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Consequences, Including Failure, of NEO Mitigation Space Missions

R. Albrecht, Ed.
Contributors: TBS in appendix

Note: during the editing process each chapter contains, at the end, in italics, the requirements identified for the respective area at the Vienna Topical Workshop in Feb 2019 and during the PDC in Apr 2019

1.0 Introduction

1.1 Task 5.8 in the context of SMPAG

TBD (Gerhard? Stephan?)

1.2 Scope and goals of the report

A space mitigation mission designed to protect the Earth from a major asteroid impact, will have significant consequences. These range from the need to establish international cooperation during the preparation phase, to obtaining the necessary funding and resources, to emergency measures in case of the failure of the mission. Even successful missions will have consequences, as the threat to our species will influence the socio-economic environment and the relationship among nations.

The scope of the report is to give an overview of all possible consequences in all possible areas, in order to serve as the basis for planning. The different areas are covered to different levels of depth, depending on available expertise. It is expected that the report will mature as discussions evolve and more relevant expertise is being brought into the planning process.

Note that section 2 of this report provides a comprehensive overview. Details are being elaborated in later sections. A certain degree of repetition is unavoidable.

1.3 Background

Even though asteroid impacts occur all the time, the effects are usually benign. The bodies are so small that they burn up in the atmosphere. Very few reach the surface and even fewer cause significant damage. However, we know that there are larger bodies crossing the orbit of the Earth around the Sun. While the probability of a collision with such a body is, fortunately, exceedingly small, the consequences of such a collision are potentially global. The result is that the probability of getting killed by an asteroid strike is orders of magnitude higher than winning the lottery. It also means that the damage caused by such a strike will be huge. Investing in a mitigation mission is thus a prudent measure in terms of cost-benefit.

It goes without saying that the preparation and implementation of a NEO space mitigation mission requires considerable public funding. This, in turn, requires awareness of the problem by the general public, and investigation of the problem by science. To attach the required importance it would be useful to address the issue of NEOs in the next decadal report.

For practical reasons a decision has been made to consider objects of more than 50 meters in diameter as candidates for a mitigation mission.

Any mitigation space mission will have consequences and ramifications. As the need for such a mission becomes obvious a number of decisions will have to be made, most likely on an international level and possibly on a rather short time scale. As the experience with international agreements show this process will not be without problems. Anticipating this, the United Nations, through the Committee for the Peaceful Uses of Outer Space have established the International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG), with the task of establishing international collaboration. There are also other branches of the Un which, while not asteroid-related, can be utilized: The comprehensive Test Ban Treaty Organisation (CTBTO) with it's network of infrasound detectors, is capable of detecting asteroid impacts, and the UN Space Based Information System for Disaster and Emergency Relief (UN-SPIDER) provides a global emergency response mechanism.

In addition, many countries have stated to prepare on the national level.

Examples of consequences which might occur as soon as the possibility of an impact and a probable impact corridor are established are: removal of critical economic resources from the impact corridor; removal of nuclear fuel from nuclear power plants; removal of objects of cultural heritage.

A significant unknown is the reaction of the general public during the different stages of the mitigation process. Will all world leaders agree? How to control the distribution of information such that general awareness can be maintained and mass panic be averted? Will the media cooperate?

There is the problem of possible false warnings. In this context it is less than helpful that the media are reporting, on a monthly basis, that the planet is being threatened by this or that asteroid. Crying wolf is counterproductive.

A potentially serious issue is the use of nuclear devices for asteroid mitigation. Not only is the usefulness not clear, there is also considerable apprehension towards nuclear explosives by large fractions of the global public. In addition, there are issues of producing, storing, and launching nuclear devices, plus the problem of how to dispose of it in case the device is launched, but not used.

The probability of radioactive contamination as a consequence of using a nuclear device is rather small, as is the probability of a significant electromagnetic pulse (EMP). There is, however, the danger of a nuclear installation suffering impact damage, leading to a Chernobyl or Fukushima type situation.

Depending on the severity of the impact there will be consequences for the economy.

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

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

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

A serious problem arises when a mitigation mission, which at first is deemed successful, turn out to be insufficient, such that the evacuation of a large area will have to be ordered on rather short notice.

- Discuss cost of mitigation actions against cost of possible damage with the int'l community 1.x
- Assume object size larger than 50 meters 1.x
- How will people react during the different stages? 1.x, 2.x
- even though impact probability might be low, the number of casualties can be high
- Find out existing UN mechanisms 1.x
- will embargoes work? 1.x, 2.x
- ESA has information plan 1.x, 3.x
- Is there a NASA report on possible impact effects in the US? 1.x, 6.x
- A report on impact effects will be/is being done by the Berlin Museum of Natural History for ESA 1.x
- Consider time to impact 1.x
- consider time scales 1.x, 2.x, 3.x

- consider “false warning” 1.x, 2.x,
- The introduction should have a review of possibilities   1.x
- Describe the differences between other natural disasters (hurricanes) and asteroid impacts   1.x, 2.x
- where to keep? (nuclear?)   1.x, 2.x, 3.x
- EMPs from nuclear options negligible 1.x
- impacts can cause EMPs   1.x, 6.x
- substantiate the need for an international response 1.x, 2.x, 3.x
- use careful language: suggest, recommend, advise 1.x, 2.x
- Resources 1.x, 2.x, 3.x
- Priorities: include in next decadal survey   1.x
- Disruption of financial system   1.x, 2.x, 6.x
- Rapid mission development   1.x, 2.x, 5.x, 7.x
- Incomplete mitigation   1.x, 5.x
- CTBTO   1.x, 7.x
- Cooperation with emergency services 1.x, 2.x, 7.x

2.0 Mitigation Scenario

2.1 Threat Overview

Given the current efforts to discover NEOs, we can assume that large PHOs will be detected and tracked with months if not years of lead time. For smaller bodies this situation might be very different, as the experience from, for example, the Chelyabinsk event shows.

It is generally agreed that a mitigation space mission will be initiated if the asteroid is at least 50 meters in diameter. Even though airbursts caused by smaller objects also are known to cause destruction, the cost-benefit calculations in such cases argue against expensive mitigation missions.

Several impact scenarios have been played out in exercises conducted during various Planetary Defense Conferences: https://cneos.jpl.nasa.gov/pd/cs/

Large Body, long lead time: While a large body represents a high level of danger, the long lead time would allow the careful planning of a mitigation mission, including a pathfinder mission to determine the characteristics and the composition of the object

Small body, long lead time: In many ways this is the most benign scenario

Small body, short lead time: To mount a mitigation mission might be challenging, but while the consequences might be quite severe they would not be cataclysmic

Large body, short lead time: This is the most challenging scenario. It will require a predefined, well prepared mission, with mitigation assets ready to go. It might require the nuclear option as a last-ditch effort to at least reduce the effects of the collision.

2.2 Mitigation Overview

Evacuation: while evacuation is not necessarily connected to a space mission, it will have to be considered in case the space mission fails, produces incomplete results, or as a contingency measure. Evacuation includes issues of transportation, food and shelter, safety and security, resources, as well as the special needs of several groups: handicapped, elderly, and gravely ill persons

Slow approach missions: missions which are designed to arrive at the target and remain on station for the purpose of monitoring the object, of installing hardware on the object, or to remain in the vicinity and inflict gravitational pull.

Fast approach missions: missions which are designed to impart kinetic momentum on the object in order to deflect it.

Any actual mitigation campaign will most likely involve a combination of the above mission scenarios. The nuclear option could utilize either a slow or a fast approach option.

2.3 International response

The United Nations, through COPUOS, IAWN and SMPAG. Have established an asteroid monitoring and alert system. In case the mitigation criteria are met (impact probability 1, object size larger than 50 Meters), IAWN will issue a level 3 alert. At this point SMPAG will propose appropriate mitigation measures, including an assessment of the cost-effectiveness, and the risks, of the various options

In order to implement these measures high level decision will have to be made to ensure funding, coordination and cooperation.

2.4 Communication aspects

Communication at the various levels will have to be tightly controlled in order to avoid rumors, speculation, and possibly counterproductive reactions of population groups. While communication among governments will probably be controllable, the transmission of information through the mass media is not predictable. News embargoes might not work.

2.5 Undefined issues

Threats can materialize on very different time scales. It is not clear to what extent the existing international and organizational structures can cope.

What to do in case a warning turns out to be false, but significant and costly decisions have been taken, some of them irreversible?

What to do with a nuclear payload, launched as a mitigation measure of the last resort, but ultimately not required?

It is not clear how the public will react to an imminent serious threat. Reactions can vary from the determination to solve the problem to a disregard of all social rules and conventions.

More TBS

- *Threat assessment 2.x*
- *The role of the UN 2.x*
- *Decision making 2.x*
- *Consider communication aspects 2.x*
- *It is important to monitor the deflection 2.x*
- *Assume impact probability = 1, IAWN has issued a level 3 alert 2.x*
- *How will people react during the different stages? 1.x, 2.x*
- *Consider different levels of communication: public, media, government-to-government 2.x, 3.x*
- *will embargoes work? 1.x, 2.x*
- *important: transparency, danger of speculation/rumors 2.x, 3,x*
- *How to communicate the nuclear option? 2.x,3.x*
- *What to do with the spacecraft in case it turns out the mission would not have been necessary 2.x, 5.x*
- *What to do with a nuclear payload in such a case? 2.x, 5.x*
- *consider cost-effectiveness of different possible missions 2.x, 3.x*
- *Identify organisational interfaces 2.x, 5.x*
- *consider time scales 1.x, 2.x, 3.x*
- *consider "false warning" 1.x, 2.x,*
- *consider standoff explosion/nuclear 2.x, 5.x*
- *Assess asteroid fragmentation 2.x, 5.x*
- *Describe the differences between other natural disasters (hurricanes) and asteroid impacts 1.x, 2.x*
- *Redundancy. Should different agencies /different countries work independently? 2.x, 4.x*
- *Payload to be designed ahead of time 2.x, 3.x, 5.x*
- *Needs to be updated to reflect evolving technology 2.x, 3.x, 5.x*
- *where to keep? (nuclear?) 1.x, 2.x, 3.x*
- *substantiate the need for an international response 1.x, 2.x, 3.x*
- *use careful language: suggest, recommend, advise 1.x, 2.x*
- *Resources 1.x, 2.x, 3.x*
- *Problems predicting impact location 2.x, 6.x*
- *Rapid mission development 1.x, 2.x, 5.x, 7.x*
- *Communication: consider the effect of incomplete mitigation on other countries2.x*

- Cooperation with emergency services 1.x, 2.x, 7.x
- Evacuation problems: traffic, lodging, food 2.x, 3.x, 7.x
- Evacuation problems: elderly, handicapped, hospitals 2.x, 3.x, 7.x
- Effects on the Internet 2.x, 6.x, 7.x

3.0 Pre-Launch Consequences

- Coordination and interfaces
- Redundancy
-

- Discuss impact corridor vs. impact location 3.x
- option to do nothing has to be retained, even after launch 3.x
- Consider different levels of communication: public, media, government-to-government 2.x, 3.x
- important: transparency, danger of speculation/rumors 2.x, 3,x
- ESA has information plan 1.x, 3.x
- How to communicate the nuclear option? 2.x,3.x
- consider cost-effectiveness of different possible missions 2.x, 3.x
- consider time scales 1.x, 2.x, 3.x
- Reference DLR technology roadmap 3.x
- consider impactor vs nuclear 3.x, 5.x
- Payload to be designed ahead of time 2.x, 3.x, 5.x
- Needs to be updated to reflect evolving technology 2.x, 3.x, 5.x
- where to keep? (nuclear?) 1.x, 2.x, 3.x
- substantiate the need for an international response 1.x, 2.x, 3.x
- Resources 1.x, 2.x, 3.x
- Evacuation problems: traffic, lodging, food 2.x, 3.x, 7.x
- Evacuation problems: elderly, handicapped, hospitals 2.x, 3.x, 7.x
- Health and medical services 3.x, 6.x, 7.x
- Disruption of financial system 1.x, 2.x, 6.x

4.0 Consequences of a Successful Mission

- International Cooperation
- Re-imbursment of cost
-

- positive effects: science, int'l collaboration, funding, UN 4.0
- Redundancy. Should different agencies /different countries work independently? 2.x, 4.x

5.0 Failure Scenarios

Preparation phase

- Inadequate political situational awareness

A significant mitigation campaign will require global collaboration. At a minimum there will have to be agreement on the legality of such a mission, but also on policy and possibly on funding. Not all world leaders and governments might be sufficiently aware of the problem.

- Inadequate societal situational awareness

A significant mitigation campaign will require the support of global society. Not all people/s might be in agreement, depending on their level of education and on their religious background.

- Inadequate international collaboration

The required international collaboration has been started by the United Nations in the form of IAWN and SMPAG. However, in the case of a substantial threat a group with a more powerful mandate will be required. Such a group will have to include political and economic decision makers. It might be difficult to establish this level of coordination on short notice. Steps to establish such an ad-hoc group should be taken.

- Inadequate detection capabilities

The prerequisite to threat awareness is the capability to detect threatening objects. While significant progress has been made in this area, we still cannot be absolutely certain that we will be able to detect PHOs on a time scale which would allow the implementation of a mitigation mission.

- Inadequate monitoring capabilities

Once an object is detected it will have to be monitored in order to determine the probability of impact. This will, at a minimum, require a network of moderately large ground based telescopes. To get around the problem of solar proximity space assets will be required, at a minimum in L1, but possibly in L4 and/or L5

- Inadequate threat assessment

Due to observational limitation it might not be possible to adequately assess the level of threat associated with a particular object. An underestimate is an obvious problem. but an overestimate is equally dangerous as it might lead to complacency. In this context it is not helpful that the world media are reporting dangerous objects on a monthly basis.

Planning Phase

- Policy problems

Policy decisions are required with respect to the legal basis of a mitigation campaign: adherence to the global space legal framework, or the use of certain technologies, e.g. nuclear devices.

- Interface problems between agencies

A global mitigation effort will require the collaboration of a number of space agencies. While bilateral and trilateral agreements have been implemented in the past, they also show that setting up such collaborations is far from easy. As the number of organizations grows and as time pressure increases it will become more difficult to define and implement the required interfaces.

- Competition between agencies

While some agencies will be comfortable with a well defined support role, this might not be the case for other agencies. They might be reluctant to relinquish control over their assets and their activities to another decision maker: national security, intellectual property, technology transfer, dual use assets, etc.

- Hierarchy of agencies

The implementation of a complex project on a tight schedule requires a well defined organizational structure. At a minimum there will have to be a lead agency. The definition, well ahead of time, of an interagency coordination group, equipped with an appropriate agreed upon mandate should be considered.

- Funding levels/funding cycles

It goes without saying that a significant level of funding is required for a major mitigation campaign. As the funding will have to be available on relatively short notice this will necessitate the allocation of funds outside of the regular funding cycles of the participating agencies.

Design Phase

- Funding

The design phase will require a significant increase of personpower, either through re-allocation of staff from other projects or through new hires. Funding, including sizable contingencies, will have to be made available on short notice.

. Resource limitations

Even if other projects are stopped and preference is being given to the mitigation campaign there might be shortages of vital assets for technology development and testing.

- Inadequate requirements analysis

SMPAG is tasked with the requirements definition on the highest level. For a particular campaign these level 1 requirements will have to be refined into more detailed requirements in terms of spacecraft capabilities, size, mass, velocity, power consumption, etc., of a mitigation payload.

- Competing economic interests

Any major project, such as a global mitigation campaign, has significant economic aspects, both in terms of opportunities and in terms of obligations. Different countries and/or companies might have different preferences as to the allocation of contracts.

- Schedule problems

It is a sad fact that many space projects suffer from schedule problems. In the case of a mitigation campaign this is unacceptable. The only solution to this problem is sufficient funding and sufficient assets, to be made available on short notice.

- Procurement problems

The regular procurement procedures of most agencies are not suitable for a global mitigation mission. If a company challenges the award of a sizable contract to a competing company in court this usually introduces an immediate schedule slip of several months, which in turn will impact subsystem developments which might be on the critical path. Emergency contract award procedures will have to be developed.

Implementation Phase

- Funding

During the implementation phase there will have to be a significant increase in the level of funding. This funding is required on rather short notice.

- Interface problems

Schedule pressure and the increase in the number of the participating agencies and contractors will require very strict interface definitions. Possible problems range from the simple, like ambiguous conventions for time and date, and mixups between metric and imperial units, to the complex, like the definition of frequencies and bandwidths, and the specifications for technical components.

- Management problems

Depending on the degree of urgency the standard project management procedures might be too time consuming. On the other hand, it is important to properly control the project in order to achieve the desired results. To resolve this catch-22 situation it might be prudent to check into the project control procedures used by some of the private space flight initiatives.

- Resource limitations

As it will be necessary to prepare more than one launch vehicle and payload for roughly the same launch date the resources required (labs, clean rooms, launch facilities, etc.) might get overbooked.

- Technology development problems

Some of the mitigation payloads might require the fast track development of new technology. Experience shows that quite often there are problems associated with such development programs.

- Testing limitations

Testing is a crucial step in project development. Thorough testing requires time and resources, both of which might not be available. Tradeoffs will have to be made, which opens up risk areas.

Execution Phase

- Launch failure/s

This is the failure, which is most visible to the public, but quite often it is the consequence of a failure which occurred earlier in the project development cycle. At the same time a launch failure has the capacity to endanger the population around the launch site, in particular if the launch involves a payload which includes hazardous material.

- Trajectory failure

Performance problems of the booster stages or problems with the navigation systems might lead to vehicles being inserted into improper trajectories.

- Communication failure

To allow the proper monitoring of the vehicles in flight and to retain the possibility to upload commands, including go/nogo decisions, robust communication is required. This might fail for a multitude of reasons with the in-flight systems or the ground support equipment.

List possible failures and probabilities 5.x
- What to do with the spacecraft in case it turns out the mission would not have been necessary 2.x, 5.x
- What to do with a nuclear payload in such a case? 2.x, 5.x
- Identify organisational interfaces 2.x, 5.x
- consider standoff explosion/nuclear 2.x, 5.x
- consider impactor vs nuclear 3.x, 5.x
- Assess asteroid fragmentation 2.x, 5.x
- Payload to be designed ahead of time 2.x, 3.x, 5.x
- Needs to be updated to reflect evolving technology 2.x, 3.x, 5.x
- Rapid mission development 1.x, 2.x, 5.x, 7.x
- Incomplete mitigation 1.x, 5.x

6.0 Consequences of a Failed Mission

From the US FEMA Catastrophic Evacuation Plan:

A catastrophic incident is defined as "Any natural or manmade incident, including terrorism, that results in extraordinary levels of mass casualties, damage, or disruption severely affecting the population, infrastructure, environment, economy, national morale, and/or government functions. A catastrophic event could result in sustained national impacts over a prolonged period of time; almost immediately exceeds resources normally available to State, local, tribal, and private-sector authorities in the impacted area; and significantly interrupts governmental operations and emergency services to such an extent that national security could be threatened. All catastrophic events are Incidents of National Significance"

6.1 Post-impact scenarios

6.1.1 Minor impact at a well determined location

Given sufficient lead time an impact at a well determined location can be mitigated by using procedures which are similar to those used to evacuate large population groups in case of a hurricane. Even though the impact location might be devastated the infrastructure in the surrounding areas will still be functioning. The different national emergency systems will be able to cope with such an event quite efficiently.

6.1.2 Minor impact at unknown/surprising location

The situation is different if the exact impact location cannot be determined with sufficient accuracy to allow a meaningful evacuation. The threat might also materialize so fast that evacuation is not any more possible. The loss of life will be larger, but the national emergency services will be able to cope with the situation.

An example of such an event is the Chelyabinsk air burst. In fact, it is probably a good thing that the asteroid impacted without warning: any attempt to evacuate the city of Chelyabinsk on short notice will have led to mass panic and probably to significant lawlessness, as people were frantically trying to save themselves. This would have caused more casualties, including fatalities, than were produces by the surprising event.

6.1.3 Multiple minor impacts

Depending on the internal structure of the object there might be multiple impacts of smaller bodies, either because the object breaks up due to differential gravitational forces (e.g. SL-9), or because the attempt to deflect the body resulted in a breakup. So far, there is very limited geological evidence for this - almost all craters (above a certain diameter) are single craters caused by single objects.

6.2 Major impact on land

TBS

6.3 Major impact in the ocean

TBS

6.4 Consequences

6.4.1 Socio-economic effects

The impacts of a small body will have effects similar to the effects of other natural disasters, like earthquakes, tsunamis, or the eruption of a volcano. From experience we know that such events can be absorbed by the socio-economic system on a timescale of months or years. However, earthquakes, volcanic eruptions, etc, happen only in certain areas on Earth. An impact can happen anywhere. At this point, we have no experience with eruptions of supervolcanos during human history (e.g., what happens if Yellowstone really blows..); this might be comparable tot he impact of a large asteroid and will cause long-term disruption of (for example) agriculture in large parts of the planet.

The predicted impact of a large body, in particular an impact which was caused by the failure of a mitigation mission, will have major effects on the socio-economic fabric of society.

6.4.2 Mass panic and fear

As soon as the estimate of an impact corridor becomes known, some part of the population will want to leave to affected area. In the case of a large impact corridor this might not be possible for the majority of the population. As we can infer from current migration problems there might be resistance from the population in the areas where people want to flee to.

6.4.3 Emergency evacuation

Hurricane evacuations in the southern US are examples of mass evacuation. There are, however, differences: hurricane evacuations have been done numerous times. The Evacuation routes are well marked. Concrete structures and underground shelters can withstand a hurricane, but nor an asteroid impact. The emergency services, which normally provide assistance and restore order might not be available.

It is important that all agencies which will have to be involved in emergency evacuations be given the possibility to gain experience through appropriate exercises.

An additional problem is the possible need to coordinate between different countries.

6.4.4 Sheltering and provisioning

Measures will have to be taken to provide shelters for the population which evacuated a probable impact area. Sustenance will be required.

An important aspect is the prevailing weather in the affected area. Loss of power and thus of heating presents and additional medical hazard.

6.4.5 Economic upset

As people try to leave the predicted impact corridor the economic activity in the affected are will come to a standstill.

At the same time there might be uncontrollable economic developments for goods which are in high demand in an emergency (black market). This includes food, water, fuel, means of transport and objects of intrinsic value.

6.4.6 Power outage

Our society depends heavily on the availability of electrical power. Financial transactions, even cash-based, require electronic support. Cash will be in short supply without ATMs.

Food will start to decay without refrigeration within three days. Deep freeze goods survive one week. Water supplies depend on electrical pumps. Sewage disposal will cease, leading to outbreaks of disease.

The power grids in the US and in Europe, as well as the power lines in other industrialized countries, are extremely vulnerable. An unplanned event in a power grid has to potential to produce cascading failures of large portions of the grid, or, in fact, of the whole network.

Power used to be generated where it was being needed: large cities typically had large power plants. The need to distribute local surplus and meet needs in other locations caused the large area power grid to be developed. Additional drivers were the need to locate nuclear power plants away from population centers, and the need to establish power plants were energy was available (hydro-electric power plants). Increasingly, we harvest energy far away from the end users (off-shore wind parks, desert-based solar power plants), which requires very long high capacity power lines, either under ground, or, more often, above ground. All this makes the power grid extremely vulnerable. Outage of a portion of the grid will have serious consequences for the entire area covered by the grid.

A benign example is the recent lowering of the grid frequency throughout the European power grid. Because of a political conflict between Serbia and the Kosovo the generation of power in the area fell below minimums. The discrepancy was taken from the grid, which could only cope by lowering the net frequency. There were no major power interruptions, but all net-frequency based clocks, all over Europe, slowed down. They were up to six minutes slow
In the past power plants were situated close to the end users (e.g. large cities). With the tendency towards the production of renewable energy (offshore wind parks; photovoltaic power plants in rural or in desert regions), the availability of electricity depends on long high-voltage trunk power lines. Interruption of these lines will lead to area-wide blackouts (Greilich, 2018).

All this is mostly referring to the western world; but third-wold countries, which make up most of our planet, have different problems.

6.4.7 Fuel shortage

Private industry will discontinue the transport and the distribution of fuel into areas which might be affected by an impact. All fuel required to sustain the infrastructure will have to be organized by the authorities, most likely the military.

6.4.8 Effects on the banking system

The values of properties in and near the impact corridor will decrease dramatically. This will trigger the default of a large number of mortgages with consequences for the banking system. Depending on the size of the affected area the results will be similar to the subprime crisis of 2007-2011

Of course this will mostly be the case if an impact occurs in a western country; if it happens in, say, Congo, the banks will be mostly unaffected, but there would be many more casualties.

6.4.9 Effects on national currencies

While the intrinsic value of large currencies, like the US Dollar and the Euro will probably only suffer major effects by the impact of a large asteroid or the threat thereof, the effects on the currency of smaller countries in or near the impact corridor might be significant.

6.4.10 CBRN hazards

Nuclear power plants are being operated by many countries. A failed mitigation mission is the kind of threat that these facilities were not designed for. This could lead to Fukushima-type events. This also extends to industry dealing with hazardous chemical and biological material.

6.4.11 Physiological hazards

Physiological hazards will be produces by primary and secondary effects. The impact itself will cause a large number of casualties right away. The resulting damage to the economic and social infrastructure will increase the number.

6.4.12 Natural hazards

In densely populated areas the environment is being controlled by sophisticated structures. Large parts of the Netherlands, for instance, are below sea level. In case of damage to the dams there will be widespread flooding.

6.4.13 Social hazards

The breakdown of the social fabric of a country has the potential to cause civil unrest. As is well known from hurricane evacuations in the US, looting and burglaries start as soon as law enforcement personnel is not available any longer.

- Other consequences
-

- Mass panic 6.0
- Is there a NASA report on possible impact effects in the US? 1.x, 6.x
- Radiation hazard from nuclear power plants 6.x
- asteroid itself might be radioactive because of (solar)irradiation 6.x
- impacts can cause EMPs 1.x, 6.x
- Problems predicting impact location 2.x, 6.x
- Disruption of financial system 1.x, 2.x, 6.x
- Effects on transportation infrastructure 6.x
- Effects on agriculture 6.0
- Water impact 6.x
- Health and medical services 3.x, 6.x, 7.x
- Effects on the Internet 2.x, 6.x, 7.x

7.0 Strategic Planning

- Organisational preparations
- Technical preparations
-

- *Redundancy. Should different agencies /different countries work independently? 2.x, 4.x*
- *Rapid mission development 1.x, 2.x, 5.x, 7.x*
- *Recon mission(s) 7.x*
- *Combination recon plus nuclear 7.x*
- *Redundancy 7.x*
- *Begin work on kinetic impactor 7.x*
- *CTBTO 1.x, 7.x*
- *Cooperation with emergency services 1.x, 2.x, 7.x*
- *Evacuation problems: traffic, lodging, food 2.x, 3.x, 7.x*
- *Evacuation problems: elderly, handicapped, hospitals 2.x, 3.x, 7.x*
- *Health and medical services 3.x, 6.x, 7.x*
- *Effects on the Internet 2.x, 6.x, 7.x*

Appendix

A. Glossary

AO	Area of Operations
ASF	Austrian Space Forum
COPUOS	Committee for the Peaceful Uses of Outer Space
CTBTO	Comprehensive Test Ban Treaty Organization
CBRN	Chemical Biological Radiological Nuclear
DSN	Deep Space Network
EMP	Electromagnetic Pulse
EMS	Emergency Medical Services
ESA	European Space Agency
ESO	European Southern Observatory
FEMA	(US) Federal Emergency Management Agency
FFG	Forschungsförderungsgesellschaft/Ausrian Space Agency
IAEA	International Atomic Energy Agency
IAWN	International Asteroid Warning Network
NASA	(US) National Aeronautics and Space Administration
NEO	Near Earth Object
NHM	Naturhistorisches Musuem (Natural History) Vienna
OST	Outer Space Treaty
PDC	Planetary Defense Conference
PHO	Potentially Hazardous Object
SMPAG	Space Mission Planning Advisory Group
TBD	To be determined
TBS	To be supplied
TDRSS	Tracking and Data Relay Satellite System
UN	United Nations

B. Contributors

TBS

C. Case studies

TBS

D. Differences between asteroid impacts and other natural disasters

In case a failed mitigation mission leads to one or more impacts the result will be similar, but not identical, to other natural disasters. It is thus useful to draw the comparison.

These comparisons are limited to the impact of bodies up to 100 meters in diameter. Bodies larger than 100 meters will cause global effects for which no comparison exists.

In fact, the result will be even more similar to a military large scale bomb attack, or the detonation of a nuclear device. However, this will not be considered in this report, as the circumstances of a wartime scenario are different, and because there is no recent experience with such events.

Kinds of disasters

Natural disasters with effects most similar to an asteroid impact are earthquakes, tsunamis, and tropical storms (hurricanes, typhoons, etc.). There is serious destruction in a limited area, but at some distance from ground zero the infrastructure, social and economical, is largely intact.

Other natural disasters like climate (hot or cold), floods, drought, and misharvest, happen on different time scales. These might be considered when dealing with the long-term consequences of impacts.

Predictability

Earthquakes and tsunamis are very difficult to predict, except that they are more likely to occur in certain regions of the Earth, or, in the case of hurricanes, at a certain time of the year. Impacts of small asteroids (of the Chelyabinsk type) are also difficult to predict, especially if the asteroid encounter happens after the object swings around he sun.

For larger objects, which present a serious hazard, we are confident that we will be able to observe them well ahead of time. Ideally, the lead time should be in the order of years.

Location

Asteroid impacts can happen anywhere. As the majority of the asteroids populate the plane of the ecliptic, and an impact on the equator, with the movement of the object, of the Earth, and of the Earth`s rotation combining to produce a vertical relative trajectory is unlikely, we have to expect the object to hit at an angle, quite often producing a grazing impact. Experience shows that such impacts cause explosions in the atmosphere as the objects, or parts thereof, are vaporized by the frictional heat.

In case the object had been observed for a considerable period of time it will be possible to calculate an impact location. Given the unavoidable uncertainties of the measurements and of the influence of the atmosphere during the time immediately prior to impact, the predicted location will be an ellipse, known as the impact corridor.

Mitigation

As most other natural disasters occur preferentially at certain locations and/or at certain times it is possible to prepare: stockpile food and fuel, prepare shelters. This type of preparedness is impossible for asteroid impacts. Measures should be taken to make sure that such preparations can be ocrrued out on short notice should an asteroid hazard be identified.

Another potentially crucial issue is the evacuation of large population groups from a predicted impact corridor. “Asteroid evacuation routes” in analogy to “Hurricane evacuation routes” are not possible. Such routes would have to be identified on short notice. In addition, depending on the severity of the impact, the ground zero area might become totally uninhabitable, such that large numbers of people will have to be permanently relocated.

Transportation is another critical area. In the case of most regular natural disasters we know how to re-establish the transportation infrastructure. In the case of an asteroid impact this might be different: depending on where exactly the impact hits, the electrified rail lines, so common in Europe, might become totally inoperable as the power grid goes down.

Survivability

While we do have considerable experience in handling natural disasters as they occur almost every year in one way or another, we have absolutely no experience in handling an asteroid impact scenario. This is true for society as a whole, but also for the political, administrative and economic leadership.

We know that earthquakes, tsunamis and hurricanes are survivable. In the case of a predicted asteroid impact we do not know this, so we have to assume that everybody in the impact corridor will want to evacuate. So even though the post-impact effects might be more benign than the aftereffects of a major hurricane, the problems associated with the evacuation of the impact corridor might be significantly worse.

Short term effects

The short term effects of any natural disaster, asteroid impact or other, are very similar, at least in the case of a minor impact. For a major impact we have to assume that large areas of a certain region will become uninhabitable. This will have effects in terms of infrastructure and food production.

Long term effects/Recovery

Except in the case of a cataclysmic impact it should be possible to recover from an asteroid strike over a number of years. In fact, the need to re-build a significant part of the global infrastructure might give rise to an economic boom as could be observed during the post-war periods in countries like Germany, Japan, Korea and Vietnam.

E. Detailed technical issues for future task items

TBS

F. Reference Material and Web links

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