**Surviving Global Risks Through the Preservation of Humanity’s Data on the Moon**

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Alexey Turchin

Science for Life Extension Foundation, Russia, Moscow, Prospect Mira 124-15

<http://scienceagainstaging.com/>

email: alexeiturchin@gmail.com,

corresponding author

David Denkenberger

Global Catastrophic Risk Institute; Tennessee State University

Alliance to Feed the Earth in Disasters; 3500 John A Merritt Blvd, Nashville, TN 37209, USA

<http://allfed.info/>

email: david.denkenberger@gmail.com

**Abstract**: Many global catastrophic risks are threatening human civilization, and a number of ideas have been suggested for preventing or surviving them. However, if these interventions fail, society could preserve information about the human race and human DNA samples in the hopes that the next civilization on Earth will be able to reconstruct Homo sapiens and our culture. This requires information preservation of an order of magnitude of 100 million years, a little-explored topic thus far. It is important that a potential future civilization will discover this information as early as possible, thus a beacon should accompany the message in order to increase visibility. The message should ideally contain information about how humanity was destroyed, perhaps including a continuous recording until the end. This could help the potential future civilization to survive. The best place for long-term data storage is under the surface of the Moon, with the beacon constructed as a complex geometric figure drawn by small craters or trenches around a central point. There are several cost-effective options for sending the message as opportunistic payloads on different planned landers.

**Keywords**: Global catastrophic risks, existential risks, moon, time-capsule, METI

**Highlights**:

* Catastrophic risks could be survived if the next civilization on Earth will reconstruct humanity.
* The next non-human civilization may appear on Earth around 100 million years from now.
* Time-capsules with DNA and data could help reconstruction of humanity.
* The most logical place for such data preservation is the Moon.
* Drawings on the surface of the Moon made of small craters can serve as a beacon.

# Introduction

Global catastrophic risks (GCRs), which have received increasing attention in recent years, are those risks that have the potential to harm our long-term future [1,2]. Many authors [3,4] think that there are significant chances of a global catastrophe from one of more than ten possible causes, including asteroid impacts, nuclear war, supervolcanic eruption, molecular nanotechnology, engineered pathogens, and dangerous artificial intelligence (AI) [5].

There are many ideas for preventing such catastrophes, such as using international cooperation or benevolent superintelligence. Additionally, the catastrophe could be survived using space bunkers [6], underground refuges [7,8], or retrofitted nuclear submarines [9]. Moreover, Seth Baum explored the value of space exploration from a consequentialist ethics point of view [10].

A more radical idea involves preserving data about human civilization for the next civilization to appear on Earth, which may arise if the global catastrophe kills off only humans but not all life on Earth. The most suitable place for such preservation may be the Moon.

The idea of preserving information about humanity on the Moon has attracted the attention of researchers before. Mautner suggested using Moon polar craters to cryopreserve the genetic data of many species [11]. From 2000 to 2009, Shapiro and others organized The Alliance to Rescue Civilization with the main goal of using the momentum of a George W. Bush-era plan to return to the Moon for the creation of a constantly inhabited refuge there [12]. In 2007, the Phoenix report suggested a lunar archive, which would be able to send data back to terminals on Earth in the event of a catastrophe [13]. Mission One used crowdfunding in 2014 to collect funds for sending a lander with data to the Moon’s polar regions, but the project did not get enough funding [14]. The Moon was also recognized as a possible place to search for alien artefacts [15,16] or remnants of previous Earth civilizations [17]. A recent extensive review of all efforts in the creation of space time capsules is in the article by Guzman [18]. The creation of a Moon sanctuary, containing a full back up digital and biological data, which will communicate with humans by radio after a global catastrophe, was suggested by Shapiro [19], but it is a weak idea, because if any radio receivers on Earth survive, they could also store data. Furthermore, if active transmitters are on the Moon, they cannot survive more than several hundred years based on current technologies. Also, if humans survive on Earth, they will probably be able to reconstruct most of human civilization.

This article explores the problem of how to preserve humanity’s data in order to help our species survive GCRs. To solve this problem, several questions have to be answered:

1. When could a new human or non-human civilization appear on Earth after a global catastrophe?
2. What kind of global catastrophes could result in human extinction but permit a new civilization to appear on Earth?
3. How could one make a new civilization interested in reconstructing biological Homo sapiens and human culture?
4. Where, and how, should one place a message so that it survives until the appearance of a new civilization?
5. How can one make the message visible to a new civilization as early as possible?
6. How can the message help the next civilization to prevent its own extinction, and thus commence a mutually beneficial “trade” between two civilizations, with the goal of helping each other to prevent permanent extinction?
7. How can all this be accomplished at relatively low cost, so it will avoid being a significant opportunity cost for other existential risk (X-risk) prevention strategies?
8. What should the content and the size of the message be?

The answers to these questions are interconnected, and the requirements are sometimes contradictory. This article argues that the best solution is to put the main message under the surface of the Moon in a polar region and to draw a beacon image on the Moon’s surface, pointing to the location of the message. It would be beneficial to add a smaller version of the message to any spacecraft and to some stable Earth locations, such as underground nuclear waste storages in old stable rock formations called cratons. The first launch of the Falcon Heavy to Mars in 2018 is not only carrying a Tesla Roadster; it is also carrying the data archive disk with Asimov’s Foundations books by Arch Mission [20].

Section 2 explores the probability that the next civilization will appear on Earth after human extinction. Section 3 is devoted to long-term data storage methods. Section 4 presents the benefits of the Moon as a place for civilizational backup, while section 5 analyzes individual projects for Moon backup based on various budgets. Next, section 6 discusses other ideas for very long data preservation, including cratons, and section 7 runs through the possible content of the message. Finally, section 8 describes the cost-effectiveness of the various preservation methods.

# 2. The future of Earth and the chances of a new civilization appearing in the astronomical future

## 2.1. Future evolution of the Sun and the Earth

According to *The Life and Death of Planet Earth* [21], complex plant and animal life will disappear 600 million years from now as CO2 levels diminish, and all life will become extinct in 1 billion years, after the oceans evaporate due to the growing luminosity of the Sun. More recent estimates suggest 1.3 billion years for a climate suitable for human life [22]. The types of human and alien artefacts that could survive on Earth are surveyed in [23]. However, uncertainty about the future of life is high, as many life-ending catastrophes on Earth could occur earlier.

This article does not take into account observation selection effects, which could lead to underestimating the rate of large-scale natural catastrophe, and thus to shorter biosphere life expectancy [24]. The discussion will not include the mediocrity principle, which suggests that if humanity is the first civilization, it is atypical for catastrophes to kill all humans yet leave the biosphere intact, and thus several civilizations on one planet is a rare event [25]. The reason for not including these ideas in the present analysis is that they only lower the chances of success of the project while not making it impossible. There is also a very small chance that the current civilization is not the first one here on Earth [26].

Six hundred million years as the life expectancy of complex life on Earth is a very long time—similar to the time that has passed since the Cambrian explosion when almost all known multicellular life appeared [27], and it should be enough for the appearance of another intelligent species.

## 2.2. Two sweet spots for new civilizations appearing and corresponding methods for communicating with them

Based on the description of catastrophes above, two sweet spots for the appearance of a new technological civilization can be identified: an order of magnitude 10,000 years from now, based on Homo sapiens survival, and an order of magnitude 100 million years from now, based on a completely different animal lineage. Somewhere between these time frames is less probable, as it would require a specific type of catastrophe that preserves the great apes, like a biological pandemic. However, many dangerous pathogens, such as a flu virus, could affect other species as well.

For the first sweet spot, humans could preserve information in underground bunkers, which could have approximately the same survival time as caves, where typical ancient human remains were found, which is around one million years.

For the second sweet spot, the Moon seems to be more promising, as its surface is changing much more slowly.

## 2.3. Information exchange and “acausal” trade between past and future civilizations

Sending time capsules is mostly a symbolic or an entertainment activity [28], but recently humans have started to invest in long-term data preservation with an altruistic goal of helping our remote descendants. Likely the most famous of such projects is the Svalbard Global Seed Vault in Norway. Helping the remote future is a good example of effective altruism [29].

 If our society is able to send a message through time to the next civilization on Earth, it could be win-win for both civilizations:

For the human civilization, it would mean an escape from extinction, as human beings could be returned to life based on human DNA (or maybe frozen embryos), and human culture could be restored based on recordings of languages, books, and videos.

For the next civilization, it would be a source of important information about how human extinction happened, what humanity tried to do to prevent it, and how our attempts failed. In order to achieve the last condition, the senders may need to implement the ability to constantly add information to the database by remote means, like recording a news stream. The information store will be also a source of a large amount of valuable astronomical, anthropological, and biological scientific data, as well as entertainment, especially if discovered early in the new civilization’s development.

There was an idea to search for signs of previous civilizations on Earth (or perhaps on Venus and Mars) by retrieving remnants of their space exploration [26]. Thus, humanity could also find a message from a previous civilization, though it is unlikely, based on existing archeological, astronomical, and paleontological data.

There is also a small chance that an alien civilization will appear and will visit our Solar System in the future and will find remnants of human civilization and use our data to return humanity to life. This could happen even after Earth becomes lifeless, so it would be advantageous to create space repositories that are even more durable and remote from the Sun (because it will turn into a red giant).

Sending messages to a future Earth civilization is similar to Messaging to Extra-Terrestrial Intelligence (METI), but the former does not have the risks of attracting the attention of dangerous aliens [30].

Sending data to the remote future is a form of an “acausal” deal, similar to the prisoner’s dilemma. Both sides would win if Civilization 1 (us) invests in sending useful data in the future, and Civilization 2 recreates us based on our DNA. However, Civilization 2 could defect and only use our data but not recreate us. Some authors have explored cooperation between different sufficiently advanced civilizations [31,32].

## 2.4. Reconstruction of extinct species based on DNA samples

The Long Now Foundation is considering the possibility of reconstructing around 11 species that lived in the past, including the Wooly mammoth and Tasmanian tiger [33]. This mammoth could be returned to life, and it is considered a proper scientific task [34]. The return to life of Neanderthals seems technically possible given that most of their DNA has been found, but it is currently considered unethical [35].

It may be assumed that it would be ethical to reconstruct extinct Homo sapiens if it is done together with human culture. A human being raised without human culture cannot be regarded as a true human, as in the case of feral children.

Thus, human DNA should be preserved together with a long enough recording of human life and child-rearing processes so that the future civilization would be able to reconstruct us together with our culture. The future civilization would probably do this using advanced AI systems to model the needed environment.

Additionally, reconstructing an individual based on his/her cryopreserved brain also seems ethical, if s/he consciously declared the desire for this. Synapses in the brain are larger than DNA coding regions and could survive for a longer time, while DNA could be damaged by internal radiation from potassium (K-40). The question of cryonics on the Moon will be discussed later.

# 3. Existing methods and attempts to preserve information about humanity

## 3.1. Long Now Foundation and other existing long-term data preservation efforts

There are several ongoing projects to send data to the remote future, explored in detail by [18]. They include The Long Now Foundation, which is working on long-term solutions for information preservation. One of their main projects is the Rosetta disk [36], which uses HD-Rosetta technology [37].

This disk is a long-term storage device based on engraving a nickel alloy onto a silicon disk. It also includes technology for self-evident reading of plain text on such disk using a microscope. The disk includes some form of a beacon, which consists of a spiral of letters that start large and get smaller, helping the disk to be recognized as an information carrier. Each disk includes tens of thousands of pages of plain text.

The first version of the disk was put on the Rosetta spacecraft, which delivered it to the comet Churyumov-Gerasimenko. But as comets are not very stable space objects, it will not survive there for millions of years, and even if it did survive, it would not be easy to find the message.

Given an expected survival time on Earth of 10,000 years, it could be used only to address the first type of global catastrophes—those in which humans survive. The technology was initially created in Los-Alamos National Laboratory to preserve data after a nuclear war.

The Long Now Foundation chose to preserve human languages via 1000 different translations of Genesis, which are engraved on disks they created [38]. However, preserving human languages may be not the most valuable information for future generations, and it will not help to resurrect humans or human culture. Nevertheless, the technology of long-term data storage already exists and could be used for other projects.

“HD-Rosetta” manufacturer Norsam also suggests HD-ROM technology with the following disk characteristics, if it is used as a digital-only carrier: “50 nm pit size •165 GB per 120 mm disc • 15 msec access time • Write rates 20 - 50 Mbytes per second • Read rates 6 - 10 Mbytes per second”. According to Norsam, HD-ROM is 24 months from production, while HD-Rosetta is ready for production [39].

Near the **Svalbard Global Seed Vault** on Spitzbergen is an Internet archive, which uses microfilm to store information and is expected to last 500-1000 years [40].

**Lunar Mission One (LM1)** is a project to send a probe into the Shackleton crater on the Moon, bore a hole 20-100 meters deep, and put public and private data inside the hole, as well as pieces of DNA and hair [41]. The founders want the project to be funded by people who will pay to preserve their private data. It has a planned launch date in 2024 but is currently experiencing funding difficulties. LM1 has plans to run a prize for the best beacon design, which they expected to be built on later stages of the project. LM1 suppose that it is not currently known if digital DNA preservation as well as the neuroscience of the working of the brain could be effectively recovered, but they are sure that LM1 provide best opportunity for that, if it is possible. LM1 is now developing new bore drilling technology based on wireline drilling, so the depth of drilling depends only of the cable. The one area of high risk is the need for a casing (a lining for the drilled borehole) to prevent borehole collapse. This LM1 have now researched to the point that they know the principle of how to do it. LM1 signed a contract for a lighter mission with *Astrobotic* with expected launch in 2019.

**Memory of Mankind (MoM)** is aneffort to encode some information on clay plates and bury the plates in a salt mine [42]. This project also plans on using microtext; each plate will be able to carry 5 million characters and will be 1 mm thick. The time capsule is expected to last one million years [43]. The organization is going to distribute tokens with maps, which will help future generations find the burial place. They also selected a location that is self-sealing, above seawater level, and geologically stable. They are planning to deliver six ceramic MoM microfilms to the Moon during the Google X-Prize competition. However, one million years is too short a time period to reach non-human civilizations, and not much attempt is being made to preserve human DNA, which is necessary for human resurrection. The beacon tokens are also likely too fragile to survive millions of years. These plates may have a longer survival time on the Moon, but they are heavy.

**The Human Document Project** is an international consortium of scientists aiming to preserve data for one million years. They are exploring different preservation technologies, like amber coating or the use of luminescence to attract attention. They hold regular conferences [44].

**The Keo Project** is a satellite that will return to Earth after 50,000 years in orbit [45].

**The Arch Mission** is planning to use 5D silico quartz technology to send large archives as opportunistic payloads on different spacecraft. They will encode Wikipedia and digitalized DNA. They already sent their first disk, which contains Asimov’s *Foundation* novel, to heliocentric orbit on the Falcon Heavy in 2018. Their goal is for the data to help after a possible global catastrophe: “Long-term future: In the unlikely event that something terrible wipes out our civilization and/or species on Earth or across several planets, the Arch Libraries will be treasure troves of knowledge for any humans who survive, in eventually rebuilding civilization. They may also potentially be useful to future humanoids that survive and/or evolve again in our solar system, long after our species is gone, millions or billions of years in the future” [46]. They plan to distribute thousands of Arch libraries to by 2020.

All these projects are oriented to different timescales, and most of them are aimed at the next human civilization. Only LM1 and Arch Mission aim at very long-term data storage that could reach a future non-human civilization on Earth.

## 3.3. New information carriers

Besides HD-Rosetta, several new types of long-term information carriers, which may be used for long-term preservation of large amounts of data, have been explored.

**M-disks:** These are Blu-ray disks with a glass coating that the manufacturers claim can survive 1000 years [47]. They may survive longer in colder places, but the problem is that they will not be easy to decode without Blu-Ray drives and modern computers, which could decay much faster. Currently, the largest capacity disks are 100 GB and weigh around 20g, so this means storage of 5TB per kg. One 100 GB disk costs around 20 USD and could be recorded at home using standard Blu-ray drive.

 **5D storage in silico glass: Glass with 3D structure, created with a laser:** A 2016 breakthrough in long-term information preservation involves creating a three-dimensional laser engraving inside silica glass, with two additional “dimensions” created by polarization. The creators claimed that 360 TB of data could be recorded into a piece of quartz the size of a coin, and the coin could preserve information for 13 billion years at +190ºC. However, only a small piece of text was actually recorded. Therefore, the technology seems feasible, but it is not commercially available. It will also require a sophisticated reading device [48,49], and current laser-powered recording time is extremely long.

 **Tungsten in silicon nitride lithography**. De Vries created disks using very hard and durable materials [50]. Thermal tests showed that the disks could survive one million years at room temperature and perhaps as much as 1030 years. The size of the features on the disk is of an order of magnitude of 100 nm, which implies a raw data density of 1 GB per square cm, or around 100 GB on a DVD-sized disk. However, the actual information content will be smaller because of needed redundancy for error correction.

As a rule, steady progress is being made in increasing the density and durability of specialized solutions for data preservation, while consumer solutions are short-lived. It could be expected that by 2030 some technology like recording data in quartz will mature, so humanity will be able to record hundreds of terabytes (TB) of data in a small and durable carrier. However, the longer humans postpone the creation of civilizational data storage, the larger the chances that a catastrophe will happen before the backup occurs.

From this review, it is obvious that technologies to record a lot of data in the small and very durable carriers already exist, but they are mostly in the experimental phase (except cheap M-disks). The early stage technologies could be very expensive, which could be a problem for small projects; however, for a larger project, they could be scaled up.

## 3.4. Preserving biological samples at low temperatures

The practice of cryogenically preserving humans originated in the 1960s. Using the Arrhenius Law, it can be shown that chemical processes slow down during cryopreservation [51].

To slow the decay of a human body enough to preserve it for the next civilization, the chemical processes should be slowed down 50 trillion times, so one minute will be equal to 100 million years. According to the Arrhenius Law, liquid nitrogen produces a slowdown of 700 trillion times compared to the speed of chemical processes at +37ºC [52]. Thus, constant storage at -196ºC (77 K) is needed. This temperature is above the lowest temperature found on the Moon, but it is important that the preservation temperature remain relatively constant throughout the future, as even a 10 K temperature jump will increase the decay rate 100 times in this temperature range. To find a suitable place under the surface of the Moon, a large excavation is required. The median subsurface temperature on the Moon is estimated at 100 K in the pole region, which is not low enough. Therefore, only permanently shadowed craters are suitable, as they have surface temperatures of 30-40 K.

However, another process—radioactive damage from K-40 decay, which exists in any biological tissue at 120 ppm—may damage biological tissue [53]. Additional damaging processes include space radiation and fracturing during cooling. Space cryopreservation on Moon craters has been suggested for the protection of endangered species [11].

Cryopreserved human embryos have maintained viability for many years and have been used for successful births.

Humanity could preserve the human species in several forms:

1. *Digitalized DNA data*: It is not known if the Human Genome Project provides enough data for the successful resurrection of a human being, because there could be errors and epigenetics or information about some other cell structures are not included.
2. *Tissue samples with preserved DNA in cells*, perhaps chemically fixed: DNA strands could be broken but suitable for reconstruction, like Neanderthal DNA data from bones.
3. *Viable human embryos*: Sending these into space may produce political protests from medical ethicists and slow the project.
4. *Bodies of dead humans or their frozen brains*. These would provide the most information about human beings, but bodies are heavy, and it is expensive to send them. However, if a lunar colony is established, some people may be buried on the Moon. Alternatively, people on Earth could pay for eternal cryopreservation and be transported to the Moon.

# 4. The Moon as the most suitable place for long-term storage in the Solar System

Traces of our civilization on Earth will decay relatively quickly because of erosion and plate tectonics [54]. Even if some traces remain, human DNA, the content of human libraries, and the content of the Internet will disappear even sooner.

If humanity wants to send a message to the remote future, it should look to the sky for a suitable object. The Moon as a stable body has attracted attention of space archeologists [16] and has been identified as the most suitable place for long-term data preservation.

## 4.1. Shackleton and Hermite craters are the most logical places to put the message on the Moon

Shackleton, the south lunar pole crater, has existed with little damage for around three billion years [55]. This crater will naturally attract the attention of any future civilization, as it is extremely cold and it may contain water ice. Inside the crater the message should be put either near the central peak or near some water deposits [56]. The exact location may be underlined by crater-drawings (see section 5.1). The crater was chosen by the planned Blue Origin Moon lander. The temperature in the Shackleton crater is 88-90 K, but there are even colder craters on the Moon. LM1 is planning to land near the South Pole, but not inside a crater, at a peak of near-eternal sunshine which will provide electric power for the drilling. They expect that the temperature in the bore will be around -150C (120K).

Some craters near the South pole are 35 K, and the Hermite crater near the North pole is only 26 K [57], which is colder than Pluto. To preserve biological samples for 100 million years, one needs constant temperatures below 77 K.

Preservation of digital data could be possible even on the surface, but micrometeorite erosion likely requires at least 1 m of protection. Erosion of the crater’s walls could result in debris accumulation at the bottom of the crater and damage any equipment there.

The required weight of machinery to dig in the extremely harsh environment of the cold Moon poles will grow quickly with the depth of the hole. The LM1 suggestion to drill 20-100 meters under the surface is based on the new technology of wireline drilling, which will weigh much less than a typical drilling rig on Earth. The Soviet automated Luna-24 station drilled a very thin probe only 2 meters into the regolith (unconsolidated material).

If there is significant ice concentration, a heated probe could melt through ice, but the possibility of such a situation cannot be known before extensive exploration.

It may be assumed that the Lunar axis of rotation will be stationary regarding its surface for the next billion years, as it was mostly stationary for the last two billion years [55]. Therefore, poles will not move, and colder regions will not become warmer.

However, for pure digital data preservation, subsurface locations in the equatorial zone are suitable. The temperature is stable at 0.5 meter subsurface there and is around -20 C [58]. Beacons on equatorial planes would be much more visible.

## 4.2. Meteorite risks

There are three types of meteorite risk: micrometeorites, small bodies, and cratering impactors. Micrometeorite risk is well quantified and produces a minimum erosion rate of 0.2–0.4 mm per million years [59], and cratering impacts seem to be rare, as most of the surface of the Moon is old. The main question is in regards to small meteorites.

For example, 1 kg bodies have an impact rate of around 210,000 per year on the Earth [60], which translates into 1 impact in 2500 years on every square km, and 1 in 25 million years for every 10 m x 10 m square. It could be expected that this rate would be similar on the Moon. The impact energy will be around of 100 kg of TNT. Flying debris from the impact may damage a nearby lander. This means that any surface lander will likely be destroyed by small impactors in an order of magnitude of 10 million years. An empirical rule for crater diameter is that they are 1 order of magnitude larger than their impactor’s diameter, so the crater of a 1 kg (~0.1 m diameter) body will be around 1 m diameter.

The conversion of impacts into seismic energy in the case of the Moon’s regolith is small, around than 10,000:1 [61]. Therefore, a small time capsule several meters deep would likely be safe from 1 kg impactors.

The main question is whether the mission should dig 2 m deep holes, which have proven to be in the reach of robotic or manned landers, or go much deeper, such as 20 m. This greater depth was suggested in the LM1 proposal, but that proposal involves combining data preservation with sample analysis, as well as sending very large amounts of data, like 10 Petabytes plus millions of hair samples. These materials combined could be 10 m long, according to a personal communication from David Iron. The deeper drilling should provide more scientific information. More research is required to determine the well’s depth required as a function of the message survival time.

The level of protection also depends on the fragility of the message carrier in relation to the shock waves from the impacts. Small crystals, as well as small DNA samples, could withstand such shock (but should be tested).

Digital storage could likely survive everywhere under regolith on the Moon at depths of several meters for hundreds of millions years. Some uncertainty exists about the effects of radiation and small impacts, which may be compensated for by deeper drilling.

 Biological samples need to be preserved on permanently cold pole craters for many millions of years and may need deeper underground storage to prevent radiation damage.

# 5. A beacon is the most important part of the message

## 5.1. Creating a beacon by drawing with small craters

Placing the information in a lunar pole crater is useless if it is never found or if it is found too late to help prevent the next civilization’s GCRs. It will be beneficial if such information is found as early as possible, because it will increase the chances of the next civilization’s survival. It would also increase the probability that they decide to resurrect us based on gratitude for providing them important information earlier.

Our proposal is to create a beacon directing attention to the exact location of the information storage around the place where the information is buried that is highly visible from Earth and is clearly an artificial feature. However, if the data storage were in a polar crater, which is not visible from Earth, the beacon should consist of two parts: one that is visible from Earth and provides directions to the relevant crater, and the second that is inside the crater and pinpoints the exact location of the information carrier.

One possible construction technique for such a beacon is using multiple small impact craters to draw a picture on the Moon’s surface that is clearly artificial and that shows the location of the repository. Ten-meter diameter craters could be created by a group of impacting satellites moving in order. Figure 1 shows a possible drawing created using craters that point to a central location. The Lunar Reconnaissance Orbiter (LRO) mission impact created two craters. The Centaur impactor weighed two tons and created a 20 meter diameter crater, which is not visible from Earth [62] because of fundamental diffraction limits that limited the size of visible features on the Moon. (For example, a telescope with a mirror of 2.5 m, like Hubble, will have an angular resolution of 2.5x10-7 rad, which is equal to around 100 m for a pixel on the Moon’s surface. To actually recognize a crater, an observer would likely need 2-3 pixels, so only objects 200-300 meters will be observable, and this does not take into account atmospheric aberrations for ground-based telescopes [63].)



Figure 1. Drawing using cratering of the Moon’s surface to show the location of the data storage in the center.

Such cratering should be located on the visible side of the Moon and in equatorial regions, so it could be viewed from Earth by a telescope even before the space era. To be viewable in a 1 m telescope, which has existed since the beginning of the twentieth century, the craters would need to be at about 500 m across, based on optical resolution limits. This would require a nuclear weapon or a many thousand-ton projectile.

A pattern of much smaller craters, 5-10 m diameter, could be drawn by impacts of 1 ton projectiles like the LRO, but they would likely only be found after space flights restart. (Turchin suggested a similar method for sending images over intergalactic distances using Dyson sphere drawings on a galactic plane [64]).

However, as was shown above, the equatorial part of the Moon may not be the best location for the primary storage of biological samples. Thus, it would be wise for the center of the drawing to include only the most important part of the information (that is needed to prevent X risks) as well as directions to the location of the biggest part of the message stored in a polar crater.

The message to the future could be divided into two parts:

a) an urgent and visible part, which will be engraved on the Earth side of the Moon by craters

b) a longer part, which will consist of human DNA, frozen biological tissues, and texts (preserved in a polar crater)

## 5.2. Engraving the message on the Moon’s surface using craters as dots

It is possible to draw even larger pictures on the Moon’s surface, using cratering as the drawing technique. Using 10 m diameter craters, society could put 10 kbit of information on a square kilometer of surface, and it could be readable for a hundred million years if no large impact occurred in this area. A larger pixel message using 200 m craters could even be readable from Earth and provide some short but urgent advice, such as “never experiment with new biological viruses!” in the form of a pictogram.

The beacon may be the most expensive part of the project if visible via Earth telescopes. At least 10 dots may be needed to draw a clearly artificial “arrow”. Many smaller craters may produce a crater field, like a hatch work, which could be part of the drawing.

Remnants of the last stage of lunar transport could be used as a cratering tool almost for free. Several last stages of Apollo were deliberately crashed into the Moon, and each weighed around 10 tons [65]. The crater size was around 40 m, but it was only found in 2016 [66].

## 5.3. Different ways to cost-effectively create the beacon drawing on the lunar surface

There are several other ways to create a beacon image on the surface of the Moon that may be cheaper than cratering, but they may require a special robotic lander to create them.

* An electrically powered tractor could slowly “print” a message by excavating dots or channels in lunar regolith, creating something like Nazca lines [67]. A major problem is that solar power will not work inside a polar crater. Radioactive decay could power a thermo-electric generator for the tractor, but it would also be extremely expensive and is beyond the reach of current technology because the trenches would have to be deep enough to last 100 million years. Such tractors were suggested for the mining of Helium-3 [68].
* A robot could collect stones and put them into lines or pyramids, which would be elements of an image. Humans also did this on Earth in Neolithic time when they created spirals.
* Creating tracks in lunar dust could create the drawing. It has been claimed that the footprints of astronauts will survive for millions of years. However, they may still erode in the 100 million years timescale because of meteorite ejecta and the ability of lunar dust to move by electrostatic forces.
* The beacon could be also created by a gradient of a rare and clearly artificial element (radioactive or not) that could point to the message location. An example of this approach working is a European meteorologist who was able to pinpoint the location of a Russian leak of Ruthenium-106 by its gradient distribution of this rare material over Europe [69]. This would likely not be detectable from Earth early in a future civilization’s development.
* Aluminum foil could be formed into an image that will be able to reflect light (but in that case, it should be on the side of the moon facing the Earth, not in a polar crater). Aluminum foil could also reflect radar (in this case, it could even be covered by dust). Even if the foil is destroyed by micrometeorites, its fragments will probably still provide enough reflection for ground-penetrating radar searching for water, and such radar will very likely be applied to shadowed pole craters.
* Aluminum powder could be sprayed by a lander around its location in some geometric form like a cross, which might differently reflect radio waves.
* A very stable and visible dye could be dispersed.
* Explosives could be placed on the surface for cratering in exact locations.
* It may be possible to put electric wires on the surface, and due to their conductivity, they could slowly attract electrostatically charged particles of lunar dust and form a visible drawing.
* A wall of stones would create long, visible shadows during sunset, 10 times larger than the wall height or more. Or, lunar dust could be used as a building material for such walls. Lunar dust could be used to produce something like waterless concrete (Lunacrete) [70].
* A very thin balloon could be used to stretch the material over surface. That is, a large inflatable structure is able to cover a large surface after it deflates.

# 6. Construction of the vault on the Moon for different budgets

## 6.1. Adding M-disks, Rosetta disks, and DNA samples to already planned Moon landers

The least expensive solution would be adding disks with information and some human DNA samples to the planned lunar missions in the near future. These could be more expensive Rosetta disks, where custom disks start at 25,000 USD, or M-disks. As an M-disk weighs only 20g, it would not change the total price of the mission significantly. Most problems would be organizational, such as creating data collection for the disk and negotiating with the mission providers. The coding system may also need to be changed so that it will be easy to decipher without a reader.

One company suggested a price of around 1.2 million GBP per kg for Moon delivery [71], so it would be 20,000 USD for one disk. Moon Express plans to charge 1.5 million GBP per kg for Moon delivery, and the first test flight was planned for the end of 2017 (now delayed to 2018) [72]. Only one mission actually landed on the Moon in the last 40 years (as of August 2017); that is Chang’E. It is not easy to estimate its price, as it was a Chinese government project. The lander mass was 1200 kg.

A small message could be put inside one of the legs of a lander, which naturally goes into the regolith around 10 cm during landing [73]. Many landers will drill for scientific purposes, and a small message could be put in the resulting hole.

A cheaper version of a subsurface message may be possible if a smaller digital-only message (no DNA) is placed 1-2 m below the surface. This could be near the lunar equator and would only carry around 10 TB of data (not 100 TB, as in case of LM1). An unrolled strip of foil could be used as a simple beacon. Electrostatic drawing in the surface using wires may be the cheapest variant, but its feasibility needs research.

A depth of 1-2 meters seems enough to protect against most temperature variation, micrometeorite, lunar dust, and radiation issues. Small crystal carriers could withstand the shockwaves of nearby small meteorite impacts. Using tungsten–nitride silicon technology, it is possible to make small disks, around 1 cm diameter, which could be put inside each leg of a spacecraft and in any hole a spacecraft would drill in the regolith. Many coin-size disks could lie on top of each other. A hundred of such disks may be able to provide storage of 100 GB of data, which is the minimum needed (see below). DNA samples would be even smaller. If the message is cheap and small, many copies of it could be added to landers, like tungsten data disks the size of a coin.

Micrometeorites will take a toll, probably in 10-100 million years (based on 1 mm in a million year natural micrometeorite erosion rate of the regolith [74] – see more in section 4.5), and could destroy the uncovered lander. If the disk is not covered by a large spacecraft, it would be damaged earlier.

The cheapest and earliest solution is adding disks with information to planned polar landers. However, Lunar One is experiencing difficulties, and the European Space Agency (ESA) has postponed its planned lander. The company Blue Origin has plans for a polar lander, capable of delivering 4 tons of cargo, in the Shackleton crater for 2020 [75]. The Chinese Chenge’4 may land near the lunar South Pole in 2018.

Beginning in 2017, plans for around two landers in different places on the Moon per year have been proposed by different players, including Japan, India, China, US private companies, and Google X prize competitors. Manned flights are realistic around 2030.

Based on the known tendency for delays in space program and organizational difficulties in funding and creating information carriers, the first disks could be delivered to the Moon in the early 2020s.

## 6.2. Specially designed lander with protection cover and boring equipment

The next stage could be designing a specialized lander with relatively large mass (like one ton, which has a one billion USD launch cost) that will work as a digital fortress. One variant is that it will require a sufficiently heavy shield in order to protect the information from temperature jumps, radiation, and micrometeorites.

The lander should be made from material that could be easily recognizable as an artificial object and may be covered by a reflective material. As the cover will be weathered, it could create a blot of remains around the lander, which may reflect radar and attract attention.

Another option for an automatic lander is to equip it with a drilling mechanism, which will drill several meters deep and put a payload into the hole, where it will be more protected from various potential damages. However, a large, specially designed probe could easily cost one billion USD.

However, a future research mission will almost surely drill into the Moon’s surface, especially near a pole, to explore its ice deposits, search for life, or get useful water. Thus, working with another similar mission could be advantageous.

In order to survive micrometeoritic weathering for 100 million years, if the spacecraft material were as resilient as the regolith, it would need to be 1 m thick. However, it is possible that the material used will be much more resistant to this weathering and a thinner layer would be adequate. If the casing needed to be 1 m thick, the spacecraft would weigh several tons, which is in reach of the proposed Blue Origin Moon cargo transport. However, it could still be damaged by nearby 1 kg range impacts.

The Moon has hundreds of pits from collapsed lava tubes, where a message could be put without deep drilling. These would provide greater protection but increase the complexity of building a beacon [76].

A bunker-buster bomb could penetrate deep under the lunar surface (tens of meters) and will be technically simpler than lander. However, its usability depends on the ability of the memory carriers to withstand the shock of impact and explosion.

## 6.3. Habitable Moon colony as building yard for very long-term information storage

Future manned lunar expeditions will include a lot of data and DNA samples, so they could be tasked to preserve some of it.

Elon Musk suggested creating a million-person Mars colony as a backup for Earth [77]. However, an intermediate and much cheaper step would be to create 10-100-person colony on the Moon. Using current technologies, it would still be 10 times more expensive than the International Space Station and would cost over 1 trillion USD. However, reusable rockets, robots, competition, inflatable stations, and additive manufacturing, as well as robotics with advanced AI, could make it much cheaper, with estimations starting at 10 billion USD [78].

Such a colony may not provide full sustainability, but it could provide a 5-10 year refuge, which would be helpful in a rather small range of catastrophes, like impacts or biological or radioactive contamination [7]. Most such catastrophes could be survived in Earth-based refuges [9].

Nevertheless, a habitable colony could be used to search for the most stable place on the Moon, like exploring pole craters and lava tubes, as well as building a surface drawing as the beacon (see below) by excavating trenches or by moving large stones. This project could be financially supported by space tourists, who would pay for the right to work on it.

The colony would be able to build much more durable storage, tens or may be even hundred meters below the surface, as well as much larger beacon drawings. Scientific research *in situ* will provide much more durable solutions, and the colony could record the data about the location.

If the colony were to fail, remnants of the colony itself and of its dwellers would remain for a very long time and would provide a snapshot of human life, as well as a large source of information, for future space archeologists. The parts of the colony under the surface will survive particularly long. Such a Moon colony would be able to create the most durable and most visible information storage in the Solar System, which could probably survive one billion years. In addition, multiplying types and numbers of storages will ensure protection from random events like meteor impacts and mistakes in prediction of the future evolution of the Solar System.

# 7. Content of the message

## 7.1. Language of the message

This section explores the content of an ideal message, which is one without size constraints and that is aimed at the resurrection of humanity. The problem of maximally clear messages (anti-cryptography) was explored in METI [79]. Turchin explored self-evident messages consisting of drawings and videos in [64]. Wolfram has a large review of messages language [80].

At first, the message should teach the next civilization human language, probably using pictures and movies. Also, Rosetta disks could help teach language, as their content was designed specifically to do this. It may be assumed that a complete textbook is possible, but creation of such a textbook may be an expensive part of the whole project. Existing sources, like movies and ABC books, could be recorded.

## 7.2. The message must persuade the next civilization to recreate us

The message introduction should try to persuade the receivers that:

1. It is safe for them to return Homo sapiens to life.
2. Humans very much want to be resurrected.
3. Human reconstruction will be beneficial to the next civilization.
4. It will be fair from the cooperative decision theory point of view.

There are risks associated with receiving messages from aliens, that is SETI-attack [81]. It is clear that a future civilization may hesitate to recreate human beings and human culture if it feels any threat to itself. This is especially true if they know that humans created a catastrophe that caused human extinction. It would also require much more complex biotechnology to resurrect humans than currently exists. Therefore, the next civilization would probably do it only after they master their own powerful AI [5] and can be sure that humanity’s message does not contain any dangerous code. They may also have some moral consideration regarding resurrection, just as current humans have about recreating Neanderthal man and fearing that they will suffer in a world to which they are not adapted.

Safety should be guaranteed by the fact that they should try to recreate us only after their civilization has become more advanced than ours was at the moment of the sending. Also, if another civilization is able to appear after our demise, then that generally indicates that the global catastrophe was lower-tech and did not destroy all life and that it happened before humanity was able to create our own AI or molecular manufacturing. (If Earth survived, high-energy collider risks are also excluded.)

The message senders should also provide the most useful information, probably about global risks, first so that the receiving civilization could implement it immediately. However, humans do not currently know what our worst global risks will be, and e may not know until days before the end. That is why it would be valuable to have a constantly working recording device at the Moon storage, which could record data based on the latest updates from Earth, like a news stream. Such a device would only need to record a rather small amount of information, perhaps 100 kB a day, which will be enough to reconstruct events on Earth in the days before the catastrophe. But to be able to do so, it must constantly record for years, and it should be located at an equator storage location (while the largest and most fragile part will be at a pole crater because it will not be needed urgently). If transmission from Earth stops, the recording device would place the prepared disk into a deep hole beneath itself and fill the hole with protective material from above.

## 7.3. Information content of the message

The next part of the message will have the majority of the valuable information.

1) Human DNA. Human DNA from different people should be preserved in digital form. DNA from hundreds of people would guard against inbreeding. However, as some molecular mechanisms, such as ribosomes or even genetic code, could change in the next 100 million years, it will not be enough, and other information about human cells should be preserved. DNA should be preserved as a small, dry piece of tissue, like dried blood (perhaps chemically fixed).

2) Biological samples. These should include frozen human embryos, seeds, or even cryopreserved patients (who may pay for such long-term storage and cover part of the price of the project). Different methods of chemical fixation could be used. There is little hope that these biological samples will remain viable even at -245 C in the coldest places, because of the many types of damage to very small features, but they could be analyzed and help in the reconstruction of humans. Other animals and seeds may be also cryopreserved.

3) Cultural and scientific information. This includes the most valuable books about humanity, a snapshot of the Internet, an archive of scientific data, and movies.

## 7.4. The size of the message

Larger messages are more expensive, and smaller coding regions are more vulnerable to radiation and other damage. However, in order to maximize the probability of the resurrection of humanity, one needs to send a very large amount of information that can last for a very long time—at least 100 million years. This is much larger than was previously sent on satellites or in time capsules. The larger the information content of the message, the greater the chances that humanity will be adequately resurrected with all its valuable features.

The minimal size of the message should be around the 100 GB, and this is possible with existing technologies. A typical book size is around 1 MB. The English Wikipedia text size is around 10 GB [82]. In digital form, a full human genome has three billion base pairs, which is equal to 700 MB of information [83]. One could preserve just the differences between many thousands of human genomes because humans are 99.9% similar to each other [84]. Therefore, sending something like 100 GB will provide a large part of human culture and sufficient human genetic diversity. An advanced form of the HD Rosetta technology is HD-ROM, which could store 160 GB, and the latest M-discs could also store 100 GB each.

# 8. Discussion/future work

## 8.1. Framing the cost-effectiveness problem

There are many “ifs” in the question of this proposal’s cost-effectiveness. The catastrophe that destroyed humanity would need to be of a narrow enough range to kill humans but not all life, and no more catastrophes of similar magnitude could happen after. Then, either a new civilization needs to appear on Earth after the present civilization’s demise, or aliens would need to visit. The message also needs to survive long enough and be found. Furthermore, the next civilization needs to be willing and able to re-create humanity. This re-creation could be a small fraction of the current number of individuals and would have uncertain duration. Since there is already another civilization that could colonize the galaxy, the potential value added by re-creating human civilization would likely be much less than the value of having one civilization (unless the message reduced X-risk for the new civilization). Therefore, there is great uncertainty in assigning the value of this proposal relative to other X-risk reduction opportunities.

As for the cost, opportunistic payloads, with a weight of no more than 1 kg, on already planned scientific missions are possible in the next decade (2020s). In that case, this means preserving less than 1 TB of data and budgeting around one million USD. However, chances of a successful civilizational resurrection from such single messages are minuscule, as they will most likely be lost. However, if an opportunistic payload is connected to some lunar polar lander that is going to take underground probes, this increases chances for long-term data survival and for some future civilization to find the probe, as the pole provides shelter from temperature and temperature fluctuations and will attract the attention of any future civilization. Data storage could be an opportunistic goal for future manned missions.

If the effort were able to tap into funding opportunities such as lunar tourism and personal immortality quests and/or burials, more expensive projects might be feasible; advertising of the new preservation technologies like silico glass 5D storage may also help.

If sentiment changes in the next decade and X-risk prevention becomes a global priority, or if space exploration technologies become much cheaper, larger projects could be undertaken. For instance, there could be lunar drawings, deep polar drilling, and new data preservation technologies undertaken after 2030, which could provide more data storage for a longer time and with better visibility.

## 8.2 Alternate locations for information preservation

There are several other possible places for data preservation, including Mars, metal asteroids like Psyche 16, Earth’s satellites on the graveyard orbits, and even cratons on Earth. Mars and asteroids are more expensive to reach than the Moon, and the information would likely be located later in the next civilization's development. They do have the advantage of surviving a greater increase in solar output. Graveyard orbits around Earth are typically higher than geosynchronous. These could be stable for long periods of time, though they would be more exposed to bombardment than if they were under the Moon's surface. There would also be some thermal cycles. On Earth, long-term storage is already built for radiological waste preservation [85]. These are generally not built to withstand a greater than 100 million years timescale. However, micro fossils have been preserved this long [86], so it may be possible to choose a location that is not likely to be destroyed. The temperature underground would be higher than on the Moon's equator. However, choosing materials with very low mass diffusivity, like nickel or quartz, could still preserve information over long periods as long as the feature size is not too small. More research (e.g., on the impact of the radioactivity on information preservation) is required to establish the feasibility of this technique. Since radioactivity is likely to have long dissipated, it may be that archaeologists will explore these mines early in the next civilization's development.

## 8.3 Plan of action for information preservation

Based on the expected reduced price of space exploration in the future, as well as the decreased size and increased capacity of information carriers, including several steps in the message creation process will likely be the most cost-effective plan (though the authors do not claim that this would be more cost effective than other X risk interventions).

1. Currently, the most cost-effective solution would probably be to invest in creating a high-quality message within the size range of 100 GB – 1 TB and with a mass of ~20g. The plan would be to explore ways to add it for near free to all planned lunar landers and space probes, especially the ones that are going to explore and drill in polar regions. Copies could also be put in some special locations on Earth, like nuclear waste depositories. This may require a budget of several million USD and a few years.
2. After cheaper access to the Moon is established, a specialized mission could be planned, which could include a surface drawing tractor and subsurface boring machine, similar to LM1. It should also include the capability to constantly record a data stream from Earth to “catch” information about a catastrophe. Such a system could be created after 2030 or earlier if large funding is attracted. The later the message is created, the higher the chances that a catastrophe will happen before the message is deployed.
3. If a habitable lunar colony is created, it could work as backup information storage with large subsurface bunkers and surface beacons, as well as a refuge for a small group of people to survive shorter and reversible catastrophes.

# Conclusion

This article explores possible ways to preserve enough information about human civilization for it to be reconstructed by the next civilization on Earth. The analysis includes the size of the message, required duration of its preservation, the places where it could survive until a new civilization appears, the use of a beacon to attract the attention of the future civilization, and the motives and arguments that could encourage the next civilization to reconstruct our civilization.

Several relatively low-cost ways to send such a message were identified. One method is the use of opportunistic payloads on the Moon landers, and, later, the use of a Moon base for data preservation. Another method is putting the message on Earth in a nuclear waste repository. Future work is required to assess the cost-effectiveness of these proposals in comparison to other X risk reduction interventions.

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# Appendix A. Alternative locations of long-term data storages

## 1. Cratons on Earth and beacons in them created using cavities

The most stable places on Earth’s surface are cratons, some of them include very old rock with age 3-4 billion years. These pieces of crust were not recycled by plate tectonics, as they have higher buoyancy. Scientists will probably be able to calculate which part of Earth will remain on the surface for the next billion years, and most probably it will be the same old cratons. Based on resent models, the age of cratons is ending [87], as mantle viscosity grows and increases convection stress. However, we assume that some cratons may exist for the next several hundred million years or more.

The oldest rocks will attract attention of future scientists. But if a hole is drilled in a large crystal massif and a small disk is placed inside, it will probably never be found. So the main problem would be creating a beacon, which will show where the message is located. Remnants of underground nuclear explosions inside a crystal shield may play the same role as crater drawings on the Moon. Another option to create a beacon is use the gradient of a rare element interesting for future scientists to point to the direction of the message.

A large project exists of geological storage of radioactive waste at 420 m depth in a granite shield: Onkalo project in Finland [88]. Burial places are selected to be very stable (but may be not the best in the world because of social factors) Rare materials and radioactivity from the storages could be used as a beacon, the same way as isotopic changes helped to identify natural uranium nuclear fission reactor in Gabon, which remained in place for 2 bln years [89]. If empty tunnels are filled with concrete after the project is finished, they may remain their structure for a very long time.

If the data were placed in the Onkalo hole, there will be zero expenditures on construction, and positive PR for the project by data preservation, so it could be funded from its advertisement budgets. It expected to provide protection for at least 100 000 years and able to survive weight of a new glacier during next Ice age. Steel containers are designed to withstand pressure even if the rock wall collapses. The price of the project is around 5 billion USD [85]. The main problem is to make future archeologists interested in excavating the tunnels. Many copies of the messages may be placed in the different places of the tunnels for a small percent of the total project.

Another nuclear waste management project is drilling a 5 km borehole in North Dakota, U.S. in crystalline rock.

The fact that scientists have found large skeletons of dinosaurs, or early insects’ imprints inside rock, demonstrate that information can be sent on Earth hundreds of millions of years into the future. If the message is imprinted in solid stone, it could survive geological epochs.

## 2. Mars and other celestial bodies

Mars is less attractive than the Moon for long-term information storage. Mars has an atmosphere and weathering is much greater. Also, Phobos will fall on Mars in a relatively short time (30-50 mln years), and as it has 8 times bigger volume than the Chixulub asteroid that likely wiped out the dinosaurs. A Phobos impact would create a planetary catastrophe, which probably will cover most spacecraft with dust and other ejecta. So, Mars could be used as a place of information preservation for no more than 30 mln years.

Most icy moons are too unstable, and the only other big rocky moon of Jupiter, Io, is very volcanic. Most Oort cloud objects are also icy and very distant. Mercury is difficult to reach and hotter.

After the Moon, rocky or metallic asteroids could be the best places for information preservation, but they don’t provide easy access or simple beacon-creating opportunities.

## 3. Metal asteroids and 10 billion year information preservation

Preservation of information for even longer time, such as 10 bln years, may require use of a metal asteroid as its carrier, located as far as the Oort cloud, where it could survive the Sun’s red giant phase. However, we do not know of any metal objects in the Oort cloud, as it mostly consists of icy comet bodies. Some inner Solar System material may be ejected there [90], and from 8 billion ejected asteroids some could be large metallic ones.

One of the possible candidates for very long-term preservation is 16 Psyche, which is the biggest metal asteroid in the main belt, and the 10th largest overall asteroid, which will surely attract attention of future scientists. Metal asteroids could provide better protection from impact damage, radiation, and energetic particles than rocky or icy surfaces, as well as being stable at higher temperatures. As Sun loses its mass, asteroids will migrate to further regions of the Solar system and probably escape falling into the Sun in the red giant phase or evaporation [91].

Metal asteroids will be attractive to any civilization mining asteroids, so a message on it could be found by an alien civilization, which may visit remnants of the Solar system.

Placing a message on a metal asteroid could be done in parallel with asteroid mining, which would provide funding for such a project as well as transportation to the metal asteroids and needed tunneling equipment.

NASA plans to send a probe to Psyche in 2023 with ETA of 2030, so there is a chance for an opportunistic payload.

Use of self-replicating robotics will enable quick exploration of Solar system, and even creation of “live remnants”, that is some form of mechanical life, which could live after humans, like space grey goo. But after creation of self-replicating nanotech, the field of possible global risks will change.

## 4. Satellites

A heavy satellite on relatively high Earth orbit could exist a very long time. The main risks for a satellite are micrometeorite erosion, temperature changes, and gravitational perturbations. A specially designed satellite with a message could be a large lead ball in an orbit above geosynchronous orbit. Its orbit should be orientated in a way that tidal forces will make it rise, the same way as the Moon’s orbit is constantly rising. With an equatorial orbit, the number of light dark cycles would be far higher than on the moon. However, a polar orbit could avoid light dark cycles if the orbit remained stable.

The benefits are that many satellites already exist and some information carriers could be added to new satellites. Satellites are easily observable even with naked eye, and their artificial origin would be rather obvious based on their chemical composition. One planned data storage satellite is Asgardia [92]. The Russian company Kriorus is planning to send frozen brains into orbit [93]. Students are planning a space time capsule [94].

In 1976, the satellite LAGEOS was sent on an orbit 6000 km above Earth with a plaque with a message to the future designed by Carl Sagan. It is estimated that it will fall into Earth in 8.4 mln years (Popular Science, 1976).

In 2012, an artist created a silicon disk with 100 images and put it on geostationary satellite Echostar 16, which will be later moved to a graveyard orbit, where it is expected to remain for billions years [96].

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# Bio:



Alexey Turchin (1973) is the author of several books and articles on the topics of existential risks and life extension and has been published in the journal *Futures* and *Informatica*. He graduated from Moscow State University where he studied Physics and Art History (1997).  Since 2010 he has worked on various topics involving life extension and risk prevention for the Foundation Science for Life Extension.  He is a contributing author on IEET. His main publications:

1. Turchin, Alexey, and Brian Patrick Green. "Aquatic refuges for surviving a global catastrophe." Futures 89 (2017): 26-37. https://www.sciencedirect.com/science/article/pii/S0016328716303494

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4. Turchin, Alexey, and David Denkenberger. Military AI as a convergent goal of the self-impriving AI. In edited volume: Artificial intelligence safety and security, CRC, 2018



Dr. David Denkenberger received his B.S. from Penn State in Engineering Science, his M.S.E. from Princeton in Mechanical and Aerospace Engineering, and his Ph.D. from the University of Colorado at Boulder in the Building Systems Program. His dissertation was on his patented expanded microchannel heat exchanger. He is an assistant professor at Tennessee State University in architectural engineering. He is also an associate at the Global Catastrophic Risk Institute. He co-founded and directs the Alliance to Feed the Earth in Disasters (ALLFED). He received the National Merit Scholarship, the Barry Goldwater Scholarship, the National Science Foundation Graduate Research Fellowship. He is a Penn State distinguished alumnus and is a registered professional engineer. He has authored or co-authored over 75 publications and has given over 90 technical presentations.