Space Mission Planning Advisory Group

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Work Plan

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Definitions and Hierarchy of Activities

The term 'Activity' is used as a general term describing tasks, subtasks and any additional work needed to fulfill the work plan without implying any hierarchy.

The activities outlined in this plan constitute a work programme.

The work programme consists of different tasks as described in section 5 of this document.

Each task may be comprised of several subtasks.

Actions are specific activities of limited scope with well-defined actioners, and timeline.

Tasks and subtasks will be divided up among the programme participants and executed as projects.

Projects will be carried out using the project management methodology of the organizations in charge of the various projects.

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1 Executive Summary

This Work Plan introduces the collective efforts of the Members of the Space Mission Planning Advisory Group (SMPAG) to prepare to meet the threat to our planet by hazardous Near Earth Objects (NEOs) through the definition and implementation of appropriate mitigation strategies. The goal is the global protection of the ecosystem, of human beings and their properties on Earth, and of the civilisation of humankind.

2 Abbreviations and Acronyms

ASE	Association of Space Explorers
ASI	Agenzia Spaziale Italiana
AT-14	Intersession Action Team No. 14 of the COPUOS
CCB	Configuration Control Board
CNES	Centre National d'Etudes Spatiales
COPUOS	Committee for the Peaceful Uses of Outer Space (United Nations)
CSA	Canadian Space Agency
CNSA	Chinese National Space Agency
DART	Double Asteroid Redirection Test
DLR	Deutsches Zentrum für Luft- Und Raumfahrt
ESA	European Space Agency
ESO	European Southern Observatory
ESOC	European Space Operations Centre (ESA)
ESRIN	European Space Research Institute
FEMA	Federal Emergency Management Agency (US)
GA	General Assembly (UN)
GSFC	Goddard Space Flight Center (NASA)
HST	Hubble Space Telescope
IAC	International Astronautical Congress
IAU	International Astronomical Union
IAWN	International Asteroid Warning Network
JAXA	Japanese Space Agency
LEO	Low Earth Orbit
MOID	Minimum Orbit Intersection Distance
MPC	Minor Planet Center
NASA	National Aeronautics and Space Administration
NEO	Near Earth Object
NGO	Non-Government Organization
PHO	Potentially Hazardous Object
S/C	Steering Committee
SGAC	Space Generation Advisory Council
SMPAG	Space Mission Planning Advisory Group
SWF	Secure World Foundation
STSC	Scientific and Technical Subcommittee of COPUOS
ToR	Terms of References
UN	United Nations
VIC	Vienna International Centre

3 Purpose and Scope

SMPAG Objectives as per Terms of Reference:

> The purpose of the SMPAG is to prepare for an international response to a NEO impact threat through the exchange of information, development of options for collaborative research and mission opportunities, and NEO threat mitigation planning activities.

The ToRs identified four main work areas with a total of 13 specific issues to be addressed by SMPAG. This document defines different specific SMPAG tasks in terms of scope, content and schedule which have been identified to meet the scope of the SMPAG ToR. It also assigns responsibility for the different work areas to individual organisations.

This Work Plan defines, at the highest level, the interdependence of the individual tasks. It will include all planned, on-going, and completed activities. It will serve as a tool for the SMPAG Steering Committee to check on the progress of the overall effort for the purpose of reporting to the relevant organizational bodies.

This document is not a full management plan, as it is understood that the activities will be implemented on voluntary and non-binding basis. However, it is expected that participating organisations adhere to the plan. If this should turn out to be impractical for any reason it is imperative that the SMPAG S/C be notified as soon as possible.

4 Applicable Documents

4.1 <u>Binding Documents</u>

Terms of Reference for the Near-Earth Object threat mitigation Space Mission Planning Advisory Group, V 1.0, 5 February 2015

4.2 <u>Reference Documents</u>

A/68/20: Report of the Committee on the Peaceful Uses of Outer Space, Fifty-sixth session (2013)

A/69/20: Report of the Committee on the Peaceful Uses of Outer Space, Fifty-seventh session (2014)

Final report of the Action Team on Near-Earth Objects (A/AC.105/C.1/L.330)

Recommendations of the Action Team on Near-Earth Objects for an international response to the NEO impact threat (A/AC.105/C.1/L.329)

A/RES/68/75 General Assembly Resolution on International cooperation in the peaceful uses of outer space

5 Activities Overview

The following activities are the result of discussions in SMPAG. They are not exhaustive and not in order of importance or priority. Several activities should be performed in close collaboration with the IAWN.

5.1 CRITERIA AND THRESHOLDS FOR IMPACT THREAT RESPONSE ACTIONS

5.1.1 Lead

- NASA
- Support by IAWN

5.1.2 Rationale

The establishment of criteria and thresholds is a key element for determination of when real-world NEO detection and characterization events will trigger required actions for both SMPAG and IAWN (and across the two groups), as well as activate necessary interface with emergency management officials and government leaders.

5.1.3 Activity Description

The purpose of this task is to develop agreement among the SMPAG members, in close collaboration with IAWN, on what real-world scenarios represent a credible impact threat, as defined by specific criteria, and therefore deserve increased attention and action beyond the normal course of daily activities.

Collaborate with the IAWN Steering Committee to develop a set of criteria, based on observable parameters and characteristics of a NEO impact risk, to be used to establish thresholds for action.

The criteria may be graduated based on orbit-related parameters that determine probabilities for impact and estimated physical characteristics of the object of interest, among other things. The crossing of a threshold would trigger a specific set of actions by IAWN, SMPAG and other identified entities to begin work on preparations and recommendations for an actual, real-world, mitigation campaign. The thresholds might also be graduated, and actions could involve, on the part of IAWN, increased focus on observations of the object of interest and tasking additional assets to assist with observations, while SMPAG could begin working with specific space-capable entities to define a viable set of mitigation campaign activities to adequately address the real-world scenario.

5.1.4 Schedule

- 2015 SMPAG: Define initial conditions, study scenarios, and task schedule
- 2016 SMPAG: Present preliminary study results
- 2017 SMPAG: Submit final report

5.1.5 Output

A Summary Report that includes threshold criteria to address potential real-world scenarios in the event of an imminent asteroid impact.

5.2 MITIGATION MISSION TYPES AND TECHNOLOGIES TO BE CONSIDERED

5.2.1 Lead

- UKSA
- Support by ESA, ROSA
- Input from NEOShield

5.2.2 Rationale

There are two primary ways to mitigate impact of potentially hazardous Near Earth Object (NEO), the first is to modify the trajectory of the object so that it does not collide with the Earth, the second is to modify the object by breaking it up so that the resulting fragments do not collide with the Earth or their smaller size reduces the subsequent hazard posed to the Earth. There are further sub-categories of these techniques depending on the extent of the energy involved and associated timeframe, and also combinations therefore. A comprehensive and coherent set of potential mitigation solutions presents the mission planner with a range of possible options should an impact threat be identified.

5.2.3 Activity Description

To identify and categorise the different planetary defence mitigation mission types and technologies that have a potential role to play in addressing the impact threat from a potentially hazardous NEO.

Conduct a comprehensive survey of the possible planetary defence mitigation missions and their associated technologies in order to consider the procedure for both planning a mission to negate the threat posed by a potentially hazardous NEO but also to identify the critical technologies required to be at a necessary level of technology readiness should a mitigation mission be required at relatively short notice and to prioritise technology demonstration opportunities as they arise.

Development of a consistent taxonomy and categorisation of the suite of potential impact mitigation missions and identification of the key/critical technologies/techniques required to deliver mission assurance of the required planetary defence objectives.

5.2.4 Schedule

April 2016 Define NEO threat cases and preliminary reference mission for each scenario
August 2016 Present a set of reference mission study results
April 2017 Submit the final report

5.2.5 Output

Taxonomy and description of mitigation missions and associated technologies

5.3 MAPPING OF THREAT SCENARIOS TO MISSION TYPES

5.3.1 Lead

- ESA
- Support by ASI, UKSA

5.3.2 Rationale

In task 'Reference missions for different NEO threat scenarios' a set of representative reference space missions addressing a variety of potential NEO impact scenarios and deflection/disruption possibilities will be defined. These missions may be of different type depending on the physical, dynamical and orbital parameters of the object.

Deflection missions all aim at transferring impulse to the object in a direction along or opposite to the object velocity. This slightly changes its orbital period and initiates a drift so that as time goes on the along track location of the object in its orbit will deviate more and more form the location of the non-deflected orbit. A collision with the earth is avoided if the shift in location is sufficiently large at the time of the original encounter. A long drift period between deflection and earth encounter is needed for this.

The fastest deflector is the kinematic impactor, which transfers the impulse by hitting the object with a high velocity of several km/s.

A gravity tractor performs a rendezvous with the object, positions itself behind or in front of the object and counteracts the small gravity attraction of the object with electric propulsion. The inverse gravity force is acting on the object along its velocity, which changes its period. Due to the small gravity forces involved and the large impulse transfer needed, a long rendezvous period is needed in addition to the long drift period before earth encounter.

Attaching a S/C to the object can also transfer the impulse. The S/C then rotates with the object and activates its electric propulsion engine occasionally when it is in the direction opposite or along the object velocity. Also here, a long thrust phase is needed.

Other reference missions may be in-situ observation missions, which perform a rendezvous with the object to characterize its properties and in particular its orbit. Radiometric data from a S/C orbiting the object provide a much better knowledge of the object orbit than earth or space based long distance optical measurements. This allows to narrow down the uncertainty associated with the encounter of the earth.

The objective of the current task is to establish decision points and event timelines for these reference missions. Typical question that have to be answered are:

- Optimal time slots for launch and deflection
- Latest time for launch and deflection
- Observation periods allowing to reduce impact uncertainty
- Opportunities for implementing in-situ observation missions

5.3.3 Activity Description

To achieve the objective, a high level design of the launch, transfer trajectories and the impulse transfer is needed. This information will be collected from available study results and complemented with additional study work. The information will contain, timeline of events (launch, arrival at object, duration of impulse transfer phase and drift phase), launch data (injection orbit, performance), transfer trajectories, arrival conditions at the object (velocity and sun phase angle at approach), S/C propulsion and fuel needs.

The design will be parametric, as it depends on many object characteristics and selectable mission parameters. The major ones are the properties of the object like its perihelion and aphelion distance, its inclination, its mass and the time left to collision. Other ones are the assumed launcher performance and electric propulsion system and fuel characteristics.

5.3.4 Schedule

In a first phase this activity will be performed for the kinetic impactor mission assuming ballistic and chemical propulsion transfers and considering Earth planetary gravity assist only. This should be completed by end 2015.

2015 SMPAG : Completion of first phase

2016 SMPAG: Interim report

2017 SMPAG: Final report

5.3.5 Output

High level, parametric design report for the reference missions and decision rules derived from this reports.

5.4 REFERENCE MISSIONS FOR DIFFERENT NEO THREAT SCENARIOS

5.4.1 Lead

- ASI
- Support by ESA, UKSA
- Input from NEOShield

5.4.2 Rationale

- For a real impact threat, time is too short to work out details
- The reference mission will allow to define what is still needed
- Allow testing existing capabilities and mission feasibility
- In compliance with the SMPAG mission statement, in case of a NEO threat confirmation (IAWN as the recognized authority), SMPAG shall be capable of identifying the "suitable" reference mission providing the most effective response.

5.4.3 Activity Description

The first step is to define a number of typical NEO threat cases on the basis of relevant parameters such as time to closest approach, material characteristics (e.g. mass, porosity, density etc.), and dynamical properties (e.g. orbit, spin, etc.). For each case, a reference mission shall be identified and evaluated in order to select the "best" strategy that would imply a deflection of the NEO, rather than its disruption.

These reference missions shall be developed in accordance with the criteria and constraints defined preliminarily (e.g. time between the impact alert and the launch window opening, object dimensions, etc.).

Several deflection strategies have been proposed:

- Use of a kinetic impactor hits the asteroid by imparting a sufficient linear momentum to the center of gravity of the celestial body;
- Use of a spacecraft, equipped with advanced electrical low-thrust engines, grabs/anchors the asteroid and provides sufficient delta-velocity, adapting the thrust direction to avoid rotational effects;
- Use of a massive spacecraft hovering the asteroid gravitationally tows the celestial body (gravity tractor);
- Use of the thermal force acting on the asteroid due to the Yarkovsky effect, by artificially heating locally its surface (e.g. by use of laser beams or concentrated solar power);
- Use of a combination of the above actions.

In order to get significant advances in the verification of the technical feasibility of a deflection strategy for the reference missions, an in-space demonstration that includes rendezvous, capture or a kinetic impactor test shall be properly investigated.

In fact, deflecting an asteroid trajectory is not necessarily a valid strategy if the technology maturity does not guarantee a very accurate control on the magnitude and direction of the imparted delta-velocity.

On the other side, the strategy of disrupting an asteroid, unless one has a very realistic modelling and good knowledge of the size of the resulting pieces, does not necessarily decrease the damage, or at least not enough.

The expected outcome of the establishment of the criteria and thresholds is also the definition of the ranges of the *n* selected parameters characterizing the NEO impact threat (e.g. mass=[min; max]; velocity=[min; max]; time-to-closest-approach=[min; max]; Center of Impact Point on Earth, etc…).

Input:

- A combination of the values of the above parameter determines a specific threat case (defined as scenario);
- A set of representative scenarios shall be defined.

Task: to define a feasible and effective mission for a specific scenario (reference mission). Effective means capable of mitigating the threat; feasible means compliant with all kind of constraints, not only in a technical and programmatic framework. In fact, for each reference mission political and financial implications shall be investigated and considered as constraints in the risk mitigation analysis (e.g. use of ICBMs or nuclear warheads for some tests in space; etc. not limited to the task 'Study of the nuclear device option')

5.4.4 Schedule

2016 SMPAG: Define NEO threat cases and preliminary reference missions for each scenario

2017 SMPAG: Present a set of reference mission study results

5.4.5 Output

- List of reference missions
- Phase 0 study of each reference mission (team composed by SMPAG members) that includes:
    - Mission timeline
    - Mission Design & development planning
    - Costs (recurring and non)
    - Technology mapping (TRL)
    - Technical performance and options
    - Demonstration tests (on ground qualification / in-orbit validation)
    - Precursor missions or studies (e.g. ARM-like missions, DART-like missions)

5.5 A PLAN FOR SMPAG ACTION IN CASE OF A CREDIBLE THREAT

5.5.1 Lead

- NASA
- Support by IAA

5.5.2 Rationale

Potential failures due to human error, hardware failure, software errors, and other factors must be considered in the overall planning of a deflection campaign. As a result, no single launch vehicle or payload will have sufficient reliability for this critical mission--multiple launch sites, launch vehicles and payloads, possibly from several nations, must be made available to increase the probability of success. In addition, such an effort will have unprecedented attention from the public and world leadership. Marshaling necessary resources will require space agencies to work together to understand the details of the threat, to develop an agreed and coordinated course of action, and to execute a successful deflection campaign.

5.5.3 Activity Description

SMPAG will develop a Planetary Defense Action Plan (PDAP) to define how SMPAG members will work together to understand the nature of the threat, develop basic goals of a deflection or disruption campaign, and develop an agreed course of action in response. The plan will consider approaches for two basic scenarios: a short warning event, where a response must be mounted quickly, demanding use of existing launch vehicle and payload resources, and a longer-range threat where resource demands are not immediate. The plan will include:

- Identification of launch site, launch vehicle, payload hardware, and other critical resources required for a deflection campaign
- Timeline for the response effort, including critical milestones and decision points
- Technology readiness level of required systems
- Approach for authorizing and coordinating a multi-nation cooperative effort
- Recommendations for assuring open communication and transparency on the development and execution of the threat response
- Information that each participating agency should maintain on availability of resources that might be used in a deflection campaign

- Identification of and contact information for individuals to be notified of a credible threat
- Possible impediments to timely and effective action and potential remedies

5.5.4 Schedule

February 2016	Discuss proposed concept; delegations suggest revisions for discussion at next meeting of SMPAG.
November 2016	Present draft outline of Planetary Defense Action Plan; discuss fictional test case(s) and process for developing international response. Each delegation to hold internal discussions on suggestions for international response to first test case.
February 2017	Delegations present results of internal discussions on international response.
November 2017	Second draft of PDAP presented for review.
February 2018	Version 1 of PDAP presented to STSC of UNCOPUOS.

5.5.5 Output

Planetary Defense Action Plan

5.6 COMMUNICATION GUIDELINES IN CASE OF A CREDIBLE THREAT

5.6.1 Lead

- NASA
- Support by IAWN, UNOOSA, ESA

5.6.2 Rationale

For potential asteroid impact threats it is essential that communications be clear, correct, consistent, and concise. The development of communication guidelines will help provide a template that IAWN and SMPAG can quickly reference. The guidelines are intended for use by members of SMPAG on the nature of, and methods for, communicating to the public and governmental decision makers.

5.6.3 Activity Description

This task is closely related to and follows the task 'Criteria and thresholds for impact threat response actions'. However, this task is an effort to engage a broader audience and effectively communicate the nature of a predicted impact threat beyond the expert community.

Develop agreement on guidelines to be used by members of SMPAG on the nature of and methods for communicating to the public and/or governmental decision makers about the work proceeding and recommendations to be presented by SMPAG in the event a credible impact threat is detected by the IAWN. Development of this agreement should involve expertise from the fields of risk and crisis communications and be sensitive to international concerns and the sovereign rights of member states.

The purpose of the task is to develop communications guidelines to be used by SMPAG members in the event of a credible real-world impact threat when announcing and discussing SMPAG activities and recommendations with the public, governmental authorities, and the international community.

In September 2014, a two-day workshop on NEO communications was held in Broomfield, Colorado. A primary focus of the workshop was the analysis of historical cases of communications developed by the NEO community to convey information about NEO impact warnings and associated impact probabilities. The results of that workshop will be useful in accomplishing this task.

5.6.4 Schedule

- Early 2016 SMPAG: Produce an outline of guidelines
- 2016 SMPAG: Provide initial versions of guidelines and templates
- 2017 SMPAG: Submit final report

5.6.5 Output

This task and the task 'Criteria and thresholds for impact threat response' are nearly in synchrony with one another. However, this task, in the form of a summary report, should be written with a broad non-expert audience (i.e., public and decision makers) in mind.

5.7 PRODUCE A 'ROAD MAP' FOR FUTURE WORK ON PLANETARY DEFENCE

5.7.1 Lead

- DLR
- Support by NASA

5.7.2 Rationale

The results of increased international activity in the fields of NEO discovery, monitoring, and physical characterization over the past few decades now more accurately enable us to understand the scientific and practical issues relating to the impact hazard and NEO mitigation, and better define the problems that need to be tackled in the future. However, the diverse research efforts in different countries and fields need to be better focused and efforts are required to improve their coordination. A regularly updated road map is needed, taking account of current international activities, as a guide to future efforts.

5.7.3 Activity Description

Produce a 'road map' for work that is needed in the future to support planetary defense. Establish an inventory of relevant activities worldwide and identify areas not adequately covered. Maintain an overview of international collaborative ventures and funding availability from national and international agencies. As new scientific results and technological developments become available, the road map will need to evolve accordingly.

Monitor worldwide activity in the field of the impact hazard and identify areas in which further scientific research and technical development work is necessary. Examples of currently relevant technological and scientific activities are efforts to:

- Identify and update the most effective means of deflecting a NEO in the light of improving scientific understanding and technological capabilities,

- Reduce the risk of a NEO deflection attempt failing (e.g. by improving GNC performance in the case of the kinetic impactor, or the reliability of autonomous control systems and thrusters in the case of the gravity tractor),
- Facilitate more accurate predictions of the possible consequences of a deflection attempt (which may succeed, only partially succeed, or fail completely) and/or an impact on the Earth,
- Design and develop deflection demonstration missions and in-situ reconnaissance missions,
- Physically characterize NEOs, especially potentially hazardous objects, including laboratory experiments and modeling/analysis work.

In the light of current activities of space agencies and other organizations, develop/update an international strategy for future missions and mission-related research and development work in support of planetary defense.

Analyze and report on the effectiveness of international collaboration and funding of mitigation activities.

Generate a document identifying technological and scientific activities relevant for defense against NEO impacts that require emphasis in the future. One objective of the work is to inform funding agencies of relevant research questions requiring attention.

5.7.4 Schedule

- 2014 SMPAG: Define initial conditions
- 2015 SMPAG: Produced a draft version of the live document on this SMPAG task.
- 2016 SMPAG: Produced version 1.0 of the live document, and there was agreement in SMPAG that it could be made publicly available.
- 2017 SMPAG: Version 2.0 will be presented to SMPAG.
- 2018+ SMPAG: Updates and enhancements of the live document.

5.7.5 Output

Regular updates of a live document, including brief details of relevant worldwide activities and their status, and requirements for future work in the framework of an overall international strategy.

5.8 CONSEQUENCES, INCLUDING FAILURE, OF NEO MITIGATION SPACE MISSIONS

5.8.1 Lead

- ESA
- Support by FFG (Austria), UKSA

5.8.2 Rationale

An important aspect of the proposed task is the analysis of possible failure scenarios. These possible failure scenarios are numerous, among them management and interface problems during the planning phase, launch failures and the dangers associated with them (especially when considering nuclear payloads), communication problems during the cruise phase and target acquisition problems.

A potentially very serious problem is the non-availability of critical items within the required time frame. The task will have to identify such failure points and explore the possibility of building a store of spare parts to be immediately available.

Even if the mission develops according to plan, there is still no guarantee of success. The momentum imparted on the target might not be sufficient; destruction, for example using the nuclear option, might not be complete enough; deflection might even be counterproductive in the sense that the impact location might change from a relatively unpopulated area to an area of high population density with little chance of timely evacuation.

5.8.1 Activity Description

5.8.2 Schedule

TBD

5.8.3 Output

TBD

5.9 CRITERIA FOR DEFLECTION TARGETING

5.9.1 Lead

- ROSA

5.9.2 Rationale

Criteria are required which specify the target goal for any NEO deflection mission. Such criteria include first of all the minimum acceptable Earth-miss distance for a given deflection. This shall consider uncertainties in the target orbit and in the impact prediction geometry. Other criteria should address future encounters with Earth (and the Moon and other planets) as a result of the deflection, e.g. minimum time until next hazardous encounter, etc.

5.9.3 Activity Description

An important aspect of establishing criteria for NEO deflection mission is the orbit knowledge of the potential target. The importance of precise position of a newly discovered object will be investigated in the frame of the newest measurements offered by the European Space Agency GAIA mission. The use of the newest GAIA-DR catalogues will quantify the gain in accuracy for groundbased observations. Examples of activity:

- estimation of accuracy for preliminary orbits for NEOs using small arc of orbit (in order of days or weeks);
- estimation of accuracy of orbital elements using groundbased observation and the high precision astrometric catalogs GAIA-DR1 and future releases.

Another important objective of investigations is the evolution in time of orbital elements and the error propagation of dynamical elements over a period lesser than 100 years using an accurate dynamical reference frame. Examples of activity:

- estimate the probability of evolution of orbits for fictions objects (clone approach).
- estimate of evolution using several dynamical system and precompiled ephemerides.
- compute the future encounters with Earth, telluric planets and Moon, and define the new

aspects related to orbit perturbation of the target.

5.9.4 Schedule

October 2017 - Preliminary report on astrometry of newly discovered objects.

5.9.5 Output

Report, updated versions

5.10 STUDY OF THE NUCLEAR DEVICE OPTION

5.10.1 Lead

TBD

5.10.2 Rationale

Since nuclear explosion effects offer the most energy efficient means currently at our disposal for diverting or destroying a threatening NEO, their use must be considered in any realistic planetary defence strategy, particularly for a warning scenario of less than a few years. In the very unlikely case of a moderate to large threatening asteroid, and/or inadequate time for the deployment of other deflection techniques, a nuclear device may offer the only technically feasible solution. However, there are obvious political issues associated with launching nuclear devices and their use in space.

A SMPAG position paper exploring the technical utility of the nuclear option is required, albeit with cognizance of the potential political, legal, and public reaction drawbacks. Technical issues, such as the circumstances in which a nuclear device may be a realistic and necessary option, the relative merits of an explosion close to, on the surface of, or beneath the surface of a hazardous NEO, and requirements for further research and development work, should be addressed. The paper should then consider current international agreements and laws that may prevent the testing and deployment in space of nuclear devices for the purpose of deflecting a hazardous NEO. It should also identify open points related to the relevant political and legal background and address how the UN, or the international community, might proceed in an emergency scenario to implement a response deploying the nuclear option.

5.10.3 Activity Description

TBD

5.10.4 Schedule

TBD

5.10.5 Output

5.11 TOOLBOX FOR A CHARACTERISATION PAYLOAD

5.11.1 Lead

- CNES
- Support from Belgium, UKSA, ESA

5.11.2 Rationale

The aim of this task is to reach a consensus among SMPAG members regarding the objectives of a space mission designed for a NEO characterization and then the instruments that can be made available for achieving such a mission. This consensual definition of a 'straw man payload' would be available on a reasonably short notice for a characterization mission targeted to NEOs that present a potential threat.

5.11.3 Activity Description

The feasibility of any mitigation mission is highly dependent of the small body it is aimed to. The main parameters to select the most effective mitigation method for a specific NEO are beyond its figure, its surface and subsurface characteristics, its internal structure homogeneity and composition. To be able to launch an effective mission as rapidly as needed, it is necessary to maintain a list of devices that can be ready to fly for collecting the requested data.

This task could be sequenced in the following steps:

- Summarize the outcomes of a study dedicated to Apophis (CNES)
- Identify some short notice mission scenarios and specify the objectives of the associated characterization mission
- Specify the instruments and mission requirements for achieving these objectives
- Review available existing instruments and, in case of gaps, assess the need for the development of new instruments
- Provide with cost estimates of such instruments, if available

5.11.4 Schedule

June 2015 – Summary report of Apophis example

Mid-2016 – Intermediate report

Mid-2017 – First reference version of live document

5.11.5 Output

D1 – APOPHIS 2029 MISSION, a strawman payload for a potentially hazardous asteroid characterization mission

Establishment and regular updates of a live document

6 Reporting and Approval

Task leaders report the status at the SMPAG meetings.

It is expected that regular progress is achieved and status reports made for on-going tasks.

If for any on-going task updates or status reports are not provided during two subsequent SMPAG meetings, the SMPAG may decide to appoint a different task leader.

The SMPAG secretary maintains a SMPAG web site.

Final versions or new reference versions of reports will be submitted to the Steering Committee for approval and for a decision on public release.

7 Schedule and Milestones

7.1 Schedule

The schedule for the individual tasks will be reported as part of the Project Plans of the respective items.

The milestones provided here are supposed to allow a high level overview of the activities for the purpose of coordination among the tasks.

Activity	Date	Status
Finalize ToR	Feb 2015	Completed
First reference version of Work Plan	Nov 2015	Completed
Completion of first tasks	From 2016	

8 Resources

Each Member shall provide its own funding and resources for its SMPAG activities.

GLOSSARY

Albedo	A value between 0 and 100 representing the percentage of incoming light reflected by an object.
Aphelion	For a solar-orbiting object, that point in the orbit farthest from the Sun, directly opposite the perihelion.
Apparition	Because NEOs orbit the Sun at different orbital periods than the Earth, they are typically visible for a certain period of time until their apparent distance to the Sun is too small to allow night-time observations. They will stay invisible for a certain time (months to years) until they can be seen again in the night sky. One of these visibility periods is called apparition.
ASE (Association of Space Explorers)	The international professional organization of astronauts and cosmonauts.
Asteroid	A small rocky and/or metallic body orbiting the Sun. Most asteroids orbit in the main asteroid belt between Mars and Jupiter. Near-Earth asteroids (NEAs) are asteroids with an aphelion of <1.3 AU, i.e. they follow paths that approach or cross the orbit of the Earth.
AU (Astronomical Unit)	The average distance between the Earth and the Sun, about 150 million km (93 million miles).
Center for NEO studies (CNEOS)	The Center of NEO Studies at the Jet Propulsion Laboratory is the element of the NASA's NEO Observations Program responsible for performing high precision orbit calculations for NEOs, predicting their future motions, assessing their impact hazard, and making these results publicly available on the NEO Program website.
Chelyabinsk event	A superbolide that occurred over the Russian city of Chelyabinsk on 15 February 2013. The objects diameter was estimated to be around 20m.
Comet	A small, rock-and-ice primordial body orbiting the Sun. Comets were formed in and largely orbit the Sun in the outer reaches of the solar system. Perturbations cause some to enter orbits that bring them into

	the inner solar system.
Database (NEO)	The NEO database contains the orbital parameters of all NEOs discovered and tracked to date.
Discovery (NEO)	A NEO discovery is the initial sighting of a NEO which, to be officially recorded, must be independently confirmed.
Hayabusa	An unmanned spacecraft developed by JAXA, launched on 9 May 2003, to return a sample of material from a small near-Earth asteroid named 25143 Itokawa to Earth for further analysis. Hayabusa had a rendezvous with Itokawa in mid-September 2005, studied the asteroid's shape, spin, topography, color, composition, density, and history. In November 2005, it landed on the asteroid and collected samples in the form of tiny grains of asteroidal material, which were returned to Earth aboard the spacecraft on 13 June 2010.
IAWN (International Asteroid Warning Network)	Advisory network on near-Earth objects recommended by the Working Group on near-Earth objects of the STSC during its 50th session in February 2013 and formally endorsed by UN COPUOS at its 56th session in June 2013 and by the 68th session of the UN General Assembly in December 2013. It has the following tasks: discover, track and observe NEOs, coordinated internationally; find them as early as possible; process the observations, provide orbit predictions and any potential impact warnings; prepare public communications; In case of credible impact threat, ensure that more information on object is gathered expeditiously, and inform COPUOS.
Impact probability (NEO)	The probability that a specific NEO will actually impact Earth. The astronomical community analyzes the orbit of each NEO for potential impact within the next century and assigns an impact probability, which is updated following each subsequent sighting of the NEO.
Inner solar system	Generally, that portion of the solar system inside the orbit of Jupiter.
JPL (Jet Propulsion Laboratory)	The NASA center in Pasadena, California, responsible for the design and operation of many planetary missions, and for managing NASA's NEO Program.
Keyhole (NEO)	A small region in space near the Earth through which a passing NEO would be redirected by the Earth's gravity onto a path which impacts

	later on. Keyholes are often identified by the year when the NEO would subsequently impact or by the ratio of orbital periods (a resonance of orbital periods). For example, when the asteroid Apophis passes by the Earth in 2029, we consider the possibility that it could pass through the 7:6 keyhole, leading to impact in 2036, in which case Apophis would travel exactly 6 times around the Sun and impact the Earth exactly 7 years later.
Main Asteroid Belt	That region of space between the orbits of Mars and Jupiter within which the vast majority of asteroids orbit. NEAs are thought to be asteroids whose orbits have been perturbed (through collisions and gravitational interaction with Jupiter) such that they now approach Earth's orbit.
Mitigation (NEO)	Generally, any action reducing the consequences of a threatening NEO impact.
MPC (Minor Planet Center)	The Minor Planet Center of the International Astronomical Union is responsible for the designation of minor bodies in the solar system and the efficient collection, checking, and dissemination of observation and orbits for minor planets and comets.
NEA (Near-Earth Asteroid)	An asteroid whose orbit approaches that of the Earth; defined as having a perihelion distance, q, less than 1.3 AU (195,000,000km).
NEC (Near-Earth Comet)	A short period comet whose orbit is indistinguishable from those of the near-Earth asteroids and is therefore treated in a similar manner.
NEO (Near-Earth Object)	Any asteroid or comet whose orbit approaches that of the Earth; defined as having a perihelion distance, q, less than 1.3 AU (195,000,000km).
NEOCC (Near Earth Objects Coordination Center)	ESA's Near Earth Object Center at ESRIN in Frascati, Italy.
NEODyS (NEO Dynamic System)	The University of Pisa's system that analyzes and publishes information (including impact prediction) on all discovered NEOs. NEODyS performs a function similar to that done by NASA's JPL SENTRY system.

Orbital elements	A set of six values that fully characterize the orbit of an asteroid or other celestial body.
Orbital period	The time it takes an orbiting body to complete one revolution around the central body.
PATM (Panel on Asteroid Threat Mitigation)	The panel of international experts organized by the ASE NEO Committee to oversee and edit the development of a decision-making program for asteroid threat mitigation.
Perihelion	For a solar-orbiting object, that point in the orbit closest to the Sun, directly opposite the aphelion.
Planetary Defense Coordination Office (PDCO)	The organization element at NASA Headquarters to manage NASA's programs on NEOs and Planetary Defense, hosted by the Planetary Science Division within the Science Mission Directorate.
Radar telescope (NEO)	A radio telescope which has the capability of active radio transmission, used to obtain precision tracking of NEOs. Radar tracking complements optical tracking and, when available, can significantly improve predictions of NEO orbits.
Risk corridor	A virtual locus of points, unique to each NEO, within which an NEO may impact the Earth. While it can extend across the entire planet, the corridor is often only a few tens of kilometers wide. Physical effects of the impact may extend well beyond the corridor.
Risk table	A table of NEOs, computed and published by both JPL and NEODyS, containing a list of NEOs which, in the next 100 years, may pose a risk of one or more possible impacts with Earth.
Sentinel Mission	The first privately funded interplanetary mission consisting in a space-based infrared (IR) telescope to discover and catalog 90 percent of the asteroids larger than 140 meters in Earth's region of the solar system. The mission should also discover a significant number of smaller asteroids down to a diameter of 30 meters. Sentinel will be launched into a Venus-like orbit around the sun, which significantly improves the efficiency of asteroid discovery during its 6.5-year mission. This mission is not yet fully funded.
SMPAG (Space Mission Planning Advisory Group)	Advisory group on near-Earth objects recommended by the Working Group on near-Earth objects of the STSC during its 50th session in February 2013 and formally endorsed by UN COPUOS at its 56th session in June 2013 and by the 68th session of the UN General Assembly in December 2013. It has the following tasks: recommend and promote mitigation mission-related research and studies on an international and

	cooperative level; develop and adopt a set of reference missions – both on technical detail and operational level; develop applicable decision criteria/thresholds and timelines.
Spaceguard Survey	The informal name of the NEO discovery and tracking program that the U.S. Congress has directed NASA to perform. The initial Spaceguard goal (1998) was to discover, by 2008, 90% of all NEOs larger than 1 kilometer in diameter. The recently revised goal directs NASA to discover, by 2020, 90% of all NEOs larger than 140 meters in diameter.
Threat (NEO)	The potential for a near-Earth object to impact Earth. NEO threats range from a few megatons of TNT-equivalent explosive energy up to infrequent, but devastating, impacts with millions of tons of TNT explosive energy.
Tunguska Event	An asteroid impact that occurred over Siberia on June 30, 1908, releasing the energy of approximately 3-5 megatons of TNT. Although the asteroid exploded in the atmosphere, it destroyed over 2,000 square kilometers of forest. The blast was capable of devastating a modern city.