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Near-Earth objects

Near-Earth objects, 2012-2013

Final report of the Action Team on Near-Earth Objects

I. Introduction

1. The Action Team on Near-Earth Objects[1] 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 fifty-first session, in 2008, 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 its Scientific and Technical Subcommittee and by the Action

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[1] A near-Earth object (NEO) is an asteroid or comet whose trajectory brings it within 1.3 astronomical units of the Sun and hence within 0.3 astronomical units, or approximately 45 million kilometres, of the Earth's orbit. This includes objects that will come close to the Earth at some point in their future orbital evolution. NEOs generally result from objects that have experienced gravitational perturbations from nearby planets, moving them into orbits that allow them to come near to the Earth.

Team on Near-Earth Objects and endorsed the amended multi-year workplan for 2009-2011,[2] as contained in the report of the Subcommittee (A/AC.105/911, annex III).

3. At its fifty-fourth session, in 2011, the Committee on the Peaceful Uses of Outer Space endorsed the recommendation of the Scientific and Technical Subcommittee and its Working Group on Near Earth Objects[3] (A/AC.105/987, annex III, para. 9) that the multi-year workplan on near-Earth objects be continued for the period 2012-2013, as follows:

2012 Consider the reports submitted in response to the annual request for information on near-Earth object activities and continue intersessional work. Review progress on international cooperation and collaboration on NEO observations. Facilitate, for the purpose of NEO threat detection, a more robust international capability for the exchange, processing, archiving and dissemination of data. Continue the work begun during the intersessional period on drafting international procedures for handling the NEO threat and seek agreement on those procedures. Consider updated information as presented in an interim report of the Action Team on Near-Earth Objects. Review progress made in activating the work of the NEO Information, Analysis and Warning Network (IAWN) and the mission planning and operations group.

2013 Consider the reports submitted in response to the annual request for information on near-Earth object activities and continue intersessional work. Review progress on international cooperation and collaboration on NEO observations and on the capability for the exchange, processing, archiving and dissemination of data for the purpose of NEO threat detection. Finalize the agreement on international procedures for handling the NEO threat and engage international stakeholders. Consider the final report of the Action Team on Near-Earth Objects. Review progress made in activating the work of IAWN and the mission planning and operations group, and assess their performance.

4. The present final report represents the response of the Action Team to the terms of reference stated in paragraphs 1 (a) through 1 (c) above. In preparing the report, the Action Team agreed that IAWN would henceforth stand for "international asteroid warning network".

5. The present final report covers activities and issues relating to the NEO hazard, the current understanding of the risk posed by NEOs and the measures required to mitigate that risk. More detailed descriptions of activities are provided in the annual national reports provided to the Committee by Member States, the reports of specialized bodies to the Committee and the presentations made by the Committee's members and observers at the annual session of the Scientific and Technical Subcommittee.

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[2] *Official Records of the General Assembly, Sixty-third Session, Supplement No. 20* (A/63/20), para. 153.

[3] Ibid., *Sixty-fifth Session, Supplement No. 20* (A/65/20), para. 137.

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

A. Near-Earth object detection and remote characterization

6. The Action Team noted that the first step in addressing the risk posed by an NEO was to detect its presence and determine its trajectory, as well as infer its size from its observed brightness and, if available, its albedo. The United States of America had made 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 had funded five NEO search teams over the past decade to operate nine separate 1-metre survey telescopes in the south-western United States and in Hawaii and, until 2012, one in Australia, capable of detecting objects, on average, to a visual magnitude of as low as 20. The NASA Near-Earth Object Program also supported the Minor Planet Center (MPC) of the International Astronomical Union (IAU). MPC was the international clearing house of all small body observations; it was supplemented by orbit follow-up observation activities carried out by a variety of professional and amateur astronomers around the world.

7. The Action Team was pleased to learn that the European Space Agency (ESA) had started its space situational awareness programme, which contained a segment dealing with the NEO threat. As documented in the user requirement document, part of that programme consisted of activities focusing mainly on follow-up observations. Among other telescopes, the Optical Ground Station, a 1-metre ESA telescope on Tenerife, Spain, had been made available for NEO observations four nights every month since 2010. The telescope was being used primarily for follow-up observations and to test survey strategies. A so-called “wide survey” had been proposed in ongoing studies as an important contribution by ESA to ongoing survey activities under the space situational awareness programme. The Action Team was also pleased to learn that ESA had supported part of the operations of the Near-Earth Objects Dynamic Site (NEODyS), the priority list of the Spaceguard Central Node and the European Asteroid Research Node database.

8. The Action Team recognized that significant efforts were being made internationally to detect and, to a lesser degree, follow up observations of potentially hazardous NEOs larger than 1 kilometre in diameter. As reported on the Near-Earth Object Programme page of the NASA Jet Propulsion Laboratory website (neo.jpl.nasa.gov), as at 1 December 2012, 859 near-Earth asteroids (NEAs) with a diameter larger than 1,000 metres (including 154 potentially hazardous asteroids) had been discovered, 13 of which had been found in 2011 and 17 in 2012 (to 1 December). The estimated number of NEAs larger than 1,000 metres had increased to 981±19;[4] the figure of 859 NEAs larger than 1,000 metres corresponded to about 88 per cent of the total estimated number of large NEAs. As at 1 December 2012, the total number of known NEAs of all sizes was 9,354, while the total number of near-Earth comets was 92, which brought the total number of known NEOs to 9,446. IAU regularly updated those figures on its website (www.iau.org/public/nea/).

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[4] See http://neo.jpl.nasa.gov/stats.

9. Finding an NEO larger than 1 kilometre in diameter had become an unusual occurrence. Nevertheless, the Action Team noted that objects with diameters ranging from 100 metres to 1 kilometre, for which the current surveys were not optimized, still posed a significant impact threat. Those estimates were based upon an assumed mean albedo of 0.14 for all the discovered NEAs and hence were only rough estimates. Using near-infrared data provided by the Wide-field Infrared Survey Explorer (WISE) spacecraft in 2010 and early 2011, the NEOWISE team had been able to determine diameters and albedos for 250 NEAs, with a minimum uncertainty of 10 per cent and 20 per cent, respectively. Hence, it was able to determine the albedo distribution of those objects with known diameters, and that distribution was then used to compute diameters for previously known NEOs with known absolute asteroid magnitude (H) values but unknown diameters or albedos. The NEOWISE team provided an estimate of 981 (±19) NEAs as the total population of NEAs one kilometre and larger. At the time of its analysis in the spring of 2011, the NEOWISE team also estimated that 911 (±17) of those large NEAs had already been discovered (93 per cent). Although both estimates were uncertain to within a few per cent, the latter estimate should be considered more accurate than the previously given 88 per cent.

10. The Action Team encouraged NASA, along with its international partners, to continue to seek ways in which the threshold for the detection of NEOs could be reduced to at least 140 metres, as such objects were likely to pose a more immediate threat to the Earth than the smaller number of kilometre-sized objects. The Action Team encouraged ESA to implement its plans for follow-up and characterization and to support survey programmes, as proposed by current studies. Emphasis should be placed on establishing observing capabilities in the southern hemisphere. Further, 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 rapidly processing the discovery data were essential. The Action Team also noted that some NEOs were binary in nature, that is, they had accompanying moons which were themselves large enough to pose a hazard and might complicate considerations for deflection plans. The Action Team was therefore pleased that the planetary radar at Arecibo, Puerto Rico, which was operated by SRI International under cooperative agreement with the United States National Science Foundation, would be operating during the apparition of Apophis in 2012 and 2013. That had been made possible by new funding provided by the National Science Foundation and NASA. The use of Arecibo during that period would be important for determining whether Apophis posed a serious threat of impact with the Earth in 2036 or later in the century.

11. The Action Team agreed that a coordinated campaign for the observation of Apophis should be implemented at the end of 2012 and the beginning of 2013, when Apophis would have an apparent magnitude of approximately 16 (mv~16), in order to refine its ephemeris and in particular characterize the magnitude of the non-gravitational forces (Yarkovsky effect), which needed to be known for accurate orbit extrapolation. Given that Apophis would be most easily observed in the southern hemisphere, it was expected that such a campaign would involve observatories in Africa, Australia and South America.

12. The Action Team was pleased to learn that the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS), funded by the United States Air Force,

had started regular survey operations and had begun providing data to MPC in 2010. The capability to detect moving objects in the collected image data and extract observations for newly discovered objects, as well as known objects, had been completed with NASA funding. NASA was also funding a portion of the operations of the Pan-STARRS 1 telescope for NEO search purposes. It was expected that many thousands of observations would be provided to MPC as the project matured. The Planetary Science Division of NASA had also funded efforts to incorporate NEO detection capability within the data-processing segment on the WISE mission, sponsored by the Astrophysics Division of NASA. The primary mission of the spacecraft was to produce a detailed map of the extragalactic sky in four infrared bands; however, during the collection of those data, the infrared signature of many NEOs and other asteroids and comets, including those which did not reflect much visible light, were being extracted, processed and sent to MPC. The transient image data would also be archived for use in making more accurate size estimates of known objects and to provide another resource for making pre-discovery detections. Pre-discovery observations allowed the extraction of observation data from existing image archives in such a way that, once an object as discovered, its previous positions could be calculated and correlated with the archived image sets.

B. Current challenges and plans

13. The Action Team recognized the importance of observational efforts to physically characterize the NEO population using ground-based telescopes, including, in particular, infrared telescopes (for sizes, albedos, composition, surface characteristics and thermal properties) and radar (surface characteristics, shapes, sizes and rotation characteristics), and expressed appreciation for efforts by agencies to make resources available to strengthen that activity in the relevant programmes.

14. There was a need to search for inner-Earth objects (IEOs), a particular class of NEOs with orbits lying completely within the Earth's orbit and an apparent magnitude of as low as 18.5. Because of their proximity to the Sun, IEOs were extremely difficult to discover from the ground. About 9,450 NEOs had been discovered, of which only 12 were IEOs. However, it was thought that more than 1,000 such objects, with diameters greater than 100 metres, existed.

15. The Canadian Space Agency had informed the Action Team that the Near-Earth Object Surveillance Satellite (NEOSSat) project would now be launched in 2013 and become operational shortly thereafter. The objective of that microsatellite was to understand the orbital distribution, physical characteristics, composition, origin and history of NEOs. It was being developed to survey the near-Sun region, the only part of the sky where asteroids orbiting entirely inside Earth's orbit could be found. It would also be an efficient discoverer of Aten asteroids. Aten asteroids were a group of NEAs with orbital semi-major axes (a) of less than 1 astronomical unit and aphelion distances of greater than 0.9833 astronomical units. It was estimated that 6 per cent of the total number of NEAs were Aten asteroids. The Action Team encouraged agencies to consider other opportunities to address such complementary primary and secondary objectives for future prospective missions.

16. The Action Team welcomed the news of progress in the Warm Spitzer NEO Survey with regard to the observation of about 750 known NEOs in the two warm Spitzer channels (3.5 and 4.5 microns) and the fact that sizes and albedos had been derived for most of the targets. Apart from establishing the size distribution of the NEO population via direct measurements, the following findings from the ExploreNEOs programme were of particular relevance to impact-threat mitigation issues: that there was a very broad range of albedos, and implied compositions, within the NEO population; and that the fraction of the population having a cometary origin was less than 10 per cent.

17. The Action Team was pleased to learn that the B612 Foundation, a United States non-profit corporation, was continuing the development of its Sentinel infrared space telescope, which it planned to deploy into a Venus-like solar orbit in 2017-2018. The telescope, which matched the recommendations of both the United States National Research Council and the NASA Advisory Council for the next increment of NEO discovery and tracking, was contracted to Ball Aerospace and Technologies Corporation and would be launched on a SpaceX Falcon 9. In its first six and one-half years of operation, Sentinel was expected to discover over 90 per cent of all NEOs greater than 140 meters in diameter and approximately 50 per cent of those greater than 40 meters in diameter (see www.b612foundation.org). While the B612 Foundation would own and operate the spacecraft, the data link to Sentinel would be via the Deep Space Network of NASA, and the processed NEO tracks would be delivered immediately to MPC per the terms of a Space Act Agreement signed with NASA in 2012.

18. NEO discoveries by future large ground-based survey telescopes (e.g. the 8-metre Large Synoptic Survey Telescope in Chile) and future space-based infrared telescopes (e.g. Sentinel) would require that necessary follow-up observations of those discoveries be made by telescopes of similar sizes and capabilities.

19. The Action Team recognized the "Find An Asteroid" campaign of the Space Generation Advisory Council (SGAC) to partner with the International Astronomical Search Collaboration (http://iasc.hsutx.edu) to involve its members in the search for NEOs. The International Astronomical Search Collaboration was an educational outreach programme that gave schools the opportunity to examine telescope images to identify NEOs. During the five-week campaign, SGAC teams had discovered three main belt asteroids and had made several more NEO observations. The "Find An Asteroid" campaign would become an annual project directed at raising awareness of NEOs among youth.

20. The Action Team was informed that in November 2012 an important step had been taken in the Russian Federation towards establishing a space situational awareness programme aimed at revealing and counteracting space threats (including asteroid/comet impact hazard). Initial practical steps had been taken, such as allocating financial support for the completion of a 1.6-m survey telescope near Lake Baikal. The Russian Federal Space Agency (Roscosmos) stated that it had started to actively participate in international cooperation in that field.

C. Orbit determination and cataloguing

21. The Action Team considered it important for objects detected from the ground to be uniquely identified and their orbits refined to assess the impact threat to the Earth. MPC was fundamental in that process. MPC was operated by the Smithsonian Astrophysical Observatory, in coordination with IAU, on the basis of a memorandum of agreement giving MPC an international charter. Pursuant to the memorandum of agreement, MPC had, since 1978, served as the international clearing house for all asteroid, comet and satellite astrometry (positional) measurements obtained worldwide. MPC processed and organized data, identified new objects, calculated orbits, assigned tentative designations and disseminated information on a daily basis. For objects of special interest, MPC solicited follow-up observations and requested archival data searches. MPC was responsible for the dissemination of astrometry observations and orbits via "minor planet electronic circulars" (issued as necessary, generally at least once a day) and related catalogues. In addition to distributing complete orbit and astrometry catalogues for all small bodies in the solar system, MPC facilitated follow-up observations of new potential NEOs by placing candidate sky-plane ephemerides and uncertainty maps on the Internet via the NEO confirmation web page. MPC focused specifically on identification, short-arc orbit determination and dissemination of information pertaining to NEOs. In most cases, observations of NEOs were distributed to the public free of charge within 24 hours of receipt. MPC also provided 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. MPC also maintained a suite of computer programmes to calculate the probability that an object was a new NEO, on the basis of two sky-plane positions and magnitude. Links to those Internet resources could be found on the website of MPC (www.minorplanetcenter.net/iau/mpc.html). The Action Team also noted that, as at March 2010, the IAU website had a page listing past and future close approaches of known NEAs to the Earth and providing information on relevant meetings and literature (see www.iau.org/public/nea/).

22. The Action Team recognized that the role of MPC was critical to the dissemination and coordination of observations and welcomed the confirmation by NASA of its increased sponsorship of MPC. That had allowed MPC to upgrade its capability to process all observations received from observatories worldwide and to disseminate the resulting orbit information without charge via the Internet. In addition, MPC could accommodate the anticipated significant increase in NEO observation data with "next-generation" search efforts. The Action Team noted the benefit of establishing a "mirror" capability complementing MPC, possibly hosted 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, perhaps performing the same operations on a different subset of the observation data while independently maintaining a complete database. The two sites could also serve to validate and verify their more critical respective outputs. The Action Team recognized that ESA had started a discussion on how to support MPC, possibly by setting up a back-up capability in Europe, as part of its NEO programme. The Action Team encouraged the continuation of that discussion and the conclusion of a support agreement. In particular, it encouraged ESA and NASA to discuss that issue and come to a mutually agreed plan.

23. MPC made NEO astrometric data available, on a daily basis, to the Near-Earth Object Program Office at the NASA Jet Propulsion Laboratory and to a parallel but independent orbit computation centre in Pisa, Italy. Through the Sentry System at the Jet Propulsion Laboratory (see http://neo.jpl.nasa.gov/risk), risk analyses were automatically performed on objects that had a potential for Earth impact, usually when the object had been recently discovered and lacked the lengthy data interval that would make its orbit well determined. Those objects were prioritized by 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 updated the orbits of approximately 70 NEOs per day, and close-approach tables were generated and posted on the Internet (see http://neo.jpl.nasa.gov/cgi-bin/neo_ca). Approximately seven risk analysis cases were performed each day, with each uncertainty analysis providing 10,000 multiple solutions up to the year 2112. Those processes were also performed in parallel using NEODyS in Pisa; significantly non-zero-probability Earth-impact cases were manually checked at the Jet Propulsion Laboratory and at the orbit computation centre in Pisa before the risk analysis data were posted on the Internet. For recently discovered objects of unusual interest, MPC, the Jet Propulsion Laboratory and the centre in Pisa would often alert observers that additional future or pre-discovery observation data were needed.

24. The Action Team noted that the Sentry System and NEODyS were completely independent systems that employed different theoretical approaches to providing impact risk assessments. Hence, if the long-term orbit propagations from each converged upon a single solution, the wider community could have some confidence in the predicted outcome. As with the operation of MPC, the Action Team considered that a capability that was independent but complementary to the Sentry System was critical for the purposes of independent verification and validation of predicted close approaches.

25. The Action Team was informed that, within the ESA technology programme, a number of activities were ongoing that were relevant to the NEO topic. One of them was the planetary database, covering planets, moons and small bodies of the solar system. The database had been modified to serve as the backbone of the newly established ESA Space Situational Awareness NEO data centre on precursor services, which provided information about the impact risk of NEOs (see http://neo.ssa.esa.int).

26. Having recognized the critical role that MPC played and the fact that the Planetary Science Division of NASA was continuing to fund its operations and upgrades, the Action Team noted with satisfaction the progress currently being made by the ESA space situational awareness programme in establishing firm funding for the NEODyS service, the physical properties database and the European Asteroid Research Node of the German Aerospace Centre (DLR) in Berlin and the ESA Spaceguard Central Node, which provided a "priority list" for observations of NEOs. Those services were now part of the precursor services of ESA.

D. Consequence determination

27. The Action Team recognized that, in considering a science-based policy to address the risk posed by NEOs, it is important for Governments to evaluate the societal risk posed by such impacts and to compare those risks 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 felt that more work needed to be done in that area, especially on impactors of less than 1 kilometre in diameter. The issue was discussed in detail at the Tunguska Conference, held in Moscow in June 2008, hosted by the Russian Academy of Sciences. The 1908 Tunguska airburst from a small asteroid had generally been estimated to have had an energy of 10-15 megatons. The corresponding size for a rocky impactor was roughly 60 metres in diameter. The Action Team noted that new supercomputer simulations developed at Sandia National Laboratories (United States) required less energy in the explosion because of the inclusion of a substantial downward momentum of the rocky impactor, rather than modelling it as a stationary explosion. If that revision (down to an estimated energy of 3-5 megatons and a corresponding diameter of perhaps as little as 40 metres) was correct, the expected frequency of such impacts would change from once every couple of millenniums to once every few hundred years, with consequent implications for hazardous impact event statistics. At present, less than 2 per cent of the population of NEOs that were between 30 and 300 metres in diameter was known. The Action Team welcomed the fact that further scientific and technical results would be presented at the 2013 Planetary Defense Conference of the International Academy of Astronautics, to be held in Flagstaff, Arizona (United States) in April 2013.

28. The Action Team considered as timely an international initiative on the construction of a databank of asteroid impact consequences, e.g. geographical or economical. The initiative had been launched at the Action Team meeting in Vienna in February 2012. The databank was considered to be similar to those elaborated or under development for tsunami and climatic hazards in various countries.

E. In situ characterization

29. The Action Team noted the importance of the Hayabusa (MUSES-C) mission, which had rendezvoused with the near-Earth asteroid 25143 Itokawa in late 2005 and provided scientific knowledge on the characteristics of the asteroid, such as topography and composition. The mission had also provided important operational lessons that had been learned from rendezvous and proximity operations in a very low-gravity environment. Those lessons had implications for future in situ investigations and possible mitigation activities. Hayabusa followed a long line of successful missions, such as Near Earth Asteroid Rendezvous, Deep Space 1, Stardust and Deep Impact, which had provided unique insights into the characteristics of the surprisingly diverse population of NEOs. Detailed NEO characterization could not be derived from remote observations. The Action Team noted that the asteroid sample capsule of the Hayabusa spacecraft had returned to Earth on 13 June 2010 and that the materials brought back had been analysed by the initial analysis team of the Hayabusa project. The first announcement of opportunity

for Hayabusa sample research had been issued by JAXA in January 2012. As a result of that announcement, 17 out of 31 research proposals had been accepted. Now JAXA was preparing for the second announcement of opportunity, which was scheduled for January 2013. The results of Hayabusa were important not only for science, but also for Spaceguard, since Itokawa was the type of asteroid that might approach the Earth closely. In addition, JAXA was now preparing the next sample-return mission from an NEO of a different type than Itokawa. That new mission, named Hayabusa-2, had started in May 2011. It would be launched in 2014, and would arrive at the target NEO in 2018. It would return to Earth in 2020.

30. The Action Team was encouraged by the news that, in June 2010, the Space Council of the Russian Academy of Sciences and Roscosmos had agreed on a coordinated and comprehensive response to the asteroid and comet impact hazard problem. A feasibility study for a low-cost space mission to a selected asteroid (Apophis had originally been considered) after 2020 had been initiated. The major goal of the mission was to put a transponder in a circum-asteroid orbit, thereby improving the accuracy of the asteroid orbit determination. ESA had concluded three parallel industrial studies for a sample-return mission from an NEO called Marco Polo. NASA had funded the participation of a United States science team in that study. ESA had launched a new mission study, called MarcoPolo-R, which was a follow-up to Marco Polo, to continue studying an asteroid sample-return mission with a possible launch date between 2020 and 2024. The study was part of the Cosmic Vision programme of ESA. NASA had approved a sample-return mission to a C-type near-Earth asteroid, 1999 RQ36. That mission had been named the Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer, or OSIRIS-REx. The launch was planned for September 2016, with an arrival at the asteroid in October 2019 and a sample return to Earth in September 2023. The preliminary design phase of OSIRIS-Rex was scheduled to be completed by summer 2013.

F. Mitigation

31. Mitigation in the present context was the process of either negating or minimizing the impact hazard posed to Earth by the subclass of NEOs called “potentially hazardous objects”, either 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.

32. The Action Team noted that, in addition to the probability of impact and the time to impact, other parameters that would influence the response strategy would be the anticipated locus of possible impact points on the surface of the Earth and the vulnerability of that area to the impact. The various options for deflection and the implications (technical readiness, political acceptability, cost of development and operation and translation of the locus of possible impact points) of a particular deflection strategy would also have to be weighed against the alternatives. The Action Team acknowledged that it was possible that a specific impact might threaten only non-spacefaring nations and that the threat would need to be addressed internationally. It might be considered more attractive for one capable actor to take the lead in mounting a particular deflection mission, rather than a group of agencies 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 range of options, with agreed responses to a range of impact scenarios and with identified players performing specific roles. In that respect, the Action Team had identified the need for an international technical forum wherein a range of probable impactor scenarios could be determined and a corresponding matrix of mitigation options developed to a level of maturation to permit reliable mission timelines to be mapped onto a decision timeline for the international community in response to a specific threat. Further, the Action Team considered that the current state of knowledge provided an inadequate basis on which to decide the relative effectiveness of different mitigation strategies, recognizing that while the Deep Impact mission had demonstrated some elements of kinetic deflection, the deflection was not measurable, owing to the size of the target comet (6 kilometres in diameter) and the effects of cometary outgassing. Accordingly, the Action Team considered that a true demonstration of kinetic deflection remained to be done, that the development and execution of mitigation test missions were prudent and top-priority goals for the near future and that those tasks should be carried out with international participation.

33. The Action Team further noted that the Seventh Framework Programme of the European Commission had included a call for proposals issued on 20 July 2010 with the title "Prevention of impacts from Near-Earth Objects on our Planet". In the call for proposals, consortia, which were encouraged to include partners from major non-European-Union space-faring states such as the Russian Federation and the United States, were invited to design projects addressing the impact hazard and mitigation techniques. The Action Team noted with satisfaction that the selected project, entitled NEOShield, involved 13 governmental and non-governmental partners from France, Germany, the Russian Federation, Spain, the United Kingdom of Great Britain and Northern Ireland and the United States, and was being coordinated by the DLR Institute of Planetary Research in Berlin. The NEOShield workplan included research into the mitigation-relevant physical properties of NEOs, the observational techniques required to efficiently gather mitigation-relevant data, laboratory investigations using gas guns to fire projectiles into asteroid regolith analog materials, computer simulations to investigate how an NEO would respond to a pulse of energy applied in a deflection attempt, and technical and engineering studies of practical means of deflecting NEOs with current technology. NEOShield was aimed at providing detailed designs of feasible mitigation demonstration missions, targeting NEOs of the kind most likely to trigger the first space-based mitigation action. A further goal of the project was to formulate a global impact-hazard response campaign road map. Overall, funding of €5.8 million for a project lifetime of three-and-a-half years starting in January 2012 had been approved.

34. The Action Team welcomed the work of SGAC and its recognition of the importance of the International Year of Astronomy in serving as a framework to raise awareness about NEO issues among the public and, in particular, young people. Among its initiatives, the Move an Asteroid technical paper competition, held annually since 2008, had focused on NEO detection, deflection methods and warning systems. The entries were reviewed by experts, and the winner of the competition was awarded a trip to present his or her paper on a novel deflection method at the Council's annual Space Generation Congress and at the International Astronautical Congress. The Council intended to continue raising awareness and

involving young people in the NEO field, as well as to inform them about current issues, such as the work of the Action Team.

G. Actual Near-Earth Object Threat Assessments

35. It was instructive for the Action Team to review a few examples of NEO threat assessments made in recent years. Three real-world scenarios were presented: the cases of asteroids Apophis; 2008 TC3; and, more recently, 2011 AG5.

36. Apophis was one of the celestial bodies that had captured the public's interest since it was discovered to be in a hazardous orbit in 2004. The asteroid was approximately the size of two-and-a-half football fields. Initially, Apophis was thought to have a 2.7 per cent chance of impacting Earth in 2029. Additional observations of the asteroid allowed NASA scientists at the Jet Propulsion Laboratory to recalculate its path and rule out any possibility of an impact in 2029. The refined path also indicated a significantly reduced likelihood of a hazardous encounter with Earth in 2036. Updated computational techniques and newly available data indicated the probability of an Earth impact on 13 April 2036, for Apophis had dropped from one-in-45,000 to about four-in-a million. Nevertheless, the asteroid was expected to make a record-setting, but harmless, close approach to Earth on 13 April 2029, when it would come no closer than 18,300 miles above the Earth's surface. A majority of the data that had enabled the updated computation of the orbit of Apophis had come from observations Dave Tholen and collaborators at the University of Hawaii (United States) Institute for Astronomy in Manoa had made with the university's 88-inch telescope, located near the summit of Mauna Kea. Tholen had made improved measurements of the asteroid's position in the images, enabling him to provide the Jet Propulsion Laboratory with new data sets that were more precise than previous measures for Apophis. Measurements from the Steward Observatory's 90-inch Bok telescope on Kitt Peak in Arizona and the Arecibo radar observatory on the island of Puerto Rico were also used in the calculations. The information provided a more accurate glimpse of the orbit of Apophis well into the latter part of the twenty-first century. Among the findings was another close encounter by the asteroid with Earth in 2068, with the chance of impact currently at approximately three in one million. As with earlier orbital estimates, in which Earth impacts in 2029 and 2036 could not initially be ruled out, owing to the need for additional data, it was expected that the 2068 encounter would diminish in probability as more information about Apophis was acquired.

37. The Action Team was particularly encouraged to note how effectively the asteroid impact detection process outlined in section II.C above had been implemented in the discovery and subsequent impact of 2008 TC3. That very small object (of about 3 metres in diameter) had been discovered by the United States Catalina Sky Survey team just 20 hours before it had entered the Earth's atmosphere on 7 October 2008. Within eight hours of collection of the discovery observations, MPC had identified the object as a potential impactor and alerted both NASA headquarters and the NASA Jet Propulsion Laboratory. While MPC requested follow-up from all available observers and the Jet Propulsion Laboratory produced more precise predictions and compared results with NEODyS, NASA headquarters started the actions required to alert the global community to the impending impact. During the subsequent 12 hours, the worldwide NEO network provided MPC with

589 observations from 27 different observers. On the basis of the precise predictions provided by the Near-Earth Object Program Office at the Jet Propulsion Laboratory, NASA provided information for public release and dissemination via diplomatic channels to the effect that the entry would take place over northern Sudan on 7 October 2008 at 0246 hours UTC. Released six hours in advance, the information was accurate to within two seconds of the entry observed by meteorological satellites and detected by infrasound sensors.

38. Of more recent note was near-Earth asteroid 2011 AG5, a potentially hazardous asteroid discovered by the NASA-supported Catalina Sky Survey on 8 January 2011. Owing to the limited observations collected on that object to date, within the current uncertainty of the asteroid's predicted orbit positions was a 0.2 per cent chance the asteroid could impact the Earth in February 2040. Should such an impact occur, the estimated 140-metre asteroid could create an energy release roughly equal to 100 megatons of TNT. The 2040 impact would occur only if the asteroid first passed through a 365-km region in space, called a keyhole, as it passed within a few million kilometres of Earth during February 2023. There was likewise only a 0.2 per cent chance of that occurring, given current understanding of its orbit. The asteroid was currently unobservable, as it was in the daytime sky, but once it became easily observable again in fall 2013, the data expected to be collected would improve the computation of its orbit and could drop the position uncertainty at the 2040 Earth encounter from its current area of over 200 Earth diameters down to two or three Earth diameters. Additional observations expected in the period 2015-2020 could reduce that uncertainty further. Observations of the asteroid before fall 2013 would be useful, but the object was small and distant and would spend much of the time until then on the opposite side of the Sun. Only the largest ground and space telescopes had even a fleeting opportunity to observe it. Using observations gathered in fall 2013 to improve computation of the orbit of 2011 AG5 had a 95 per cent chance of eliminating the 2040 impact scenario, while further observations in 2015 and 2016 could drive that to ~99 per cent eliminated. On the other hand, in the very unlikely event that the asteroid was actually on an Earth-impacting trajectory, the 2013 observations could find the computed impact chance rising to between 10 and 15 per cent, and the observations in 2015 and 2016 could find it rising further, to ~70 per cent. Only additional observations in 2013 and 2015 would increase the accuracy of those predictions.

H. Policy development

39. The Action Team recognized that the threat of impact posed by NEOs was real and that any such impact, although its probability was low, was potentially catastrophic. It was also recognized that the effects of such an impact would be indiscriminate (that is, they might not be confined to the country of impact) and that the scale of those effects was potentially so great that the NEO hazard should be recognized as a global issue that could be addressed effectively only through international cooperation and coordination. Thus, the United Nations had an important role to play in the process of developing the necessary policy.

40. A further challenge for the global community was that it would likely be confronted in the next 15 years with a perceived impact threat (although it would most likely turn out to be a near miss), making it necessary to push forward to

critical decisions about whether and what action should be taken to protect life on Earth from a potential NEO impact before the reality of the threat was completely understood. That was because of the accelerating discovery of the population of NEOs and the evolution of human capability to intervene in an anticipated impact by deflecting the NEO. The probability of the spacefaring nations having to decide between action and non-action was further heightened by the likely necessity of having to decide prior to the availability of certain knowledge that an impact would or would not occur. The need for decision-making could therefore be significantly more frequent than the incidence of impacts. Given early warning that a possible impact was predicted and knowing that a deflection capability existed to prevent the impact from occurring, humankind could not avoid responsibility for the outcome of either action or inaction. Since the entire planet was subject to NEO impacts and since the process of deflection might intrinsically result in a potential, but temporary, increase of risk to populations not initially at risk, the United Nations could be called on to facilitate the global effort to evaluate trade-offs and arrive at decisions on what actions to implement collectively.

41. Having recognized the need to advance the NEO decision-making process, the Committee on Near-Earth Objects of the Association of Space Explorers concluded, in September 2008, a series of international workshops and transmitted its widely anticipated report to the Action Team (see A/AC.105/C.1/L.298, annex). The Action Team welcomed that important contribution to a possible NEO policy framework and recognized its value in informing the workplan of the Working Group on Near-Earth Objects in its review of potential policies related to the handling of the NEO hazard and its consideration of drafting international procedures for handling such a threat.

42. The Action Team met during the forty-sixth session of the Scientific and Technical Subcommittee, in February 2009, to review the report of the Association of Space Explorers with a view to developing draft international procedures for handling an NEO threat. The Action Team completed a first review of the document during the fifty-third session of the Committee on the Peaceful Uses of Outer Space, in June 2009, and included the first draft of the international procedures in the annex to its interim report to the Subcommittee (A/AC.105/C.1/L.301). In February 2010, the Working Group reviewed the draft procedures during the forty-seventh session of the Subcommittee. At that session, the Working Group heard statements on the report entitled "Legal aspects of NEO threat response and related institutional issues", prepared by the University of Nebraska-Lincoln (United States), in which key legal and institutional issues linked to potential future threats posed by NEOs were examined. The Working Group was also informed about a workshop on the establishment of an NEO information, analysis and warning network, organized by the Association of Space Explorers and the Secure World Foundation, with support from the Regional Centre for Space Science and Technology Education for Latin America and the Caribbean, and held in Mexico City in January 2010.

43. In its report to the Subcommittee (A/AC.105/958, annex III, paras. 5 and 7), the Working Group agreed that the executive summaries of the Mexico City workshop and of the report prepared by the University of Nebraska-Lincoln could be considered by the Action Team between the sessions to be held in 2010 and 2011 and that intersessional work for the period 2010-2011 could include workshops involving experts in various subjects related to the draft recommendations made by

the Action Team. The Action Team met during the fifty-third session of the Committee, in June 2010, and considered the executive summaries referred to above. The Secure World Foundation, the Association of Space Explorers and ESA sponsored a workshop entitled "NEO Mission Planning and Operations Group", which was held in Darmstadt, Germany, from 27 to 29 October 2010 to address NEO deflection mission campaign planning and operations. The executive summary of that workshop was provided to the Action Team. The interim report of the Action Team for 2010-2011 (A/AC.105/C.1/L.308), including the draft recommendations for an international response to the near-Earth object impact threat, contained information resulting from the intersessional work summarized above.

44. At its fifty-fourth session, in June 2011, the Committee endorsed the recommendations of the Scientific and Technical Subcommittee and of its Working Group on Near-Earth Objects (A/AC.105/987, annex III, para. 10) that the Action Team should be tasked with continuing its work on the draft recommendations for an international response to the near-Earth object impact threat. The Committee also endorsed the recommendation that intersessional work to be carried out in the period 2011-2012 could include workshops held under the auspices of the Action Team that would gather experts on various aspects of the draft recommendations made by the Action Team, and meetings of experts, which could facilitate the establishment of a mission planning and operations group. A meeting of representatives of space agencies was held on the margins of the fifty-fourth session of the Committee to consider intersessional work in the period 2011-2012.

45. In accordance with the intersessional work during 2011 and 2012, as endorsed by the Committee, the Workshop on International Recommendations for NEO Threat Mitigation was organized by the Action Team in Pasadena, California (United States), on 25 and 26 August 2011. The Workshop received substantive support from the NASA Near-Earth Object Program and financial support from the Secure World Foundation. The Workshop addressed key issues related to the response and cooperation that would be needed by a mission planning and operations group in preparing for a possible NEO impact threat to Earth. The main outcomes of the workshop were a first draft of the terms of reference for a space mitigation mission planning group, which would be an essential part of the overall NEO threat mitigation system. The results of the workshop would be included in an updated version of the interim report of the Action Team that would be submitted to the Scientific and Technical Subcommittee at its forty-ninth session. The Action Team also agreed that its interim report would be separated into two reports: "Near-Earth objects, 2011-2012: interim report of the Action Team on Near-Earth objects" (A/AC.105/C.1/L.316), covering activities and issues relating to the NEO hazard, the current understanding of the risk posed by NEOs and the measures required to mitigate that risk; and "Near-Earth objects, 2011-2012: draft recommendations of the Action Team on Near-Earth Objects for an international response to the near-Earth object impact threat" (A/AC.105/C.1/L.317).

46. On 14 and 15 November 2011, a meeting of the Working Group on Media Communications and Risk Management was held at the Laboratory for Atmospheric and Space Physics at the University of Colorado Boulder (United States). The event was co-sponsored by the Secure World Foundation and the Association of Space Explorers. The Working Group, comprising reporters, media specialists and risk management experts, convened to discuss how best to inform the public of the threat

of an NEO impact in a way that would avoid misinformation and to help provide guidance on the development of an outreach and education plan that would foster accurate and timely information about the possible effects of a potentially hazardous NEO. The "Near-Earth Object Media/Risk Communications Working Group Report" was provided to the Action Team for its consideration and was available on the Secure World Foundation website.[5]

47. Following the proposal by the Action Team and the Working Group on Near-Earth objects at their meetings during the forty-ninth session of the Scientific and Technical Subcommittee, NASA had organized a workshop on 29 May 2012 to provide information on the international analysis of the potentially hazardous asteroid known as 2011 AG5. The Action Team was informed of the current knowledge, summarized in paragraph 38 above, on that asteroid.

48. The second meeting of the representatives of space agencies was held on the margins of the fifty-fifth session of the Committee on the Peaceful Uses of Outer Space, on 8 June 2012, to discuss the draft terms of reference for the establishment of a mission planning and operations group, as recommended by the Action Team in document A/AC.105/C.1/L.317. Intersessional work on the draft terms of reference would continue in 2013, with a view to finalizing them by the fifty-first session of the Scientific and Technical Subcommittee.

49. On 15 November 2012, representatives of elements which could form an international asteroid warning network (IAWN) held a teleconference to review the recommendations presented by the Action Team with regard such an international network. The participants found that many of the functions contained in the recommendations were already being performed by either elements of the NASA NEO Program or by the Space Situational Awareness Initiative of ESA. However, the participants found that those efforts could be more closely coordinated and some areas for better characterization of potentially hazardous objects were currently lacking adequate support and visibility. Participants also agreed to work towards the establishment of an international steering group to help coordinate, encourage and advise on further efforts in that area.

50. The near-Earth object impact hazards, current activities and future plans were addressed in a special session at the twenty-eighth General Assembly of IAU, held in Beijing from 20 to 31 August 2012, organized by the IAU Division III Working Group on Near-Earth Objects, covering astronomical aspects of the hazards of NEOs (see http://adams.dm.unipi.it/iausps7). The IAU General Assembly also adopted resolution B3 on the establishment of an international NEO early warning system, as proposed by the IAU Division III Working Group on NEOs.[6]

51. A review of the draft terms of reference of a mission planning and operations group was planned for February 2013 on the margins of the fiftieth session of the Scientific and Technical Subcommittee.

52. The recommendations of the Action Team for an international response to the near-Earth object impact threat, for consideration by the Subcommittee at its fiftieth session, were contained in document A/AC.105/C.1/L.329.

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[5] See http://swfound.org/news/all-news/neo-mediarisk-communications-working-group-report.

[6] Available from info.bao.ac.cn/download/astronomy/IAU2012/newspaper/IHissue09.pdf.