workshop results were controversial, the main reason the report was not released in 1981 was that many of the workshop leaders were too busy with other projects. *Id.* at 277.

29. *Id.* at 280.

30. AIAA, *supra* note 2.

31. *Id.* at 1.

32. *Id.* at 1-2. The first such object was discovered in 1932. Apollo asteroids are named after the Greek Sun god because their orbits come close to the Sun; most asteroids orbit the Sun between the orbits or Mars and Jupiter. The history and science of asteroid astronomy are discussd in detail in Chapman and Morrison, *supra* note 10, Chapters 1-12, and 19. For a table of risk estimates, see *id.* at 283.

33. AIAA, *supra* note 2, at 2-3.

34. *Spaceguard Survey, supra* note 1, at 2-3.

35. *Id.* at 3.

36. *Id.* at 1, 46.

37. *Id.* at v.

38. *Id.* at 5.

39. *Id.* The "period" of an orbiting object is the length of time it takes for the object to complete one orbit around the celestial object it is orbiting, which in the case of all NEOs, whether asteroids or comets, is the Sun.

40. *Id.*

41. *Id.*

42. *Id.*

43. *Id.* at v.

44. *Id.* Technical details of both the survey strategy and the technology involved are presented in Chapters 5, 6, and 7.

45. *Id.* at vi.

46. *Id.*

47. *Id.* at 45.

48. *Id.*

49. *Id.* at 46.

50. *Id.*

51. Letter from Dr. John Billingham, Chief (Acting) SETI Office, NASA-Ames Research Center, February 15, 1991.