THE WORKING GROUP ON AN INTERNATIONAL APPROACH TO DETECTING EARTH-THREATENING ASTEROIDS AND COMETS AND RESPONDING TO THE THREAT THEY POSE

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MANDATE

To explore the issues surrounding Earth-threatening asteroids and comets and make recommendations on how the international community should approach the issues posed by these objects.

EXECUTIVE SUMMARY

Near-Earth objects (NEOs) are asteroids and comets that periodically cross or approach the orbit of the Earth. In recent years, the scientific community has come to the conclusion that not only has the Earth been impacted many times in the past by NEOs, but that there is a real and credible threat of future impacts. Whereas the probability of an impact is low, such an event could cause a global catastrophe for all living things on the planet. The threat therefore warrants serious and immediate attention.

The international scientific and engineering communities have held a number of workshops to understand the NEO issue and to investigate whether countermeasures are possible. The general conclusion from these workshops is that current detection efforts are inadequate and that, while countermeasures to either fragment or deflect an incoming NEO are feasible, such efforts would require a large, expensive, and coordinated international effort. Current NEO activity is limited, poorly funded, and not conducted in a coordinated manner. In addition, both the general public and government decisionmakers are poorly informed on the nature and seriousness of the threat.

Several time-phased activities must be undertaken to properly address the NEO threat. NEO detection capabilities must be improved through the deployment of additional and larger ground-based telescopes, some of which should be sited in the southern hemisphere. Additional NEO science data centers need to be established to supplement the IAU Minor Planet Center (MPC), and all of these facilities should be assured of stable and adequate funding. A NEO-dedicated 1-m-class near-infrared space telescope facility should be stationed at the L2 Lagrangian point. In addition, several 25-m-class optical telescopes should be placed in space to detect long-period comets with adequate warning time for action to be taken. The pursuit of NEO-specific research in universities, laboratories, institutes, think tanks, and other organizations should also be encouraged.

Concurrent with detection, it is not premature to consider options for countermeasures. A study on how the world's current spaceflight capabilities might be used to counter a near-term NEO threat should be initiated. In the longer-term, this may evolve into a dedicated planetary defense system. Such a system should deflect rather than fragment an incoming NEO, and this should be done by non-nuclear means if possible. However, the option of using nuclear devices must be preserved as they are probably the only effective option for very large bodies or those for which we have little warning time.

To raise international awareness of the NEO issue, a second international conference on the topic should take place under the auspices of the United Nations (U.N.). It is also important to initiate a dialogue with organizations like disaster-management agencies and environmental groups that to date have not been engaged by the NEO community but need to be educated on the threat and solicited for their potential contributions. Finally, an effective executive body to coordinate international NEO activity is needed. Given the global nature of the threat, this body should operate under the auspices of the U.N..

Background

In the last few decades scientists have come to the conclusion that the Earth has been hit many times by celestial bodies large enough to cause global catastrophes for living things. The best example is the mass extinction of approximately 70% of living species, including the dinosaurs, about 65 million years ago, attributed to an asteroid impacting near the present-day town of Puerto Chicxulub, Mexico. Many smaller craters are also testament to numerous smaller impacts. It is also clear that such impacts are an ongoing phenomenon. Therefore, it is only a matter of time before a cataclysmic impact occurs in the future, one that would threaten not only human civilization but perhaps all life on Earth. This Working Group was formed to assess what needs to be done to prevent such a catastrophe. Furthermore, because the problem is inherently global in nature, it is logical that an international group should suggest possible solutions.

The threat from Earth-approaching asteroids and comets, referred to as near-Earth objects (NEOs), is illustrated in Figure 1. An impact by a NEO larger than about a few kilometers in diameter would produce global devastation by a number of effects, such as introducing large quantities of debris into the atmosphere, which would result in near total darkness persisting for months to years, killing most terrestrial life. Objects between about 100 m and 1 km in diameter would produce massive destruction and environmental disturbances that would kill millions of people, but their effects would likely tend to be local or regional rather than global. NEOs less than 100 m but greater than several tens of meters in diameter would produce large craters but few casualties and no global effects. The only good news associated with NEO impacts is that they are expected to occur infrequently, as illustrated in Figure 2; 10-km NEOs are expected to impact on average every 100 million years or so, 1-km NEOs every 100,000 years, and 100-m NEOs every few centuries. Although this does not mean that a large one will not strike next year, the probability is very small. Nonetheless, if it were to occur, the devastation would be of a horrific magnitude.

Figure 1: Expected Fatalities Due to Asteroid Impacts

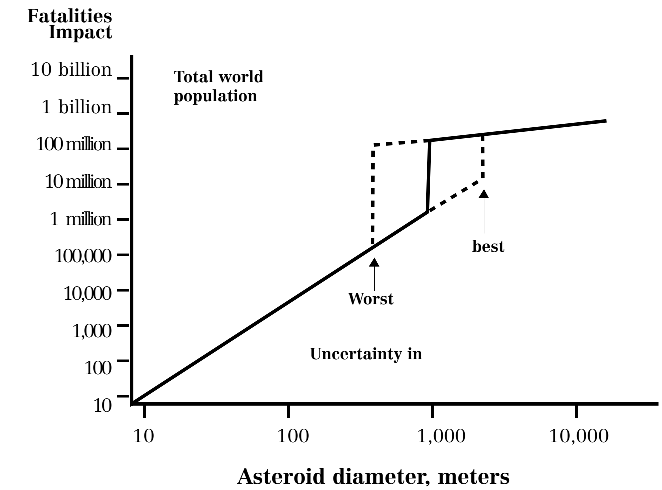
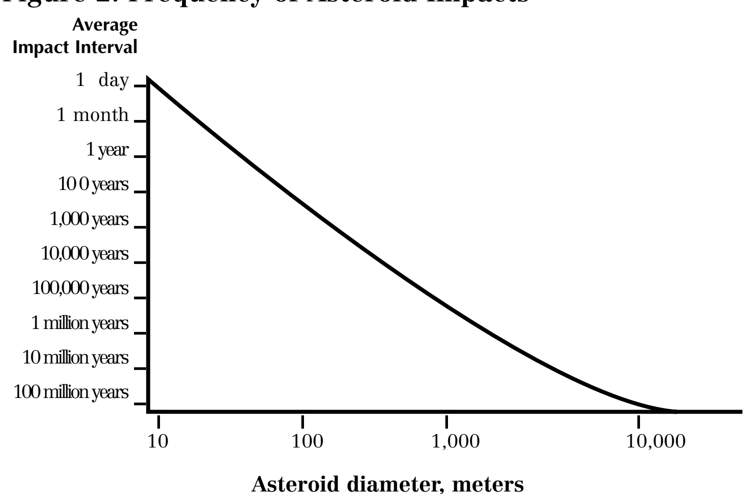


Figure 2: Frequency of Asteroid Impacts



Most asteroids reside in a belt between Mars and Jupiter and are in rather stable orbits. The potentially dangerous ones are in eccentric orbits that cross the Earth's orbit and therefore could impact. It is estimated that there are on the order of 1000 of these objects greater than 1 km in diameter, and hundreds of thousands in the 100-m-class. The orbits of many of the largest ones have been determined. Impacts can also occur from short-period comets in asteroid-like orbits as well as long-period comets that come from deep space. The latter are, in a sense, the most dangerous objects, because their number and orbits are poorly known, and they appear so infrequently that there is no detection history for them. Furthermore, long-period comets impact at much higher velocities than asteroids, and consequently their destructive effects often exceed those from asteroids of the same size.

The international scientific and engineering communities have held a number of workshops to understand the threat posed by NEOs and to determine if countermeasures are possible. The European Space Agency (ESA), the U. N., NASA, Russia, and most recently a dedicated task force in the United Kingdom have studied this issue. The general conclusion has been that current detection programs can and should be improved. Countermeasures to either fragment or deflect these objects are feasible, but are neither inexpensive, quick, nor easy (heroic movies on the subject notwithstanding). Nonetheless, it is clear that contrary to the situation faced by the dinosaurs we indeed have the ability to prevent a NEO from killing us, but only if we apply a dedicated effort to the problem.

These efforts vary in feasibility and difficulty depending on the size of the NEO and the warning time that detection systems provide us. The Working Group assembled three scenarios to scope its deliberations:

- A modest scenario in which a 500-m diameter asteroid is discovered whose orbit is predicted with high confidence to impact the Earth in 20–50 years, causing large-scale but regionally limited devastation. In this case, the preferred response would be to deflect the NEO by altering its orbit with nonnuclear devices that are attached to the object by humans or by robotic systems. Given the long advance warning, there would be time for precursor scouting missions and experiments to provide data for designing the deflection procedure and, if necessary, for multiple deflection attempts to ensure success. Existing launch vehicles could be modified and adapted with upper stages to deliver a spacecraft and its deflection payload to the vicinity of the NEO, where the final maneuvering for contact would be performed by terminal homing propulsion. In addition, sufficient time would be available for executing terrestrial precautions, such as resettling people in coastal areas, should such efforts be deemed necessary. The probability of success is good.

- A more difficult scenario would be the detection of a 1–2-km diameter asteroid with at most 10 years of warning time. The impact of such an object would be devastating, killing perhaps over one billion people. Although humanity would probably survive, civilization would likely be sent back to the Stone Age. Multiple interception attempts may still be possible in the time available. Nonnuclear methods might be attempted initially, but if these are unsuccessful then nuclear devices would have to be employed. The current spaceflight infrastructure may be employed (with modifications) initially, but a dedicated launch/interceptor system would probably have to be developed rapidly and used if subsequent deflection attempts are required. The probability of success is moderate.

- The most difficult scenario would be the discovery of a 5-km diameter or greater long-period comet with only two years of warning time (which in itself is optimistic, given the difficulty of discovering such comets even that far in advance). This NEO would destroy all humans and almost all life on Earth. The response would be a desperate, direct-ascent interception attempt using dozens of modified contemporary launchers with crash-program-developed upper stages and interceptors equipped with nuclear weapons. The impending doom would doubtless result in civil chaos, mass panic, upheaval of the social structure, and millions of deaths even before the actual impact. Attempts would be made to protect a sample of humanity, perhaps in a deep underground cavern where they would have to reside for years in the hopes of an eventual return to the surface. The probability of success is low.

The preceding scenarios constitute a representative set of situations that raise a number of technical and nontechnical issues. Although the technical factors associated with detection and countermeasures have been addressed by prior workshops, deficiencies in current capabilities and solutions to deal with them in the context of the preceding scenarios have not. Furthermore, the organizational, political, and sociological issues are as important as the technical ones, but to date these have received little attention. These issues include questions such as: Which organization or body should be in charge? How should the existence of a threat be announced to avoid false alarm and avoid panic? How should the use of nuclear devices be coordinated and regulated? Who should authorize their deployment, and how should the fear associated with their use be allayed? Finally, how should social dislocations be minimized, as these might be as damaging as the direct results of the NEO strike itself?

A NEO impact is a unique event that would cause far greater damage than that from more familiar natural disasters such as major earthquakes. But there is a crucial difference: With proper effort, most NEO impacts could be predicted and likely prevented. Unfortunately, the public has been exposed to movies and television programs that have painted an unrealistic picture of the situation, and decisionmakers are in general poorly informed of both the threat and the fact that countermeasures are possible. There exists a "giggle factor" associated with the subject of NEO impacts, which may be due to psychological denial that such improbable events could actually happen to us or our children, the lack of knowledge on the part of governments and the public, the relative scarcity of consistent and credible information (in contrast to the widely available but unrealistic portrayals offered by the media and the entertainment industry), or perhaps a combination of all of these.

In consideration of the NEO threat, the working group addressed the following issues: the adequacy of current efforts to detect and confidently predict the impact of asteroids and comets; options for mounting realistic and effective countermeasures to those that are declared a threat; and the organization of the world community to validate potential threats and minimize panic, as well as to develop, coordinate, and employ an effective and timely countermeasure when a threat has been confirmed.

Findings and Recommendations

Detection

Finding 1—A number of ground-based NEO detection programs are currently operational. For asteroids larger than about 1-km diameter, these present systems are almost adequate, but are quite inadequate for smaller asteroids, such as a few hundred meters in diameter, and other short-period bodies. Moreover, the present capability for detecting long-period comets is almost nonexistent.

Recommendation 1—NEO detection capabilities can and must be greatly improved.

The construction of at least two dedicated 3-4-m-class ground telescopes would significantly improve the detection of large and small asteroids. One should be stationed in each hemisphere, with priority given to situating such a facility in the southern hemisphere because of the present lack of any significant observational capability in that part of the world. The Large Synoptic Survey Telescope (LSST) could be an important asset to the detection effort if a well-designed NEO program were to be incorporated into its operation.

A core capability equivalent to a network of several large telescopes, stationed around the world, should be established for follow-up observations for orbit determination. This capability may be achieved in a cost-effective manner by refurbishing existing facilities that are underutilized. The use of radar for follow-up observations should also be increased as it is the best method of obtaining range and range-rate data for orbit determination.

Space-based systems should be developed to complement ground-based detection methods. This is especially cost effective when such capabilities can be derived from existing or planned missions. For example, the detection of smaller NEOs can be improved, at little further cost, through the placement of instruments aboard spacecraft bound for the inner solar system, like ESA's BepiColombo mission to Mercury. Observations by Earth-orbiting spacecraft, whether from an astronomical mission like ESA's GAIA space telescope or a dedicated NEO satellite, complement data obtained from the ground. These space-based systems are particularly effective for the detection of Atens (asteroids with a semimajor axis of less than 1 AU) and inner-Earth objects.

The detection of long-period comets is an exceptionally difficult task that can only be effectively accomplished by deploying several 25-m class telescopes in space. Innovative engineering concepts have been identified that could make such facilities practical and affordable in the longer term. In contrast to the asteroid problem, long-period comets represent an ongoing threat, as these bodies continuously enter the inner solar system from the Oort cloud.

Finding 2—The IAU Minor Planet Center (MPC) is currently the only facility that collects astrometric observations, correlates observational data to objects, and determines the orbits for cataloging.

Recommendation 2—Additional NEO science data centers should be established to complement the MPC, and all of these should be put on an adequate and stable financial footing.

As the MPC currently represents a single-point failure, multiple international institutions are required to put the NEO search and cataloging functions on a permanent and continuously available basis. The MPC has played and will continue to play a crucial role in NEO detection, and the funding of the MPC and other recommended centers should be at a level commensurate with the importance of their mandate.

Finding 3—Beyond the determination of a few basic properties, the physical characterization of detected NEOs is virtually nonexistent.

These characterization data will be essential if a threat is identified because the appropriate countermeasure is dependent on the strength and mineralogical properties of the object. Furthermore, characterization of a representative sample of NEOs of all types and sizes could enable a faster and better characterization of a threatening object when it is discovered.

Recommendation 3—Space-based systems are required to fully characterize the geophysical properties of NEOs.

Although the augmentation of ground-based telescopes recommended earlier for detection purposes would also help in characterizing some NEO properties, the full and systematic characterization of necessary NEO properties requires a dedicated infrared space-based telescope facility of at least 1-m in diameter stationed at the L2 Lagrangian point. Such a facility would also discover objects with aphelia near the Earth's orbit, as well as very dark and small NEOs that would otherwise be extremely difficult to detect. The full geophysical characterization of NEOs also requires further rendezvous and landing/sampling missions to follow-up on the findings from spacecraft like NEAR Shoemaker, Rosetta, and Muses-C.

Finding 4—There is not enough NEO-specific work being conducted in academia and research institutions.

Recommendation 4—Foster the pursuit of NEO research in universities, laboratories, institutes, think-tanks, and other organizations around the world.

There are many gaps in our current understanding of NEOs and impact effects in which research should be undertaken. The pursuit of this work should be encouraged in research organizations and institutions around the world. The university environment has the particular attributes of being cost-effective while providing a training ground for young people to continue work in the field. In addition, entities that thus far have not been involved in the NEO issue, like the social sciences departments of colleges and universities, should be engaged to conduct work such as studying the sociological implications of the impact threat.

Countermeasures

Finding 1—Countermeasures to the NEO threat are possible and have been identified. However, no plans currently exist on how such countermeasures would be implemented.

Recommendation 1—Initiate a study on how the world's current spaceflight capabilities and infrastructure could be used to counter a near-term NEO threat.

This study should address the creation of a contingency capability for countering a near-term NEO threat using the present space infrastructure. Plans should be devised on how available resources like launchers, spacecraft, ground segment facilities, and both nuclear and non-nuclear technologies should be employed. The study should also address organizational issues as well as the command and control structure that such a system would require.

Finding 2—Whereas an object may be fragmented or deflected, the latter is preferable. Both nuclear and nonnuclear options exist for deflection. The use of nuclear devices may be the only option for extremely large objects, or those for which the time from detection to impact is very short.

Recommendation 2—In devising NEO deflection strategies, deflection by nonnuclear means should be pursued where possible. However, because nuclear devices may be the only effective countermeasure means for threats with the most potential for devastation, the option of using them must exist.

Deflection is preferable to fragmentation. Fragmentation will likely just shatter a body into smaller pieces of equal cumulative mass that, if not sufficiently dispersed, would simply spread the destruction over a wider area.

Nonnuclear engagement methods are preferred and are feasible in many cases. Such technologies include solar sails, ion engines, mass drivers, and kinetic impactors, the preferred technologies being dependent on size and available warning time. The development of these nonnuclear technologies will have other long-term benefits as they may be employed for future applications such as asteroid mining and deep space transportation systems. As described in "Detection Findings and Recommendations," spacecraft are not only required for the characterization of the geophysical nature and composition of minor bodies but in doing so also demonstrate hardware and techniques that may be required for deflection, such as rendezvous, proximity operations, impactor deployment, landing/docking, and subsurface drilling. In-situ measurement and sampling missions should be pursued to follow up on current projects like Rosetta, Muses-C, and Deep Impact.

The option of nuclear devices must be available if the threat warrants their use, but the treaty implications of employing nuclear devices needs to be discussed. In particular, the ramifications of the 1963 Limited Test Ban Treaty and the 1967 Outer Space Treaty require examination. This discussion should be initiated immediately, before the development of and certainly before the deployment of any kind of planetary protection system for which nuclear devices may be required.

Organization

Finding 1—A high-profile forum is required to raise international awareness of the NEO issue at all levels.

Recommendation 1—Organize an international conference on NEOs under the auspices of the United Nations.

One or more member states of the United Nations should request the U.N. Office for Outer Space Affairs to organize and host a second international conference on NEOs to bring together diverse communities to address these issues. This could be accomplished with existing financial resources, as was done for UNISPACE III. Invitees should include the environmental organizations that have cosponsored major environmental forums like the Rio and Kyoto conferences. Given that a NEO impact would result in environmental devastation orders of magnitude more severe than any known to human experience, it is imperative that the environmental, disaster management, and other relevant communities be informed of the threat and that the issue is elevated to a level of high visibility on the international stage.

Finding 2—Existing disaster-management organizations are not educated on the NEO threat. Although national organizations exist for local post-disaster mitigation and rebuilding efforts, they are not equipped to handle the kind and magnitude of catastrophe that would result from a NEO impact.

Recommendation 2—Engage disaster-management organizations in a dialogue and make them aware of the NEO threat.

Existing disaster-management organizations need to be educated on the existence, nature, and magnitude of the impact threat. These organizations should then be solicited to bring their expertise to bear on the NEO impact problem. An international workshop should be conducted in which an impact with regional consequences is hypothesized and participants assume different roles in a simulated disaster response. Such an exercise would demonstrate capabilities and identify gaps in the current global disaster-management infrastructure for dealing with NEOs and would raise public and political awareness of the threat.

Finding 3—No global organization currently exists to address or coordinate any aspect of the NEO threat. The United Nations is currently not involved with the issue.

Recommendation 3—Create an effective executive body to coordinate international NEO activity and operate it under the general auspices of the United Nations.

Funding would be provided at a modest level for the initial program definition and would increase to an appropriate level as this body defines its programs. The activities of this body should include the generation and implementation of a strategic plan for communications and public awareness (i.e., communicate the reality of the threat to the public and world governments, and be a source of credible and consistent information); the coordination, validation, and announcement of an actual NEO threat; the generation and implementation of strategic plans for detection and interception; and, if necessary, the coordination of a countermeasure response execution, as well as the coordination of disaster-mitigation response measures.

Conclusions

The Working Group assessed the threat from asteroids and comets and concluded that it is real and very serious. Current detection and impact prediction efforts are insufficient, and no countermeasure plans or programs exist, even though effective ones are possible. Of equal importance is that there is currently no world mechanism or organizational body to validate and announce the existence of a threat, coordinate the execution of countermeasures, or coordinate global disaster management in the event of an impact.

Specific steps are recommended for the augmentation of current ground-based detection capabilities and the creation of more adequate ones, including dedicated space-based observatories and the development of countermeasure programs to deflect or fragment an incoming NEO. In addition, recommendations are made for establishing an organization under the auspices of the United Nations to create global strategic and implementation plans for the international coordination and execution of the programs necessary to detect and engage NEOs. Such an organization would also be a source of consistent and credible information to the public and to world governments. These conclusions were made by an international group addressing an inherently global problem, and its actionable findings and recommendations should be adopted if the NEO threat is to be properly addressed.