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First Space Mission Planning Advisory Group

Hypothetical

NEO threat exercise

Sprint 1

Version 1.3 – 01 Oct 2024

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Contents

Versions

Version 1.0	29/08/2022	Working version
Version 1.1	08/10/2023	Version circulated to delegations
Version 1.2	04/06/2024	Version with revision edits from NASA
Version 1.3	01/10/2024	Added UK contributions

Acronyms

IAWN	International Asteroid Warning network
NEO	Near Earth Object
SMPAG	Space Mission Planning Advisory Group

1 Introduction

1.1 Introduction

The **first SMPAG NEO threat exercise** focuses on the inter-agency procedure to organise a coordinated response to the threat. The document is organised as follows: Section 1.2 presents the objective of this exercise, Section 1.3 reminds of the terms of reference of the SMPAG. Section 1.4 describes the target chosen for the NEO threat exercise. The SMPAG exercise tasks are explained in Section 1.5 and the organisational aspects are explained in Section 1.6. The following chapters contains the contribution by the following SMPAG delegations:

Table 1. SMPAG delegation contributions.

Country	Chapter
Austria (FFG)	Chapter 4
France (CNES)	Chapter 8
Germany (DLR)	Chapter 5
Israel (ISA)	Chapter 3
Italy (ASI)	Chapter 2
European Space Agency (ESA)	Chapter 7
National Aeronautics and Space Administration (NASA)	Chapter 6

1.2 Objectives

Primary objective

The objective of this exercise is:

- to define the tasks required for a SMPAG coordinated response to the Exercise NEO threat
- to define which entity/ies would be responsible for these tasks.
- to identify the procedures internally to each SMPAG member to propose a response to the SMPAG

Secondary objective

Aside the minimum aim of the exercise described above, a desired but not requested aim of this first SMPAG exercise is to simulate and perform the actual tasks or part of them for the selected threat scenario. This secondary objective can be done collaboratively between contributing SMPAG members.

1.3 Mandate and terms of reference of SMPAG

The SMPAG introduced the proposal for such an exercise, following its 16th meeting, to the Scientific and Technical Subcommittee of COPUOS as part of its reporting.

In its report in 2021, the Committee on the Peaceful Uses of Outer Space (COPUOS) noted …"that SMPAG had proposed the idea of performing an exercise aimed at testing its real-world capabilities to support planetary defence in the case of an actual threat, and that the Italian Space Agency would organize a splinter meeting to evaluate the proposal, define timelines for the exercise and identify contributing agencies." (A/76/20, para. 112)

See also SMPAG TORs, https://www.cosmos.esa.int/web/smpag/terms_of_reference_v2

Objectives:

[…] The objectives of SMPAG are to develop cooperative activities among its members and to build consensus on recommendations for planetary defense measures.

Scope

(e) Develop decision and event timelines for a variety of potential Earth impactors and trajectories identified in the applicable reference missions.

1.4 NEO target selection

According to the "Status report on work package 5.1 from workplan "Recommended criteria and thresholds for action for a potential NEO impact threat", SMPAG-RP-003/1.0, 2018 Oct 18" the criteria for a response to a potential NEO impact threat is

- Minimum diameter 50 m
- 1% impact chance within 50 years

For this exercise a synthetic NEO is selected taking an asteroid close to the top of the ESA NEO risk list but with a synthetically magnified higher impact risk. With this idea in mind, the object to be considered is 2021QM1. The diameter is about 50 m, with possible impact in April 2052. The currently computed impact probability of 1/3322 is synthetically increased to 1/32. All the data corresponding to the impact threat can be retrieved in [1] while the modified covariance matrix can be distributed in the coming months.

1.5 Exercise tasks

1.5.1 National coordination (Sprint 1/3)

The first sprint will focus on the national organisation and coordination and on defining the lists of tasks to be performed in response to a threat scenario.

Task 1 List the required tasks for a coordinated response to the threat.

A non-complete list of tasks is reported here below as example. It is asked to each delegation to complete this list.

- Refinement of risk of impact
- Improved orbit determination
- Trade-off of possible mission architectures and impact mitigation strategies
- Selection of the deflection strategy and eventual investigation mission
- Perform mission analysis of selected mission
- Perform system design of selected mission
- Approval at SMPAG-member level of the proposed mission
- Others…

Task 2 List the entities involved at the national (SMPAG-member) level for the completion and coordination of these tasks at the national (SMPAG-member) level

List all the different entities involved at the national (SMPAG-member) level for the completion of this tasks, describe how the coordination of these tasks is performed at the national level.

Explain which tasks can be performed at the national level as there is internal capabilities to perform them and for which tasks there is no internal capabilities.

Task 3 Explain the internal (SMPAG-member) procedure for performing and advancing the tasks identified at Task 1 at the national (SMPAG-member) level

1.5.2 SMPAG collaboration (Sprint 2/3)

To harmonise the national (SMPAG-level) efforts into a SMPAG coordinated action this must be organised at

- communication level
- technical level
- decision level

The second sprint will focus on discussing how the coordination is done among different SMPAG delegations.

Task 4 Identify the tasks distribution among SMPAG members for a coordinated NEO response

The tasks identified in Task 1 need to be coordinated and performed in a collaborative effort at the SMPAG level. To this aim this Task will identify the tasks distribution among multiple SMPAG members for a SMPAG NEO response and will discuss how the coordination at the level of SMPAG members is achieved.

Task 5 Identify data exchange mechanics and formats

For a fruitful collaboration the data exchange mechanics need to be defined together with the data formats. This task will be completed through a discussion at the SMPAG level.

1.5.3 SMPAG coordination and communication (Sprint 3/3)

The third sprint will deal with communication and coordination issues within SMPAG.

Task 6 Define the milestone for inter-SMPAG-member coordination

Define the milestones during the mission planning and preparation for communication and discussion within SMPAG in a threat case

- Define the required milestones for communication and data exchange during the response
- Define the time schedule and milestones for coordination with other delegations
- Define the communication channels within SMPAG
- Define how the coordination with International Asteroid Warning network (IAWN) should be implemented
- Recall how a decision is taken in SMPAG and propose approaches for ensuring an easy achievement of consensus within SMPAG. For example, the steering group at SMPAG coordination might be performed by the SMPAG chair.

Task 7 Define the communication lines within a threat event

This Tasks will review and consolidate the communication procedure of an impact hazard at the SMPAG level, in collaboration with IAWN and communicating such options to member states at COPUOS STSC.

Task 8 Procedures in case of failures of the deflection action

This task will define the procedure in case of failure of the first deflection mission achieved though the previous task. This Task will define a back-up procedure if the deflection mission fails including:

- Asteroid/fragment re-entry coordination
- National security coordination
- International security coordination

1.6 Exercise organisation

The SMPAG NEO threat exercise will be performed

- through telecons among participating SMPAG members and
- through work at the national SMPAG-member level work

The SMPAG NEO threat exercise will be organised in 3 sprints each of them Kicked-Off (KO) and completed by a SMPAG telecon. Additional ad-hoc splinter meetings will be organised at need.

The aim of each sprint is described below:

1.6.1 Sprint 1/3

Aims:

- Compare the task lists defined by each SMPAG member **[Task 1]**
- Compare and discuss the entities involved at the national (SMPAG-member) level for the completion and coordination of these tasks at the national (SMPAG-member) level **[Task 2]**
- Compare and discuss the internal (SMPAG-member) procedure for performing and advancing the tasks identified at Task 1 at the national (SMPAG-member) level **[Task 3]**

KO: 17 Dec 2021

END: Sep 2024

1.6.2 Sprint 2/3

Aims: Discuss how to compare the results and procedures derived at the national level in the SMPAG

- Identify the tasks distribution among SMPAG members for a coordinated NEO response **[Task 4]**
- Identify data exchange mechanics and formats **[Task 5]**

KO: [TBC]

END: [TBC]

1.6.3 Sprint 3/3

Aims: Define the milestones for inter-SMPAG-member coordination

- Define the milestone for inter-SMPAG-member coordination **[Task 6]**
- Define the communication lines within a threat event **[Task 7]**
- Procedures in case of failures of the deflection action **[Task 8]**

KO: [TBC]

END: [TBC]

1.7 Expected outcomes

The output of the exercise will be a final report containing all the output of Sprint (1/3) on the national coordination, Sprint 2/3 on SMPAG collaboration and Sprint 3/3 on SMPAG coordination and communication. The report will have single delegation part and SMPAG part depending on the tasks.

During the whole exercise each participating delegation will be requested to input contributions using a template for that will be shared.

The desired output of the first SMPAG NEO threat exercise is to draft a:

- Single-delegation (SMPAG members) coordination plan
- SMPAG-common coordination plan

The resulting report and presentation could form a conference paper for information under NEO agenda item of the Scientific and Technical Subcommittee of COPUOS.

References

[1] Risk List - NEO (esa.int), last retrieved 11/10/2021.

2 Italian Space Agency (ASI)

Contributors: Camilla Colombo[(1)], Marco Castronuovo[(2)], Alessandro Gabrielli[(2)], Alessandra Di Cecco[(2)], Marta Albano[(2)], Pierluigi Di Lizia[(1)]. [(1)] Politecnico di Milano [(2)] Italian Space Agency, ASI.

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2.1 Task 1: Required tasks for a coordinated response to the threat

We report in the following the required tasks for a coordinated response to the threat:

1. Earth-based observational campaign
   1.1. Multiple and series of repeated observation campaigns through national and international assets
   1.2. Physical characterisation (i.e., mass, material, chemical composition, rotational state, rubble pie or monolithic object, optical properties) of the threatening objects though radar or optical observations
2. Refinement of risk of impact (periodic)
   2.1. Improved orbit determination: definition of expected orbits (i.e., orbital parameters) and covariances
   2.2. Orbit propagation with uncertainties considering position and velocities covariances and distribution of physical properties (i.e., reflectivity coefficient, Yarkovsky effect, etc.)
   2.3. Refinement of orbit models considering outcome of observational campaign
3. Definition of models of the threatening object based on Earth-based observational campaign
   3.1. Model of asteroid as a rigid body (i.e., rotational state, attitude, type) considering results of campaign and physical properties distribution.
   3.2. Models of kinetic impact enhancement factor (β).
4. Evaluation, planning and implementation of **"Fast-track" recognition mission** through rendezvous or fly-by of the threatening object to improve physical characterisation and orbit definition though in-situ observation. (Multiple CubeSat missions or single satellite missions to be considered)
5. Study of different mission architecture and enabling technologies for deflection mission
   5.1. Single or multiple spacecraft for deflection missions, or "deflector" and observer
   5.2. Different deflection techniques (i.e., kinetic impactor, multiple kinetic impactor, gravity tug, ion beaming, laser slow push, etc.)
   5.3. Definition of a final close approach phase (for on-board refinement of orbit and characterisation)

5.4. Different missions are characterised and analysed based on results of Earth-based characterisation (ranges of parameters are used in a Monte-Carlo fashion)

6. Trade-off and selection of possible mission architectures and deflection strategies
   6.1. Definition of the baseline and backup deflection mission architecture (e.g., single or multiple spacecraft for deflection, or "deflector" and observer)
   6.2. Selection of the baseline and backup deflection strategy missions
7. Design of **contingency mission in case of failure of baseline mission**
   7.1. Failure during the mission implementation before impact (i.e., launch failure, system failure etc)
   7.2. Failure as asteroid deflection is null or too small (effectiveness assessment)
   7.3. Response to asteroid fragmentation
8. Refinement of **baseline and backup deflection mission** and refinement of failure recovery mission design based on outcome of "Fast-track" recognition mission
9. Design and implementation of the baseline deflection mission
10. Design and implementation of the contingency mission
11. Definition of the possible casualty risk on ground and re-entry corridor and footprint in case of any of the failure above
    11.1. Failure of mission or re-entry of some asteroid fragments
12. Definition and implementation of the operational procedures of the national security response in case of re-entry
    12.1. Definition of crisis communication (at international organisations level, at the national level/public)
    12.2. Training of experts on communication of action plan
    12.3. Coordination for dissemination of technical information (at the delegation level, with experts)
13. Approval at the SMPAG-member level of the proposed mission

2.2 Task 2: Entities involved at the national (SMPAG-member) level

The Italian SMPAG delegation identified the planned steps at the national level for

- Definition of a **national charter for asteroid threat coordination** (i.e., dedicated working group, task force)
  - Recognised and tasked at the Italian governmental level, the Italian Space Agency level, the SMPAG level and the UNOOSA level
  - Is responsible to initiate and technically monitor or execute the identified technical/design/communications tasks at the national level
  - Coordinates the full implementation of technical/design/communications tasks by identified entities at the national level
  - Is responsible for the interface with civil protection for risk assessment on national infrastructures, properties, and people
  - Is responsible for the crisis communication
  - Coordinates with SMPAG
- Pre-impact threat **national charter for asteroid threat coordination** is responsible to make a survey of national capabilities

The following is a **very preliminary and therefore not exhaustive, survey** of national entities and capabilities (to be reiterated), with the aim to demonstrate that Italian delegation has relevant capabilities in most of the identified tasks.

1. Earth-based observational campaign
   1.1. Observation: all national sensors **(e.g., Loiano, Campo Imperatore, etc.)**
   1.2. Characterisation: **(e.g., INAF, etc.)**
2. Refinement of risk of impact (periodic)
   2.1. Improved orbit determination **(e.g., Politecnico di Milano, Università di Pisa, Università La Sapienza Roma 1, SpaceDyS, Telespazio, etc.)**
   2.2. Orbit propagation with uncertainties considering position and velocities covariances and distribution of physical properties (i.e. reflectivity coefficient, Yarkowsky effect, etc.) **(e.g., Politecnico di Milano, Università di Pisa, SpaceDyS, etc.)**
   2.3. Refinement of orbit models considering outcome of observational campaign **(e.g., INAF (Physics and images and data), Politecnico di Milano (asteroid model, beta parameter model), Università di Padova (impact testing), etc.)**

3. Definition of models of the threatening object based on Earth-based observational campaign **(e.g., INAF, etc.)**
4. Evaluation, planning and implementation of "Fast-track" reconnaissance mission through rendezvous or fly-by of the threatening object to improve physical characterisation and orbit definition though in-situ observation **(ASI, National companies, Universities, etc.)**
5. Study of different mission architecture and deflection technologies for deflection mission **(ASI, National companies, Universities, etc.)**
6. Trade-off and selection of possible mission architectures and deflection strategies **(ASI, National companies, Universities, etc.)**
7. Design of failure recovery mission in case of failure of baseline mission **(ASI, National companies, Universities, etc.)**
8. Refinement of baseline and backup deflection mission and refinement of failure recovery mission design based on outcome of Fast-track" recognition mission **(ASI, National companies, Universities, etc.)**
9. Design and implementation of the baseline deflection mission **(ASI, National companies, Universities, etc.)**
10. Design and implementation of the failure recovery mission **(ASI, National companies, Universities, etc.)**
11. Definition of the possible casualty risk on ground and re-entry corridor and footprint in case of any of the failure above **(e.g., INAF, CNR, Politecnico di Milano, Università La Sapienza Roma 1, ASI, etc.)**
12. Definition and implementation of the operational procedures of the national security response in case of re-entry **(e.g., Italian civil protection, ASI, etc.)**
13. Approval of the proposed missions at the SMPAG-member level.

2.3 Task 3 Internal task implementation procedure

The ASI delegation proposes a **lean IADC-like procedure** to be used possibly both at the national and delegation levels.

In the following a description for a SMPAG IADC-like organisation and structure is proposed for discussion [2].

The SMPAG IADC-like structure is composed of a **Steering committee**, made up of the head of each delegation and of a **set of Working Groups** which are responsible of the definition and the implementation of technical tasks. The working group contains members from each delegation. The Steering committee defines guidelines and objectives for the overall activities, and approves the proposed **Action Item or Internal Tasks**.

The **Action Items** can be proposed at WG level and approved at Steering committee level, or they are recommended by the Steering committee to the working group. **Internal Tasks** are promoted at WG level to advance and propose some investigation to identify the needs and requirements for new Action Items. Internal tasks can be promoted to Action Items when they reach the desired technical maturity. Action Items are technical activities in the broad sense, and they are structured with their objectives, subtasks, deliverables, and time plan. Each Action Item or internal task produces a report that is an official document from which international guidelines are drafted.

Working groups are defined based on the **expertise areas** identified (e.g., mission design, crisis communication, observation, and orbit determination, etc.). Each delegation is invited to propose experts as delegate for each working group.

In case of a threat event, the SMPAG IADC-like structure is activated for the coordination, discussion, comparison, and definition of all the required tasks for a coordinated response at the international level.

During non-critical times, the SMPAG IADC-like structure works based on realistic exercises, and during a critical time (in case of a threat event) the SMPAG IADC-like is well trained to implement the realistic case. All the results of past Action Items are exploited as background knowledge, tools, and methods.

References

[2] IADC website, https://www.iadc-home.org/

3 Israel Space Agency (ISA)

Contributors: Harel Hary Ben-Ami[(1)]. [(1)] Isarel Space Agency (ISA).

3.1 Task 1: Required tasks for a coordinated response to the threat

- Define the leading SMPAG team (3/5 person only).
- Wise coordination with the observational campaign managed by IAWN.
- Implementing the fastest reconnaissance mission to the asteroid.
- Define the thresholds and stages for the specific mitigation campaign (including failure).
- Create space mission managing team.
- Inform UNOOSA about countries that are at risk.

A. 5.6 COMMUNICATION GUIDELINES IN CASE OF A CREDIBLE THREAT

1. Inform the COPUOS/United Nations Security Council/Other
2. Find the proper platform for SMPAG members to communicate throughout the campaign
3. Consider creating communication sub-committee

B. 5.8 CONSEQUENCES, INCLUDING FAILURE, OF NEO MITIGATION SPACE MISSIONS

1. Inform the UN/Other about the threat and the danger zones
2. Informing UN-Spider
3. Other

C. Budget

1. Coordination
2. Other

D. Legal

1. Escort by the legal sub-committee

3.2 Task 2: Entities involved at national (SMPAG-member) level

As far as we understand today, the entities involved at national level would be the Israel Space Agency (ISA) itself. Moreover, astronomers, other academy scientists and space experts, Home Front Command, and other (TBD) would also be involved. Tasks that can be performed at the national level

are improved orbit determination and asteroid characterisation etc. The coordination of these tasks is performed at the national level by ISA.

3.3 Task 3 Internal task implementation procedure

ISA only started working on our initial protocol/program for a Planetary Defense campaign, but future thoughts and plans are:

- To create a bigger team of astronomers and space experts to advise in case of a real threat scenario.
- To create a protocol for coordination between ISA and our Emergency Management organisations- National Emergency Management Authority (NEMA) and Home Front Command (HFC).
- To find the suitable and best chain of decision makers.
- To create our own internal hypothetical NEO threat exercise and implement it every few years.
- To wisely combine NEO threats in the HFC App that provides real-time life-saving alerts.

4 Austria delegation

Contributors: Rudolf Albrecht[(1)], Stephan Mayer[(1)]. [(1)] Austrian Space Forum [(2)] Austrian Research Promotion Agency

4.1 Task 1: Required tasks for a coordinated response to the threat

- Refinement of risk of impact
- Improved orbit determination
- Trade-off of possible mission architectures and deflection strategies
- Selection of the deflection strategy and eventual investigation mission
- Perform mission analysis of selected mission.
- Perform system design of selected mission.
- Approval at SMPAG-member level of the proposed mission
- Define and codify the formal notification channels between IAWN, SMPAG, COPUOS, UNOOSA, UN-GA, Security Council, and the national government.
- Estimate the severity of a possible impact and design/propose mitigation strategies.
- Define resources which can be used for mitigation.
- Ascertain the continued availability and functioning of resources which might be required for mitigation.
- Produce and/or stockpile required resources.
- Coordinate with the affected country or countries.

4.2 Task 2: Entities involved at the national (SMPAG-member) level

The different entities involved at the national (SMPAG-member) level for the completion of these tasks at the Austrian level are listed below.

- Austrian delegation to SMPAG/COPUOS
- Permanent Mission of Austria to the UN in Vienna
- Austrian Foreign Ministry
- Austrian Council of Ministers
- Austrian Armed Forces
- Academy of Sciences (via the Science Ministry)
- Universities
- Industry (via the Ministry of Technology)
- Media (via the Austrian Press Agency APA and government radio and TV (ORF))

- Coordination: the soon to be enacted Krisenvorsorgegesetz foresees a crisis coordination panel at the level of the Chancellor of the Republic.

4.3 Task 3 Internal task implementation procedure

- There are currently four Austrian members in SMPAG. Their background is science, technology and legal.
- These persons will use any available channel, formal and personal, to alert the Austrian Government and advocate appropriate reactions.
- There are, however, no formal procedures to instigate and to coordinate the work specified in Task 1 at this point in time.

5 Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR) German Aerospace Center - Space Agency

Contributors: Prof. Alan Harris, Dr. Michael Lage, Felix Lerner, Martin Reynders. Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR) German Aerospace Center - Space Agency

5.1 Task 1: Required tasks for a coordinated response to the threat

1. Adjusting to a first real warning report

All subsequent steps are not part of an emergency plan that is rehearsed or challenged on a regular basis, a stark difference to many other emergency cases. It would be a first, with a foreseeable adjustment phase in which:

- Responsibilities in the light of a real danger are scrutinized and presumably adjusted on federal and state level (“Bund” and “Länder”)
- Body of sources of information and guidance which are then officially relied upon will further evolve with the unfolding events.

2. Improved orbit determination

[Requires astronomical observations. Given observational data from, maybe DLR/German Space Operations Center, GSOC, or the Lander Control Center (LCC) in Cologne could contribute. Germany would mainly rely on ESA, NASA, MPC/IAWN for orbit updates. (The GSOC has “tracking and calculating flight and orbital paths, planning and executing corrections to flight and orbital paths” amongst GSOC’s responsibilities. This refers to man-made satellites and spacecraft but, in an emergency, GSOC may be able to adapt its programs to include natural objects.)

The fundament for orbit determination is the availability of accurate astrometric observations. The DLR institute of Planetary Research (DLR PF) has a multi-decadal experience on the acquisition of optical astrometry of asteroids. The institute has guaranteed access to the 1.2 m reflector at the Calar Alto Observatory, Spain, with DLR-owned equipment, optimized for astrometric and photometric work. Routine observations enable reporting of accurate astrometric positions to the Minor Planet Centre down to a magnitude V=21.5, while observations of special targets can be performed down to a magnitude V=22.5. A typical example is the improvement of the orbit of (152830) Dinkinesh – the first fly-by target of the NASA Lucy mission on Nov 1, 2023 – for which our institute has provided critical astrometry.

DLR-PF uses orbital integration software for many purposes, in particular for mission planning and for the natural orbital evolution of spacecraft, moons and small bodies. The software incorporates perturbations by other solar system bodies, higher terms of the gravity field, solar radiation pressure and other relevant perturbations. The software has not been applied to the evolution of NEAs but could be adapted for that purpose. Required adjustments for the application to the evolution of NEAs would incorporate orbital changes due to thermal radiation emitted from the asteroids.

The German Space Operation Centre (GSOC) operates its own telescope stations (SMARTnet) in South Africa, Australia, and in the near future (end of 2023) in Chile. Each station is equipped with a smaller telescope (20-25 cm aperture) and a bigger telescope (50 cm aperture). The bigger telescopes allow for observations of objects down to 18.7 mag with an exposure time of 8 s in white light. GSOC operates these stations with the main objective of cataloguing resident space objects, and also supports individual campaigns like the DART mission in 2022. Since January 2023, GSOC has been supporting ESA with short-notice targets of opportunity observations of NEOs that are of exceptional interest.

3. Refinement of risk of impact

Germany would mainly rely on ESA, NASA, MPC/IAWN. GSOC could perhaps contribute. Germany utilizes the risk assessment of the ESA NEOCC (ESA NEO Coordination Centre) within an officially implemented notification chain: Close approach fact sheets (CAFS) issued by NEOCC trigger the German Space Situational Awareness Centre (GSSAC) to produce corresponding documents to inform the Federal Office for Civil Protection and Disaster Assistance – (BBK).

Among the different aspects involved in risk assessment are the determination of the impactor shape, rotation state and size. Shape and rotation state can be retrieved if accurate photometric series (light curves) are available that cover a wide range of illumination and viewing geometries. Light curve inversion techniques then allow the retrieval of the pole direction, the spin rate, and a low order convex approximation of the object's shape. If additional measurements from complementary techniques such as radar imaging, adaptive optics or stellar occultations are also available, then the absolute size, the intrinsic brightness (albedo) and the presence possible concavities can also be determined. The institute of DLR-PF has been active in the field of shape inversion of asteroids for many years, both in terms of light curve acquisition and numerical modelling.

GSOC will be active in the field of light curve acquisition and numerical modelling to derive rotational parameters of high-altitude objects (research starts in 2023). This technique can be applied to asteroids as well.

4. Discussions/agreement on funding contributions to an international mitigation mission

DLR, appropriate federal ministries

5. Trade-off of possible mission architectures and deflection strategies

DLR space agency (e.g. Space Operations and Astronaut Training, Institute of Robotics and Mechatronics, Institute of Space Systems and other space research institutes).

6. Selection of the deflection strategy and eventual investigation mission

DLR space agency in coordination with the respective ministries, Industry: Industry in consultation with international partners, especially ESA and the EU.

7. Discussions, agreements with international partners regarding individual national contributions, potential usage of ESA as coordination forum for ESA member states, (e.g., spacecraft, scientific instruments, to selected mission, and funding arrangements).

DLR Space Agency, appropriate federal ministries and relevant authorities.

8. Perform mission analysis of selected mission

DLR space agency, DLR -and other space research institutes, Industry:

9. Perform system design of selected mission

DLR space agency, DLR -and other space research institutes and Industry. For instrumentation and other mission components a number of German universities, R&D institutes, industrial companies, could potentially contribute. Above that Germany could also envision to contribute through ESA.

DLR-PF has extensive expertise in designing, planning, and analysing spacecraft observations of asteroids (Rosetta, Dawn, Hayabusa 2). PF is currently the PI institute for the Asteroid Framing Camera that will fly on Hera and was also involved with the design of DART and Hera.

10. If the impact-risk corridor crosses German territory or that of neighbouring countries, ensure national disaster management organizations are informed and given resources to make necessary preparations in case a deflection attempt fails

Supported by DLR-GSSAC etc. and/or appropriate federal/state ministries; alert civil and military forces.

As mentioned above, procedures to coordinate the national disaster response in case of a NEO-impact are yet to be established.

In Germany, civil protection (excluding civil protection in case of an armed conflict) and disaster relief operations are a responsibility of the federal states (Bundesländer). Within the federal states, the Ministries of Interior are in charge of civil protection (excluding civil protection in case of an armed conflict) and disaster relief operations.

On the federal level, the Federal Office for Civil Protection and Disaster Assistance (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe, BBK) was established and is tasked inter alia with coordinating the necessary emergency responses to nationwide disasters and coordinating the use of federal resources (armed forces and THW) in support of operations at state level. Therefore, it maintains information and coordination services by operating the German Joint Information and Situation Centre (GMLZ).

11. Investigate the potential international legal implications (for the German government) if the mission is, or is not, carried out

Led by DLR Space Agency- in close collaboration with appropriate federal ministries and national space law institutions, eventual responsibility rests with the federal government.

12. Approval at the SMPAG-member level of the proposed mission

DLR Space Agency, appropriate federal ministries.

5.2 Task 2: Entities involved at the national (SMPAG-member) level

Task 2 responses have been incorporated into the Task 1 list and are listed below. Coordination would be carried out by DLR, in close cooperation with appropriate federal and/or state ministries. Potential involved entities are given in the list. Germany relies mainly on international agreements for access to astronomical telescopes (e.g., ESO). While German astronomers have much relevant observational experience, at the national level Germany (i.e., astronomers using assets native to Germany) would probably be unable to contribute significantly to points 1 and 2 in the above task list. For all other points Germany has internal capabilities.

Summary breakdown of entities involved per task:

1. Adjusting to a first real warning report
2. Improved orbit determination: **DLR/German Space Operations Center (GSOC), DLR Institute of Planetary Research, LLC**

3. Refinement of risk of impact: **GSOC, DLR Institute of Planetary Research**
4. Discussions/agreement on funding contributions to an international mitigation mission: **DLR Space Agency, appropriate federal ministries.**
5. Trade-off of possible mission architectures and deflection strategies: **DLR space agency, DLR- and other space research institutes, Industry**
6. Selection of the deflection strategy and eventual investigation mission: **DLR space agency, DLR- and other space research institutes, Industry in consultation with international partners.**
7. Discussions, agreements with international partners re. individual national contributions, **e.g., spacecraft, scientific instruments, to selected mission, and funding arrangements: DLR space agency, appropriate federal ministries, BMWK with BMI, BMVg**
8. 7. Perform mission analysis of selected mission: **DLR space agency, DLR- and other space research institutes, Industry**
9. Perform system design of selected mission: **DLR space agency, DLR- and other space research institutes, Industry, for instrumentation and other mission components a number of German universities, R&D institutes, industrial companies, could potentially contribute.**
10. If the impact-risk corridor crosses German territory or that of neighbouring countries, ensure national disaster management organizations are informed and given resources to make necessary preparations in case a deflection attempt fails: **Supported by GSSAC, etc. and/or appropriate federal/state ministries.**
11. Investigate the potential international legal implications (for the German government) if the mission is, or is not, carried out: **Led by DLR Space Agency - in close collaboration with appropriate federal ministries and national space law institutions, eventual responsibility rests with the federal government**
12. Approval at SMPAG-member level of the proposed mission: **DLR space agency, appropriate federal ministries.**

Germany relies mainly on international agreements and cooperation for access to astronomical telescopes (e.g., ESO). While German astronomers have much relevant observational experience, at the national level Germany (i.e., astronomers using assets native to Germany) would limited to contribute significantly to points 1 and 2 in the above task list. For all other points Germany possesses internal capabilities.

5.3 Task 3 Internal task implementation procedure

As explained in Section 5.2 Task 1 tasks would be coordinated by a special task force, set up by DLR Space Agency and appropriate federal ministries, consisting of appropriate scientific, technical,

administrative, industrial, and ministerial/government personnel. It is assumed that this team would contribute to an international coordinating body established at around Task 3 in the table, with a global UN mandate to coordinate internationally agreed actions necessary to protect the planet.

6 National Aeronautics and Space Administration (NASA)

Contributors: Lindley Johnson, L.A. Lewis, Dan Mazanek

6.1 Task 1: Required tasks for a coordinated response to the threat

The required tasks for a coordinated response to the threat and timing are listed below:

1. Improved orbit determination
2. Refinement of risk of impact
3. Notification of governmental authorities of impact risk
4. Trade-off of possible mission architectures and deflection strategies
5. Determination if in-space mitigation is achievable
6. Present recommended deflection strategy/campaign to interagency task force
7. Selection of the deflection strategy and eventual campaign
8. Perform mission design for selected campaign mission(s)
9. Perform system design of selected mission(s)
10. Present campaign design to international collaborative planning (SMPAG)

The different entities involved at the national (SMPAG-member) level to be involved in the case of a threat case associated to each task identified are listed below. All tasks would be performed at the national level:

1. Improved orbit determination: **MPC and CNEOS**
2. Refinement of risk of impact: **CNEOS (in collaboration with NEOCC) and ATAP**
3. Notification of governmental authorities of impact risk: **NASA and FEMA**
4. Trade-off of possible mission architectures and deflection strategies: **NASA centers and associated institutions**
5. Determination if in-space mitigation is achievable: **NASA with input from supporting agencies/institutions**
6. Present recommended deflection strategy/campaign to interagency task force: **NASA/PDCO**
7. Selection of the deflection strategy and eventual campaign: **Interagency Task Force**
8. Perform mission design for selected campaign mission(s): **Involved agencies and institutions**
9. Perform system design of selected mission(s): **Involved agencies and institutions**
10. Present campaign design to international collaborative planning (SMPAG): **NASA/PDCO**

6.2 Task 2: Entities involved at the national (SMPAG-member) level

NASA PDCO Planetary Defense Officer.

6.3 Task 3 Internal task implementation procedure

NASA PDCO would coordinate tasks through established national-level working groups as designated in the U.S. "National Near-Earth Object Preparedness Strategy and Action Plan".

https://www.nasa.gov/sites/default/files/atoms/files/ostp-neo-strategy-action-plan-jun18.pdf

References

NASA, "National Near-Earth Object Preparedness Strategy and Action Plan", https://www.nasa.gov/sites/default/files/atoms/files/ostp-neo-strategy-action-plan-jun18.pdf

7 European Space Agency (ESA)

Contributors: Richard Moissl; Detlef Koschny (1). (1) European Space Agency

7.1 Task 1: Required tasks for a coordinated response to the threat

In our inputs, the individual defined and envisioned tasks are identified with uppercase letters (A..M) in the first part (Q1 inputs).

The second part (Q2 inputs) lists the relevant ESA entities with lowercase letters (a..g). In order to clarify which entity is involved in which task, all tasks to which an entity contributes are involved is provided as a list of uppercase letters.

The third part (Q3 inputs) refers to the established procedures for our routine tasks and to specific procedures which are currently in the process of being developed internally.

TASK 1: LIST THE REQUIRED TASKS FOR A COORDINATED RESPONSE TO THE THREAT (D > 50M, IP > 1%, TIME TO EVENT < 50 YEARS)

A) Request/perform follow-up observations

- These are routine tasks performed for NEOs with an IP > 0

B) Improved orbit determination

- This is also a routine task performed for all known NEOs

- Potential impact corridor calculated if IP > 0.1%

C) Refinement of risk of impact

- Also a routine task for all NEOs with an IP > 0

D) Estimation of Impact effects

- Routine task. Currently only rough estimate of kinetic energy and classification of damage level

- A tool for detailed assessment of Impact effects is under development

E) Communicate astrometric and known physical parameters to general public

1) Creation and distribution of Close Approach Fact Sheets (CAFS), containing relevant information about the NEO

2) Provision of media communication plan and ESA communication channels

F) Communicate priority information (impact corridors, impact effects estimates, eic.) to national and international partners (i.e., SMPAG members)

1) Additional information ("third page") added to the CAFS and additional Asteroid Impact and Close Approach Messages (AICAM).

2) NEOCC expert support

N.B.: The following tasks are not fully implemented yet, they are work in progress:

G) Assess options for reconnaissance and/or deflection missions

1) Internal task, performed by experts in related fields

2) Collaborative task, done in coordination with other space agencies/at the SMPAG-member level

H) Selection of deflection strategy and/or reconnaissance mission

- Collaborative task in coordination with other space agencies/at the SMPAG-member level

I) Perform mission analysis of recommended mission

- Collaborative task in coordination with other space agencies/at the SMPAG-member level

J) Perform system design of recommended mission

- Shared task in coordination with other space agencies/at the SMPAG-member level

K) Agreement at the SMPAG-member level on the recommended mission

L) Adoption and implementation of selected mission(s)

1) At programmatic ESA level

2) In collaboration with other agencies and SMPAG members

M) Mission operations

- In collaboration with other agencies and SMPAG members

7.2 Task 2: Entities involved at the national (SMPAG-member) level

TASK 2: ENTITIES INVOLVED AT ESA LEVEL (Links to Tasks provided in Q1 provided as list of uppercase letters)

a) Planetary Defence Office
1) Performing all routine tasks (A,B,C,D,E,F)
2) Head of Office and Mitigation activities Coordinator trigger specific activities (G,H,I,J,K,L,M) and interact with other internal entities (b,c,d,e,f)

b) Communications Office
- Support communication to general public (E-2)

c) Mission Operations Directorate (OPS)
- Mission studies, analysis, implementation and operations (G,I,J,M)
- Nomination of personnel contributing to internal taskforce

d) Technology, Research and Development Directorate (TEC)
- Mission studies and implementation (G,H,J,L-2)
- Nomination of personnel contributing to internal taskforce

e) Science Directorate (SCI) and/or Exploration Directorate (HRE) [To be defined internally]
- Mission studies, analysis and contributing scientific expertise (H,I,J,M)
- Nomination of personnel contributing to internal taskforce

f) Director General (DG)
- Overall responsibility for ESA contributions and interface with Member States (g) on programmatic level tasks (K,L)
- Instructing internal taskforce (a-2,c,d,e)

g) ESA Member States (MS)
- Approval of ESA contributions, mission adoption and dedicated financial contributions (L)

Please consult Q2.1 inputs for identification of internal tasks and tasks to be performed in coordination and/or collaboration with external entities.

This information is provided via the identification of tasks (lists of uppercase letters) to which each entity contributes and the description of their roles (more information is provided in the existing documents and the documents currently being prepared).

7.3 Task 3 Internal task implementation procedure

TASK 3: INTERNAL TASK IMPLEMENTATION PROCEDURES
The procedures for routine tasks (A,B,C,D,E,F) are described in the following documents:
[AD01] ESA-S2P-PD-PR-0001 NEOCC Operational Procedures (A,B,C,D)
[AD02] ESA-SSA-NEO-PL-0017 NEO information plan (E,F)

The procedures for specific tasks (E,G,H,I,J) are currently being iterated internally and will be made available via the following documents (*)

[AD03] ESA-S2P-PD-PL-0078 Planetary Defence Contingency Management Plan (G,H,I,J)
[AD04] ESA-S2P-PD-PL-0079 Planetary Defence Crisis Media Communication Plan (E-2)

The mission adoption (L-1), implementation (L-2) and operations (M) will follow the established ESA governance procedures

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*) Outline for the envisioned specific tasks procedures:

G) The H/PDO and Mitigation activities Coordinator (a-2) shall trigger and support the other internal tasks (G-1) and involved entities (b,c,d,e) and inform the Director General (f) exhaustively. At the same time they shall act as delegates to SMPAG (G-2), acting under instructions of the DG.

H,I,J) It is intended to define an ESA taskforce with representatives of the different internal entities (a-2,c,d,e) to conduct/coordinate the mission studies, analysis and design. The same taskforce would be interacting and collaborating with all external partners for said tasks, while providing timely and frequent updates to ESA decisionmakers (f,g)

8 French Space Agency (CNES)

Contributors: Pascal Faucher[(1)], Aurélie Moussi[(2)], Pierre-William Bousquet[(1)]. [(1)] CNES

8.1 Task 1: Required tasks for a coordinated response to the threat

Hereafter is a list of tasks required for a coordinated response CNES can contribute to, this list is not exhaustive:

- Confirmation and refinement of the risk of impact: confirmation crosschecked by several teams (CNES with the support of national assets) for each potential risk; inputs and assumptions used for risk's characterization detailed, risk parameters detailed (including modelling of the potential damage (TBC))
- Improved orbit determination of the hazardous object: request for observation campaigns to gain additional/updated inputs, computation of the updated orbit, refinement of the risk based on this up-to-date orbit (might be a progressive task with several loops), distribution of the computed orbit and ephemerid to the national community (and international partners or SMPAG PoC)
- Improvement of knowledge on the object nature/structure (internal structure, surface, thermal parameters, etc.) and detailed modelling of the object
- Trade-off of the up-to-date deflection strategies applicable and associated mission architectures
- Feasibility studies for pre-selected deflection strategies based on the national delegation skills available (system, mission analysis, technology, etc.)
- Ranking/selection of the best deflection strategies (selection committee and representatives to be defined)
- Mission analysis for the best pre-selected missions (higher rank) and refinement of the ranking based on technical or other criteria (to be defined) to select a nominal strategy/mission
- System design of the selected mission including milestones, national concerned assets and project calendar

8.2 Task 2: Entities involved at the national (SMPAG-member) level

The table below details the main assets available at the national level (France) to support a coordinated response. All tasks described above in Section 8.1 could be supported at the national level by the French assets but on a best effort basis for now. This exercise did not unveil a task which is no internal capability (at least partly).

Note: some tasks might require the support of several national assets regarding the task.

Note: Only civilian assets are described hereafter.

ASSET OWNER	ASSET ID	Asset category	Contribution
IMCCE	Ephemerids Services	Service	Risk confirmation Orbit determination
IMCCE	M4ST (Modelling for Asteroid)	Software	Object characterization
OCA	Minor Planet Physical Properties Catalogue (MP3C)	Database	Object characterization
IMCCE/OCA	Virtual Obervatory Solar System Open Database Network (SsODNet)	Database	Object characterization
IMCCE	Gaia-FollowUpNetwork-SSO	Service	Observation
OCA	Gaia-DPAC asteroids	Database	Object characterization
LESIA	Planetology Laboratory	Research team	Observation Object characterization
IMCCE	Fireball Recovery and InterPlanetary Observation Network (FRIPON)	Observation	Observation
IMCCE	CABERNET	Observation	Orbit determination Observation
IMCCE	MALBEC	Observation	Observation
IPG	Planetary Science Team	Research team	Object characterization
ISAE-Supaero	SSPA team	Research team	Object characterization
OCA	Theories and Observation in Planetology Team (TOP)	Research team	Object characterization Modelling
IMCCE	DynAstVO/VESPA	Database	Modelling
IMCCE	PEGASE	Research team	Orbit determination Modelling
Paris Observatory	Paris Astronomical Data Centre (PADC)	Service	Modelling
IMCCE	NAROO	Service	Observation

CNES/CNRS	Small bodies Data Hub	Database	Support to initial tasks (risks confirmation and characterization)
CNES	Expertise or support in orbit determination, Modelling, mission analysis, system design, operational coordination	Engineering and science team	Support to all tasks, main PoC

The first internal task for CNES delegation was to identify these assets and their potential contribution. The next task will be to define a coordination process in case of a potential threat (still on-going).

8.3 Task 3 Internal task implementation procedure

The main French internal contributors and their expertise fields are now identified but the national implementation procedure in case of the NEO threat is still under discussion. The contribution to the next steps of this exercise will be perform on a best effort policy.

9 United Kingdom Space Agency (UKSA)

Contributors: Edward Baker[(1)]. [(1)] UKSA

9.1 Task 1: Required tasks for a coordinated response to the threat

- Implement the UK Space Agency's Standard Operating Procedure for planetary defence:
    - Notify relevant UK Government departments and stakeholders via the orbital analysts and agreed distribution list and template for 'Potential Impact Risk' events. Departments should take receipt of the notification and take proportionate action.
    - While the UKSA would primarily rely on NASA, ESA and the International Asteroid Warning Network (IAWN) for observational data, the UKSA would identify which of its own national assets can conduct follow up observations on the object to improve orbit determination.
    - Convene a meeting between UK SMPAG government, academic, legal leads, the Cabinet Office, Ministry of Defence and the UKSA Space Security and Resilience team to discuss present situation and next steps.
    - Review and update current planetary defence Lines to Take (LTT) and consider issuing a public statement, aligning messaging with international partners.
- Establish contact and coordinate activities with other countries within the predicted impact corridor as well as the NASA PDCO and ESA NEOCC.
- Engage with UK academic community for Subject Matter Expertise (SME) on risk level and understand options for possible mission.
- Communicate agreed next steps to relevant international partners via SMPAG and the UNOOSA.

9.2 Task 2: Entities involved at national (SMPAG-member) level

The table below details the stakeholders who would be involved in the initial response to this event, including their role and responsibilities.

Stakeholder	Type	Role and Responsibility
Cabinet Office COBR Unit	Government	Central coordinating function for national and regional crises within UK Government.
UKSA NSpOC	Government	Lead Government Department for planetary defence, responsible for escalating NEO events and tasking UK sensors to conduct follow up observations.

UKSA Senior Leadership	Government	Overall responsibility for decision making within the UKSA and briefs to government ministers.
UK SMPAG Academic Lead	Academia	Provide UKSA and wider UK Government with Subject Matter Expertise on NEO and planetary defence matters.
UK SMPAG Legal Lead	Government	Advise UKSA and wider UK Government on relevant legal frameworks.
UKSA Space Security and Resilience	Government	Coordinate UKSA-wide response and resilience activities and liaise with ESA Space Safety Programme on any possible missions.
UKSA Office of the Chief Engineer	Government	Provide technical and engineering Subject Matter Expertise to UKSA NSpOC, security/resilience and Senior Leadership.
UKSA Communications	Government	Coordinate and public and news media messaging
Space Command (1SOS)	Government	Support via NSpOC with data from RAF Fylingdales.

This list is not exhaustive and there are likely other stakeholders not outlined here who would be involved in the response.

9.3 Task 3 Internal task implementation procedure

The UK Space Agency NSpOC would follow the steps set out in its planetary defence Standard Operating Procedure (SOP). This would begin with the UKSA Orbital Analyst (OA) team, who work within the NSpOC, receiving the notification from IAWN/SMPAG and compiling a report to be sent to stakeholders outlined in Task 2 as well as other UK Government departments. Following the release of this report, the NSpOC would convene and chair a meeting between the UK SMPAG delegation, UKSA teams and other high level UK Government stakeholders to decide:

1. Appropriate next steps for UK Government, focusing on national and regional resilience.
2. How public messaging should be handled and agree lines to take.
3. Options for possible mission contributions from the UK to international efforts; focusing on academic and industry sector expertise and resources as well as options for government funding (using ESA RAMSES as a case study).

The UKSA NSpOC, as UK Government lead for SMPAG, will provide the overall coordinating role for all UK SMPAG activities. This includes the receiving and distribution of alerts across UK Government, convening relevant stakeholders into next steps planning meetings and tasking UK sensors to perform follow up observations if possible. NSpOC will also provide the link be the main point of contact for all other SMPAG delegations.

The UK SMPAG academic lead will be responsible for providing Subject Matter Expertise to UK Government. They will also be responsible for providing a bridge between the wider UK academic sector and UK Government decision makers. The role of the UK SMPAG legal lead is having not been extensively defined as of the completion of Sprint 1 but would likely advise UK Government on relevant legal frameworks and engagement with UNOOSA/COPUOS.