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Near-Earth objects

Near-Earth objects

Interim report of the Action Team on Near-Earth Objects (2007-2008)

I. Introduction

1. The Action Team on Near-Earth Objects was established in response to recommendation 14 of the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III) and was given the following terms of reference:

(a) Review the content, structure and organization of ongoing efforts in the field of near-Earth objects (NEOs);

(b) Identify any gaps in the ongoing work where additional coordination is required and/or where other countries or organizations could make contributions;

(c) Propose steps for the improvement of international coordination in collaboration with specialized bodies.

2. At its fiftieth session, in 2007, the Committee on the Peaceful Uses of Outer Space noted with satisfaction the work carried out by the Working Group on Near-Earth Objects of the Scientific and Technical Subcommittee and the Action Team on Near-Earth Objects and endorsed the following new multi-year workplan for 2008-2010:[1]

* A/AC.105/C.1/L.293.

[1] *Official Records of the General Assembly, Sixty-second Session, Supplement No. 20* (A/62/20), para. 138.

2008 Continuation of intersessional work and consideration of reports submitted in response to the annual request for information on NEO activities. The presentations would focus on national, regional and international collaborative activity for observation and analysis of NEOs. While much progress is being made to reach current targets and new targets are under consideration, there remains a need to coordinate observations better and ensure timely follow-up. Updating of the interim report of the Action Team on Near-Earth Objects.

2009 Continuation of annual reporting on NEO activities and intersessional work in preparation for the 2009 theme, which will include an update on NEO missions and submission of an outline programme of draft procedures related to threat handling at the international level. Review and updating of the interim report.

2010 Continuation of drafting (or agreeing on) international procedures for threat handling and review of progress on cooperation and collaboration on observations. Review and updating of the interim report.

3. The present interim report is a summary based on input received from members of the Action Team on Near-Earth Objects for 2007-2008 and serves as an update to its previous interim report, which covered the period 2006-2007 (A/AC.105/C.1/L.290). The present report covers the activities and issues relating to the NEO hazard, the understanding of the risk posed by NEOs and the measures required to mitigate that threat. In accordance with the terms of reference of the Action Team, it is expected that an updated interim report will be issued each year to reflect the existing state of knowledge, related activities and the general consensus on prioritization of the issues to be addressed and their possible solutions. More detailed descriptions of activities can be found in the annual national reports provided to the Committee by Member States and in the presentations by the Committee members and observers at the annual session of the Subcommittee.

II. Interim report of the Action Team on Near-Earth Objects

A. Near-Earth object detection and remote characterization

4. The first step in addressing the risk posed by an NEO is to detect its presence and infer its size from its trajectory and observed brightness. The United States of America makes the most significant contribution to the field of NEO detection and remote characterization. The Near-Earth Object Program of the National Aeronautics and Space Administration (NASA) of the United States funds five NEO search teams to operate nine separate 1-metre class survey telescopes across the south-western United States and one in Australia, which can detect objects, on average, down to magnitude 20. Those five search teams are listed below together with the related websites containing further information:

(a) The Spacewatch project of the Lunar and Planetary Laboratory of the University of Arizona operates two telescopes on Kitt Peak, Arizona (http://spacewatch.lpl.arizona.edu);

(b) The Near-Earth Asteroid Tracking programme of the Jet Propulsion Laboratory of NASA operates a detection camera on a telescope at Palomar Observatory, California (http://neat.jpl.nasa.gov);

(c) The Lincoln Near-Earth Asteroid Research project of the Lincoln Laboratory of the Massachusetts Institute of Technology, under a United States Air Force contract funded by NASA, operates two telescopes near Socorro, New Mexico (http://www.ll.mit.edu/LINEAR);

(d) The Lowell Observatory Near-Earth Object Search of the Lowell Observatory near Flagstaff, Arizona, operates a 0.6-metre wide field telescope (http://asteroid.lowell.edu/asteroid/loneos/loneos.html);

(e) The Catalina Sky Survey, carried out by a separate team at the Lunar and Planetary Laboratory of the University of Arizona, operates two telescopes on Mount Lemmon, Arizona, and one at the Siding Spring Observatory, Australia, the first asset in the southern hemisphere (http://www.lpl.arizona.edu/css/).

5. The United States also operates two planetary radars capable of observing NEOs. For a short data arc, single apparition orbit solution, radar data are extremely powerful in reducing orbital uncertainties; radar observations can extend the orbital prediction capability to approximately 4.5 times longer than a comparable orbit solution using only optical observations. The Goldstone radar is located in southern California, in the Mojave Desert. It uses the 70-metre antenna of the NASA Deep Space Network, which is currently equipped with a 450-kilowatt transmitter and can receive on that dish or other nearby antennas of the Deep Space Network. Because it is steerable, the antenna can reach much of the sky and can follow the often rapid apparent motions of NEOs. The second radar, located at Arecibo, Puerto Rico, is owned and managed by the National Science Foundation and operated by Cornell University under a cooperative agreement with the Foundation. The radar has an aperture of 305 metres and a transmitter power of 900 kilowatts. Its reach is further than that of Goldstone, but because it is a fixed antenna it can look only about 20 degrees off its zenith position.

6. In Europe, scientists at the Institute of Planetary Research of the German Aerospace Centre (DLR) have been involved in observation campaigns for the physical characterization of NEOs using ground-based and space-based optical telescopes. Unlike the operational status of the United States detection systems, observing time on these telescopes is awarded on a competitive rather than dedicated basis. Observational work in the thermal infrared region is led by the United States and entities such as DLR of Germany, the Massachusetts Institute of Technology and the University of Hawaii of the United States, the Queens University Belfast of the United Kingdom of Great Britain and Northern Ireland, the University of Helsinki and the Turin Astronomical Observatory of Italy.

7. Currently, a major area of activity for Germany is observational work in the thermal-infrared spectral region with telescopes such as the Keck and the NASA Infrared Telescope Facility, both on Mauna Kea in Hawaii, and the NASA Spitzer Space Telescope. The data from those observations allow crucial parameters such as the sizes and albedos of NEOs to be determined and provide information on surface characteristics via the thermal inertia. The interpretation of these observations requires extensive theoretical work and computer modelling of the physical characteristics of NEOs. In addition to these front-line research activities, an online

database of physical properties of all known NEOs is maintained by DLR (http://earn.dlr.de) and is updated daily.

8. In addition, a partnership of astronomers in the United Kingdom, from Durham University, Queen's University Belfast and the University of Edinburgh, has joined a group of institutions in Germany and the United States in using an advanced new telescope, the Panoramic Survey Telescope and Rapid Response System, which is equipped with the world's largest digital camera and is located in Hawaii, on the island of Maui, to discover, observe and determine the characteristics of NEOs.

9. Photometric light curve observations can be used to infer rotational properties and indicate the presence of binary objects. In 2006, the Calar Alto Observatory in Spain began operation of a 1.2-metre telescope for photometric and astrometric observation of NEOs.

10. China reported that at the Purple Mountain Observatory, located at 118°28′E and 32°44′N, a 105/120-centimetre Schmidt telescope with a 4K x 4K high-sensitivity charge coupled device camera had become operational and would contribute to the global effort to discover and conduct follow-up observation of NEOs.

11. Japan contributes to the field of remote observations through the Bisei Spaceguard Centre, which has a 1-metre diameter optical telescope and a 50-centimetre diameter tracking telescope specifically designed for the observation of NEOs.

12. The joint NEO project team of the Korea Astronomy and Space Science Institute and Yonsei University Observatory has 50-centimetre robotic telescopes in South Africa and Australia. Operating in fully automated mode, they are used to discover and conduct follow-up observation of fast-moving NEOs in parallel with other scientific programmes. The joint project team reports asteroid and NEO detections to the Minor Planet Center. In addition to survey efforts, the project team is performing NEO survey simulations in order to evaluate how long it would take to discover all kilometre-class objects and derive better detection strategies for ongoing survey programmes.

13. In 2006, the Institute of Astronomy of the Russian Academy of Sciences began operating a 2-metre telescope, at Terskol, Russian Federation, for photometric and astrometric observations of NEOs.

14. Along with the Ondrejov Observatory of the Czech Republic, DLR is a leader in the European Fireball Network, a network of all-sky cameras that record the tracks of large meteoroids colliding with the Earth's atmosphere.

15. In Latvia, the Ventspils International Radio Astronomy Centre (VIRAC) and the Institute of Astronomy of the University of Latvia, in cooperation with the Academies of Science of the Russian Federation and of Ukraine, are in the process of joining a 5-gigahertz frequency band radio-location observation network of NEOs. The corresponding receiver has been designed and tested. It is anticipated that their incorporation into the observation programme will be completed from 2007. Researchers from VIRAC and the Institute of Astronomy process the collected data.

16. The Action Team recognized that, overall, significant efforts were being made internationally to detect and, to a lesser degree, conduct follow-up observations of potentially hazardous NEOs larger than 1 kilometre. As at 15 September 2007, 721 objects larger than 1 kilometre had been found, out of a population estimated to be fewer than 1,000 such objects. However, the Action Team noted that objects in the range of 100 metres to 1 kilometre, for which the current surveys were not optimized, still posed a significant impact threat.

17. In recent years, NASA has studied the magnitude of risk to human life and property associated with the threat posed by smaller objects, which has resulted in a call from the United States Congress in its 2005 NASA Authorization Bill for NASA to plan, develop and implement a near-Earth object survey programme to detect, track, catalogue and characterize the physical characteristics of NEOs equal to, or greater than, 140 metres in diameter. The goal is for the survey programme to achieve 90 per cent completion of the catalogue within 15 years. The analysis of alternatives conducted by NASA in 2006, and reported to Congress in March 2007, found that such a goal was achievable using a combination of ground-based and space-based sensors. Some ground-based telescope systems, already in planning and acquisition stages by agencies of the United States federal Government, will have capability to detect NEOs down to 140 metres, but not sufficient to achieve the goal of 90 per cent completion before 2021. To achieve that goal, either a large ground-based telescope dedicated to finding NEOs must be acquired by 2015, or a modest space-based observatory mission must be acquired and launched to enter operations before 2017. Although either solution was determined to be outside of the budgeted priorities established for NASA, in an attempt to achieve the goal of completing the hazardous NEO catalogue within the legislated timeframe, NASA committed to continuing to pursue the required capability by taking advantage of opportunities that may arise for dual-use of ground-based telescopes and spacecraft, partnering with other agencies.

18. Recognizing that NEOs equal to or greater than 140 metres pose a more immediate threat to the Earth than the smaller number of kilometre-sized NEOs, the Action Team encouraged NASA, along with its international partners, to continue to seek ways in which the threshold for detection of NEOs could be reduced to 140 metres. The Action Team noted that discovery and precision orbit determination were the critical first steps in characterizing an NEO threat and initiating a mitigation action, and that facilities and capabilities for collecting and quick processing of the discovery data were essential. The Action Team also noted that some NEOs were binary in nature (i.e., they had accompanying moons), which were themselves large enough to pose a hazard, and that these should be included in deflection plans. The Action Team therefore expressed concern that the planetary radar at Arecibo, which had the world's best capabilities for determining the orbit of NEOs such as Apophis, as well as estimating their size and spin state and detecting accompanying bodies, was planned to be shut down during the 2012-2013 apparition of Apophis. The Action Team recognized that the use of Arecibo during that period was essential to determining whether Apophis posed a serious threat of impact with Earth in 2036, and it would probably have a similar critical value as new objects were discovered.

B. Orbit determination and cataloguing

19. It is important that objects detected from the ground are uniquely identified and that their orbits are refined to assess the impact threat to the Earth. The Minor Planet Center is fundamental to that process. It is operated by the Smithsonian Astrophysical Observatory, in coordination with the International Astronomical Union, based on a memorandum of agreement giving the Center an international charter. Pursuant to the memorandum of agreement, the Center has, since 1978, served as the international clearing house for all asteroid, comet and satellite astrometric (positional) measurements obtained worldwide. The Center processes and organizes data, identifies new objects, calculates orbits, assigns tentative designations and disseminates information on a daily basis. For objects of special interest, the Center solicits follow-up observations and requests archival data searches. The Center is responsible for the dissemination of astrometric observations and orbits via the Minor Planet Electronic Circulars (issued as necessary, generally at least once a day) and related catalogues. In addition to distributing complete orbit and astrometric catalogues for all small bodies in the solar system, the Center facilitates follow-up observations of new potential NEOs by placing candidate sky-plane ephemerides and uncertainty maps on the Internet via the NEO confirmation page. The Center focuses specifically on identification, short-arc orbit determination and dissemination of information pertaining to NEOs. In most cases, observations of NEOs are distributed to the public free of charge within 24 hours of receipt. The Center also provides a variety of tools to support the NEO initiative, including sky coverage maps, lists of known NEOs, lists of NEO discoverers and a page of known NEOs requiring astrometric follow-up. The Center also maintains a suite of computer programs to calculate the probability that an object is a new NEO, based on two sky-plane positions and magnitude. Links to these Internet resources can be found on the Center's website (http://cfa-www.harvard.edu/iau/mpc.html).

20. In 2006, the Executive Committee of the International Astronomical Union set up an advisory committee of experts in recognition of the essential role the Union plays in formal scientific policy on NEOs and in influencing and informing society at large.

21. The Action Team recognized that the role of the Minor Planet Center was critical to the dissemination and coordination of observations. The current system was already working at capacity and it was questionable whether it could cope with the significant increase in tasks associated with the anticipated goal of reducing the systematic detection threshold from 1 kilometre to 140 metres. The Action Team considered that a possible way forward, offering a number of benefits, would be to establish a "mirror" capability to the Center, hosted possibly in Europe or Asia. The two nodes could share analysis protocols and processes and could have a common data management and access policy, but would perform a complementary operational role, possibly performing the same operations on a different subset of the observation data but independently maintaining a complete database. The two sites could also then act to validate and verify their more critical respective outputs.

22. As part of its NEO observation programme, NASA has established the Near-Earth Object Program at its Jet Propulsion Laboratory. On a daily basis, the Minor Planet Center makes NEO astrometric data available to the Near-Earth Object

Program and to a parallel, but independent, orbit computation centre in Pisa, Italy, with a mirror site in Valladolid, Spain. Through the Laboratory's Sentry System (http://neo.jpl.nasa.gov/risk), risk analyses are automatically performed on objects that have a potential for Earth impact – usually when the object has been recently discovered and lacks the lengthy data interval that would make its orbit secure. Those objects are prioritized for the Sentry System according to their potential for close approaches to the Earth's orbit and according to the existing quality of their orbits. The Sentry System automatically updates the orbits of approximately 40 NEOs per day and close-approach tables are generated and posted to the Internet (http://neo.jpl.nasa.gov/cgi-bin/neo_ca). Approximately 5 risk analysis cases are performed each day, with each analysis providing 10,000 multiple solutions up to 2105. That process is also performed in parallel in Pisa, Italy, and significantly non-zero Earth-impact cases are manually checked at the Laboratory and the centre at Pisa before the risk analysis data are posted on the Internet. Since the inception of the Sentry System in 2002, approximately 400 objects have appeared on the Sentry risk page (http://neo.jpl.nasa.gov/risk). For recently discovered objects of unusual interest, the Minor Planet Center, the Laboratory and the centre at Pisa will often alert observers that additional future or recovery observation data are needed.

23. The Joint Propulsion Laboratory maintains a searchable database containing data on 350,000 small bodies for the international community. The Laboratory's "HORIZONS" online system is an interactive ephemeris-generation site that automatically generates some 3,000 ephemerides a day for the international science community (http://horizons.jpl.nasa.gov).

24. The Action Team noted that the Sentry System and the Near-Earth Object Dynamic Site system were completely independent systems that employed different theoretical approaches to providing impact risk assessments. Hence, if the long-term orbit propagations from each converge to a single solution, the wider community can have some confidence in the predicted outcome. Whereas the Sentry System is funded as part of the Near-Earth Object Program of NASA and thus its operational future can be considered relatively secure, the long-term funding for the Dynamic Site system was not so clear. As with the operation of the Minor Planet Center, the Action Team considered that an independent but complementary capability to the Sentry System was desirable for the purposes of independent verification and validation of predicted close approaches.

C. Consequence determination

25. Significant work has been done in the United States to assess the impact hazard posed by NEOs. Much of that work is led by NASA with support from the University of California at Santa Cruz, with an emphasis on the threat posed by impact-induced tsunamis. The University of Arizona has created an easy-to-use, interactive website for estimating the environmental consequences of an impact on Earth. By providing inputs for the distance from ground zero and the projectile's diameter, density, velocity and impact angle, this program will estimate the ejecta distribution, ground shaking, atmospheric blast wave and thermal effects of an impact and the size of the crater produced (http://www.lpl.arizona.edu/impacteffects).

26. In the United Kingdom, the University of Southampton is conducting research into the effects of impacts by small NEOs. A tool has been created to tackle the hazard on both a local and a global scale, tracking the consequences of an impact on the human population. The overall hazard assessment of an NEO impact event is rated according to the potential number of casualties and the level of infrastructure damage.

27. The Action Team recognized that in considering a science-based policy to address the risk posed by NEOs, it was important for Governments to evaluate the societal risk posed by such impacts and to compare that with the thresholds established for dealing with other natural hazards (for example, meteorological and geological hazards) so that a commensurate and consistent response could be developed. The Action Team thus felt that more work needed to be done in that area, especially on impactors of less than 1 kilometre in diameter.

D. In situ characterization

28. The Action Team recognized the importance of the Hayabusa (MUSES-C) mission, which rendezvoused with the near-Earth asteroid 25143 Itokawa in late 2005, not only because of the scientific knowledge gained on the asteroid's characteristics, such as topography and composition, but also because of the important operational lessons learned from rendezvous and proximity operations in a very low gravity environment and because of the consequences for future in situ investigations and possible mitigation activities. Hayabusa followed in a long line of successful missions such as Near Earth Asteroid Rendezvous, Deep Space 1, Stardust and Deep Impact, which provided unique insights into the characteristics of the surprisingly diverse population of NEOs. Detailed NEO characterization cannot be derived from remote observations and the Action Team looked ahead with anticipation to the upcoming missions to NEOs.

29. One of the next major opportunities for in situ examination of asteroids will be the Dawn Discovery mission of NASA, which launched in 2007 and will visit Vesta in 2011 and Ceres in 2015. In addition to the spacecraft and instrumentation developed by the United States, Italy and Germany are providing main instruments for the mission. Italy is providing a visible and infrared mapping spectrometer for the mission. Visible and infrared mapping can provide data on the mineralogical composition and distribution of NEOs, which help determine evolutionary processes and infer internal structure and bulk properties. The Max Planck Institute in Germany is providing the dual framing cameras for the main scientific imaging to be performed by the mission.

30. In cooperation with countries such as France, Germany, Spain and Sweden, Italy has provided a number of payloads for the Rosetta orbiter and Philae lander, launched towards comet 67P/Churyumov-Gerasimenko for rendezvous in 2014. Among the suite of payloads is a visible and infrared mapping spectrometer to help study the coma of the comet, while a drill will provide samples for in situ investigation and characterization.

31. At the Open University of the United Kingdom, in addition to theoretical studies aimed at understanding the formation of smaller bodies in the solar system, a number of experimental programmes are also under way, among them the

development of a penetrometry rig to simulate a high mass, low-speed impact of a penetrometer fixed to a landing spacecraft. Penetrometers will be a key element in enabling in situ measurements on an NEO surface, which is likely to be delicate in nature, and they can yield structural and mechanical information on the body that is critical for its successful mitigation and negation.

32. The Action Team welcomed the news that NASA had accepted the proposal to extend the Dawn Discovery mission, put forward by scientists from the University of Maryland for the Deep Impact spacecraft and from Cornell University for the Stardust spacecraft. The new mission for the Deep Impact spacecraft, called the Deep Impact Extended Investigation, will use the surviving spacecraft's three working instruments (two colour cameras and an infrared spectrometer) to study a new target, the comet Boethin, in December 2008. The second mission, called Stardust New Exploration of Tempel, will fly the Stardust spacecraft closely past comet Tempel 1 (the Deep Impact target body) in February 2011 to collect images of more of its surface and possibly the crater created by the Deep Impact's impactor two years ago. The Dawn Discovery mission has also selected for detailed concept study a full mission proposal – the Origins Spectral Interpretation, Resource Identification and Security mission – to bring back a surface sample from primitive near-Earth asteroid 1999 RQ36. A decision on whether to move that mission proposal forward to the second phase of project formulation is pending.

E. Mitigation

33. Mitigation in this context is the process of either negating or minimizing the impact hazard posed to Earth by the sub-class of NEOs called potentially hazardous objects, through some form of intervention or interaction with the risk body, or by minimizing its impact on the population through evacuation or a similar response.

34. The European Space Agency (ESA) has supported industrial and academic research studies on NEOs in the past. Those activities made it possible to identify a project enabling Europe to make a significant yet realistic contribution to international efforts to assess the NEO hazard. The result of that analysis was the Don Quijote NEO technology demonstration mission, currently being defined by European industrial teams. As a response to the call by the Council of Europe for ESA to take an active role in the assessment of the NEO impact hazard, several scientific and technical assessments were conducted. These were immediately followed by parallel mission feasibility studies, whose outcome was assessed by the Near-Earth Object Mission Advisory Panel of ESA, an independent panel of recognized experts on various aspects of the NEO problem, which was set up by ESA for that purpose. In accordance with the recommendations of the Panel presented in July 2004, work focused on the Don Quijote mission concept, which consists of two elements: a SMART-1-class, mini-satellite asteroid orbiter and a modified upper stage serving as an asteroid impactor. The orbiter, called "Sancho", would rendezvous with a small, 500-metre near-Earth asteroid and study it before the arrival of the impactor, called "Hidalgo", which would hit it at a very high relative speed. The Sancho orbiter would observe the impact and its results, especially the resulting deflection in the asteroid's trajectory. Suitable launch opportunities for the first element, the orbiter, will begin in 2011. The impactor could be launched four or five years later, which would allow for an independent or

staged development of the two mini-satellites. The choice of the launch vehicle and the suitable launch windows largely depends on the selection of the target asteroid, which will be revisited by the Panel in the coming months. The mission has a modular architecture, two separate small spacecraft and the possibility of an independent asteroid "surface package", which would facilitate its implementation in the context of a cooperative project.

35. ESA recognizes that the efforts of major space agencies are now heading in similar directions and are reaching the critical mass needed to attain concrete developments with respect to space missions. Preparatory activities have enabled ESA to gain a good understanding of the key issues of a realistic NEO technology demonstration mission and have placed it in a good position to explore a way to benefit from this convergence of interests or, at least, to establish an opportunity partnership with another agency with the aim of identifying cost-sharing and/or programmatic advantages.

36. With respect to observatory missions, the ESA Near-Earth Object Mission Advisory Panel noted that improvements in the performance of the existing surveys and, in particular, plans for larger facilities, had led to a dramatic increase over the past few years in expectations for NEO discovery from the ground. The Panel concluded that 80-90 per cent completeness for H<20.5 bodies (roughly 300 metres in size) could be achieved within the next decade without a space observatory. The Panel therefore recommended that the case for a space-based NEO observatory be reconsidered in 10-15 years, after the residual hazard from NEOs that are not accessible by ground-based surveys had been better defined.

37. On the other hand, the ESA Advisory Panel recognized that the current lack of precise knowledge of the physical characteristics of NEOs would be a critical limitation, should a potential impactor be identified. It therefore concluded that rendezvous mission concepts were of significantly higher priority in terms of risk assessment and mitigation than the observatory mission concepts. The Panel also pointed out that given the variety of objects already known, it was improbable that any rendezvous mission would investigate an NEO identical to the next impactor. It therefore stressed the importance of a precursor mission concept aimed at determining all the relevant quantities – size, density, internal structure, momentum transfer, etc. – required to conduct an actual mitigation mission.

38. In February 2007, the Working Group on the Asteroid-Comet Impact Hazard was established in the Russian Federation. Most governmental, research and educational organizations in the Russian Federation are involved in the activities of the Working Group. The Working Group is shortly to present a national programme on the asteroid-comet impact hazard problem, which will include detection and remote characterization, orbit determination and cataloguing, consequence determination and mitigation at both the international and local levels.

39. The Institute of Planetary Research of DLR, in cooperation with the Dresden University of Technology, is investigating potential techniques for diverting asteroids and comets and is developing a tool that can determine an optimal deflection strategy for a given impactor. Various potential techniques for diverting asteroids and comets from a collision course with the Earth have been investigated and modelled. In the course of that work, a software package to simulate a possible impact scenario and to determine an optimal deflection strategy has been developed.

The formation of craters and associated effects of asteroid or comet impacts on the Earth, both on continents and on oceans, are currently being analysed in a theoretical study involving advanced computer modelling and simulations.

40. The Institute of Planetary Research has also proposed the establishment of a German Spaceguard Centre, which, like its existing counterparts in the United States (the Jet Propulsion Laboratory) and the United Kingdom (the NEO Information Centre), should act as a link between research activities and the general public, convey scientific information in understandable terms to the public and Government departments, and be prepared to support policymakers in administering German participation in international activities in relation to the impact hazard and NEO mitigation plans. This proposal has been considered by the authorities in DLR and a decision on establishing the Centre is pending.

41. The United Kingdom funds a number of activities related to the mitigation of the NEO hazard. The objective of the work conducted at the University of Glasgow is to develop fundamental optimal control theory and apply it to the interception of hazardous NEOs. The study has been moving along two parallel paths. The first is the global optimization algorithms for an interplanetary trajectory. The tools that have been developed are used to generate a number of possible trajectories to intercept NEOs. Future work will develop more accurate models of the static and dynamic properties of asteroids in order to study how those properties might influence or even invalidate certain deviation methods. Assessments of other deflection methods, such as the gravity tractor and the Yarkovski effect, will continue.

42. The Action Team noted with interest the recent report of NASA to the United States Congress, as requested by Congress in its 2005 NASA Authorization Bill, to analyse possible alternatives that NASA could employ to divert an object on a probable collision course with Earth. In that study, the NASA team assessed a number of approaches that could potentially be used to divert an NEO on a predicted collision course with Earth. The approaches are roughly divided into two categories: “short impulse” options, where the diversion energy is applied in a near instantaneous event; and “slow push” options, where the energy is applied over an extended period of time. Important factors that require consideration in determining the most effective techniques are: how much lead time the option requires or, in other words, how much time would be available from detection of an impact threat until the collision event, commonly referred to as “warning time”; how difficult it would be to reach the threatening object (which is mostly a function of its orbital path relative to the Earth’s); physical characterization of the threatening object; and how much energy resource would be required to apply an effective amount of force to the threatening object.

43. According to the findings of the NASA study team, the most promising short impulse techniques were found to be the use of a stand-off nuclear device, in particular for larger objects and especially when warning times were only a few years, and the kinetic energy impactor. Both techniques make use of relatively mature technology, almost all of which has been demonstrated at least in scenarios similar to interplanetary space missions, and could be packaged into effective systems placed on interplanetary trajectories with current lift capabilities.

44. A variety of slow push techniques were presented to and analysed by the NASA study team. However, almost all of the techniques are technically immature (some are only preliminary concepts) and would have very limited application with respect to the NEO threat unless warning times allowed mission durations of many years or decades of diversion force application. The only viable slow push techniques for further study were the space tug, which would attach to the threatening object and change its trajectory with high-efficiency propulsion systems, and the "gravity tractor", which has the potential to alter the course of an object using the gravitational attraction of a spacecraft station keeping in close proximity to the object. Both techniques could be effective in scenarios that require only small increments of velocity change (millimetres per second) and that concern relatively small objects (less than 200 metres in the largest dimension). However, the space tug would require more detailed characterization of the object, more robust guidance and control and surface attachment technologies that are not available in the near term.

45. The Action Team noted that the analysis by NASA of deflection options covered only relatively large NEOs and did not consider the precision needed during a deflection to avoid the potential of placing the NEO on a return impact trajectory.

46. The Action Team noted, overall, that in addition to the probability of impact and time to impact, the other parameters that would influence the response strategy were the anticipated intersect locus on the surface of the Earth and the vulnerability of that area to the impact. The different options for deflection and the implications of a particular deflection strategy – technical readiness, political acceptability, cost of development and operation, translation of intersect locus – will also have to be weighed up in relation to the alternatives. The Action Team acknowledged that it was possible that a specific impact might threaten non-space-faring nations only. It might be considered more attractive for one capable actor to take the lead in mounting a particular deflection mission rather than a grouping of entities with different roles, owing to the complexity of the mission and the political expediency of protecting sensitive technical information. The Action Team therefore envisaged a matrix of options setting out agreed responses to a range of impact scenarios and identifying actors to perform specific roles. In that respect, the Action Team identified the need for an international technical forum, where a range of probable impactor scenarios could be determined and a corresponding matrix of mitigation options to respond to a specific threat could be developed to a level of maturation that would permit reliable mission timelines to be drawn up with a corresponding decision timeline for the international community.

F. Policy

47. The Action Team recognized that the impact threat posed by NEOs was real and that such an impact, although a low probability event, would be potentially catastrophic. It was also recognized that the effects of such an impact would be indiscriminate (that is, it was unlikely that they would be confined to the country of impact) and that the scale of an impact's effects would be so great that the NEO hazard should be recognized as a global issue that could be addressed effectively only through international cooperation and coordination. No country was

known to have a national NEO strategy. Thus, the United Nations had an important role to play in informing the process of developing the required policy.

48. A further challenge for the United Nations was that in the next 15 years it was likely to be confronted with making critical decisions about the actions to be taken to protect life on Earth from a potential NEO impact. That situation was due to the accelerating pace of the discovery of NEOs and humankind's increasing ability to prevent an anticipated impact by proactively deflecting the NEO. The probability of the United Nations having to decide between action and inaction was further heightened by the probable necessity of having to make a decision prior to the availability of certain knowledge that an impact would occur. The frequency of decision-making might therefore be in an order of magnitude greater than the statistical incidence of impacts themselves. Given that early warning of an NEO impact and the capability to prevent such an impact were now both possible, it was recognized that humankind could not avoid responsibility for the consequences of its action or inaction. Since the entire planet was subject to the threat of NEO impact and since the process of deflection intrinsically caused a temporary increase of risk to populations not otherwise at risk, the United Nations would inevitably be called upon to make decisions and evaluate trade-offs. Out of concern for that issue, the Association of Space Explorers had established a committee on NEOs and has committed itself to bringing the issue to the attention of world leaders and institutions and to help them respond to that challenge. At the forty-third session of the Scientific and Technical Subcommittee, the Association of Space Explorers had expressed its intention to facilitate that process by convening a series of workshops, calling on experts from around the world with relevant experience to address the challenge in detail and to prepare a draft NEO deflection protocol for consideration by the Committee. Those workshops would be conducted over the next two years to develop the draft protocol, which would be submitted by the Action Team to the Committee on the Peaceful Uses of Outer Space at its fifty-second session, in 2009. The Association of Space Explorers had reported that it had successfully conducted its first workshop from 9 to 12 May 2007 at the International Space University in Strasbourg, France. That workshop, the first out of four in total, brought together a panel of individuals experienced in asteroid threat mitigation, with a view to drafting an agreement on an international response to the NEO impact hazard. The first workshop included expert briefings on the NEO impact threat and status of the global search and detection programmes; technical methods for NEO deflection; international legal precedents for an NEO agreement; and an outline of diplomatic and programmatic efforts that may best address the threat. The panel laid out goals for the next three workshops, including the outlines of its proposed international framework for making decisions concerning NEOs. The United Nations was represented at the workshop by observers of the Committee on the Peaceful Uses of Outer Space and the Action Team. The second workshop was convened from 12 to 15 September 2007 in Sibiu, Romania.

49. Some of the scientific issues that need to be addressed are reported in *Comet/Asteroid Impacts and Human Society*,[2] published in 2007, which summarizes

[2] Peter T. Brobrowsky and Hans Rickman, eds., *Comet/Asteroid Impacts and Human Society* (Berlin, Heidelberg, Springer, 2007).

contributions made to a workshop under the same title, sponsored by the International Council for Science in 2004.

G. Planetary Defense Conference, 2007

50. Experts from a number of Member States attended the Planetary Defense Conference, held from 5 to 8 March 2007 at George Washington University in Washington, D.C. The primary objectives of the meeting were to highlight the current state-of-the-art in NEO detection, characterization and mitigation; to understand the threat posed by asteroids and comets and possible responses to an NEO impact; and to consider political, policy, legal and societal issues that would affect the ability to mount an effective defence. Conference participants recognized that while significant scientific and technological advances had been made since the previous conference, in 2004, it was clear that effective planetary defence against NEOs and planning for mitigation of an impact disaster, should it occur, were in their infancy. In particular, the primary findings of the conference were as follows:

(a) While search and discovery efforts have successfully found most of the large, "civilization-killer" 1-kilometre and larger objects, efforts to find the much more prevalent and, for that reason, more frequently dangerous objects in the 140-300-metre size range are only just beginning. An impact by an object in that size range could occur with little or no warning and could cause serious loss of life and property over a broad area;

(b) Earth-based resources, such as the Arecibo radar, are seen as critical for refining the orbit of a potentially hazardous object and providing basic information required for deflection. Arecibo will play an essential role in refining understanding of the threat posed by NEO Apophis;

(c) Deflection of a threatening object is currently in the conceptual phase. Efforts to identify the options available to deflect an object are just beginning and techniques that might be used have yet to be designed or tested. No complete mission to deliver one or more deflection devices has yet been designed and requirements to assure a high probability of success for the overall deflection campaign have not been considered;

(d) There are serious technical, political, policy, legal and societal issues involved in deciding whether and how to respond to a threat of an NEO impact. NEO impacts have the potential to cause disasters that would equal or exceed anything ever faced by recent civilizations. Moreover, that type of threat has never been adequately considered by any entities that are likely to have responsibility for responding. In addition, it is uncertain where responsibility for coordination of all aspects of the NEO threat lies, from detection to deflection to impact aftermath;

(e) Understanding, analysing and dealing with a potential NEO threat is an international problem demanding international cooperation. Considerable work is required to develop a foundation for international cooperation and action in all areas related to planetary defence. That foundation may extend beyond defence and include a benefit of international manned and unmanned space exploration.

51. A series of recommended actions was also proposed at the Planetary Defense Conference, as follows:

(a) Characterization of Asteroid 99942 Apophis and refinement of its orbit during the 2012-2013 apparition;

(b) Support for the operation of facilities critical to NEO discovery, orbit determination and tracking;

(c) Immediate initiation of actions to locate threatening objects in the 140-metre class;

(d) Initiation of a programme, perhaps in collaboration with planetary science objectives, for the in situ characterization of potentially hazardous objects;

(e) Research into and characterization and demonstration of technologies associated with the most promising impulse and slow-push techniques;

(f) Characterization of NEO response to a deflection attempt;

(g) Development and documentation of complete designs of a deflection campaign, including launch vehicle and payload requirements, ground support requirements, overall mission reliability, mission timelines and milestones and costs;

(h) Conducting of an impact response exercise: a well-scripted and designed desk exercise, driven by improved gaming, modelling and simulation resources to increase understanding of the evolution of an impact disaster and demands on response entities and communication systems;

(i) Incorporation of the NEO hazard into the mandates of entities, both national and international, that are currently charged with addressing very large-scale natural and man-made catastrophes;

(j) Conducting of additional research towards understanding the relationship between NEO size and event consequences, a relationship critical for setting the lower limit of detection efforts;

(k) Development of an international protocol for use in situations when critical decisions relating to threat and disaster mitigation are required;

(l) Increase of international collaboration in efforts aimed at detection, characterization and mission planning and in research related to deflection. The concept suggested is to establish a group similar to the current Inter-Agency Space Debris Coordination Committee;

(m) Development and implementation of a mechanism to maintain funding to critical technologies and efforts over the long term. Initiation of discussions to understand the issues and develop a framework for the use of nuclear explosives before a credible threat is identified;

(n) Development of international agreements limiting the liability related to making impact predictions or to taking or not taking action on an NEO threat;

(o) Engagement and sustainment of the interest of professionals and practitioners from the social and behavioural sciences;

(p) Development of a strategy for educating elected and Government officials and the public on the nature of the NEO threat and what to expect in regard to NEO detections and warnings. An appropriate time to showcase such a strategy and associated initiatives could be 2009, which will feature the International Year of Astronomy (http://www.astronomy2009.org). The International Year is coordinated by the International Astronomical Union, which has established a central secretariat for the Year. The Union should be more strongly involved in NEO-related discussions;

(q) Examination of how social factors such as individual and group psychology, culture and political and religious beliefs might affect the decision to move forward on an NEO deflection effort.

52. A more detailed report of the Planetary Defense Conference can be found on the Internet (http://www.aero.org/conferences/planetarydefense/). The Action Team welcomed the report of the Conference and it is anticipated that these recommended actions will be discussed by the Action Team during the forty-fifth session of the Scientific and Technical Subcommittee.