NEOShield-2

Science and Technology for Near-Earth Object Impact Prevention

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Table of Contents

1 Introduction

1.1 Scope

The purpose of this technology roadmap is:

- to provide a compact overview of the technological capabilities required for a set of NEO-related reference missions
- assess the development status of these technical capabilities
- identify needed activities to bring the identified technologies to TRL 6

The set of reference mission includes the missions studied under the NEOShield and NEOShield-2 projects, as well as other NEO missions that are deemed relevant to mitigation, characterisation, or utilisation. Missions are included for which sufficient information is available from work under NEOShield(-2) or other study activities of the NEOShield-2 consortium. The focus is on demonstration missions rather than operational missions (e.g. real threat mitigation), which in absence of a real threat are seen as the intermediate goal of most technology development activities.

The technology readiness level evaluation is based primarily on a European perspective, i.e. gives an assessment of the technological capabilities within Europe. This allows an assessment of the development needs that are implied by the decision to pursue different missions or mission contributions (e.g. in international collaborations) by European actors. The assessment focuses on the development needs in order to reach TRL 6, since this is the ideally required level to support an implementation decision with a reasonable amount of schedule and financial risk. Higher TRL generally implies the decision to implement the technology in an actual mission.

The document also gives some preliminary recommendations about how the technology development can be focused and prioritised, while pointing out that this is obviously also a decision based on programmatic / mission priorities.

1.2 List of Abbreviations

AD	Applicable document
AIDA	Asteroid Impact and Deflection Assessment (Mission)
AOCS	Attitude and orbit control system
CAM	Collision avoidance manoeuvre
CoG	Center of gravity
EM	Engineering model
ESOC	European Space Operations Center
FDIR	Failure detection isolation and recovery
FM	Flight model
FOV	Field of view
GNC	Guidance Navigation and Control
GSFC	Goddard Space Flight Center
GT	Gravity tractor
HIL	Hardware in the loop
IBS	Ion-beam shepherd
KI	Kinetic Impactor

LEO	Low earth orbit
MIL	Model in the loop
NEO	Near Earth Object
NEOTωIST	Near-Earth Object Transfer of angular momentum (ω) Spin Test
OBC	Onboard computer
ODM	Orbital departure manoeuvre
PIL	Processor in the loop
QM	Qualification model
RD	Reference document
S/C	Spacecraft
SIL	Software in the loop
TRL	Technology readiness level

1.3 Applicable Documents

[AD1] NEOShield-2: "Science and Technology for Near-Earth Object Impact Prevention", Grant Agreement no. 640351, 28.10.2014.

1.4 Reference Documents

[RD1] NEOShield-2, D3.4 GNC Technology Validation Test Report, Issue 1.1, 21.09.2017

[RD2] NEOShield-2, D8.2 Report on NEO Orbit Determination and Monitoring Strategy, Algorithms Design and Functional Validation, Issue 1.0, 30.06.2017

[RD3] Memo: Examination of asteroid flyby visual navigation - feasibility and performance, 31.08.2017, DeMichele Emmanuel

[RD4] NEOShield-2, D6.1 Technologies for Return and In - situ Analysis of NEO Samples, Issue 1.0, 26.01.2016

[RD5] NEOShield-2, D6.3 Sampling Device: Design and Test Report, Issue 1.1, 29.04.2016

[RD6] NEOShield D8.2 NEOShield Kinetic Impactor Demonstration Mission Detailed Design, Issue 1, January 2015

[RD7] Asteroid Impact & Deflection Assessment mission ; ESA website ; http://www.esa.int/Our_Activities/Space_Engineering_Technology/Asteroid_Impact_Mission/Asteroid_Impact_Deflection_Assessment_mission ; retrieved Sept. 2017

[RD8] Engel et. al., NEOTωIST - An Asteroid Impactor Mission Featuring Sub-spacecraft for Enhanced Mission Capability, IAC-16,B4,8,7,x34163, International Astronautical Congress 2016

[RD9] NEOShield, D8.4 NEOShield Blast Deflection Demonstration Mission Detailed Design, issue 2.0, 20 February 2015

[RD10] NEOShield, D7.1: Gravity Tractor Feasibility Report, issue 1.0, 1 March 2013

[RD11] NEOShield, D7.5.4: Ion Beam Shepherd Deflection Concept, issue 1.0, 15 Sept 2013

[RD12] NEOShield-2, Reference Mission Definition: Sample Return, issue 2.0, 23.06.2016

2 Missions and required functionalities

This chapter provides a short description of the reference mission concepts that are considered. At the end there is a summary of the key functionalities/ technical capabilities implied by each mission concept.

(A) Classic Kinetic Impactor demonstration mission - classic

The space segment of this mission consists of two spacecraft, the Explorer and the Impactor spacecraft. Depending on the chosen design, launch and cruise of both spacecraft may be designed to be joint or separate. The Explorer arrives and rendezvous with the NEO prior to the Impactor and performs a physical of the object characterisation (mass, CoG position, rotational state, topography and surface properties) before the Impactor arrives. This includes in particular a precision orbit determination of the NEO, as well as observation of the object geometry and size. The latter is used for improved Impactor targeting accuracy, using visual navigation. After completion of this NEO characterisation phase the Impactor spacecraft arrives and impacts the NEO at hypervelocity, thus transferring momentum to the target NEO and changing its orbit slightly. In many cases the impactor will consist of the mission spacecraft as well as the transfer or launcher upper stage, in order to increase the impacting mass. The impact itself will be observed by the Explorer from a safe position. After the impact, the Explorer performs another precision orbit determination in which together with the NEO properties allows quantification of the momentum change imparted by the Kinetic Impactor.

For details of the NEOShield KI mission see [RD6]

(B) Classic Kinetic Impactor demonstration mission - classic with surface science

The two-spacecraft KI mission architecture described above, can also be expanded and enhanced by a small mobile surface science probe. In this case the Explorer spacecraft would deploy a small probe for in-situ surface characterisation of the target object, e.g. for improved understanding of NEO composition and structure. This surface science probe may be designed for a passive or (semi-)controlled touchdown. The later significantly reduces the demands on the Explorer spacecraft, since the small probe can be deployed more safely from a greater distance. The Asteroid Impact and Deflection Assessment Mission (AIDA), as originally foreseen, is an example of this mission type [RD7].

(C) Kinetic Impactor Demonstration Mission - NEOTωIST concept

NEOTωIST stands for Near-Earth Object Transfer of angular momentum (ω) Spin Test. This describes a demonstration mission intended to develop the capabilities required to execute an effective kinetic impactor NEO deflection mission. The chosen measurement technique and employment of small sub-spacecraft for observation purposes represent a novel approach to achieving the main goals of such a demonstration mission. The approach promises comparatively low cost and features capabilities that are unique and valuable for an operational deflection mission. Most standard deflection demonstration missions propose to quantify momentum transfer from the impactor spacecraft to the target object by measuring a change in its heliocentric orbit. The change is typically so small that it must be performed via radio-science from a second observer spacecraft which rendezvous with the NEO prior to impact. In our case the NEO is struck off-center which changes its spin rate. This rate change, which can be measured from Earth via light curve measurements, allows quantification of the transferred momentum. Using this measurement method the need for an observer spacecraft for the purpose of NEO orbit measurement is eliminated. The second function of the observer spacecraft is the close-up observation of the impact event for improvement of impact effectiveness modelling. The NEOTωIST mission achieves this observation by deploying several small sub-spacecraft from the main impactor spacecraft shortly before impact. These sub-spacecraft allow observation of the impact event from multiple vantage points some of which are unique because their destruction is accepted. At least one sub-spacecraft trajectory is planned such that survival is guaranteed, which enables it to receive observation data from the other spacecraft for delayed transmission to Earth.

For details on the NEOTωIST mission concept see [RD8].

(D) Blast deflection (with & w/o surface science)

Blast deflection missions are a category of missions in which a blast in most is induced on or near the surface of an NEO. The NEO material which is either blasted off the surface or vaporized carries momentum thus imparting momentum on the NEO and changing its orbit. In many cases the mechanism of inducing a sufficiently powerful blast is through a nuclear device. Typically, the mission architecture would consist of an Explorer spacecraft which characterizes the NEO and determines its orbit precisely before and after the blast event to verify and quantify the deflection. In this case the blast device is carried by a sub-spacecraft which is deployed near the NEO surface by the Explorer. While the sub-spacecraft positions and triggers the blast device, the Explorer attains a safe position. Details on the blast deflection concept studied under NEOShield can be found in [RD9].

(E) Orbiting Explorer mission / Remote prospector

This mission scenario describes that of a spacecraft which performs a rendezvous and observes and characterizes the NEO remotely using a suite of remote sensing instruments. This would typically also include precision orbit determination and gravity measurements via trajectory measurements. This type of Explorer mission will in many cases be part of other missions such the KI missions described above. A stand-alone example is the Dawn mission. The mission scenario and capabilities are also representative of an orbital prospector mission in the context of resource prospecting/extraction scenarios. The instrumentation will obviously be tailored to the priorities of the mission.

(F) Gravity tractor

This “slow-push” concept is a technique for fine-tuning the orbit of an asteroid that has already been deflected by other means. It exploits one or more solar-electric propulsion engines to provide a gradual thrust that changes the NEO target and the S/C orbits together, maintaining a fixed distance between the two elements during the whole operations performance. The force from the spacecraft is applied to NEO via gravitational attraction. To achieve a reasonable force this implies a certain minimum spacecraft mass. The thrust must be applied along or against the orbital vector in order to “affect” the orbital parameters of the NEO target, and in particular to change its period. However, the thrusters must be canted to prevent propellant from hitting the asteroid (which would push it away). The longer the thrust is applied, the greater the change in period will be. And the longer the NEO target is observed, the more apparent this period change will be. The GT in practice can simultaneously make small adjustments to the asteroid orbit and provide the information needed for a very precise tracking of it from the Earth. In other words, it almost matches the functionalities of a KI observer or explorer S/C as described in the previous sections.

Taking into account the above considerations, it turns out that a Gravity Tractor mission is expected to be designed and launched for the following purposes:

- to refine the asteroid deflection achieved by using another deflection spacecraft, enabling a better and more controlled tuning of the NEO target orbital parameters
- to support the operations of another deflection spacecraft, e.g. the Kinetic Impactor, providing advanced GNC and monitoring capabilities, generating data about the asteroid

orbital parameters before and after the use of another deflection technique and also during the use of the Gravity Tractor concept.

Details on the concept studied under NEOShield can be found in [RD10].

(G) Ion-beam shepherd

The Ion-Beam Shepherd is able to gradually deflect an asteroid, simply by firing propellant at the asteroid, to produce a gradual change in the asteroid's momentum and velocity. A counteracting thrust is required to prevent the Ion-Beam Shepherd from drifting away. Both the thrust and the beam hitting the asteroid would typically be created by an electric thruster. Like the gravity tractor method, the Ion-beam shepherd allows fine tuning the asteroid trajectory very precisely, and has low sensitivity to the cohesive properties or rotation of the target object.

For details on the concept see [RD11].

(H) In-situ Explorer mission / In-situ prospector

This scenario describes a mission which puts a vehicle on the surface of a NEO which carries a suite of sensors and laboratory instrumentation for in-situ analysis of the object properties. The architecture may be either a single vehicle which performs the cruise, rendezvous and surface operations, or in many cases a two vehicle design with an orbiter and a mobile surface probe deployed from the orbiter. In this case some mission designs conceivably allow for a relatively small surface probe which has the potential to simplify the mission and reduce overall cost. In both architectures the fundamental functionalities are similar regardless of whether they are provided by a single vehicle or distributed among two. In most cases this mission scenario will also perform orbital remote characterisation for a synoptic view. The surface instrumentation may include for instance the, drills, mass spectrometers, cameras, microscopes, thermal sensors.

The mission scenario is broadly representative of missions with several different types of focus, i.e. such surface examinations may serve deflection preparation, scientific interests or resource prospecting purposes.

This mission scenario has not been explicitly studied in detail under the NEOShield(-2) projects.

(I) Sample Return mission

This mission describes a scenario where a sample of Asteroid material is extracted from the target object and returned to Earth for laboratory examination. The typical architecture consists of a single vehicle which rendezvous with the Asteroid, performs some orbital characterisation, touches down for sample extraction, then returns to Earth and releases the sample in an entry capsule for atmospheric entry descent and landing. Finally the capsule and sample is retrieved on ground. Depending on the objectives and design the sample extraction may be from the surface or subsurface of the NEO. Further, different extraction methods either require full landing and standstill on the surface or allow for a "touch and go" approach where the sample is extracted during a brief non-stationary surface contact. The later method is the one employed by the most prominent mission examples already implemented, that is Hayabusa and Osiris-Rex. The NEOShield-2 work on a sample return mission scenario is summarized in [RD12].

(J) Flyby Characterisation / Mini remote prospector

This mission describes a scenario where a spacecraft encounters a NEO on a flyby trajectory. The relative velocity is typically several km/s. In cases this is the fastest and cheapest (low delta-v, small vehicle) possibility to gain some preliminary information about an unknown object. This may include improvement of the NEO trajectory, constraining the size, mass, geometry and possible composition. The mission scenario is typically discussed when information about a potentially hazardous object is required quickly and a rendezvous trajectory would take too long to achieve or the more complex mission is not justified by the impact probability. Such missions may also have a role to play for preliminary resource prospecting even though the value to cost is yet to be determined. The mission utility is in some cases significantly lower than for a rendezvous mission. Consequently it is attractive to consider small/ low cost vehicle designs, especially in scenarios where no imminent threat is present. Such a vehicle would share many features with the Flyby Module proposed under the NEOTωIST scenario.

Table 2-1: Major mission functions by mission type

		A	B	C	D	E	F	G	H	I	J
#	Function / Mission	KI Demo classic	KI Demo with surface science	KI Demo NEOTωIST	Blast deflection (with & w/o surface science)	Orbiting Explorer	Gravity tractor	Ion beam shepherd	In-situ Explorer	Sample Return	Flyby characterization
Guidance, Navigation and Control											
1	Impactor GNC	x	x	x							
2	Reconnaissance/ Orbiter GNC [1]	x	x		x	x	x	x	x	x	
3	Autonomous proximity hovering GNC[8]						x	x			
4	Landing / Sample Return GNC		x		(x)[2]				x	x	
5	Precision NEO orbit determination	x	x		x	x	x	x	(x)[3]	(x)[3]	
6	Flyby navigation			x							x
Observation and analysis capabilities											
7	Orbital observations - ejecta	(x)[4]	(x)[4]		(x)[4]						
8	Orbital observations - crater	x	x		x						
9	Orbital observations - NEO physical properties	x	x		x	x	x	x	x	x	
10	Flyby observations -ejecta			x							
11	Flyby observations - NEO physical properties			x							x
12	Surface science package		x		(x)[2]				x		
13	Earth-based determination of rotation period			x							
Various platform and mechanism capabilities											
14	Small deep space platform		x	x	(x)[2]				(x)[5]		X[6]
15	Surface mobility / multisite capability		(x)[7]						(x)[7]		
16	Sample extraction and storage									x	

		A	B	C	D	E	F	G	H	I	J
17	Ion-propulsion / Ion-shepherding beam						x	x			
18	Blast deflection payload				x						

1) Reconnaissance orbiter GNC contains the sub-functionalities of: Close Approach, Inertial Hovering, Body-fixed hovering (See [RD1] for details)

2) If blast application is preceded by surface reconnaissance

3) Nice to have

4) Ejecta observation may not be possible safely for orbiting S/C, depends on mission concept, e.g. sub-spacecraft could be employed

5) The assumed mission concept would be more affordable with a small mobile surface probe

6) The mission utility of a Flyby characterisation is comparatively lower, such that a "small" low-cost platform enables more reasonable mission utility to cost ratio

7) Surface mobility/ multi-site capability would potentially add significant value, but is optional depending on the scope of the mission and the precise questions to be addressed

8) The GNC required for slow push methods (GT and IBS) is considered different and more challenging than the typical orbiter GNC, since the spacecraft must remain stationary much closer to the neo Surface (< 100s of m) for much longer periods (months - years)

3 Overview of Technologies and TRL

This section provides an assessment and justification of the current TRL for the individual technical capabilities that are given outlined in the previous chapter.

Table 3-1: Evaluation technical capabilities by TRL status and needed development effort

#	Mission / Function	TRL	Justification of TRL	Main points needed to reach TRL 6 /other study needs	Dev. effort
Guidance, Navigation and Control					
1	**Impactor GNC**	**5**	MIL, PIL, HIL test campaigns. Details in D3.4 [RD1]. Closed-loop simulation missing for to reach TRL 6.	- Closed loop simulation - Use of flight representative camera hardware	Medium
2	**Reconn-aissance/ Orbiter GNC**	**5-6**	MIL, PIL, HIL test campaigns. Details in D3.4 [RD1].	- To mitigate the scaling effects the following points shall be taken into consideration: 1)Make use of existing/available narrow angle camera hardware for Close Approach and Arrival Inertial Hovering for 6h phases (not the case in Body-Fixed Hovering phase using wide angle camera) 2) Include real altimeter in the verification chain (considering ways to overcome the limitations in available HIL test benches) - Perform full verification of the scenarios including FDIR functions where CAM manoeuvres shall be triggered in the HIL campaign. - The software testbed shall also compatible in form and fit with the FM/EM OBC. - The costs to realize the QM/FM models shall be fully determined. (See [RD1])	Medium
3	**Autonomous proximity hovering GNC**	**2-3**	Not studied in NEOShield-2, no significant capability known in Europe	Full development effort required including. MIL, PIL, HIL campaigns, verifying critical functions in relevant environment and with flight representative hardware	Signific.

#	Mission / Function	TRL	Justification of TRL	Main points needed to reach TRL 6 /other study needs	Dev. effort
4	**Landing / Sample Return GNC**	**5-6**	MIL, SIL, PIL, HIL test campaigns. Details in D3.4 [RD1]	The following recommendations have been worked out to increase the achieved TRL to 6. -To mitigate the scaling effects the following points shall be taken into consideration: 1) The right FOV shall be taken for the final validation. 2) Dedicated hardware tests are proposed to have a validated altimeter model. 3) The landing conditions shall be harmonized. -CAM manoeuvres shall be triggered in the HIL campaign. -The software testbed shall also compatible in form and fit with the FM/EM OBC. -The costs to realize the QM/FM models shall be fully determined. Software tested on breadboard processor unit which is representative in terms of function. Not representative in terms of form and fit. No radiation hardened components have been used. (See [RD1])	Medium

#	Mission / Function	TRL	Justification of TRL	Main points needed to reach TRL 6 /other study needs	Dev. effort
5	**Precision NEO orbit deter-mination**	**5**	-Development of on-ground processing algorithms to perform orbit determination and monitoring of small NEOs with very weak gravity fields. - The technology development has been validated up till a technology readiness level of TRL5 achieved by validation/demonstration of the technology in a relevant environment. In a first step, the validation of the relative referencing link was performed using HIL test facility data. Thereafter, the validation was performed using simulated mission data covering cases not addressed in the HIL test facility. ODM on-ground and momentum enhancement factor estimation algorithms are implemented in a Matlab & Simulink language. Details in D8.2 [RD2].	A more profound feasibility study involving the ESOC and/or GSFC teams to further refine the interface definition. Porting them to the operational environment at ESOC and/or GSFC would allow reaching TRL6.	Medium
6	**Fly-by navigation**	**3**	Setup of filter and simulation that shows basic feasibility. (See [RD3])	- Confirmation of hardware assumptions, in particular camera. - Modelling of AOCS performance and contribution to navigation errors. -Full MIL, PIL, HIL test campaigns.	Signific.
Observation capabilities					
7	**Orbital obser-vations - ejecta**	**3**	It is assumed that ejecta can be observed by means of optical camera. Deep impact shows that this is fundamentally possible. However, the understanding of the optical properties of the expected NEO ejecta is not yet sufficiently well understood to judge the performance of different available cameras.	- Develop reliable models of optical properties of ejecta. -Check these against available camera hardware for feasibility. - Verify performance for selected hardware.	Signific

#	Mission / Function	TRL	Justification of TRL	Main points needed to reach TRL 6 /other study needs	Dev. effort
8	**Orbital obser-vations - crater**	**5**	General performance requirements consistent with existing optical cameras. However, no actual equipment selected.	Refinement of performance requirements. Selection, performance verification, and qualification of actual camera system.	Modest
9	**Orbital obser-vations - NEO physical properties**	**(4)**	Evaluation depends on precise observables to be assessed. Heritage exists for a good portfolio of remote sensing equipment.	- Refine selection of observables and performance requirements. - Selection, performance verification, and qualification of actual instrument hardware.	Signific
10	**Flyby obser-vations - ejecta**	**3**	It is assumed that ejecta can be observed by means of optical camera. Deep impact shows that this is fundamentally possible. However, the understanding of the optical properties of the expected NEO ejecta is not yet sufficiently well understood to judge the performance of different available cameras.	- Develop reliable models of optical properties of ejecta -Check these against available camera hardware for feasibility - Verify performance for selected camera hardware - Development of imaging pointing mirror mechanism to EM level	Signific
11	**Flyby obser-vations - NEO physical properties**	**4**	Evaluation depends on precise observables to be assessed. Heritage exists for a good portfolio of remote sensing equipment.	-Refine selection of observables and performance requirements. -Selection, performance verification, and qualification of actual instrument hardware	Signific
12	**Surface science package**	**(4)**	Evaluation depends on precise instrumentation and desired analysis. Heritage exists for a good portfolio of remote analysis equipment.	- Refine selection of observables and performance requirements. - Selection, performance verification, and qualification of actual instrument hardware. - For small surface science probe concepts, downscaling of some existing instrument concepts may be required.	Signific
13	**Earth-based determi-nation of rotation period**	**9**	Light curve measurements for rotation period determination have been performed with sufficient accuracy.	**n/a**	Low

#	Mission / Function	TRL	Justification of TRL	Main points needed to reach TRL 6 /other study needs	Dev. effort
Various platform and mechanism capabilities					
14	**Small deep space platform**	**4**	Flexible LEO Platform (FLP2) development activities at Airbus. High performance small LEO platform. Software verification facility. Hardware partially integrated.	Design and component updates for mission specifics and radiation hardness. Software modification for deep space applications. Functional testing of new functionalities, environmental testing, especially radiation. Deep space communications hardware. Selection or development of suitable propulsion system (chemical or electrical).	Significant
15	**Surface mobility / multisite capability**	**3**	Early trade studies and conceptual designs for surface mobility concepts (e.g. CORE concept, Astrone).	-Selection and refinement of vehicle concept. -Selection of thruster technology and configuration. -Development and verification of GNC concept.	High
16	**Sample extraction and storage**	**3-7**	Various concepts, in various stages of development. See [RD4] for details. NEOShield development at TRL 4-5 [RD5]	Selection of specific sampling principle based on mission objectives and constraints. Development program to TRL 6	Significant-High (depends on type).
17	**Ion-propulsion / Ion-shepher-ding beam**	**7**	Assumption is that QintiQ T6 would be a good candidate for a demonstration mission. NEOShield looked at a scaled up version of the T6 for an operational mission. The T6 is under qualification for the BepiColombo program	-No technology development anticipated. -Detailed study to confirm preliminary assessment that T6 is suitable for a demonstration mission.	Low
18	**Blast deflection payload**	**3**	No heritage for blast deflection payloads in Europe. Some conceptual work under NEOShield Project. Some GNC and platform functionalities can be reused for deployable free flying payload.	- Selection of blast principle. - Development of key technologies to TRL 6	High

4 Recommendations for future developments

Development priorities for technologies clearly depend on desired missions and capabilities, which is ultimately a political and programmatic decision which must be made by the stakeholders in Europe, likely considering the positions and plans of international partners.

Absent of a clear prioritisation of specific missions we can order the above described capabilities into three broad categories which also represent a tentative prioritisation.

Category 1:

These are capabilities that are applicable to many (almost all missions), which makes them inherently valuable to a NEO exploration and protection programme, independently of the precise mission priorities. As visible in Table 2-1, this includes the following:

- #2 Orbiter GNC
- #5 Precision NEO orbit determination
- #8 Orbital observations - crater (in many cases included in #8)
- #9 Orbital observations of NEO physical properties
- #13 Earth-based determination of rotation period (included because valuable science tool and already quite mature)
- #14 Small deep space platform

In most cases the remaining effort to TRL 6 is also limited. The wide applicability and generally modest development effort makes these capabilities potential development priorities as long as specific missions have not been prioritised.

Category 2:

The capabilities in this category are generally more mission specific, and on average need more development effort but also offer high value in terms of knowledge return. The capabilities are largely those associated with the classic KI scenario, the NEOTωIST scenario or the in-situ/sample return study of asteroid material. This includes the following capabilities:

- #1 Impactor GNC
- #3 Autonomous proximity hovering GNC
- #4 Landing GNC
- #6 Flyby navigation
- #7 Orbital observations-ejecta
- #10 Flyby observations-ejecta
- #11 Flyby observations- NEO physical properties
- #12 Surface science package
- #15 Surface mobility / multi-site capability
- #15 Sample extraction and storage

Note that #15, #4, #12 implicitly describe a small surface science probe which is a valuable yet relatively affordable asset in many mission scenarios.

Category 3:

This summarizes technologies which can be considered low priority for the European NEO effort, for one of the following reasons:

- Already being developed in the context of other activities anyway #17 Ion propulsion/ shepherding beam
- Currently judged to be low priority activities in Europe (# 18 Blast deflection payload)

Recommendations

The following recommendations are made with regard to technology development:

1) Define at a political and programmatic level, with scientific and engineering input, specific European reference mission(s) or mission contributions as soon as possible. Table 4-1 shows a preliminary categorization of mission scenarios according to main objectives and relative funding required. The NEOShield-2 consortium believes that a deflection demonstration mission is the critical next step in significantly moving ahead the state of preparation for a real threat scenario, i.e. a substantial increase in the deflection capability. Assuming that funding challenges for such a mission are non-trivial, the NEOTωIST concept is an attractive mission to study in depth since it promises somewhat lower cost than most other deflection demonstration missions. Alternatively or in addition, a mobile surface probe is a mission element that is an attractive contribution to surface science activities at asteroids and many other mission scenarios.

2) Revise prioritization of the associated capabilities based on selected mission(s). Absent of such definition pursue capabilities roughly in the sequence of Category 1-3

3) More specifically, it is recommended to initiate, as soon as possible, development programs to achieve TRL 6 for all Category 1 capabilities. This is recommended since it can be achieved with modest resources and is useful in most future programme scenarios.

4) It is recommended to initiate in depth system studies for at least two mission scenarios / system concepts. As discussed above NEOTωIST and a surface science probe would be attractive options.

5) It is recommended to simultaneously start development programmes for the technologies associated with these missions, with the goal of reaching TRL 6.

Note that some of the presented recommendations would need to be modified if the programmatic status of the AIDA programme changes (currently no European participation foreseen). Some of the recommendations would already be implemented in this case, i.e. to select a European mission contribution and develop the associated technologies.

Table 4-1: Most attractive reference missions depending on main interest and funding levels

Main interest / funding	€€€	€€	€
KI deflection demonstration	Classic KI Demo mission (optionally with surface science)	NEOTωIST	
Scientific characterization / prospecting	Sample return	Orbiter with small mobile surface probe	Small surface probe as mission contribution
Slow push deflection demonstration	Gravity tractor or IBS		
Slow push deflection demonstration and scientific characterization	Gravity tractor or IBS with small mobile surface probe		Small surface probe as mission contribution

Table 4-2 outlines a rough timeline into which technology development tasks and system/ mission study tasks could be organized to support a sustainable and dynamic NEO deflection demonstration mission programme.

Table 4-2: Preliminary high-level timeline for technology development and mission study activities

Preliminar technology development timeline											
				KO Programme		Mission selection	Start mission implement.				Mission launch
Activity	**Start**	**End**	**Year Qarter**	**1** 1 2 3 4	**2** 1 2 3 4	**3** 1 2 3 4	**4** 1 2 3 4	**5** 1 2 3 4	**6** 1 2 3 4	**7** 1 2 3 4	**8** 1 2 3 4
Development of Category 1 technology to TRL 6	KO (T0)	KO + 2 years									
Mission/ System Phase A/B1 study for NEOTωIST	KO (T0)	KO + 2 years									
Mission/ System Phase A/B1 study for surface probe	KO (T0)	KO + 2 years									
Development key Cat-2 technologies for NEOTωIST to TRL 5/6	KO (T0)	KO + 3 years									
Development key Cat-2 technologies for surface probe to TRL 5/6	KO (T0)	KO + 3 years									
Consolidation of selected mission concept	K0 + 2 years	KO + 3 years									
Consolidation of technologies of selected mission	K0 + 2 years	KO + 3 years									
Implementation of demonstration mission	K0 + 3 years	KO + 7 years									

Annex

D12.3b NEOTωIST Mission Scenario and System Design Concept