Asteroid 2013 PDC-E Post Exercise Report

Addendum

Response Activities

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INTRODUCTION

The aim of this report is to provide the additional information resulting from the post-exercise analysis activity described in the 2013 IAA Planetary Defence Conference White Paper. As that reference noted, participants each self-selected into groups representing different points of view and responsibility. Individuals and groups were then given an initial warning time of fifteen years and asked to prioritise their initial actions, describing both their individual and organisational roles and responsibilities along with their notification protocols.

Participants in the NEO Discovery and Follow-up, NEO Characterisation, Mitigation Techniques and Missions, Impact Effects, Consequence Management and Education, and Space Agencies (with a launch capability) were asked to prioritise their initial actions, describe both their individual and organisational roles and responsibilities and notification protocols, and provide their recommendations with regard to media liaison.

Participants assigned to the Media and Risk Communication, Single Nation Concerned, the United Nations, and the General Public syndicate groups were asked to provide their initial reactions to the warning.

The following text, distilled from individual feedback forms written by members of the aforementioned groups, may include some duplication.

1. PRIORITISATION OF INITIAL ACTIONS BY EACH GROUP

1.1 NEO DISCOVERY AND FOLLOW-UP

Given the initial warning, the NEO Discovery and Follow-Up group's actions would be to:-

1. Reduce the uncertainty of the orbit by utilising Space based tracking and/or observation in preference to ground based facilities, determine how best to communicate with the public, and consider methods for defining tracking and characterisation via space missions to the threatening object. In particular, conduct observations using the Spritzer IR spacecraft as well as Sentinel (if it becomes operational as expected in 2018) would be important.

2. Learn more about the object by obtaining the historical data from past observations, determine the reliability and the uncertainty of its orbit, obtain accurate size measurements, and propagate the orbit back in time in order to search for pre-discovery observations in archived data.
3. Provide assistance with the planning of a rendezvous mission to improve the orbital solution and obtain spectra for characterisation. The mission should be combined with deflection planning to alter the orbit of the asteroid. Observations of a disruption event should also be performed with assistance provided to the physical characterisation group, along with conducting pre-discovery searches in addition to the upgrading of radars. The observations should continue until a beacon is sent to the asteroid to determine its orbit. Orbit refinement should be conducted utilising two spacecraft, the structure of the keyhole should be defined, consideration should be given to analysing the magnitude of non-gravitational effects such as the effects from Yarkovsky and cometary component, and the Keyhole structure should be refined.
4. Effective impact probability and the impact location should be determined, as well as ensuring that follow-up observations are co-ordinated by MPC/JPL when it is possible to do so. Other actions include working to plate pre-discovery data in Schmidt images[1], co-ordinate follow-up observations (ground based optical and radar) with MPC and JPL to improve orbit and determine shape and light curve, and to determine whether or not the object is binary.
5. The search for NEOs should also be continued along with surveying the sky so that other hazardous objects are not missed. In summary high quality, astrometric observations are required early and often and an information page needs to be set up to include opportunities for observing. The importance of observations needs to be discussed along with the best time for observations, in order to improve the orbit, needs to be selected. The entire observing timeline needs to be established and observations from state-of-the-art facilities should be requested.
6. The University of Arizona (as a NASA NEOO-funded optical ground-based follow-up station, of the Spacewatch Project) will try to recover the object and update its position. Measurements of the object's position and brightness will be reported to the Minor Planet Centre (MPC) and if requested, to any other organization or person(s) requesting them.
7. As the object is a priority, extraordinary efforts will be made at the telescopes to re-observe the object repeatedly despite its small angular elongation from the sun and its faintness. It should be noted that Spacewatch has recovered NEOs as close as 46 degrees from the Sun and as faint as 24th magnitude. Time will be requested on larger telescopes than usual through various official and unofficial (informal) channels.
8. The astronomers have made standard calculations about when the geometry would permit acquisition of better information (primarily on NEO position so as to lessen the uncertainty). It was considered that there needed to be more awareness that securing telescope time (Earth-based, space-based, radar) would not be limiting and that it would be possible to obtain more, thorough use of telescopic resources.
9. Examine whether classified systems such as Keyhole, New Crystal, Lacrosse and SBIRS can be used.

[1] Many Schmitt plates have now been digitised

1.2 NEO CHARACTERISATION

1.2.1 NASA JSC

The threshold for launching two characterisation missions needs to be defined. Consensus on what level of probability will prompt the decision to launch also needs to be obtained. Engagement with ground-based and space-based assets is required in order to acquire the most detailed information on the physical characteristics on the NEO. Representatives from the Space Agencies (with launch capabilities) need to be convinced to make launch vehicles available at the earliest opportunity. The necessary payloads also need to be clearly identified for providing essential information that is required to determine the trajectory of the NEO (will it hit the keyhole or not) and the physical characteristics needed to inform the deflection techniques to be implemented.

1.2.2 OPEN UNIVERSITY, UK

The initial actions would be to adjust work schedules in order to provide time to assist with the characterisation programme. The priority would be to advise on a mission scenario for a rendezvous mission, or missions, as well as to assist in mitigation mission planning as early as possible. There should be an early flight, before the impact probability reaches one hundred per cent.

1.2.3 UCLA

1. A low noise receiver needs to be design and fabricated for the Arecibo Planetary Radar, which will almost double the sensitivity of that radar system.
2. The ordering and installation of 2-4 additional klystrons on the Arecibo Planetary Radar needs to be made in addition to upgrading the power generators, which will increase the sensitivity by an additional factor of 2-3.
3. With the increased sensitivity, Arecibo Planetary Radar observations need to be conducted of the asteroid at every Earth close approach, securing range measurements as early as possible. These range measurements will dramatically improve the trajectory predictions and the impact risk probability calculations.
4. Obtaining these radar images will also allow us to determine if the asteroid is a binary (1 in 6 probability), and will provide preliminary estimates of the size, shape, and spin period of the asteroid. As Radar observations are so essential in the impact hazard context serious consideration should be given to doing these upgrades now instead of waiting for a crisis.

1.3 MITIGATION TECHNIQUES AND MISSIONS

1. Characterisation for deflection (and science) is required in order to determine the mass, structure (internal) and the trajectory. The rendezvous mission should be combined with the capacity for deflection and the preferred option would be the kinetic energy impactor.
2. A Gravity Tractor/Observer spacecraft should be sent to the asteroid as soon as possible in order to determine if there will be an impact. One of the spacecraft should be used to observe a kinetic impact or nuclear deflection – as this will enable the determination of the post-deflection orbit – which, if necessary can be trimmed to avoid secondary keyholes.
3. It is important to verify the ephemeris, so that both the pre and post-keyhole Pork Chop Contour (PCC) plots are made, that the parameters and uncertainty on the size, shape and rotation are found.

4. A range of simulated kinetic impact and nuclear deflection missions should be examined. Launch capabilities also need to be arranged and confirmed. Information should be acquired on the number of vehicles that are ready, the number and locations of the launch sites and the turnaround time.
5. Information should be gathered about the cost, timelines, reliability of the observation and mission options, as well as the identification of possible "sponsoring organisations" such as governments or other agencies such as cost.
6. The best mitigation space mission option should be reviewed, updated, traded and identified from already studied possible alternatives that are based on the evolving, available information, including: technical; programmatic constraints (timeline), suppliers, resources, implementation status and needs; mandatory milestones and decision points; briefing of decision makers; and having an alternative (or plan B) scenario.
7. Very early missions could be largely based on the Deep Impact spacecraft. Some key components for a re-build of the ~20-year old design of the Deep Impact mission have been stowed away (e.g., RAD6000 computer from a classified program, labelled "radioactive" and put in hot sample storage at LANL, some parts from salvaged s/c qualification models, other parts pulled out of science institute museum displays, etc.). To remove a bottleneck in LV production, additional upper stage engines could be built.

In summary, high impact probability deflection space missions need to be planned and launched. They need to follow the approach generally agreed upon in the NEO community (e.g., as outlined in the National Research Council report of a few years ago), that an observer spacecraft be launched with a follow-on kinetic impactor. The need for independent redundancy has been recognized, so it seems that several independent observer/kinetic impactor missions need to be planned by the different space-faring nations.

It was noted during the exercise that those promoting the nuclear deflection method were all, or if not mostly, either people who are proponents of using nuclear devices for all deflections (instead of gravity tractors or kinetic impactors) or they are at least knowledgeable about utilising nuclear weapons. The group were originally part of the Deflection table, but immediately broke away to be a nuclear-only table. The NRC report generally limits the use of nuclear weapons to NEOs that are too big to be deflected by even a series of kinetic impactors (i.e., much bigger than the ~300 m asteroid defined for the exercise). However, the people within this group asserted that nuclear weapons could be used at any time, particularly if other approaches failed, and it was necessary to destroy incoming NEOs during the last months before they hit. Indeed, for the exercise, we were now at the stage where direct deflection and/or destruction by using nuclear weapons were options for the people within this group.

1.4 IMPACT EFFECTS

1. The energy of the impact needs to be recalculated and the uncertainties in that number also need to be identified.
2. Information needs to be requested regarding spectral properties, density and spin rate, all of which can be used to better evaluate and determine the impact effects if the object cannot be deflected and it does strike the Earth.
3. Existing graphics should be collected that are suitable for communicating issues to representative government officials (the decision makers) and the public; new graphics that are specific to this event should be sought and utilised.

4. More properties of the asteroid need to be clarified such as: spectral class, spin rate, density and whether or not binary.
5. A range of effects for possible impact areas, such as land, shallow sea, deep sea, and an airburst in sea/land should also be determined. As an example, an object with a density of between1.5 – 2.7 will have a range of KE: between 300-1400 MT.

1.5 CONSEQUENCE MANAGEMENT AND EDUCATION

1. Once the trajectory and the worst-case scenario, for potential total destruction, have been determined, it will then be possible to begin the necessary preparedness arrangements for response and recovery. The time line for this will need to be socialised in order to enable the planners to understand what can be achieved within the time available, and also allow members of the public to make their own plans and arrangements.
2. The local and national responses need also need to be determined. These include indirect consequences, damage to potential national infrastructure, and disaster recovery measures that should be taken. It is also important that the impact effects from this asteroid are understood and learned by those planning the response, along with providing an explanation that the orbit can be calculated from previous observations of the object.
3. It is important to listen to the concerns raised about asteroid 2013 PDC-E and to ensure that this information is passed up the parallel management chains of the USGS (U.S. Geological Survey) so that there can be a concerted and unified offer of assistance ready, either before NASA or the State Department calls. Additionally, NASA HQ needs to be aware of the assistance and services that USGS can provide.

Ball Aerospace and Technologies Corp.

1. Contact should be made with the US government agencies such as DOD and NASA to offer our capabilities and services. This would include providing an assessment of our current inventory of satellites under construction or easily built from our catalogue of deep space platforms.
2. The organisation would also evaluate our existing space systems for repurposing in the characterisation area, and determine how assets such as Kepler and Deep Impact can be brought into assist. Finally, we would look at factory capacity both at Ball and our suppliers for likely technologies, from technology and schedule perspectives.

1.6 SPACE AGENCIES

Those space agencies with a launch capability will be conducting a review of the work done and deciding what is required from both national and international perspectives. They will also be ensuring the complete integration of the International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG). Contacts will be made in order to provide the link to the UN Security Council. Additionally, space agencies will be making the arrangements to test and warm-up their systems, and will establish and maintain the programme offices dedicated to characterisation and deflection along with establishing and maintaining liaisons with other space agencies and the DoD. Furthermore, all existing assets (space and ground) will be surveyed relevant to the danger and to possible repurposing existing missions for planetary defense.

1.6.1 NASA

Internal Communications of Risk:
The organisation will ascertain if the International Space Station (ISS), and other NASA assets are at risk, as well as establishing and maintaining clear concise reporting on the status of the Response Team efforts to internal management.

External:
The organisation will establish and maintain liaison with international organisations and other governments, as assigned, along with other points of contact in order to build the familiar network as required.

Strategic:
The organisation will ascertain which assets and/or spacecraft are in development or about to be launched and identify those resources that might be diverted to aid in a deflection mission.

1.6.2 CNES

The organisation will be establishing the characterisation mission and requesting that all UN member states, especially the ones that are at risk, attend an information meeting at a conference organised under the UN auspices in order for them to obtain a fair and appraised understanding of the situation.

2. INDIVIDUAL AND ORGANISATIONAL ROLES AND RESPONSIBILITIES

2.1 NEO DISCOVERY AND FOLLOW UP

Senior scientists will be making recommendations, evaluating the risk, outlining options as well as co-ordinating the observations and orbit computation, designing, fabricating, integrating, testing, launching and commissioning a good infrared telescope at L-1. Informing local communities and publishing reliable information on well-known and reliable ellipses. Researchers will be analysing the follow-up imagery in order to minimise the uncertainty in impact location and probability.

Scientists will also be continuing to make observations, as well as managing the language, terminology and figures used to describe impact risk. Relationships will be established and maintained with the media and a Trust Agent will be designated from NASA. As an example, this would be Don Yeomans.

Additionally, scientists will continue to receive all observations and co-ordinating the follow-up of new NEOs, as well as archiving observations and computing orbits for all known asteroids, and updating them as new observations come in.

In summary, scientists will continue to provide ephemerides including the uncertainty, and ellipse, communicating with the public and media, and continuing to search for pre-discovery observations. Finally, the grants from the NASA/NEO Observations programme to Spacewatch are specifically to make observations of potentially hazardous asteroids that are then reported to the MPC.

2.2 NEO CHARACTERISATION

2.2.1 NASA

NASA will be providing expertise for ground-based and space based assets use and data analysis, in addition to launch vehicles and spacecraft and instrumentation as soon as a launch threshold is identified. NASA will also co-ordinate with other space agencies to provide effective spacecraft and leverage capabilities, in relation to the two spacecraft, the first JAXA/NASA led and launched and the second, ESA/Russia/China led and launched.

2.2.2 OPEN UNIVERSITY, UK

Although the Open University has no formal responsibilities as an academic institution, it has a morale responsibility is to provide expertise in an advisory capacity to ensure that the best possible decisions are made.

2.2.3 NATIONAL SCIENCE FOUNDATION

The NSF would provide access to ground-based observatory assets.

2.2.4 UCLA

UCLA will oversee the upgrade of the Arecibo Planetary Radar, plan the observations, conduct the observations, analyse the observations, and communicate the results.

2.2.5 LUNAR AND PLANETARY INSTITUTE

The Lunar and Planetary Institute (LPI) was founded by the White House and the National Academy of Sciences to provide expert advice to NASA and the nation (U.S.). In response to this scenario, the LPI will be analysing meteoritic samples of NEA to help evaluate they type of NEA and its structural integrity, as well as utilising complementary expertise in the impact of those objects with Earth to evaluate the consequences of the impact if it were to occur.

2.3 MITIGATION TECHNIQUES AND MISSIONS

Experts will be providing information on the nuclear option for mitigation, providing assistance with the other options in addition to characterisation and mitigation strategies. They will also be determining and assessing options, in relation to determining the costs and implications to transmit to decision makers and providing propulsion and propulsion expertise as needed by the mission designers, additionally providing expert engineering analysis and information as well as conducting due diligence by running all the numbers again and again.

Experts will be working in collaboration with NASA on mission planning and Livermore, et al, on nuclear devices. With regard to mitigation, experts will be involved with Space mission design, engineering, implementation for in-situ characterisation and deflection.

2.4 CONSEQUENCE MANAGEMENT AND EDCATION

The group asserted that planners will aim to provide factual, credible and timely information to the Trusted Agents, and all relevant stakeholders, whilst ensuring that the delivery of message is considered not to cause undue alarm.

2.4.1 UNITED STATES GEOLOGICAL SURVEY

Although the United States Geological Survey (USGS) has no legal responsibility in planetary defence, it has many assets that could be called upon if the US Federal government decides to get involved. It will be important to ensure other Federal agencies, especially NASA and the State Dept., are aware of what the USGS can do. Conversely, key people in

the USGS need to be made aware that they might be called upon to assist with the response to this asteroid. The head of the Hazards Mission Area would be the primary contact; however, the Director of the USGS would also need to be aware and involved.

2.4.2 BALL AEROSPACE AND TECHNOLOGIES CORP.

The organisation fulfils the needs of the US defence and space programmes with innovative space systems. Individual, senior programme managers would be responsible for managing the implementation of deep space missions for NASA. They would also help support similar efforts on the DOD/National Intelligence side of the government.

SPACE AGENCIES

The responsibilities of the space agencies are to inform and ensure understanding, to organise industry, and identify and utilise current assets, let contracts for new development and research organisations, as well as establishing panels to investigate failures.

2.5.1 NASA

NASA has the responsibility for Human Space Flight, and key individuals have the responsibility for assessing the safety of ISS by liaising with the ISS Safety Team and identifying subject matter experts on SLS, ISS, SCAN Systems and determining whether SLS is still available.

3. NOTIFICATION PROTOCOLS

Although there are no formal protocols currently in place for notifying the scientific community of an impact event of this nature, the responses below are informed on the basis of being the most likely channel for notification. A key will be full public disclosure of the facts via all forms of media.

3.1 NEO DISCOVERY AND FOLLOW UP

Notification would be provided through the NEO-O Programme and/or Minor Planet Centre. The group asserted that they would be making their recommendations to NEO-O and MPC. They would also be receiving data from the observers and be distributing precise orbit(s) to JPL for impact risk assessment and to the communications group so they know how well the orbit is determined.

The Spacewatch Project regularly monitors the web sites of the MPC and JPL, as well as email from them and from NASA HQ. We are responsible for reporting our astrometric and photometric observations to the MPC.

Universities are likely to be notified by media and/or semi-public e-mail list. They have no responsibilities for notifying any other organisations, and there are no, known, formal reporting structures within the Universities.

3.2 NEO CHARACTERISATION

3.2.1 NASA

NASA JSC would be identified through the NEO Program Office. The organisation would then notify the US President and State Department. From there the UN would be notified about the present threat. In parallel the governments of the world can then inform their emergency management organisations, defence departments and agencies, and local/state governments.

3.2.2 OPEN UNIVERSITY, UK

As the OU has no formal responsibility would expect to find out about orbit from usual sources (MPC, colleagues who calculate orbits, alert sites such as NEODys). Advice on characterisation upwards would initially go through existing national/international organisations (e.g. RAS, IAU).

3.2.3 UCLA

Radar observations are critical in any mitigation effort, and the small community of radar observers (~10) would be notified immediately by the NASA NEO program office or Minor Planet Centre. Likewise, we would relay our observations to the Minor Planet Centre and the NASA NEO program office.

3.3 MITIGATION TECHNIQUES AND MISSIONS

Notification of LLNL would occur through the DOE, if not directly from the Secretary of Energy. In Europe via the Space Agency, EU, and the media. We would also hear media reports and be notified by AF or NASA and advised what they want from us. We would have been monitoring risk tables since prior to the discovery of Asteroid PDC-E and would have been aware at the outset from online information, and would continue to work directly with NASA.

3.4 IMPACT EFFECTS

Fifteen years ago notification would probably have been from the U.S. Space Command. Today, The Lunar and Planetary Institute would likely be contacted by NASA Headquarters or others in the Administration.

3.5 CONSEQUENCE MANAGEMENT AND EDUCATION

Consequence Managers would expect to be notified by the UN Office of Co-ordination of Humanitarian Affairs. We expect the agency or organisation determining impact effects to tell us the impending consequences. We will then notify local officials. The USGS management would be notified, who would then contact NASA HQ.

3.5.1 BALL AEROSPACE AND TECHNOLOGIES CORP.

The organisation would be notified by senior officials at NASA and DOD. The organisation would notify speciality elements of our supply chain that might be needed to provide hardware for a deflection/mitigation mission.

3.5.2 NASA RESPONSE

NASA is the first organisation to be notified. Key individuals would be notified by Near-Earth Object Observation Program Executive, Lindley Johnson. The ISS management would then be notified for risk assessment. The threat to ISS would be communicated to international partners by NASA senior management.

3.5.3 SPACE AGENCIES

The space agencies will expect to be notified by the US NNSA, and in turn would be sending distilled information to disaster management organisations in each country. Realistically though notification would be made via social media, approximately 24-48 hours before NNSA is notified officially, in which case space agencies would be making contact with ither space agencies.

3.5.4 SPACE SCIENTIST

Independent space scientists would expect to be notified by personal contacts, and by accessing the SENTRY and NEODyS web pages in addition to developing ad-hoc social media networks.

4. MEDIA AND RISK COMMUNICATION

Some time was spent ascertaining group representation and it was eventually concluded that the group comprised not only of standard print/TV journalists, but also spokespeople for aerospace corporations and space agencies, reporters for specialized magazines and websites (e.g. space.com), and ordinary people using Twitter and other forms of social media. Many participants wondered about what information should be made available, who should be trusted as information sources, what to do about fanatics who put out sensationalistic or false information etcetera. It was asserted that there was inadequate awareness that a number of years had already passed with an unusually high impact probability (order of one per cent) which would have made this asteroid a significant, continuing news story throughout that time, and not as though the subject matter was suddenly new.

The first task involved obtaining accurate, credible information about the asteroid to enable the provision of 'ever green' information such as the basic facts about NEOS, keyholes, risk corridors, the number of asteroids, Earth crossing concerns etcetera. It was assumed that the subject had been background news for 6 years already (since the first detection of the asteroid in 2013). The scenario was similar to the response to the Year 2000 preparedness, in that there was a long lead time prediction with lots of uncertainty and, as a consequence, potentially a demanding management task involving experts from either side of the argument, and not a lot that an individual could do except to listen to the debate and hope that the worst case scenario did not transpire.

The focus of the group's discussion concentrated on which media and risk communication outlets need to be considered as we develop an outreach and education plan, and it was considered that the following outlets would all be utilised: CNN type news media; corporate news and info (ex Aerospace, rocket builders etc); space related reporters (ex. Space.com; Planetary Society etc); Science community (for example the news offices of universities); risk communication and PIO of Space Agencies (e.g. NASA, ESA); especially media in the risk corridor; media outlets in countries worldwide (including some that are not usually disposed to sharing information with their public); blogosphere providing space related information and other; social media and sensational media (for example, the National Enquirer and other sensationalistic news outlets).

It was also realised that consideration needed to be given to communicating from two perspectives as there are essentially two audiences and aspects of communication. The first are the groups that provide information to media (such as risk communicators and what do they need to think about in preparing information for the public?), and the second are the media groups and individuals who disseminate information to public. Therefore what information needs to be provided to them so that they can provide the accurate information to the general public? Additionally, there were two important aspects to consider in relation to developing education and information plans, firstly the accuracy of the information and what are the details that are needed and when. Secondly, what are the options for planetary defence? If there any alternative mitigation methods what are the associated risks and implications?

It would also be important to emphasise the science, technology and deflection options, and begin to see the involvement of international geopolitical decision making uncertainties and processes. The focus of attention then shifted more to mitigation methods and the decision making process about the threat, and who should be involved

A number of assumptions were made by the syndicate group, such as: NASA (and other space agencies) would be considered as the official source of scientific information for many people (including the media), that the United Nations would be likely to be involved in providing public information about how decisions will be made (although uncertainty was expressed about the effectiveness and timeliness of its communications details); NASA would continue to provide up-to-date information on its website (and via other communication channels) about all aspects of the asteroid threat as well as including the risk corridor details and evolving impact zone information.

It was ascertained that initial communications should include: Information about the asteroid (such as basic and updated information which is referred to as 'evergreen' information .and must be provided continuously in public communication in order to educate and inform people about the general, specific and imminent threat(s) involved); mission options and alternatives; government and UN plans for possible deflections; details on risk corridor and possible impact locations, in addition to an explanation as to why it's changing; evacuation information (for worst case scenarios, infrastructure failures and economic meltdown); additionally indicate that in one year more information will be made available. However it was also realised at this point, that more details need to be known about the keyhole in order to respond to the uncertainty, from both scientific and individual perspectives.

It was deemed by the group that, even at this stage, the public would want to know more about their personal consequences for the next 6 years. Additionally, each country would need to consider developing information on providing instructions for agencies, organisations, local jurisdictions and individuals; shelter versus evacuation details as well as organising the humanitarian response and how to communicate the arrangements.

The group also asserted that updated scientific, background information, about the asteroid hazard, should include: the anticipated size and impact details (including information on possible environmental effects, in addition to the number of people at risk, along with the possibility of secondary effects); how would decisions be made about the Gravity Tractor, Kinetic Impactor versus the Nuclear options for deflection and who are the geopolitical allies in responding to this threat, or is it just one country or group leading the response?

It was envisaged likely, by the group, that the 'Lead" Agency or Agencies will change over time (as more updated information on the threat is known with the passage of time).

Consideration also needs to be given to the responses and instructions that are appropriate for possible secondary effects too such as tsunamis, coastal surges, air blasts, firestorms, earthquakes, dust, interruption with essential infrastructure, the impacts on the nuclear industry and other important infrastructure within the risk corridor. Additionally there is a need to discuss the short, medium and longer-term impacts, along with the associated response and recovery.

At this stage, the group asserted that it would be likely that the scientific information will begin to decrease in influence and importance, with more emphasis being given to implementation and evacuation plans and details. NASA and the other space agencies may in some ways be deemed, by those with different perspectives, to be not as important as the emergency management community. It was further recognised that there is a strong possibility that there may be different messages and details in US versus European

communication channels. There may also be differences between the Northern and Southern Hemispheres.

It was therefore concluded that ideally discussions are needed as to whether or not there will be a rendezvous mission as opposed to a deflection mission along with an explanation provided, as it would be beneficial for people in order to understand the differences. Additionally regular updated information needs to be provided about the asteroid such as the trajectory..

Overall in 2019, people still have a long-term time frame and they will have warning and preparation time, although they may be concerned about what else may occur in the interim.

In 2023 the hazard posed by the asteroid becomes more imminent, and we now know that the point of impact will be the Mediterranean Sea and the date of impact will be November 21 2028. As a result the group reviewed the recommendations that were made in 2019 and reflected as to how they should be either updated or changed. The group recognised the shift from the scientific perspective to the geopolitical, humanitarian, evacuation, effect on infrastructure, and recovery of and rebuilding the impacted area.

The group believed that at this point in time the public would be likely to become more concerned and unnerved, and, as a consequence, would have a need for more official information. To support this provision, it was considered that the role of IAWN (Information Analysis and Warning Network) could be used for this purpose, although the transparency of the information that could be provided, for dissemination, was questioned.

Uncertainty was expressed concerning the awareness of all of the options for deflection, the nuclear option in particular, given the widespread misgivings expressed amongst the scientific community in the United States of America, even though the impact will be in the Mediterranean. Realistically there needs to be more discussion with regard to communications. It is not that the path of the asteroid is not uncertain, instead that rather the information that the group had about the path and the details were what were uncertain, however it was recognised that the information becomes more certain over time.

At the end of the 2023 phase of the exercise, it was not certain what type of communication needs to be disseminated, or how to coordinate communicating scientific information with evacuation and other advice. With five years warning of an impact event it was concluded that scientific information, as a result of the mitigation mission failures, will become secondary to emergency management communication.

4.1 MEDIA LIAISON

It would appear, from the results contained in Table 1, to indicate that consensus, from a number of individual participants in the exercise in relation to Characterisation and Mitigation seems, in the main, to have been reached in relation to it being considered that the space agencies should be taking the lead. However further analysis of the submitted responses with regard to public safety, warning, informing and advising, and education and risk communication require further debate to determine the full scope of involved parties. Perspectives varied according to not only the country of the participant but were also based on how effective local government are perceived to be in terms of responding to previous disruptive events.

4.1.1 NEO CHARACTERISATION

NASA will be the initial lead for liaising with the media, but as the threat becomes more real and firm, NASA will need to also have an advisory role with the UN, national and local

governments. This is important since there are cultural, language, and socioeconomic differences that will make communication difficult for the type of messages that need to be conveyed to the stakeholders and public on a regular and constant basis.

For NEO Discovery and Follow-up the lead organisation would initially be the Minor Planet Centre. Once the impact probability reaches one hundred per cent, or certainly close to it, we would expect a dedicated centre to be set up. Before this we would be relying on existing independent orbit calculations by JPL. Each organisation would be required to define an official spokesperson who should liaise before press releases are published, as but one example. In reality it will be impossible to control who (expert or not) will be contacted or who will talk to the media.

For NEO Characterisation and Mitigation the lead would be the Space Agencies involved in mission management.

With regard to Public Safety-Consequence Management/ Warning Informing and Advising/ Education and Risk Communication then this should be left to the existing official structures at hierarchical, international oversight, national, regional/local levels.

For characterisation then NASA would take the lead, for Mitigation it would be NASA/DOD, for Public Safety and Consequence Management the lead organisation would be FEMA, similarly in relation to Warning, Informing and Advising, then this too would be a FEMA responsibility to lead. Where Education and Risk Communication are concerned then this would be a dual responsibility for both NASA and FEMA.

4.1.2 MITIGATION TECHNIQUES AND MISSIONS

Conversely Table 2 shows that there was no consensus within the group of exercise participants, although the more international nature of this group may account for the diversity of opinion.

4.1.3 CONSEQUENCE MANAGEMENT AND EDUCATION

For NEO Discovery and Follow Up then the lead organisations should be Space Watch, JPL, NASA, ESA. With regard to Characterisation then NASA should take the lead supported by USGS and in concert with ESA and JAXA. Where Mitigation is concerned then the lead should be with USAF and the UN. Public Safety should be led by the UN, along with Warning, Informing and Advising and Education and Risk Communication.

4.1.4 BALL AEROSPACE AND TECHNOLOGIES CORP.

The organisation will follow the lead of the US government in sharing information about our work. The US government generates the messages and the organisation assists with the delivery of technical media materials and facts about our HW System.

Discovery and Follow Up – MPC, JPL
Characterisation – NASA – NEOO
Characterisation – NASA/ESA
Characterisation – NASA/ESA/ROSCOSMOS
Characterisation – MPC, JPL
Characterisation – ESA
Characterisation – JPL
Characterisation – NASA
Characterisation – Scientists
Characterisation – JPL

Mitigation – NASA, ESA, UN
Mitigation – NASA/ESA
Mitigation – ESA
Mitigation – NASA
Mitigation – Scientists and Military

Public safety/consequence management – UN
Public safety/consequence management – FEMA
Public safety/consequence management – European equivalent to FEMA
Public safety/consequence management – Government
Public safety/consequence management – UN/NASA/FEMA
Public safety/consequence management – Governments and local forces
Public safety/consequence management – Local Government

Warning, Informing and Advising – UN
Warning, Informing and Advising – FEMA/NASA/ESA or NASA NEO PROGRAM OFFICE
Warning, Informing and Advising – UN
Warning, Informing and Advising – Government/EU/ESA
Warning, Informing and Advising – JPL
Warning, Informing and Advising – media (hopefully) along with reliable help from scientists
Warning, Informing and Advising – NASA

Education and Risk Communication –NASA/ESA/FEMA
Education and Risk Communication –NASA
Education and Risk Communication – Space Agencies/Government
Education and Risk Communication – Scientists

Table 1 Perspectives on Lead Organisations for Media Liaison

Characterisation – IAWN

Characterisation – NASA

Characterisation – Ground-based: U.S. surveys (LINEAR,… Panstarrs, LSST, large telescopes) and European large telescopes (southern Europe & Chile) U.S., ESA, Japanese space mission experience

Mitigation – SMPAG

Mitigation – NASA

Mitigation - largely U.S., NASA (missions & spacecraft), USAF/USN (nuclear)

Public Safety/consequence management – IAWN[2]

[2] It is CRITICAL that this interface be handled by the FORMALLY established, authoritative, sanctioned entities – i.e. those currently being developed/defined within UN/COPUOS.

Public Safety/consequence management – FEMA
Public Safety/Consequence Management - Germany: Technisches Hilfswerk (THW), Bundeswher (Army)
Warning Informing and Advising – IAWN
Warning Informing and Advising – NASA/FEMA
Warning, Informing and Advising - Germany: I think totally TBD
Education and Risk Communication –IAWN
Education and Risk Communication –NASA/FEMA
Education and Risk Communication - Germany: I think totally TBD

Table 2 Diversity of Opinion on Lead Organisations for Media Liaison

4.1.5 NASA

For characterisation, NASA would assume the lead role, similarly this would be the case with Mitigation. However for Public Safety, Consequence Management then the lead organisation would be FEMA. The U.S. State Department would be involved in nation-to-nation communications, and NASA would communicate directly with other Space Agencies.

4.1.6 CNES

From our perspective, UNCOPUOS would lead in liaising with the media in relation to: characterisation, mitigation, public safety/consequence management, warning, informing and advising and education and risk communication.

4.1.7 SPACE AGENCIES

The space agencies would liaise with the media in relation to: characterisation, mitigation, public safety/consequence management, warning, informing and advising, education and risk communication.

4.1.8 SPACE SCIENTIST

This would become a military –led mission (many spacecraft) in which the US DoD (which spends more on space than NASA) takes the lead and takes some international assistance (e.g. Iraq and Afghanistan) and diplomatic support for its actions, but essentially acts unilaterally. Thus the U.S. (and other) governments would act as the media front but the military/ies would be doing the 'doing'.

5. SINGLE NATION CONCERNED

The nations represented in this group were namely France, Italy, Spain, the United States of America, and Africa. A decision making infrastructure was established along with arrangements for mobilising the resources for recovery, nuclear energy shutdown, environmental, declaring a state of emergency, disaster planning, and preparing a communication plan. It was also recognised that a warning needed to be devised for maritime and airspace.

It was determined that controlled evacuation measures needed to be in place with borders closed, and that it would be necessary to clear the coastlines of the Mediterranean countries, in particular France, Spain, Italy, and Africa. Provision for humanitarian assistance for the refugees from these countries also needs to be considered.

Consideration was given to the requirement to produce a strategy to garner large-scale governmental funding for the economic recovery of the region, post impact, such as that provided by The Marshall Plan[3], in order to ensure the environmental clean-up and to repair the damage to the off shore oil and gas infrastructure and the nuclear industry.

In response to the 2023 exercise phase it was realised that:

1. A committee of experts needed to be established comprising trusted representation from the scientific community (affiliated with international experts), those involved with conducting risk assessments.
2. A response committee also needs to be convened, comprising senior officials from the military, civil protection, industry, non-government organisations and ministries.
3. Decision making is also a requirement and needs to include Presidents, Prime Ministers parliament, government and press and communications senior staff.
4. A response plan for evacuation needs to be produced comprising UN, EU and SETO (Southern Europe Transport Organisation) protocols in addition to communication co-ordination.
5. Following the declaration of a state of emergency, the following plans need to be activated: Disaster Response Plan, Communication Plans (both local and international), Resource Plan and the Energy Plan.
6. In preparation, the French nuclear industry response should include shutting down and removing any of the reactors that are located within 50km from the coast. A public education strategy should include public schools, high schools and college classes.
7. The issues for consideration by each country should include the religious perspectives, evacuation areas, refugees, government exploitation, financial markets and world economies, global stability, communication versus propaganda, looting, civil unrest, civil disruption, the strength of fringe groups.
8. There needs to be a determination as to whether the response to this asteroid impact event will attain international responsibility or if each nation will have to act in its own self-interest, for example the analogy of WWII.
9. The impact effects group have advised that ideally evacuation needs to be on an elevation height of 200metres in order to create a barrier between the place of safety

3

The Marshall Plan

As the war-torn nations of Europe faced famine and economic crisis in the wake of World War II, the United States proposed to rebuild the continent in the interest of political stability and a healthy world economy. On June 5, 1947, in a commencement address at Harvard University, Secretary of State George C. Marshall first called for American assistance in restoring the economic infrastructure of Europe. Western Europe responded favourably, and the Truman administration proposed legislation. The resulting Economic Cooperation Act of 1948 restored European agricultural and industrial productivity. Credited with preventing famine and political chaos, the plan later earned General Marshall a Nobel Peace Prize. http://www.archives.gov/exhibits/featured_documents/marshall_plan/print_friendly.html?page=index_content.html&title=Marshall_Plan date accessed January 12 2014

and the possible wave heights created by a tsunami when the asteroid strikes the Mediterranean Sea.

6. UNITED NATIONS

In response to the 2019 exercise phase the UN will encourage the space agencies to determine the risks to their space based assets. In response to an event of this nature occurring, the UN Security Council has the authority to mobilise resources. The UN will be looking for the assurances that the deflection methods for mitigation will be effective. It was realised that consideration was also required should the deflection mission(s) fail to remove the object from Earth's orbit and alter the trajectory so that the impact site is moved. Requests may be made to the UN to approve MAOG (Mission Authorisation and Oversight Group) to authorise potential deflection missions. Consideration needs to be given to other legal challenges as a result of the southern hemisphere nations' protest against possible deflection. Additionally, were one nation in the Security Council to veto, then there needs to be a contingency plan in place to handle such a veto

In response to the 2022 exercise phase the UN will recommend the shutdown and securing of the nuclear plants, along with recognising that France may need assistance with the decommissioning of the nuclear power plants, and help with regard to evacuation. The role of the EU, in response to this impact event, will need to be ascertained. Additionally the role of the UN also needs to be determined and explained. However, the UN will be able to render assistance to the EU in relation to evacuation planning. The UN will be seeking clarification of the arrangements for declaring a State of Emergency, and invoking Emergency Powers in France and in the UK. The UN will give consideration to invoking Article 5 in order to secure significant evacuation assistance from the NATO allies to the affected countries along the risk corridor. Additionally there needs to be a specific committee convened for the affected nations.

The UN recognises that the proposed Characterisation missions, as proposed, will require and be dependent upon international collaboration. The UN will co-ordinate the evacuation, however the EU member states will need to be responsible for the safeguarding of power, water and electricity systems. The UN will be able to provide pre-emergency funds for locally organised evacuation. The secretariat for the UN International Strategy for Disaster Reduction (UNISDR) will be alerted in order to engage all the international platforms for all disaster response communities worldwide.

In response to the 2023 exercise phase with the impact area being identified in the Mediterranean Sea in 2028, the UN will adopt an information policy for the general public in becoming a trusted agent for information. Those nations affected will need to apply to the Security Council in order to convene an executive committee in order to be able to plan for an impact. Additionally, the Security Council will need a clear statement of the consequences of the nuclear deflection. Fractioning may be acceptable.

Strategic/Tactical Option	Analysis	Recommendation
Characterisation mission	Benefit: orbit uncertainty Preparation for mitigation mission and targeting beacon	YES
Issue: Single nation interests,	Could be legal impediments for mitigation mission	NO

mitigation blocking		
Issue: Nuclear: Involvement of the military, national context		
Issue: mission failed Nuclear reactors Economic impact Evacuation plans		
Issue: Public trust and public assurance		
Single nation: international money		

7. GENERAL PUBLIC

This group had representation from all over the world, namely Washington State, Los Angeles, Colorado, Ohio, Arizona, Washington DC, UK, (including Northern Ireland), Italy and China.

On being made aware of the impact event the Initial actions and priorities included obtaining information, ascertaining what is happening, or going to happen, where the impact location will be and when the impact event will occur and what can individuals do to prepare?

Firstly the group asserted that they would turn to their 'trusted agents', which will be different people for each person, depending upon where they live. Additionally people will want to know about evacuation plans and the asteroid details. Ideally notification would be provided by someone whom people have come to trust and respect which of course will be different for each country. This person needs to be someone who everybody knows. It would also be very useful to create a specific website which is always updated, and there is absolute need for co-ordination between countries and co-ordination for information.

Following on from the trusted agents, people will then go to the news sources they are familiar with and rely on, which again will be different for each person. People need clear and consistent information across all information providers, and they also need to know what they can do to prepare. Furthermore, for those living within the risk corridor, they want to know more about the deflection options.

In the United States the people and organisations that are the most trusted are the president, Strategic Command (DoD), Don Yeomans (NASA JPL), Arlington and local government, space scientists and the UN Ambassador. In China, the national government is trusted and in Europe the Queen of England, President of Italy and space scientists.

In the United States information is obtained from Facebook, local libraries, town halls, the Natural History Museum – Department of Astronomy (via e-mail or dedicated website), Washington Post, Al Jazeera web site, JPL NEO website, Aerospace Corp. El Segundo, CNN, and Neil de Grasse Tyson[4]. In China information is obtained from the space science

[4] Neil deGrasse Tyson is an American astrophysicist, cosmologist, author, and science communicator.

website and foreign web sites. In Europe information sources include family members, the UK Space Agency, BBC News, Republica News website (Italy) and the JPL NEO website.

Members of the public would like information to be provided on the keyhole, clear and concise scientific information, such as the location of the impact site and details of the deflection missions. They indicated a preference for qualitative data to be expressed in terms of ratio rather than in percentages; that scenario practice is being conducted by the DoD; that advice should be provided on personal preparation in response to this impact event, an indication as to how much damage this event would cause, the effects from a possible tsunami and how people living within the risk corridor can be protected. In conclusion, the public would like to be provided with emergency planning information from their local government, be able to obtain NEO information from JPL and would like to know what the UN is doing for people in the risk corridor and eventual impact zone.

In response to the 2019 exercise phase it was considered that having a visual representation of the asteroid and its trajectory would be useful to help people to understand, along with an explanation on what a keyhole is. It would also be really useful if the UN could create a website on the asteroid and the response activities for planetary defence and civil protection. It was interesting to note that during the group discussion no one mentioned the use of the telephone or by word of mouth. Additionally focus group research on how to communicate with the public would be a really useful to obtain.

In response to the 2022 phase of the exercise the asteroid has not passed through the keyhole, as the three deflection missions have failed, the public would want to be provided with consistent information, and are asking if there is an International NEO Centre for information.

Ideally, when the media are explaining the environmental and economic effects from the impact event, this should be done without using jargon. On being informed that there would be global environment/economic impacts members of the group became fearful and began to lose confidence in their trusted agent which could, in turn, make people more susceptible to non-logical decision making influences.

In June 2023 the public were made aware that an impact event from this asteroid was to be expected. There would be global economic and environmental effects. During the response to this exercise phase it would be more helpful if the information being given to the public contained less jargon. As a result of the five –year warning period in addition to the failure of the deflection methods as well as the proposed nuclear deflection mission, the general public have become fearful. There is ubiquitous rumour and conjecture, where people have lost faith in science and technology. This had led to a deleterious effect on mental health and paved the way for unmanageable Religious cults to emerge.

As a result of this situation more detailed information is required to be provided on the actual weather effects, the impact on the environment and the economy, and how to purchase a nuclear bunker, or if there are plans for sheltering in place. Additionally some people would want to have more information on the role of the military and the DoD. Will post keyhole deflection missions be designed and launched, and if the nuclear method is chosen, information needs to be provided on the effects from the nuclear blast?

Some members of the population would look to relocate from Europe to the United States of America, others would expect advice to be provided as to how they should best prepare. Additionally some would expect assistance from other countries and would expect

contingency arrangements to be put in place. Some asserted that the UN already has an existing framework in place for responding to events such as the one posed by this asteroid, and that there is a set of procedures with committees activated to be in charge of each location. Conversely there are others who would like to assist their local government, and would want to travel to the UK and France in order to help distribute information.

Furthermore it was asserted that consideration of Geopolitical opportunities (similar history as CERN - European Organization for Nuclear Research,) be awarded, in addition to establishing and maintaining diplomatic relations, with other countries in order to assist with the humanitarian response.

APPENDIX A-- OPTIONS ANALYSIS & RECOMMENDATIONS

A.1 NEO DISCOVERY AND FOLLOW UP—

Strategic/Tactical Option	Analysis	Recommendation (Yes/No)
Upgrade radar facilities to get very precise orbit	If radar can tell impact/no impact – invaluable by 2021	Upgrade Radar
Continue surveying on other NEOs	Don't want to miss a new danger	Normal operations
Optical astrometric not useful	No additional refinement – no help	No ground based follow-up 2013 PDC-E
Need parallel deflection/spacecraft mission planning	When orbit uncertainty is 100/0%, need deflection mission ready to go.	Start mission planning for characterisation and deflection
Communication?	Provide summaries/charts	Familiarise communication
Impact 100% -where is it going to hit? Launch of deflection mission failed Risk is UK/France 2013 PDC-E will hit – evacuate?	Need evacuation plan	
Radar upgrade will define risk corridor	Know where to evacuate	
Know date/time	EVACUATE	Choose agency to organise
RADAR 2023 – get all the information	Convey hit swath to pinpoint impact	
Is there less loss of life or damage to ecosphere if 300m asteroid is disrupted	Damage assessment necessary	
Hit-France Mission to disrupt asteroid?	Plan a mission to break asteroid into pieces	
Need tracking telescopes again	Track pieces of asteroid	New orbits need optical and radar
Parallel mission to try deflection again		
Communication important	Discovery/follow-up Discuss methodology	
Nuclear disruption for stand-off	Imaging of fragments LIDAR/RADAR	
Use the upgraded radar	Orbit shape	
More observations Keep surveying for other object optical isn't going to help		
Spacecraft	2021	

Strategic/Tactical Option	Analysis	Recommendation (Yes/No)
Communication MPC		
Communication to public not our role		
Mission to disrupt the asteroid - Following the process		
Communication expert to talk to public (– Trusted Agent)		
Geological suprises – impacted by other object	Small chance, check for meteor showers	Continuous optical monitoring
Cometary activity	Small chance	Continuous optical monitoring
Upgraded radar	Improves impact calculation	Yes
Continue routine surveys and follow-up	Survey needed for other threats	Yes
Transponder and deflection mission preparation	Need missions ready already at 20% probability	Yes
Provide information and graphs/orbits to communication group	Communication facilitation	Yes
2019 Put up NEOCAM[5] to track	Determine impact point or close approach Have NEOCAM	Yes Launch at least 1 NEOCAM
Track after passing keyhole	Determine impact point or close approach Have NEOCAM	
Prepare public affairs package for NASA	Update as needed as information becomes available	Keep information flowing
Insert transponder on asteroid	Update as needed as information becomes available	Make contact
Transparency keeps public and decision makers informed of impact location		
Dedicate time on a big telescope in Hawaii and in Chile to acquire and track ASAP	NOW (2013)	Yes
Build and commission on orbit an IR system at L-1 to	2016/17	Yes

[5] We assumed activities would take place, such as NEOCAM was observing, radars were upgraded and could be used, a transponder was attached to the asteroid, etc. but we need feedback if assumptions were correct.

Strategic/Tactical Option	Analysis	Recommendation (Yes/No)
track the orbit and settle on composition[6]	2018	
Put a radio transponder on the object to determine the orbit before keyhole[7]		Yes
Track after keyhole[8]	2023	Yes

Notes

Manage message early and later, designate public expert

Currently 28% probability 2019, keyhole Nov 2023

300m – IR measurements obtained

Most important – space based measurement to improve orbit

Simultaneous mission to improve orbit AND deflect

Who co-ordinates requests for follow-up observations?

- MPL or JPL?
    - MPC and Sentry are recognised
    - JPL is probably central organised

Light curves very important to determine rotation state

How to rendezvous to improve orbit?

- Orbiting transponder vs. land

Object is mostly visible, sun not an issue in 2019

Sentinel scheduled to launch in 2018

100% 2022 risk corridor UK-Tunisia

Albedo	=	0.2 (20%)
Size	=	300m
Impact speed	~=	12km/s
H	=	20
Chance of impact	=	8%

[6] Arecibo as able
[7] Arecibo as able
[8] Arecibo as able

A.2 NEO CHARACTERISATION

Group Response

All ground based data are available –

- We have shape, model, rotation, pole, albedo, diameter

Need fast reconnaissance mission to:

- Get mass
- Characterise surface, especially in case pre-keyhole attempt fails and nuclear device is necessary
- Refine shape model for navigation
- Observe deflection attempt.

2 spacecraft built by two teams (international)
2 launch vehicles – orbiter

Instrumentation:

- Wide field images (binary search)
- Narrow field images (surface characterisation)
- LIDAR/Radio science package
-

Re use designs from existing SC such as Rosetta, OSIRIS-Rex

Designed for normal radiation environment and (whatever could do without jeopardising schedule and fuel for ~10 years of operation

Launched in 2020
Arrive by 2021

In the meantime procure new noise receiver for Arecibo, higher transmitter power

- In place by 2019

Characterisation Data:

Density	2.0 g/cm^3
Porosity	30%
Rotation Period	4 hrs, principal axis rotation
Composition:	S type chrondite
Refined size:	300m equivalent diameter
Shape:	Triaxial ellipsoid 2:1.5:1

No consensus on more complex spacecraft than gravity tractor

- We observed Kinetic Impactor failures.
- When nuclear devices arrive, move off 1000km, one directly behind the asteroid
- Observing after disruption, tracking all fragments, focus on the ones still on impact trajectories

A.3 MITIGATION Techniques and Missions

Before 2022:

Strategic/Tactical Option	Analysis	Recommendation (Yes/No)
1) If object passes keyhole – nuclear necessary		
2) After key hole the ΔV large possible fragmentation	Low yield – more uncertain 30-40% debris 60-70% single object	High Yield MT Small fragments
3) If impact mission attempted should include ranging ability		
4) Rendezvous mission highly required		
Radar capability just before the keyhole • Goldstone etc • Or// LIDAR/ laser detection capability measured from the ground? • Rapid response system		
K.E. impactor just before the keyhole with redundancy in the mission design.		
Pre-keyhole KI	Yes please	Y
Pre-keyhole nuclear device	Politically unfeasible	N

After 2022

Strategic/Tactical Option	Analysis	Recommendation (Yes/No)
Impactor mission with rendezvous		Mission should carry ranging package in case mission fails prepare for nuclear deflection/detonation
Object passes through keyhole		Nuclear only option
ΔV large fragmentation likely	Low yield more uncertain 30-40% debris	High yield small fragments

Strategic/Tactical Option	Analysis	Recommendation (Yes/No)
	60-70% body	
Should be >1yr before impact		
Nuclear blast after the keyhole • Many launchers from international partners.		
Post-keyhole KI	Not enough ΔV	N
Post-keyhole nuclear device	If others fail	Y[9]

NUCLEAR OPTIONS

Strategic/Tactical Option	Analysis	Recommendation (Yes/No)
Single standoff	Sufficient ΔV and dispersion No redundancy	N
Two-vehicle standoff	As above, but more effective	Y
Near contact burst (1~5 m)	More effective than standoff, narrower window	Y[10]
Surface contact burst	More than enough efficacy More difficult	N
Surface explosion	100% effective Hardest to actually accomplish	N

OVERALL

Strategic/Tactical Option	Analysis	Recommendation (Yes/No)
1. Pre-keyhole kinetic impact	Best bet both technically and politically	
2. Post-keyhole two-vehicle nuclear standoff	Success = complete mitigation	

Notes

The target area can certainly reject a nuclear mission, but it would likely fly before the impact was limited to targets – i.e. more countries involved.

Strategic/Tactical Option	Analysis	Recommendation (Yes/No)
Staged, redundant mitigation		

[9] Only if needed
[10] Only if needed

Strategic/Tactical Option	Analysis	Recommendation (Yes/No)
plan with options prior, at, post keyhole planning		
Plan A 1) Prior: Improve characterisation with moderate investment (Radar upgrade), observation in situ (beacon, remote scanning)		• Surveillance mission, ~500M€ each nice to have but not mandatory • Impactor mission and back-up (US, Japan) ~300M€
Prepare kinetic impactor mission (2016-2021) with back-up from Europe, Japan and China	Conservative sizing to avoid disintegration with margin	
Plan B 2) 22 Nov 2023 at keyhole planning (+/- minites to hours) Prepare interceptor mission using existing equipment (2020-2023) 22.11.2023 Key hole Ø1.2km Income ~10km/s C missiles launched; one needed for ΔV Incoming missile > 6 ton kinetic impactor or overkill nuclear device Stand-off explosion in front or behind for nuclear device option	Launch ballistic interceptor mission to B-plane interaction (accurately known at that time)	ΔV (along trajectory) required ~cm/sec – nuclear device required, danger of disintegration – UN 'overkill' power to deliberately disintegrate[11]
• 2 launches from Russia (Proton) • 2 launches from Europe (Ariane) • 2 launches from US (Atlas/Delta)	3 fold redundancy; only one should do. Risk of failure very low	Short preparation time, decision milestone, from technology (launch platform, GNC (US-Military), nuclear device – system ratification needed

[11] High lift capability to 50,000km > 6 tons may allow still kinetic impactor (TBC)

Strategic/Tactical Option	Analysis	Recommendation (Yes/No)
Plan C 3) In case previous attempts disintegrate asteroid, a post-keyhole mission is needed to deal with increased risk of over 50mØ		~ 1B€
New characterisation after 2021 or 2023 attempts	Start preparation ~2021 (after plan A failed); impact in 2025 time frame Nuclear device option or impactor possible Use equipment as in Plan A except for transfer module (transfer ΔV difficult)	
Plan D 4) Last stand: Nuclear device option at day of impact		Unlimited by government

GROUP SCRIBE

Strategic/Tactical Option	Analysis	Recommendation (Yes/No)
Q: political leaders ask can you … build, fly, deflect before 2023	long-lead items available for 3..5 Deep Impact rebuilds (with restrictions & updates due to old parts) – reduces protracted software development launch cadence no serious limit due to Earth-like orbit (pork chop plot)	Yes
Q: recommend start work on mission before collision certain	lead time to build spacecraft, even based on flown design, about two years *internal proposal*: • one fast flyby as early as possible • one GT observer (possibly one light, one heavy s/c	yes (have to)

Strategic/Tactical Option	Analysis	Recommendation (Yes/No)
	dragging upper stage) also for 2nd ary KH avoidance incl. after 2023 flyby • at least 3, recommended ***five*** KI launches (against launcher & s/c systemic errors) – also 1 each for 5..6 available LVs Atlas V, Delta IVH, Falcon 9H, H-IIA, Proton-Briz M & Chang Zheng (Long March – might do their own) Kinetic impactor only works before keyholes!!	
Q: rendezvous followed by impacting s/c	*internal proposal*: see above	yes
inject (Debbie) :	**OUR *FIVE* DEFLECTION LAUNCHES *ALL* FAILED**	
Recommendation: nuclear deflection ASAP	1st: standoff nuke, posigrade delta-V, deflection, not disruption (to move to NW on risk corridor) 2nd: stand by nuke disruption. As late as 2024? 3rd to 5th: spares, to fly into disruption cloud – boulder spectrum 10…120 m	
recommendation: jump into first possible launch opportunity after KH passage	just continue building, building, building – no matter what: • Launcher not such a big issue, many GEO/GTO launches a year • s/c lead time: electronics >10 year old no longer exists	

Strategic/Tactical Option	Analysis	Recommendation (Yes/No)
	for copy-buliding • Optics: take >1 year to build (just build) • Build first s/c based on existing design (DI) updated where parts are lacking ~3 years kick-off to launch pad → first launch late 2018 at the earliest	
inject (David Kring – real Tsunamis rolling in for the Cannes Festival director's choice award…) :	**OUR *FIVE* DEFLECTION LAUNCHES *ALL* FAILED** ***AGAIN !!*** *…well, the nukes worked, sort of, up to the limited test ban treaty limit of 150ktTNT after which all the devices used were developed… which you could well expect after an estimated total of 2084 tests conducted from 1945 to 2013 including North Korea's which however declined to participate in saving the planet since the demand of German luxury cars inside the country could not be satisfied in time…* *…in the same time, only around 100 interplanetary (including lunar) missions were attempted, half of which failed.*	
recommendation: fly!	»Any failure that occurred in space ... we did first. We failed in a marvelous bunch of different ways.« - a participant of the CORONA programme; ca.146 flights, mostly	

Strategic/Tactical Option	Analysis	Recommendation (Yes/No)
	successful, but 1st success only after 13 tries. »A successful launch is useless because nothing can be learned from it.« - Nikolai Pilyugin, late 1940s (Korolyov's man for guidance systems, in the era of V-2 derived rockets)	

A.4 IMPACT EFFECTS

Strategic/Tactical Option	Analysis	Recommendation
Land impact at 10° - 1400 M Ton	1.15km diameter crater wl44m in depth 6.2 Richter scale 10.5m/s winds 4.le KPa 0.6 PSI	
Land impact at 50° - 1400 M Ton	5.3km diameter 489 metre depth 6.7 Richter scale 22.7 m/s winds 10KPa 1.42 PSI	
Water impact at 10° Water depth 500m	Water crater 2.93km Sea floor multiple craters wl 3llem diameter le 7 m depth largest fragments	Tsunami 25 min 3-le m amplitude wave
Water impact at 50° Depth 500m	Water crater 6.9km Sea floor: 3.72 km diameter 432m depth No fragments	Tsunami 24 min 16.8m amplitude wave -33.lem

Strategic/Tactical Option	Analysis		Recommendation
Inject #2	2.9 density Not a binary 4 hr 30% porosity	Worst case 330m 2.0g/cm^3	
Land Tunisia 10^o	Causes airblast! Projectile fragments @ 3.4km (11,200ft) altitude Residual fragments 2.3 km/s Airburst – 670 MTon Wind velocity at 50km radius 53 m/s (118m/hr) 2.5 minutes after impact 3.5 PSI over pressure		
Land England 45^o Yield – 700 MTon	Impact energy: 600 MT Crater 3.93km diameter 443m in depth @50km: Mean frag diameter 15cm Ejecta 1.7min 19.8 KPa (2.8 PSI) Max wind 43 m/s 96 mil/hr		
Water Mediterranean 30^o ~ 1500m depth Coast of South of France	@le00km 466 MT at impact site Fragments hit in ellipse Crater 4.4km Final crater 121m on floor, 24m depth Seismic 2.9 Richter Tsunami -<2.3 meters		
* Land 2 x 150m pieces			
* Water 100 km from coast	Impact 524 MTon energy 4.7km open water crater		Tsunami arrives 15.7 min after impact

Strategic/Tactical Option	Analysis	Recommendation
35° impact angle 1500 depth	Final crater 183 diameter, 39m depth	-42m-1 lem amplitude (10-37m in other code)

A.5 CONSEQUENCE MANAGEMENT AND EDUCATION

Strategic/Tactical Option	Analysis	Recommendation
Compile consistent information	Potential for destruction – path and extent	
Share with all stakeholders both national and local	Determine stakeholders and trusted agents	
Plan to plan years ahead	Worse response to be anticipated and make public ready and reassured	
Detailed plans only after impact location is better known	Be certain to notify and plan with infrastructure agencies for response and recovery	
Detailed plans includes evacuation	Share honest information and keep the public updated as regularly as possible.	
Design a framework for consequence management and education	Needs to be applied uniquely to each community.	

A.6 Ball Aerospace and Technologies Corp.

Strategic/Tactical Option	Analysis	Recommendation
3-4 individual government response (US USA Russia China) OR 1 co-ordinated global response.	Co-ordinated response unlikely to be practical. 3-4 individual actions with close co-ordination through the UN is the best option.	Leverage existing capabilities of each space faring group and try to synchronise/co-ordinate effort.
What existing communications channels between space agencies can be used?	International Space Station provides a good working model of interagency	Important to utilise known and mature communication channels between world's space agencies
How would the UN react to a rogue nation that chooses not to co-operate in a global	Can't force governments or countries to negotiate compromises vs. dictating	Any way to build trust and co-operation ahead of a dangerous event will enhance

response?		odds of co-operation but it is not guaranteed.

NOTES

- Chaotic process/situation/consensus is unlikely

1. Time critical decision making is key
2. Agency to agency communications are in place to leverage – like ISS
3. Hard part is decision-making process, it is distributed globally.
4. There is political effort and technical effort. Top level governments is where this comes together.
5. Agencies and governments will adapt and change and react to situation.
6. UN role will be to work with governments for best possible outcome. Can't force other governments to do what 'we' want.
7. Military, civil and social elements come together at top levels of government. In US at Office of Science and Technology Policy (OSTP) level.
8. Practical aspects:
    a. World-wide inventory of s/c both in space and on the ground that can be used.
    b. Leverage unique capabilities and cultures of space faring nations.

A.7 SPACE AGENCIES

Strategic/Tactical Option	Analysis	Recommendation
DEFLECT	DO IT SOON	World-wide co-ordination
DISRUPT	TRY AND TEST SOON	World-wide co-operation and co-ordination responsibilities for real mission
Test and characterisation	No LT first	World-wide co-operation and co-ordination responsibilities for real mission.
UK Device	Trusted safety	

APPENDIX B--COMPLETED TIMED INJECTS

Inject Ref: 2

Exercise Date:	September 19th 2019	**Real time:**	0845 19th April 2013
Exercise Group:		**Impact Effects**	

Inject:

What are the current gaps in current research and what recommendations would you make, and which resources would you need to identify in order to make improvements to better understand the atmospheric effects from airburst tsunamis in relation to the following research activities:-

If the object remains intact and the impact site is in the sea or the ocean?

If an airburst were to occur in the sea or ocean?

If an airburst were to occur over the sea just off the coast?

1	**Summary discussion**

To refine estimates of impact effects we need:

1. Refine spectral class, density and spin rate.
2. Refine impact angle

At the moment, the uncertainties on impact energy is very large.

Likewise the uncertainty in impact angle and strength makes airburst vs. cratering (size of cratering) uncertain.

When will the risk corridor be reduced?

2	**Decision**

Request: Ground-based or space-based determination of spectral class, density and spin rate.

Request: refinement of impact angle or an estimate of when that information will be available ((2021-20222?) or do we have to wait until 2023?).

Request information on shape?

3	**Implications**

Space agencies are a focus for activity – helps public perception and comfort.

Inject Ref: 11

Exercise Date:	September 19th 2019	**Real time:**	0845 19th April 2013
Exercise Group:		**Space Agencies**	
Inject:			
1. Who would lead in liaising with the media? 2. How would each agency input to media statements?			
1	**Summary discussion**		
A high level group within Government (US: White House; UK Civil Contingencies Unit of the Cabinet Office, Russia: Dept/Ministry of Emergency Management). By agreed routes where 'Agency' experts support the high level group dealing with disasters.			
2	**Decision**		
The high level disaster management group in each country. The relevant national agency will have developed an agreement on the provision of information.			
3	**Implications**		
Develop an exemplar that demonstrates the ideal route to pass briefing material up and ensure it allows feedback.			

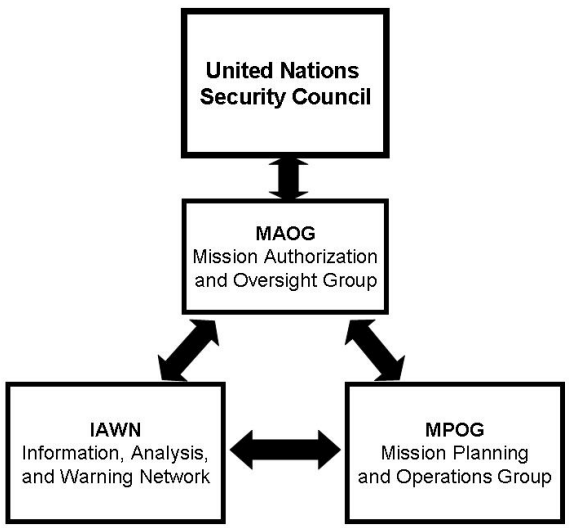
Inject Ref: 12

Exercise Date:	September 19th 2019	**Real time:**	0845 19th April 2013
Exercise Group:		**Space Agency**	
Inject:			
1. What are your recommendations in relation to overcoming the current, identified shortfalls in current inter-agency and multi-agency collaboration and cooperation? 2. How do you envisage international agencies will be able to engage and exchange best practice; how interaction with professionals in the emergency management sector can best be facilitated and how information and advice can be shared.			
1	**Summary discussion**		
1. Use the developed exemplar 2. Via exercises			
2	**Decision**		
IWAN – International Agencies and MPOG in conjunction with the Oversight group for Mission Authorisation.			
3	**Implications**		
Need to encourage the greatest acceptance of the UN agreed processes.			

Inject Ref: 13

Exercise Date:	September 19th 2019	**Real time:**	0845 19th April 2013
Exercise Group:		**Space Agency**	
Inject:			
Please provide your recommendations for the development of the strategies required in order to explain the nature and seriousness of the threat to non-space organisations and agencies, the type of information that would be available to them and the approved and authorised options that are available.			
1	**Summary discussion**		
Base on UN (Action Team 14) agreed procedures. Utilise the PDC and other media involved meetings and exercises to inform the process.			
2	**Decision**		
Base on UN (Action Team 14) agreed procedures. Utilise the PDC and other media involved meetings and exercises to inform the process.			
3	**Implications**		
Need for media briefing.			

Inject Ref: 14

Exercise Date:	September 19th 2019	**Real time:**	0845 19th April 2013
Exercise Group:		**Space Agency**	
Inject:			
What are the inter-agency command, control, communication and co-ordination arrangements and how can these be enhanced to include government and international participation in the response?			
1	**Summary discussion**		
Via UN agreed process:  12 But organisations need an agreed mandate and will require technical and making inputs and interaction.			
2	**Decision**		
3	**Implications**		

[12] MPOG is now SMPAG Space Mission Planning and Advisory Group

Inject Ref: 17

Exercise Time:	September 19th 2019	**Real time:**	0845 19th April 2013
Exercise Group:		**General Public**	
Inject:			

Please make your recommendations as to how you would prefer to be warned, informed and advised of a NEO impact hazard.

What information would you consider that you would need in order to enable you to make a decision as to how you are able to protect yourself and your family/friends?

What are your expectations, if any, from the following:-

1. Politicians
2. Space Agencies
3. Emergency Management organisations
4. Local Authorities
5. The media

1	**Summary discussion**

What does 28% chance mean? Keep it simple. Maybe use a catch phrase.
Decide who we trust locally.
1.
Access to UN/UN Ambassador
Arizona – President of USA
Washington State – US Strategic Command (DoD)
Ohio – President
China – national government
UK – Queen of England or Royal Family – Prime Minister has lunch with the Queen twice weekly
Washington DC- Don Yeomans, Arlington local government for emergency planning
Northern Ireland – Space scientists (husband)
Los Angeles – Space scientist (husband)
Colorado-UN Ambassador and Don Yeomans

2	**Response**