



Human Resilience to Giant Asteroid Impact

Clément Weinreich, Mathis Brunat, Mélissa Bruzat, Corentin Lucas,
Jean-Marc Salotti

► To cite this version:

Clément Weinreich, Mathis Brunat, Mélissa Bruzat, Corentin Lucas, Jean-Marc Salotti. Human Resilience to Giant Asteroid Impact. 72nd International Astronautical Congress (IAC) 2021, Oct 2021, Dubaï, United Arab Emirates. hal-03365973

HAL Id: hal-03365973

<https://hal.science/hal-03365973>

Submitted on 6 Oct 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

IAC-21-E5.4x63136

Human Resilience to Giant Asteroid Impact

Clément Weinreich, Mathis Brunat, Mélissa Bruzat, Corentin Lucas and Jean-Marc Salotti^{a,b,*}

^a Ecole Nationale Supérieure de Cognitique, Bordeaux INP, 109 Av. Roul 33400 Talence, France

^b Inria, IMS laboratory, UMR CNRS 5218, Bordeaux University, jean-marc.salotti@ensc.fr

* Corresponding Author

Abstract

Consequences of a gigantic asteroid impact with the Earth and survival issues are examined and discussed. Three survival scenarios have been analysed, based on the state of the art of the physical involved phenomena, human needs and the capacities and limits of the available technologies. The possible causes of humanity extinction may come from the direct consequences of the impact, linked to the size or the different characteristics of the asteroid. They can also come from the indirect consequences of the impact, such as the struggle for resources, generalized anarchy, or the mental distress of survivors, who no longer find the desire to fight for survival in very difficult conditions. Various parameters have been considered, including the diameter of the asteroid and the location of the impact. Only two scenarios are presented here in detail. In both, the warning time is about ten years before impact, as it could be expected for a long period comet.

Keywords: giant steroid impact, giant comet impact, humanity extinction

1. Introduction

Numerous authors examined the consequences of asteroid impacts [1,4,5,12]. It is well known that if the energy of the impact is high enough, numerous plant and animal species may be in danger of extinction, humanity included. However, as humans may build shelters and use dedicated technologies to survive in harsh environments, the exact cause of humanity extinction is not clear. It is proposed here to review the consequences of a gigantic asteroid or comet impact and then to discuss two case studies to better understand survival issues. In the first case, survival is possible, and in the second, humanity disappears.

2. Direct impact effects

2.1 Energy transfer at impact

When the object touches the ocean or the ground, part of its energy is converted into a shock wave, tsunami or seismic waves [1]. But most of the energy is released both in the form of thermal energy, which heats the impactor and the impact zone, and in the form of kinetic energy transferred to the ejecta.

When the object hits the ocean or the ground, series of shock waves are generated and propagate through the object and the impact zone. The pressure of these shock waves is sufficient to toss some pieces of the object back into space.

According to Shultz, the heat is sufficient to vaporize and / or melt 1 to 10 times the mass of the impactor (depending on the impactor velocity, typically between 15 and 50 km / s) [10].

If a meteorite falls into the ocean, then objects with a diameter of more than 1/12 of the depth of the ocean

will crater the ocean floor. In addition, water will be sent into the atmosphere and to space.

2.2 Shock wave

The most important local effect occurs when the object enters in the atmosphere, creating a powerful shock wave. Shock waves are devastating and may cause great damages thousand kilometres away from the impact zone. However, as their effect decreases with the distance to the impact zone, they do not represent a threat to populations located very far and cannot be the primary cause of humanity extinction.

2.3 Ejecta

When the impactor is very big, the size and number of ejected rocks are very important [1,12]. With very large objects, heavy rocks can be sent above the atmosphere and fall back onto the Earth almost everywhere, even at the antipodal zone of the impact location [6]. As they would be heated up during atmospheric re-entry, they would cause forest fires all over the world, killing almost all terrestrial plants and participating to a global increase of temperatures.

2.4 Global heat and winter impact

A global increase of temperatures is expected after the impact. The intensity and duration of this period depends on numerous parameters (size and structure of asteroid, velocity, impact location, etc.). Even if humanity survives this period, there would be a prolonged period of cold weather due to the dust and clouds that would block the sunlight [7,8,11].

3. Scenario 1

3.1 Scenario definition

This scenario is proposed to assess the survival of human species in a very hostile environment, mainly at the climatic level. An asteroid 50 km in diameter would crash into East Asia. It would be of type C and would consist of porous rocks with a density of 1.3. The asteroid would collide with Earth at a speed of 20 km / s and an angle of 45 degrees. The kinetic energy would be $4.07 \times 10^9 \text{MT}$. The crater created by the impact would have a diameter of 360 km, and a depth of 1.74 km [1].

3.2 Preparation before impact

During the 10 years of preparation, different behaviours would be observed. Part of the population would live in denial; they would not accept the idea that an asteroid is about to collide with Earth. In general, however, many shelters would be built and lots of consumables and tools would be accumulated into them. Even though the shelters would have been tested, there would remain some uncertainty about the resistance of these at the time of the impact. In this study, we do not consider the possibility of leaving the Earth and going to space.

One week before the impact, the organization and evacuation of some populations to shelters would begin. Some states would have failed to contain their population and would suffer a civil war or would have been reorganized into several communities. The most likely organization within the shelters is a pyramidal hierarchy. Opinion differences among populations could indeed cause the loss of control of the shelter and a military regime could be appropriate.

3.3 Day of impact

Just after the impact, a devastating shock wave would cross half the globe. This would cause significant damages, but it would not pose a threat on a global scale. At the time of impact, lots of ejecta would be sent back into space and then would re-enter the atmosphere. This ejecta would be heated to incandescence (+ 500 ° C). They are called the “shooting stars” by Toon et al. [12]. In addition, 0.1% of the ejecta would be pulverized (30% of the mass of the impactor). It would be sub-micrometer in size, be taken in the rise of the plume and then diffused globally around the globe, following ballistic trajectories. The soot and ash generated by such fires would envelop the Earth in less than an hour [12]. The light level would then drop quickly to too low a level for photosynthesis and human vision. People still living on the surface without protection would not survive a long time even if located at the opposite side of the Earth because of the shooting stars and fires. Because of the very random phenomenon of the fallout of shooting stars and the size of these, some shelters

would be strongly impacted and their population collapsed.

3.4 First week

The first week of survival is essential. Indeed, the survivors would be aware of the consequences of the impact, which can lead to significant trauma. The uncertainty of the situation and the lack of control will also accentuate the stress of survivors. Some of them could be plunged into confusion and could no longer make sound judgments and make appropriate decisions. Depression would also affect survivors. Discouragement and the impression that nothing makes sense could cause a physical and mental exhaustion of survivors.

This first week of survival is therefore an essential phase. Even if all the infrastructures put in place to allow the survival of the population have been tested, the risk of malfunction is not zero, which can cause stress on managers or technicians of the shelter. In addition, this week will allow the viability of the political organization of shelters to be tested. Some shelters will face unexpected behaviour from the population, such as refusals to respect established rules. Depending on the type of political regime, we can imagine more or less harsh sanctions to maintain an effective organization.

This week spent in the shelter will also cause the creation of small groups. These groups can be formed in particular according to social class or the function entrusted to the shelter. The size of these groups may have a weight in the future for the decisions made in the shelter.

Regarding the situation on the surface, the surface of the globe is facing terrible fires caused by shooting stars [12]. The light level is lower than the minimum required for photosynthesis and human vision. All populations that did not take refuge in shelters do not survive. Despite the fires and an increase of temperatures at the beginning, at the end of the week, the average temperature has finally dropped drops of 8K. The biggest cooling would take place in the northern hemisphere, with areas cooled from 0 to 10° C.

3.5 First month

A period of two weeks spent in a shelter is often sufficient to cause major psychological consequences in the population such as irritability and depression. These behaviours can lead to aggressive behaviour, and withdrawal into oneself.

There are conflicts between certain groups of people within the shelters. These conflicts can interfere with the proper functioning of the shelter, which is why they are managed quickly by the leaders. But it is possible that these conflicts will turn into riots or even overthrow of the organization and the power established in the shelter. Those reversals can sometimes be detrimental to

the survival of residents if infrastructures are impacted by conflicts. In other shelters that do not experience riots, one can imagine the appearance of new social classes according to their place in the shelter. Technicians having a very important place for the survival of the shelter can, for example, be part of the upper social classes of the shelter. Survivors who participate in the proper functioning shelter might therefore be better rewarded than other survivors. It depends obviously of the type of organizational regime established initially, and would not be applied in all shelters. We can also show optimism with very docile and reliable populations, contenting themselves with the first floor of the pyramid of Maslow.

One can imagine that from one month on, scientists study the state of the surface using sensors or remotely controlled robots to take readings in different places. These readings make it possible to study the composition of the air, debris and to deduce more precisely the dates from which it will be possible to make the first outings. Findings in this regard could be transmitted by means of telecommunication set up between the shelters.

During this period of extreme confinement underground, communities will try to find a life cycle more or less similar to their life cycle before the disaster. Establishing routines helps reducing stress and depression, it is therefore normal to wish to find a stable cycle allowing to rest on the temporal elements

Temporary education systems can be set up to allow children to continue learning despite difficult conditions. Art, entertainment and sport must also have an important place in the lives of long-term survivors.

Depending on the resources available to communities and shelters, health can also be set up to meet the needs of survivors. Survivors may experience health issues or psychological problems. It is therefore important to have doctors and psychologists. We may also consider the involvement of complementary care or health specialists such as nurses, dentists, dermatologists, etc.

Regarding the external situation, the fires are no longer active, but the level of light is still very low. A simulation of the evolution of dust clouds in the stratosphere by Pollack et al showed that the drop of light intensity below the level necessary for photosynthesis cannot exceed one year [8].

3.6 Six months after impact

After 6 months, only the communities living in shelters with a stable organization survive. A routine is probably installed within the shelter to maintain a life cycle close to a classic life cycle. However, it is quite possible that some unstable communities managed to survive, despite more difficult conditions.

There are several reasons for the disappearance of some communities.

Firstly, it is psychologically difficult to remain locked up underground for several months. One can therefore assume that riots would be the main cause of destruction of some communities. These riots may impact the infrastructure, organization or facilities that allow the shelter to function properly. These riots may lead some individuals to sabotage facilities, causing the disappearance of the community that depended on the shelter.

Secondly, there is the element of randomness that can affect the survivors. Malfunctions can occur in ventilation systems, water treatment systems or even in the water treatment systems or even the geothermal pump installation. If these malfunctions are significant and it is not feasible to make a repair, these communities can disappear.

Randomness can also intervene in the appearance of disease within the communities. It is difficult to assess the source of these potential diseases, which may be due to the food, the ventilation system, etc. Depending on the severity of the diseases, great damage can be caused within the communities, even to the point of causing the end of them. Another element of randomness is the incorrect prediction of the situation by scientists. It is quite possible that scientific research into the survival of humanity after a meteorite impact has not covered a major issue. It is also possible that some communities were relying on the presence of resources that unexpectedly disappeared as a result of the long-term damage of the impact. For example, simulations by Covey show that precipitation decreases by 90% for several months [2]. This effect dissipates, allowing the recovery of half of the average precipitation rate (before impact) at the end of the first year after impact. This would cause a global drought. This drought could negatively impact some communities that relied on water recovery from the surface. All these random parameters are part of the risks that survivors must consider.

After 6 months, light begins to return to the surface and humans can finally discern elements [8]. However, this light remains superficial because it corresponds to the light emitted at night by a full moon. The photosynthesis is still not possible. Hope returns to the survivors because the first exits on the surface are carried out by scientists. These exits allow to make an inventory of the current situation, and to foresee the possibilities concerning an extraction of the population towards the surface.

3.7. One year after impact

According to Pollack, the period during which the temperature is below 0°C corresponds roughly to twice the period without light [8]. We can therefore assume

here that the global terrestrial temperatures will start to exceed 0°C after one year. Moreover, the level of light would reach a sufficient level to allow photosynthesis. allow photosynthesis.

The temperature is still too low in the northern hemisphere to consider cultivate the land. However, in the southern hemisphere, the level of luminosity being sufficient for photosynthesis, we can suppose that certain communities are beginning to establish crops (in small proportions) around the shelters. However, the yield would probably not be sufficient to consider feeding the entire shelter. Hydroponics and insects would therefore remain the main source of food.

These outings allow some communities to plan a return to the surface. It is indeed important to study the feasibility of establishing an outdoor base.

For that, it is necessary to study several parameters such as the ground or the weather conditions. These external bases must however remain close to the shelters to allow access to drinking water, a viable food source, and enough to shelter the population from the external conditions which are still difficult.

3.8 Five years after impact

Five years after the impact, the communities that have survived so far have established camps outside the shelters. Although the shelters remain heavily used, outdoor housing is emerging. "Cities" are beginning to develop around the shelters. Survivors have even been able to meet other peers from relatively close shelters. These shelters provide for the needs of the inhabitants such as food, waste disposal, etc. The materials in the shelters are also used outside to rebuild homes, tools, etc.

Humanity is thus summarized in several agglomerations of shelters, communities scattered over the part of the globe that was not directly affected by the impact, where the shelters were present.

3.9 Twenty years after impact

Twenty years after the impact, the society is in the process of reconstruction. It is not at all comparable to the society before the impact. Agriculture has been stabilized, which allows the survivors to meet their needs. A re-implantation of certain animal species has begun as well as the planting of seeds from the Svalbard world seed reserve. This allows to start rebuilding self-regulating ecosystems as it could be the case before impact.

The large shelter agglomerations constitute large development poles which can be similar to states as we know them today.

However, the territories of East Asia are still heavily impacted by the disaster. The devastating effects of the impact are still felt in the climate and the total disappearance of any ecosystem. Some populations are

coming to resettle on the extremities of these territories, but the impact zone remains completely deserted. As a reminder, the diameter of the crater created is 360 km.

3.10 Discussion

Finally, in this scenario, humanity has managed to survive the catastrophe. However, this survival comes mostly from the human preparation before the impact. Without the establishment of shelters with all the means to provide for human needs, humanity could not have survived such a catastrophe. Furthermore, we have not found reliable information concerning the breathability of the air, which does not allow us to take into account this very important element. Finally, most of the choices are based on hypotheses or even speculations. This interdisciplinary field of research is so vast that the study of a particular part such as the facilities present in the shelters could constitute a complete research project on its own. We have therefore had to base our research on elements that are sometimes incomplete, which can impact the veracity of the scenario.

4. Scenario 2

4.1 Scenario definition

In this scenario, there is the fall of a hypothetical 100 km diameter asteroid in the middle of the Pacific Ocean. The meteorite collides with the Earth at a speed of 20 km/s and an angle of 45 degrees. The kinetic energy of the meteorite is 7.57×10^{10} MT, that is more than ten times the energy of the asteroid of the first scenario.

4.2 One week before impact

Ten years have passed since the news of the future impact. One can imagine that on a population scale, the reaction would not be so different than if the meteorite was "only" 50 km in diameter. There have been several mass exoduses, notably from the Asian (Japan, China, etc.) and American (California, Mexico, etc.) coasts. Although the planned area of destruction covers a larger area, these regions, very dynamic in globalization, have become very unstable. The host geographical areas, Europe, Africa, Central Asia, also having to think about their own population, have been put under great tension. Inevitably, many civil wars broke out. States have also fallen, either because of the hysteria of the population, or because of the covetousness of resources or advantageous territories in view of the catastrophe. In the midst of this apparent chaos, a majority of the population will have remained astonished, stunned. It is a population that will have tried to maintain its daily life by covering its eyes, not particularly active for its survival. The threat seems too great, and the hopes of escape from the Earth or of destruction/avoidance of the asteroid have been extinguished since the first year.

During these 10 years, the few States, very militarized, which will not have succumbed have put in place authoritarian regimes, and will have prepared post-impact plans to follow. It is also the case of private communities with strong power (economic, political, etc.) which will have organized themselves independently of the States, according to their means. The first ones then had the necessity to set up a plan of sorting of the population according to corruption, genetic heritage and capacities for the times to come. This sorting has still caused serious civil wars. This is not the case for the private communities which are already a limited number (of the order of several thousands), and which thus set up their solutions for all their population.

The shock arrives in a week, and the selected populations are moved to the shelters, with all the equipment and food not yet installed. These populations, which will be hastily estimated at only a few million people, are subjected to enormous psychological and moral pressure, but this is small compared to the rest of the Earth. Indeed, the forgotten of survival, condemned by all the forecasts, oscillate between collective suicides, total chaos (unleashing of violence), and mute ataraxic for the resigned.

We believe that the most likely organization within the shelters is a pyramidal hierarchy. Indeed, the decisions to be taken imply a high level of knowledge of the situation and of the possible evolutions of the surface state. Differences of opinion within the populations could then cause the loss of control of the shelter. It is also possible that democratic regimes could be established, especially in private communities. However, these regimes would likely be more unstable due to the psychological evolution of the survivors. Some shelter functions will be assigned to certain survivors to ensure the smooth running of the shelter. This could be, for example, technicians, scientists, or law enforcement personnel. For the sake of efficiency, most of the people accepted in shelters should be active. Some less specific functions such as maintaining hygiene or distributing food can be listed.

4.3 Day of impact

The final crater created by the impact has a diameter of about 1000 km, and a depth of 2.5 km [1]. Note that the crater at impact reaches a depth of 180 km. Thus, the atmosphere comes into contact with the asthenosphere. On half of the globe, all the infrastructures are destroyed by the shock wave. However, it takes 16 hours to reach the opposite point of the globe, with gusts of 150 km/h. While in only 1 hour, an earthquake of magnitude 11,9 shakes this opposite point. Nothing was designed to support such an earthquake, almost 100 times stronger than the most powerful earthquake recorded. It is very likely that

many shelters will not withstand the earthquake, dooming their populations.

During the impact, debris is sent into space and then re-enters the atmosphere. This ejecta is heated to incandescence (+500°C). These falling debris are called "shooting stars" [12]. In addition, 0.1% of the sprayed ejecta (30% of the impactor mass), of sub-micrometer size is caught in the rising plume and is diffused globally around the globe in a ballistic manner. Soot and ash generated by shooting star fires will add to the debris floating in the air resulting in an envelopment of the Earth in less than an hour. The sub-micrometer dust and soot repel light rays into space, but the soot will also absorb sunlight. The light level will then drop rapidly to a level too low for the photosynthesis mechanism and human vision. Added to this is the staggering amount of water vapor, on the order of 100 GigaTons, rising into the atmosphere.

The coastlines of the Pacific Ocean are affected by titanic tsunamis, on the order of 100 meters. A mass of water over the entire depth of the ocean has been displaced. The water movement is global, and coastlines throughout the Pacific will be razed.

People still living on the surface without protection will not survive in the long term even if they are on the opposite side of the globe from the point of impact due to shooting stars and fires. Because of the very random phenomenon of the shooting stars' fallout and their size (in fact like small meteorites), some shelters are strongly impacted and the sheltered population is doomed not to survive.

It should also be noted that despite the size of the asteroid, the astronomical constants of the Earth, i.e. the length of the day, the Earth's mass or the Earth's orbit, will not be impacted or hardly impacted at all [1].

Thus, at the end of this first day, it is predictable that most of humanity outside of a shelter will be killed (about 99%). The only potentially earthquake-resistant subsurface shelters will not be numerous, perhaps half or a third of the sheltered population.

4.4 One week after impact

During the first week, catastrophic events follow one another. Fire hurricanes have broken out in all the major forests of the world and continue to wreak havoc, still releasing huge amounts of ash and water vapor [6]. Moreover, the impact has unbalanced the earth's crust, awakening volcanoes and super volcanoes (e.g., Yellowstone) or causing new earthquakes, especially in sensitive areas such as the San Andreas Fault in California. These disasters in turn bring their share of damage and consequences, such as new tsunamis or the addition of dust and volcanic ash in the atmosphere. And this is true for the whole world.

During the first few weeks, the energy released by the impact, the fiery hurricanes, and the suspended

water vapor cause the temperature of the atmosphere to remain above 500°C [5]. It is unclear if there are areas that are not less affected by this temperature rise, but they would be exceptional.

The coastlines are certainly part of this, benefiting from the thermostat effect of the Ocean. However, we have seen that these coastlines were hardly a solution, because already ravaged by tsunamis and particularly sensitive to earthquakes (because of subduction zones). Thus, life on the surface was virtually annihilated, leaving mostly insects or small animals.

In the shelters, the cooling and air filtering systems must be optimally efficient to maintain livable conditions, and technical problems due to the extreme conditions may already occur. At this point, we may only be talking about a hundred thousand survivors spread across the globe.

4.5 The first month

As far as life in the remaining shelters is concerned, it does not diverge so far from the case of a smaller impact (50 km diameter scenario). Indeed, as long as the shelter is functioning, the external conditions do not impact the internal conditions, at least for now.

Conflicts between certain groups of people within shelters are emerging. These conflicts can be detrimental to the smooth running of the shelter, so they are dealt with quickly by the leadership. But it is possible for these conflicts to turn into riots that could overthrow the organization and power established in the shelter. These overthrows can sometimes be detrimental to the survival of the inhabitants if the infrastructure is impacted.

In other shelters that do not experience riots, one can imagine the emergence of new social classes depending on their place in the shelter. Technicians with a very important place in the survival of the shelter may, for example, be part of the upper social classes of the shelter. Survivors who are involved in the smooth running of the shelter might therefore be better rewarded than other survivors. This obviously depends on the type of organizational regime initially established, and would not be true in all shelters. One can also be optimistic with populations that are very docile and reliable, settling for the second floor of Maslow's pyramid.

During this period of extreme confinement, communities will try to return to a life cycle more or less similar to their life cycle before the disaster. Establishing a routine decreases stress and depression. Temporary education systems can be put in place to allow children to continue learning despite difficult conditions. Those of working age may be able to make themselves useful in shelter maintenance, food distribution, or other essential function that allows the shelter to function properly. Art, entertainment, and

sports should also have an important place in the lives of survivors in the long run. To allow survivors to think about something other than the disaster, sports or several forms of art may be considered. This would likely be beneficial in curing the depression of some survivors.

Depending on the resources available to communities and shelters, health systems may also be developed to provide for the needs of survivors.

Regarding the outside, the temperature remains well above 100°C, continuing to kill everything that can be killed. Volcanic eruptions have apparently calmed down, and fewer and fewer earthquakes are shaking the Earth. The atmosphere is still largely unbreathable, due to the fines particles in suspension. The weather conditions are totally unpredictable during this period. Thus, going outside is almost impossible and of little interest. Of the life on the earth's surface, there is already not much left.

4.6 Six months after impact

Again, the sheltered life is quite similar to that in the "50 km" scenario. However, the even harsher outdoor conditions (including higher temperatures) will have tended to bring more life support systems to their knees. Thus, the number of remaining shelters gets smaller and smaller.

At the end of six months, only the communities with shelter and relatively stable organization have survived. A routine is probably established within the shelter to maintain a life cycle close to a conventional life cycle.

There are several reasons that may be the cause of the collapse of some communities. Firstly, it is psychologically difficult to remain locked up underground for several months without any perspective and room for improvement. Therefore, we can assume that riots would be the main cause of destruction of some communities. These riots may impact the infrastructure, organization, or facilities that allow the shelter to function properly. These riots may lead some individuals to sabotage facilities, which may cause significant irreparable damage, causing the disappearance of the community that depended on the shelter.

Secondly, there is the element of randomness that can affect the survivors. Malfunctions can occur in many life support systems and it is doubtful that there would be enough resources and the necessary industrial tools to repair everything.

Randomness may also be involved in the occurrence of disease within communities. It is difficult to assess the source of these potential diseases, which may be due to malnutrition, the presence of toxic molecules in the air, etc. Depending on the severity of the diseases, the communities could slowly but surely collapse.

Another important issue is the difficulty to predict what are all the resources, tools and industrial processes that are needed for survival. The lack of a single important resource could lead to the collapse of the community. It could be for example water. As a severe drought is expected on the surface, some communities that relied on water recovery from the surface or from a small underground reservoir would die. All these random parameters are part of the risks that survivors must consider.

Although the external luminosity goes up a little, the temperature remains above 100°C. However, the coastlines are cooling faster. In fact, at this stage, the outside is not an issue for survival. The only elements allowing the survival of the tens of thousands of people remaining are inside the shelters.

4.7 One year after impact

It is around this period that we will witness a reversal of the phenomenon. For almost a year, the Earth was overheated. But the impact winter will finally begin. Indeed, it has been a year since solar energy was almost completely absorbed by the pile of ash, dust, and water vapor in the atmosphere. And a large part of these elements has not yet fallen back to the ground. Thus, the planet will see a drastic decrease in its average temperature compared to normal (about 7 degrees less). More than a third of the Northern Hemisphere would then be under ice, with another third resembling the tundra of the Siberian deserts. The final third would have no life at all, even if outside conditions would be more favorable.

4.8 Five or ten years after impact

The duration of the overheated period is not clear. It could be five to ten years, perhaps more. At some point, however, the impact winter should settle down durably. The life annihilated by the post-impact period cannot restart under these conditions. The climatic and meteorological conditions hardly allow expeditions outside the shelters, which for the most part have already reached their limits and seen their population die out.

From a physical point of view, most of the surviving humans are at the end of their tether, due to the lack of vitamins and the lack of physical exercise. As for the mental state of the survivors, it is difficult to determine, between resignation, hope, questioning, fear, frustration etc. It is likely that the population of numerous remaining shelters has fallen below the threshold of healthy reproducibility. And the perspectives are bad.

4.9. Decades after impact

After ten years or perhaps decades, terrestrial temperatures will drop down and become livable for simple organisms and plants in some places on Earth.

However, even if some people were still alive in well-organized shelters, there is no guarantee that these places would be safe and full of useful resources for living. There are numerous reasons to believe that nobody would survive [9]:

- Environmental issues

New volcanoes and tsunamis could destroy the remaining shelters. The atmosphere could also become unbreathable due to the presence of toxic gases. Acid rains could be dangerous to all terrestrial life forms.

- Insufficient resources

For survival, huge amounts of water are needed, to grow plants and for many other usages. As 100% recycling is not possible, many shelters might collapse due to a lack of this resource if their reservoir is limited. Similar issues exist for repairing capabilities.

- Insufficient energy

Lots of energy is needed, especially in the form of electricity, for the photosynthesis of plants using artificial lighting, and also for many complex systems (life support, pumps), and industrial processes.

- Insufficient human resources

There is an issue with genetics and also with the needs to implement all human activities required for survival (maintenance of life support, agriculture, industry, growing babies, etc.) [9].

- Anarchy

A strong and effective organization is required to obtain a synergy of all human activities and avoid riots and wars among the different communities.

- Insufficient adaptation capacities

Without experience, the communities will have to face many unexpected problems without appropriate tools and solutions.

For all these reasons, the total annihilation of humanity cannot be demonstrated, but the long term survival capability seems to be very weak. Regarding living organisms in general, they will resume from the ocean floor, or close to hydrothermal vents but the settlement of the surface will probably last centuries.

5. Conclusions

In view of these scenarios, the limiting size of the asteroid allowing for human resilience in the event of an impact with the Earth is in the range 50-100km. In spite of the effort made in the research and the linkage of the latter, these scenarios remain nevertheless the result of several choices made in the analysis and of several assumptions. This is moreover why the range given is wide. However, we do manage to obtain an order of magnitude of asteroids fatal to humanity. This allows us to better situate the risks and to better evaluate the need to protect ourselves from this kind of impact, for example by colonizing new exoplanets.

References

- [1] G. S. Collins, H. J. Melosh, and R. A. Marcus, Earth Impact Effects Program: A Web-based computer program for calculating the regional environmental consequences of a meteoroid impact on Earth, *Meteoritics & Planetary Science* 40 (6), 817–840, 2005.
- [2] C. Covey, S. Thompson, P. Weissman and M. MacCracken, Global climatic effects of atmospheric dust from an asteroid or comet impact on Earth. *Global and Planetary Change*, vol. 9, p. 263-273, 1994.
- [3] K. C. Engvild, A Review of the Risks of Sudden Global Cooling and Its Effects on Agriculture, vol. 115, *Agricultural and Forest Meteorology*, p. 127–137, 2003.
- [4] C. Gritzner . K. Dürfeld . J. Kasper, S. Fasoulas, The asteroid and comet impact hazard: risk assessment and mitigation options, *Naturwissenschaften*, 93: 361–373, 2006.
- [5] A.W. Harris, M. Boslough, C.R. Chapman, L. Drube, P. Michel P., Asteroid impacts and modern civilization: Can we prevent a catastrophe? In *Asteroids IV* (P. Michel et al., eds.), pp. 835–854. Univ. of Arizona, Tucson, 2015.
- [6] M.M. Marinova, O. Aharonson, E. Asphaug, Geophysical consequences of planetary-scale impacts into a Mars-like planet, *Icarus* Vol. 211 (2), p. 960-985, February 2011.
- [7] W. M. Napier, Giant comets and mass extinctions of life, *Monthly Notices of the Royal Astronomical Society*, Volume 448, Issue 1, Pages 27–36, 21 March 2015.
- [8] J.B. Pollack, O.B. Toon, T.P. Ackerman, C.P. McKay, and R.P. Turco, Environmental effects of an impact-generated dust cloud: implications for the cretaceous-tertiary extinctions. *Science* (New York, N.Y.), 219 (4582), p. 287–289, 1983.
- [9] J-M. Salotti, Minimum Number of Settlers for Survival on Another Planet, *Scientific Reports*, vol.10 (9700), June 2020.
- [10] P. H. Schultz and D. E. Gault, Prolonged global catastrophes from oblique impacts, book chapter, in *Global Catastrophes in Earth History; An Interdisciplinary Conference on Impacts, Volcanism, and Mass Mortality*, Geological Society of America, 1990.
- [11] N.H. Sleep, K. J. Zahnle, J. F. Kasting, and H. J. Morowitz, Annihilation of ecosystem by large asteroidal impacts on the early Earth, *Nature*, 342, 139-142, 1989.
- [12] O.B. Toon, K. Zahnle, D. Morrison, R.P. Turco, C. Covey, Environmental perturbations caused by the impacts of asteroids and comets, *Rev. Geophys.*, 35(1), 41– 78, 1997.