Phoenix

Final Report

International Space University

Summer Session Program 2007

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Abstract

Since the birth of the Solar System, the Earth has periodically suffered from catastrophes that have caused temporary extreme environmental changes and mass extinctions. The question is not if, but rather when the next mass extinction will occur. The main unknown is whether or not humanity will survive. Humanity can deal with this threat in two ways: by attempting to avert destruction and by planning its recovery. Should a catastrophe prove unavoidable, one method of recovery would be the establishment of an accessible archive of human knowledge in a safe location off Earth.

We, the members of the ISU 2007 Summer Session Program Phoenix team project, contend that this archive should be placed on the Moon, where it will be safe from damage, degradation, and interference. We recommend the creation of a Lunar Archive Program to manage the archive and a system of complementary terrestrial repositories. Additionally, we delineate the advocacy, design, implementation, content insertion and updating steps necessary to establish and maintain an archive that will aid in the short-term survival, mid-term societal growth, and long-term recovery of the human race and its creations.

In writing this report, we members of the Phoenix project team intend to attract world attention to the issue of perpetuating human civilization in the face of known threats. We are aware of other similar initiatives. We present this Lunar Archive Program as an alternative characterized by lower initial cost and greater reliance on advanced robotic technologies. Through new ideas and rigorous argument, we intend to demonstrate the validity of this program concept. We exhort other professionals to study the feasibility of our recommendations and expand on the initiatives presented here. We believe that only through thorough study, public examination, and long-sustained resource commitments can this Lunar Archive Program become reality. If successfully launched and made a part of our heritage, a lunar archive can possibly one day help rebuild a shattered human civilization.

Faculty Preface

The three purposes of ISU team projects are (a) to address an issue of current world importance, (b) to give students experience in intercultural teamwork under pressure of time and resources, (c) to generate a report influential in the world beyond ISU and beneficial to the students in their later careers. This report deals with risks to our civilization on Earth. Global catastrophes, greater than any known in human history, have happened and will happen again. Modern technological societies are very vulnerable to such events. The charge to the Phoenix project team was to examine ways to increase civilization's chances of recovery. This may be possible by implanting vital information safely in the Moon and providing dispersed Earth repositories with supplies for immediate human survival and an ability to call down the stored information. This report discusses issues needing attention and offers possible solutions. The program described here presents new challenges: How far back from today's affluence will the survivors be driven? What are the most important contents of the lunar archive and the repositories, both for a rebirth of society and for its return to a creative, just, and sustainable state? What can be done to reduce the fragility of today's advanced societies? Here the members of team Phoenix present illustrative examples and argue for a vigilant, worldwide program that starts small and is intended to grow toward encompassing a great archive of human knowledge and wisdom in the Moon.

James D. Burke
Faculty Lead

Kilian Engel
Teaching Associate

Student Preface

At the top of a palm tree, a bird's nest catches fire. It has been ignited by a spark struck from the hooves of celestial steeds drawing the chariot of Ra, the Egyptian sun god. Amid the flames a beautiful Arabian bird extends its golden neck and purple wings, but instead of flying off, it dances. Eventually it is consumed by the fire and reduced to ashes; but this is not the end. Indeed, it is only the beginning; later a new bird is reborn from those ashes.

The phoenix is able to rise from its ashes when it dies. It repeatedly overcomes death and is able to continue its journey till the twilight of time. Humankind, although the most advanced species on Earth, is still highly vulnerable to a global catastrophe that would dramatically change the environment of our planet. We have the power and the means to ensure the survival of our species.

This was the mission we were given on 26 June 2007, when we joined the team project *Lunar Biological and Social Archive*. We decided to join forces to produce an innovative piece of work that would inspire others to build on this reflection. We are not proposing a particular solution. Our Phoenix team project ends on 25 August 2007. A Lunar Archive Program is a priority for humankind. We urge leaders to begin this initiative to give humanity a chance to rise from the ashes of catastrophe.

Preserving human heritage is a concern shared by human beings regardless of their origins. This same concern has allowed us, 23 people from 10 different countries, to work together and transcend our differences because we kept in mind the higher goal driving us. Our common vision explains how successful and enjoyable working together has been.

We want to thank all the people involved with this project. We hope they enjoyed it as much as we did. A particular thank you goes to our co-chair Jim Burke and our Teaching Associate Kilian Engel. They have been instrumental in the success of this work and their commitment is worthy of admiration.

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List of Acronyms

A	
AI	Artificial Intelligence
D	
DDS	Dewey Decimal System
E	
ESA	European Space Agency
G	
GDP	Gross Domestic Product
H	
HYV	High Yield Varieties
I	
ICBM	Intercontinental Ballistic Missile
IGO	Inter-Governmental Organization
ISU	International Space University
ITAR	International Traffic in Arms Regulations
J	
JAXA	Japanese Aerospace Exploration Agency
N	
NASA	National Aeronautics and Space Administration
NEO	Near Earth Object
NGO	Non-Governmental Organization
R	
RTG	Radioisotope Thermal Generator
S	
SSETI	Student Space Exploration Technology Initiative
U	
UNESCO	United Nations Educational, Scientific and Cultural Organization

Chapter 1

Introduction

孔子曰：人无远虑，必有近忧

People without long term plans, must have near term worries

Confucius

English translation by Zhang Yuhua

Mission Statement

The Phoenix Project outlines the content, technical design, and program implementation plan for a robotic lunar archive, with associated terrestrial components, to aid the immediate recovery and long-term rebuilding of Earth's dynamic and multicultural civilization following a global catastrophe.

Imagine an open-roof museum where you can see all the wonders that make human civilization great: Da Vinci's Mona Lisa and Australian Aboriginal art; China's Great Wall and Dubai's Towers; and a carefully cultivated vineyard and a field of sunflowers. What a wonderful museum it would be.

Now image that there are no notices and no one in this museum: no guards, no tour guides, no art students drawing copies of paintings. No tourists. You are alone in this museum, ambulating among all those wonders. You have tons of questions but nobody to answer them. You leave this fascinating museum without knowing more than when you entered it.

This museum is Earth. Our planet is a huge living museum, always in movement, its people are always creating, thinking, improving their knowledge, trying to understand where it all comes from and where it is going. What makes this museum so marvelous is the people living in it and explaining why it has been created, under what circumstances, and with which material. These people explain to us how to use each particular object and how it will make life better or easier.

If there is no one to transmit the knowledge and the know-how, then our museum is useless. It is a giant step back in history, a step back into a dark age. Our museum is very fragile. It is also unique, making it even more fragile. Our spaceship Earth, evolving in the deep universe, is not safe. We are constantly threatened by our surroundings that may cause extinctions of species and collapse of society. There is much evidence illustrating how past catastrophes led to massive disasters. The extinction of dinosaurs, due to a collision between Earth and an asteroid, is one example. Now, some samples of dinosaurs can be seen in our natural history museums. Our embryonic plans to avert such a collision could fail. What if *we* replace the dinosaurs in the museums one day?

The danger does not come only from outer space. Supervolcanic eruptions are possible and cannot be avoided. Thirty years ago, humanity was on the verge of global nuclear war that could have destroyed our ecosphere. We are strongly dependent on modern but vulnerable support systems such as universal electricity and fossil fuel. Our agriculture will not support a swift and unstoppable upset in ocean chemistry and global climate. Today, recognition is growing that our resources are finite, our technology is limited, and our society may face threats that we cannot neutralize. If we did face a scenario with the population devastated, the infrastructure destroyed, and the environment upset, would our civilization be lost forever? Our current system is not robust enough to survive a catastrophe. We must prepare ourselves for future catastrophes. We have to establish a planet-scale strategy to help survivors in immediate recovery and long-term rebuilding of society.

If Earth is not safe, how shall we provide this help? Let's reproduce what the ancients did when facing a problem: let's look to the heavens!

One way to increase robustness is through redundancy. The Moon is the appropriate location to store humanity's knowledge and wisdom. If an archive is not only on Earth but also a copy of it safely stored off Earth, then we do not have a single point of failure. The Moon is our backup. It is quiet, with a stable environment: almost no seismic activity or volcanism and the subsurface temperature is low and constant. If the worst happens and we are forever wiped clean off the face of the Earth, the lunar archive will be the testimony of what humankind once was.

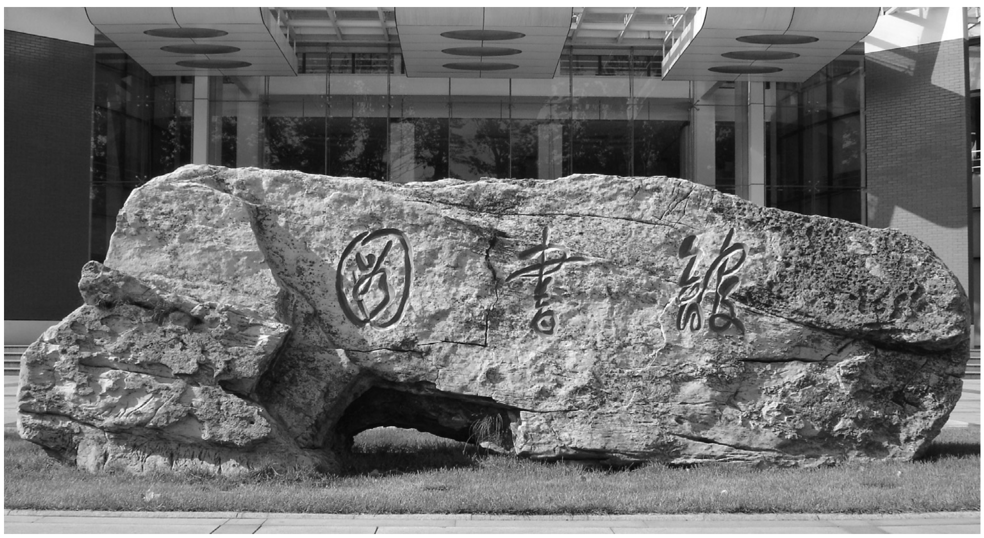

Figure 1-1: Beihang University library stone (Translation: Library)

Another reason for storing our knowledge on the Moon is its particular connection to us: everyone can see the Moon every day and no one has to manage it. In a sense, the Moon offers direct service to the consumer. After a catastrophe, there would be no immediate capability for a terrestrial communications network. Survivors with access to the lunar archive would have the essential information for them first to stay alive and later to rebuild.

The Phoenix team's report is based on the premise that, for the first time in human history, we have the technological capability to enable the survival of our civilization after a global catastrophe. An archive of our past, current, and future society could be situated on the Moon, complete with technology enabling the return of information to the Earth. This lunar archive would be part of a larger recovery infrastructure based on Earth. That infrastructure, designed as a widely distributed network of repositories around the world, would cover people's immediate survival needs as well as medium-term recovery and long-term rebuilding.

This report is not a proposal but the validation of a concept. It will address the Lunar Archive Program in four main chapters:

- Scenarios: three different scenarios describing the catastrophes and their consequences

- Content of the archive: information and equipment to be stored, both on Earth and Moon, to provide immediate help, a basis for societal growth and long-term recovery
- Technical design: design, maintenance, upgrading, and use of the lunar archive and Earth repositories
- Program implementation: gaining the support of the world community and executing the Archive Program with due regard for Earth and space law

After a catastrophe the remains of humanity will be spread sparsely across the world. An archive must include information on all cultures and be accessible to all possible survivors. We believe our report will be valuable to representatives from all national, ethnic, religious, social, and cultural groups. Let's hope the wisdom gained from awareness of our history and culture can help to create a new society, aware of our past mistakes and able to build a positive, sustainable future.

Chapter 2

Global Catastrophe Scenario

2.1 Introduction

Many possible disasters would warrant the need for a lunar archive to save what would be left of humanity. Certain scenarios are preventable, but may occur due to changes in political environment, such as a nuclear war or a world-wide biological terror attack. Some scenarios are inevitable if humanity fails to prevent an accident or simply fails to act to deal with it, such as a Near-Earth-Object (NEO) impact (NEO is a large object, asteroid or comet, whose orbit brings it close to the Earth and also gives it the possibility to hit the Earth). Other threats, such as the supervolcanic eruptions known through Earth's geologic record, are beyond any human countermeasures. This report addresses global catastrophes. The measures envisioned are also useful in the event of regional disasters. Hereafter, the word *catastrophe* refers to global scale events, the word *disaster* to regional or local events.

In the event of a catastrophe, there are two different types of destruction: massive infrastructure damage and enormous casualties. The worst events would cause both, leaving what is left of humanity without the basic needs for survival and in sparse groups unable to communicate with each other.

This report focuses on how a lunar archive is essential for catastrophes that cause both infrastructural damage and vast loss of life. The three most threatening scenarios are:

a) NEO Impact
b) Nuclear War
c) Super-volcanic Eruption

Any of these events will cause a drastic decrease in sunlight and upset ocean chemistry.

A lunar archive can contribute to recovery from other disaster scenarios that do not involve both instant, world-wide, large-scale structural damage and loss of life. Examples are global pandemics, biological attacks, and gradual, global climate change. If only large-scale loss of life occurs, the basic infrastructure would remain without people to operate the equipment. There would not be a need to store plans for building structures like power plants or water treatment facilities. These scenarios are not considered here but if they were to occur, a lunar archive could help in the recovery process.

2.2 Scenario Descriptions

2.2.1 NEO Impact

Planet Earth is continuously bombarded with small pieces of extraterrestrial material. Every day small bits of rock, ice, and dust enter our atmosphere but are vaporized without causing any ill effect. The universe is not always so kind as to provide only small objects; now and then it provides much larger objects that will not be vaporized. Instead these impacts cause widespread destruction.

The destructive power of NEOs is best shown by two examples:

- The first example is the Tunguska event of 1908 in remote Siberia. During this event an object (probably a comet) entered Earth's atmosphere, felled an estimated 80 million trees in a 2150 km^2 area and threw two reindeer herders off their feet (they later died from their injuries). Had this object hit a more populated area, its impact would have resulted in the destruction of an entire city. (Alphonso 2005 and Gallant 1994)
- The second example is the object (probably an asteroid with a diameter in the order of 15 km) that destroyed the dinosaurs 65 million years ago. Its impact created the Chicxulub Crater in the Yucatan peninsula of Mexico and ended the 100 million year reign of the dinosaurs on Earth. (Alphonso 2005, Alvarez et al. 1980, and Gosling 2004)

The geological and astronomical records say that on average Earth takes a city-destroying hit every 10,000 years (Tunguska), a country-smashing one every 100,000 years (Barringer Crater), and a devastating species-eliminating event every few million years (Chicxulub). The time between these impacts is long in comparison with most human planning horizons, but one must remember that they are statistical: any of these events could happen tomorrow. (Lewis 1996).

Let us look at the effects of a species-eliminating object impact, such the one that killed the dinosaurs. Such impacts are extensively described in other literature (for example, Alphonso 2005, Collins et al. 2005, and Gosling 2004), so only a short overview is provided here. During the impact, the large kinetic energy of the impactor is converted into other kinds of energies. The following example uses an asteroid the approximate size, density, inclination, and speed as the one that killed the dinosaurs. The effects were calculated using the software program described in Collins et al. (2005):

- Kinetic energy: Part of the kinetic energy deforms the Earth, creating an impact crater. In this example, the crater had a radius larger than 150 km.
- Heat energy: A large flame with an extremely high temperature forms, similar to a pedestal during a nuclear explosion. The heat emitted by the flame sets the environment on fire. For our example, everything in a radius of 1500 km burned.
- Seismic energy: The impact causes a huge earthquake, with the earthquake center at the ground zero of the crater. The effects of are felt around the world. In the case of a dinosaur-killing impact an earthquake of 10.6 on the Richter Scale was generated, which is 1000 times stronger than any earthquake in known history.
- Atmospheric energy: A shock wave propagates away from the impact site, compressing the air into high pressure that can pulverize animals and demolish buildings, vehicles, and infrastructures. Immediately behind the high-pressure front, violent winds ensue that may flatten forests and scatter debris.
- Tsunamis: If the NEO hits water (very likely, as the area of the Earth is 70% water) a train of tsunami waves would be created that can reach every coast around the world.
- Dust cloud: A dust cloud results in a post-impact winter. Part of the energy of the NEO throws large amounts of dust particles into the air. These particles cover the Earth and reduce the solar flux, decreasing the surface temperature.

Assuming an impact in one of the oceans, the following scenario evolves: Directly after the impact everything within a distance of 1500 km is completely destroyed. Due to the resulting tsunami all coastal areas around the world are devastated.

Due to the post-impact winter, agriculture as we know it along with civilization will almost surely collapse. After this collapse some humans might survive by returning to a pre-industrial lifestyle (Sagan 1994).

2.2.2 Nuclear War

In case of a hypothetical, global nuclear war the main effect is nuclear winter. The number of nuclear warheads (Table 2-1) and other weapons of mass destruction allow the possibility for the creation of mixed residuals of radioactive and biological dust and ashes.

Table 2-1: Nuclear warheads per country (Natural Resource Defense Council 2006)

Country	Warheads active/total	Year of first test
United States	5,735/9,960	1945 ("Trinity")
Russia (formerly Soviet Union)	5,830/16,000	1949 ("RDS-1")
United Kingdom	200	1952 ("Hurricane")
France	350	1960 ("Gerboise Bleue")
China	130	1964 ("596")
India	70-120	1974 ("Smiling Buddha")
Pakistan	30-52	1998 ("Chagai-I")
North Korea	1-10	2006 ("The Beginning")

Israel may have an undeclared arsenal of between 75 and 200 warheads. There are also some states such as Iran, Saudi Arabia, and Ukraine that have been accused of having nuclear programs.

The detonation of a fission nuclear weapon in outer space should also be taken in account (Wertz and Larson 1999). Such a detonation emits 80% of its power in X-rays, with the rest of the energy in gamma rays, neutrons and debris. An electromagnetic pulse is also generated. X-rays and gamma rays hit satellites, inducing high voltages that can damage sensitive components. The gamma radiation has a short life (μsec), but positrons, neutrons and electrons have a longer life (on the order of magnitude of years). An artificial Van Allen Belt forms that can damage a satellite by inducing charges, currents, and voltages that may burn or damage sensitive satellite subsystems. This demonstrates that an archive in low Earth orbit would be useless since it would be destroyed by a nuclear event. Furthermore, radio communications will be interrupted.

It has been estimated that a 10,000-megaton war with half the weapons exploding at ground level would tear up some 25 billion cubic meters of rock and soil. If we apply very rough yardsticks to a large-scale nuclear war in which 10,000 megatons of nuclear force are detonated, the effects on a world population of 5 billion appear enormous. Allowing for uncertainties about the dynamics of a possible nuclear war, radiation-induced cancers and genetic damage together over 30 years are estimated to range from 1.5 to 30 million for the world population as a whole.

Depending on distance and intermediate shielding from and strength of a dirty fission nuclear detonation, severe radiation poisoning can cause death within 10 days for 100% of victims, while only 50% survive moderate radiation poisoning after 30 days (Radiation Injuries 1998). Deaths from radiation peak three or four weeks after nuclear blasts and stop occurring after seven to eight weeks. It is not known how much plutonium is required to induce lung cancer in humans, but estimates are as low as a few millionths of a gram. (Martin 1982).

According to a recent National Academy of Sciences study, the effects of nitric oxides driven into the stratosphere by an all-out nuclear war (involving the detonation of 10,000 megatons of explosive force in the northern hemisphere) produced by the weapons could reduce the ozone levels in the northern hemisphere by as much as 30 to 70%.

A National Academy of Sciences report concludes that in 20 years the ecological systems would have essentially recovered from the increase in ultraviolet radiation--though not necessarily from radioactivity or other damage in areas close to the war zone. However, a delayed effect of the increase in ultraviolet radiation would be an estimated 3 to 30 percent increase in skin cancer for 40 years in the Northern Hemisphere's mid-latitudes (U.S. Arms Control and Disarmament Agency 1996)

2.2.3 Supervolcanic Eruption

The threat of a global catastrophe from a supervolcanic eruption is the only scenario considered in this report that currently has no means of being averted. A NEO can be deflected, as described in Ailor (ed.) et al. (2007). A global thermonuclear war can be avoided with political prowess. The means of preventing a supervolcanic eruption have not even been tackled in science fiction. A future eruption is inevitable; the question is not if, but rather when the next eruption will occur.

Compared to recent volcanic activity, a supervolcano is far more destructive. The eruption of Mt. St. Helens in 1980 released less than 1 km^3 of ash. The eruption of the volcano Tambora in 1815 spewed approximately 50 km^3 of ash into the atmosphere. The ash stayed in the air for several months and produced what is known in Europe as the year without a summer. (Sparks et al. 2005)

Supervolcanoes have been linked to several mass extinctions in Earth's history. Although scientists are still debating the issue, Koeberl et al. (2004) have found that there is no extraterrestrial evidence for the largest extinction in Earth's history - the Permian-Triassic boundary event, also known as the Great Dying. Most of Earth's marine species and over 75% of plant and animal life became extinct then. Prehistoric humans may also have been threatened by supervolcanic eruptions. According to Sparks et al. (2005) several supervolcanic eruptions have occurred over the past 40,000 years. The estimated eruption size of 300 km^3 of magma corresponding to 750 km^3 of ash would have had severe global consequences.

The frequency of supervolcanic eruptions is a greater concern than the threat from NEOs. Prof. Michael Rampino has estimated that a 1000 km^3 eruption would be comparable to a 1.5 km diameter NEO impact. The average frequency of supervolcanic eruptions is five times higher than a comparable NEO strike (Sparks et al. 2005).

2.3 Environmental Effects

The global effects in the three scenarios will be similar and are summarized in Table 2-2 below.

Table 2-2: Overview of the effects of the three scenarios

	Atmosphere	Surface Destruction
NEO impact	Dust clouds, stay for 5-10 years	Large at impact site, possible tsunamis (more destructive), earthquakes
Nuclear War	Radioactive dust clouds, stay for 5-10 years,	Widespread, dependent on political situation of the attacks.
Supervolcano	Dust clouds, stay for 5-10 years	Large at ground zero, widespread lava flows around ground zero, earthquakes

In all three catastrophes, there would be massive loss of life and structural damage around a large portion of the world. The entire Earth would be covered in a thick cloud layer of ash, decreasing the average solar irradiance by at least 100 W/m² (Robock et al. 2006). Within as short as one year, there would be an average global temperature drop of 8°C, but above land the temperature could drop as much as 20 or 30°C because of varying surface reflectance.

Over time, the cloud layer would dissipate as cool ash falls from the sky. This would result in a gradual increase in surface solar flux and, therefore, temperature. Ten years after the catastrophe, the solar irradiance could still be around 20 W/m² lower than present-day values. Figure 2-1 depicts these effects and their approximate time dependencies for a 150x10⁹ kg case of the nuclear winter scenario. Large NEO's and supervolcanoes produce effects that cannot be easily quantified but are similar.

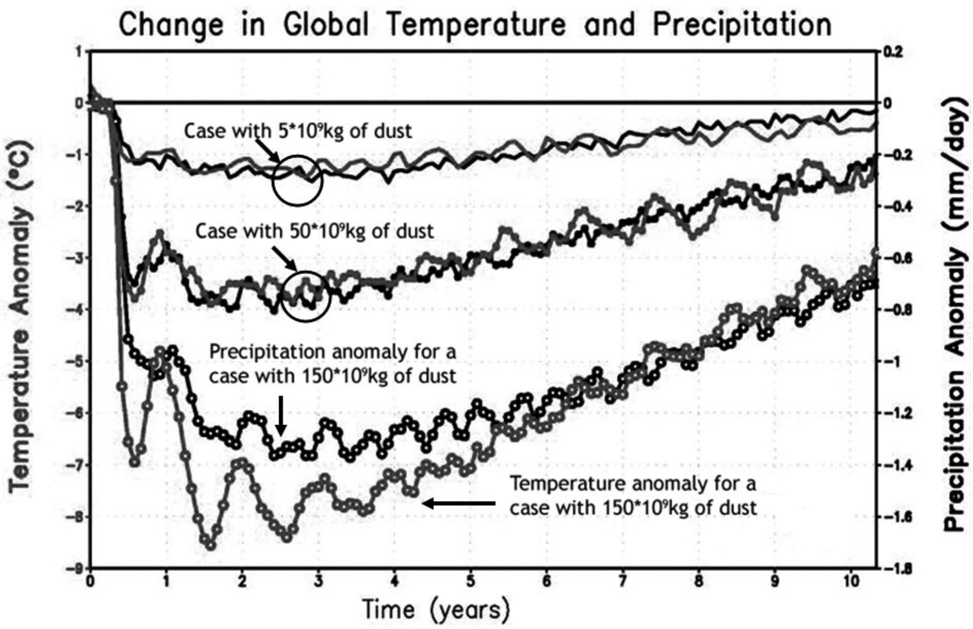

Figure 2-1: Change in global temperature and precipitation (Robock et al. 2006)

2.4 Futures Forecast

Although the environmental consequences from these catastrophes have been well documented, the impacts on global politics and the remaining human population are still being speculated. Using several forecasting methods of futures studies, the human population as a function of time can be forecast without any backup implemented and for a preferred future with the lunar archive. (Dator 2004).

2.4.1 Agricultural Collapse

The modern agricultural system is the product of what is called the green revolution. The green revolution transformed agriculture between 1940 and 1960. During this time many new farming techniques were introduced. Through these new techniques it has been possible to increase crop yield. Conway (1997) stated that cereal production more than doubled between 1961 and 1985. Yields of rice, corn, and wheat increased steadily during that period. This is further supported by Kindell (1994) who stated that world grain production increased by 250% between 1950 and 1984 without increasing the amount of agricultural land.

The five main reasons for this increase in yield are:

- Introduction of fossil-fuel-driven agricultural machinery.
  These machines make it possible for a single person to work more land.
- Introduction of High Yield Varieties (HYV).
  These genetically altered seeds grow into plants with higher yields.
- Introduction of pesticides (derived from petroleum).
  Pesticides are required to protect the HYV crops.
- Introduction of fertilizers (manufactured with natural gas)
  Fertilizers are required to provide the HYV crops with the right amount of nitrogen.
- Introduction of hydrocarbon powered irrigation (Pfeifer 2003)

The 250% yield increase was achieved by adding fossil fuels (energy) to a system that, until then, had been driven by solar power. On average, the energy flow into agriculture has increased by a factor of 50. This means that the energy input required to grow the same amount of crops has increased by a factor of 20.

The weakness and possible collapse of the modern agricultural system is extensively discussed in Pfeifer (2003) and can be summarized as follows. First, the system is dependent on the HYV crops, which are also called monocultures meaning they have a similar genetic make up. These crops lack genetic diversity, therefore they are very vulnerable to viruses or insects. Another problem with HYV crops is that only the first generation hybrids are pure enough to produce high yields. Thus the farmer must buy new seeds every year, becoming dependent on the provider. Also the system is dependent on the production and delivery of fossil fuel-based substances such as fertilizer, pesticides, and fuel for irrigation and other machines. Without precise amounts of these additives, HYV crops have a lower yield than normal, diverse crops. In addition, it is argued that the modern system uses excessive amounts of fresh water. In many situations, power-hungry desalinization devices are needed.

At this moment (2007) there is a discussion going on in the world as to whether or not the modern agricultural system is sustainable. In a scenario where the world economy has collapsed (no production/trade in HYV and the required fossil additives) and the temperature has dropped (outside the temperature range for the HYV crops), the Earth's current agricultural system would fail.

2.4.2 Economic Collapse

Hand-in-hand with the agricultural collapse would be a complete economic collapse. In the immediate aftermath there would be a loss of economically active individuals. Global markets would immediately crash as they sometimes do in times of war, localized natural disasters, and other times of great fear (Woodard 2007). Current economic practices show that problems in one region can have severe economic impacts in many other parts of the world, as seen in 9-11 attacks (Makinen 2002) and the Asian financial crisis in 1997 (Sachs 1999).

Over time, this instant crash would combine with the global agricultural collapse, and the global economy would continue to fail. Internal disaster recovery efforts rely on creating swift policy changes and rerouting resources to catch a locally destroyed economy by distributing the burden to other areas or countries (Bull 1994). Destruction on such a large scale, and worldwide instant resource limitation, quick recovery would be impossible. Areas that still have survivors would be so concerned for their own needs that rescue efforts would be driven by brave individuals during a short time period after the disaster, rather than by a concentrated official effort (Myers 1994).

2.4.3 Social/Government Collapse

Humans tend to follow a known pattern of behavior after a natural disaster. Although the names and numbers of the categories or phases may vary (Myers 1994):

- Impact (Heroic) Phase: The fight for survival is strong, heroic feats are performed, and the immediate fight for life ensues as the victims attempt to save their families and loved ones.
- Inventory (Honeymoon) Phase: Relationships are created with other victims that increase survival. Supplies are sought and immediate needs are taken care of.
- Disillusionment (Rescue) Phase: By now, the disaster has finished and the survivors are being rescued by disaster recovery programs. Survivors may feel resentment and anger.
- Recovery (Reconstruction) Phase: Survivors rebuild their lives and may even return to the disaster site for closure. Life has not yet returned to normal but they are dealing with the disaster in a healthy way.

The problem with disaster psychology studies is that they assume someone will be available to carry out a rescue operation. In the case of the global disaster scenario, almost everyone is a victim, and getting past the Disillusionment Phase would be difficult. Since the Disillusionment Phase is where the victims are the most hostile, most angry, and most bitter, the destructive potential of the human psyche will unfold as the fight for resources begins. Once the agricultural and economic collapses begin, the social collapse follows and rapidly take hold as survivors struggle for what is left of Earth's resources. As a result, governments surely fall because they cannot provide basic needs for their own citizens.

2.4.4 Futures

Here we present two possible human futures after a major disaster. The first is the future envisioned without the lunar archive and the second is with the lunar archive.

Future 1: Back to the middle ages or worse
In this scenario we assume that there is no lunar archive. The forecasted impact to the global human population is then illustrated in Figure 2-2.

At some future date, the Earth will be hit by a catastrophe as described in the previous sections. Because of the direct impact of the catastrophe, a large part of the human population will die. At the same time a dust cloud is formed that will block a percentage of the solar flux, initiating a "post-disaster winter". The "post disaster winter" and the devastation of the human population combine to cause the collapse of the economic and agricultural systems within the first two years that eventually lead to societal collapse.

After the first wave of destruction, little will happen to the human population numbers. There will still be stored food and it takes time for the systems to collapse; within the first two years the human population level also will collapse.

These collapsed systems can go two ways:

- A total disintegration (dashed line in Figure 2-2)
- A collapse followed by a disciplined society (solid line in Figure 2-2)

The disciplined society will be spearheaded by people who are currently part of the more robust cultural systems that exist on Earth. Here we have in mind people who live entirely off the land, or at least people who can be self-sufficient and are not dependent on our highly interconnected society to get their food.

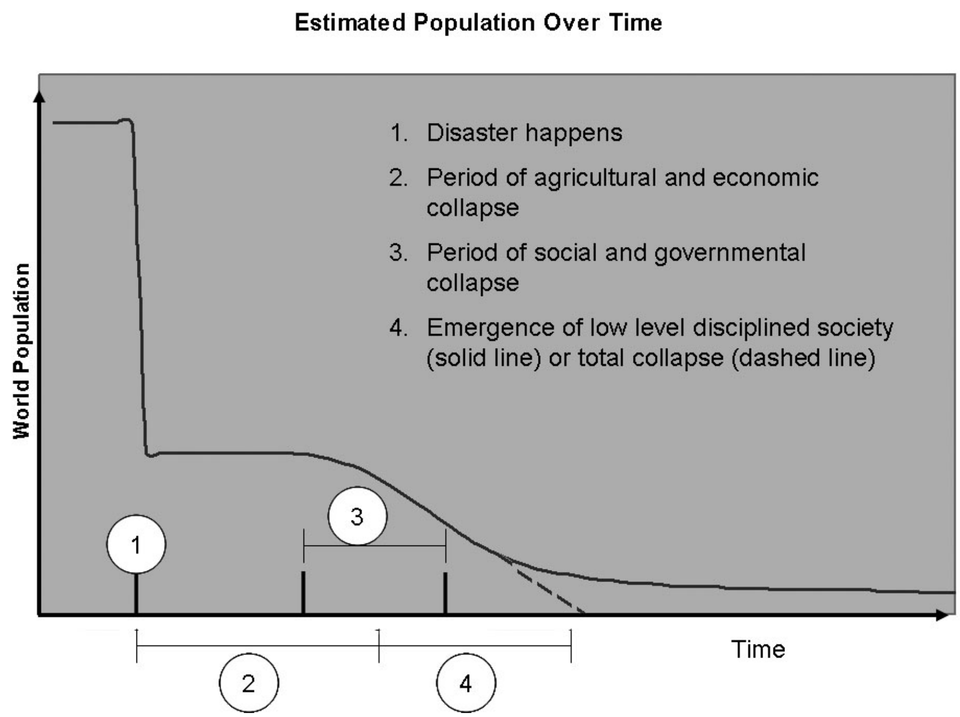

Figure 2-2: Estimation of the global human population after a major catastrophe without a lunar archive.

Future 2: A set back to be overcome

Here we assume that there is a lunar archive installed before the catastrophe. We furthermore assume people around the world know about the lunar archive and, in the best situation, some of the weaknesses in our modern society have been addressed and solved. The forecasted impact to the global human population is illustrated in Figure 2-3.

Again, the Earth is struck by a disaster, and again a large part of the population dies immediately. The dust cloud forms and a "post disaster winter" is initiated. We expect that the first part of this post-disaster scenario plays out the same way as for the case without a lunar archive. At the moment society collapses and the human population starts to collapse the effect of the lunar archive becomes visible. The lunar archive and the ground repositories will help the survivors to enter more directly into a disciplined society that is based on self-sustaining and robust agriculture. The lunar archive will thus support the initial survival of the human race and make sure that the technological and population levels will not drop as far.

After the establishment of a robust agricultural society, the lunar archive will support the growth of the surviving society in a sustainable manner. In this way the human population will slowly become bigger again as we have illustrated in Figure 2-3.

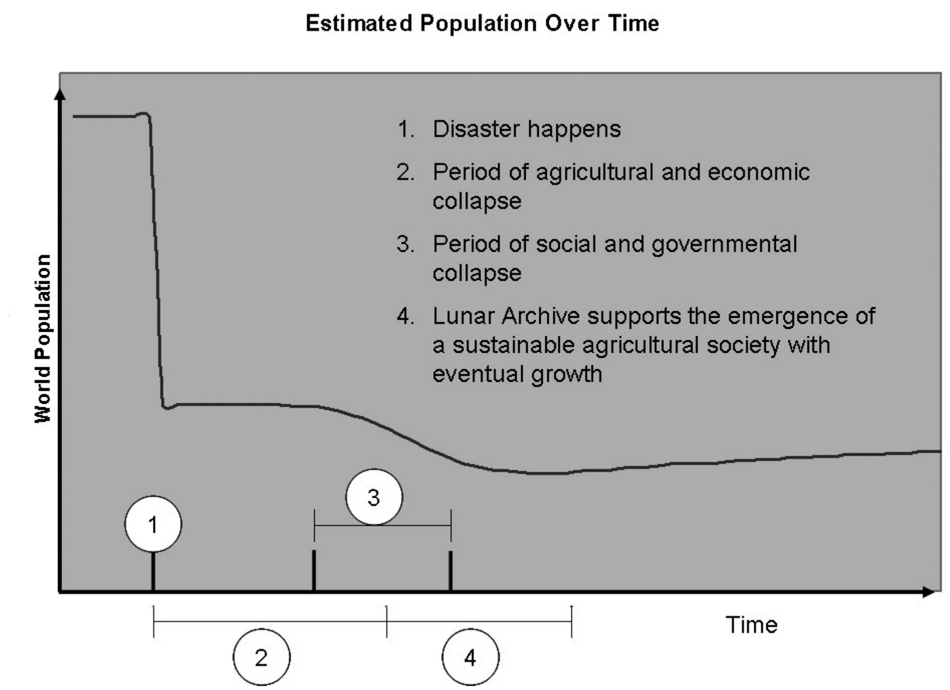

Figure 2-3: Estimation of the global human population after a major catastrophe with a lunar archive.

Chapter 3

Content

3.1 Introduction

The content of the archive, both knowledge and equipment, is determined by the needs of the surviving communities and how those needs would evolve through time. Maslow's Hierarchy of Needs (Maslow 1943) delineates five levels of need, according to their relative importance for an individual. The first four levels are linked to physiological needs and include breathing, food, and water, but also safety, friendship, and self-esteem. The fifth level refers to psychological needs for personal growth.

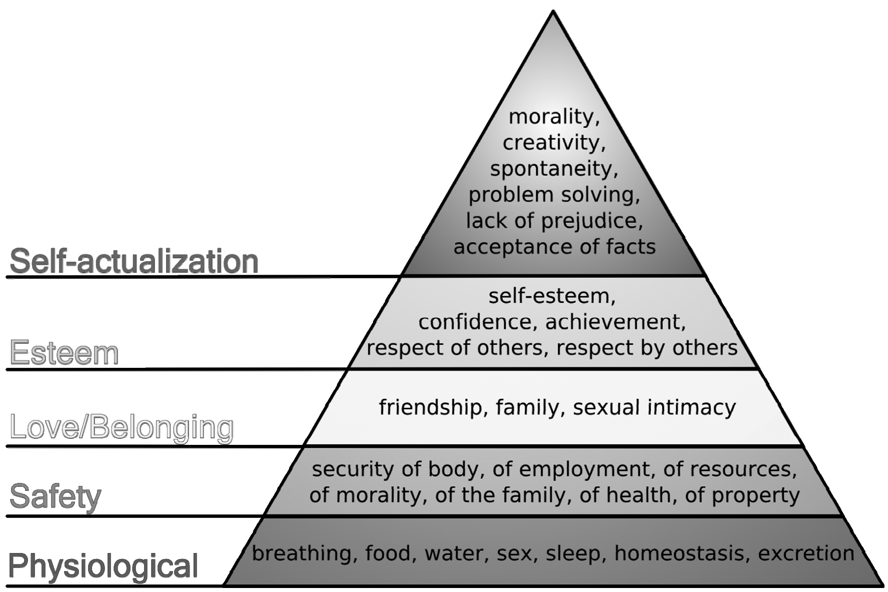

Figure 3-1: Maslow's Heirarchy of Needs (Maslow 1943)

In addition, the survivors would go through different phases after the disaster occurs. First, they would strive for immediate survival and look for water, food, shelter, and medical aid. This phase would end when the survivors become organized into relatively small communities and have reached self-sufficiency. Second, once their basic needs are secured, survivors would move on to satisfying higher needs. This is a transition phase where survivors would re-establish the basis for societal growth. It is also a learning phase, during which survivors would be taught to understand the knowledge stored in the archive. Finally, survivors organized in embryonic societies would want to revive higher living standards. They would want to be able to access and understand the deep content of the pre-disaster knowledge.

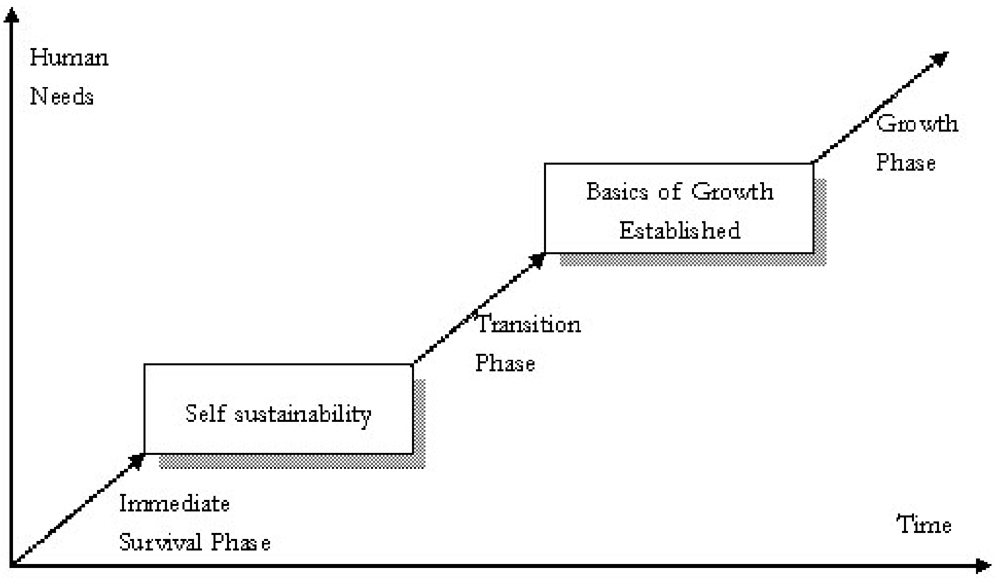

Figure 3-2: Post-catastrophic recovery phases

Based on this reflection, we have generated the following objectives for the content of the archive:

- To provide prioritized content for a lunar archive and associated Earth repositories that will ensure the immediate survival and eventual self-sufficiency of small communities;
- To provide the skills and knowledge to re-establish the basis for societal growth;
- To provide information for the long-term recovery of sustainable, productive, and creative lifestyles and social structures.

The archive infrastructure would comprise facilities both on the Earth and on the Moon. Earth repositories and their contents would be designed to address not only immediate survival needs, but also to serve longer-term needs, including the revival of Earth's ecosphere. Information only would be transmitted from the Moon. The lunar element of the information system would be a database where the content of human knowledge is stored. In the following sections, we will describe how the archive would be organized and what content would be required to meet its previously stated objectives.

3.2 Earth Repositories

3.2.1 Needs for Immediate Survival

The content provided for immediate survival is divided into three different packages: care packages for the short term survival (days); guidance package for the intermediate survival (weeks to a month); and the infrastructural package for achieving self- sufficiency. These packages are explained below.

Care Package

The care package should be based on modified Red Cross care packages providing provisions for the initial days following the catastrophe. Care packages encompass physical objects initially provided to survivors.

A manual showing supply distribution and use of the facilities would be available outside the facility. Flares and whistles could be stored outside the repositories for simple communication among survivors. Basic first aid supplies would be stored outside the secure part of the facility. Security measures should be in place to prevent the Earth repositories from being raided.

Survivors would find water, clothes, blankets, food, and matches in waterproof containers inside the facility. Toys, games, and art supplies, (Hamilton 2007), will be stored in a separate location. Other supplies such as baby supplies, medications, and extra water and food will be stored in different locations accessible only through a higher level code or password.

Guidance Package

The guidance package contains a printed user's manual informing the survivors on the use of the Earth repository and the items inside. Beyond that, it would provide an initial organizational structure and set of goals for disillusioned survivors to give them understanding of the situation, and hope for forward movement.

Initially, the survivors would be guided through the effects of the global disaster, learning how the archive could help them survive. Later, a social structure would need to be developed. No social structure will be inherent to the guidance package; but a structure valuing both competition and cooperation would be suggested for the survival strategy process. Each step on the path to self-sufficiency could have an associated reward. Meeting the objective as quickly as possible will require more than one person. Completing a quiz stored by the system would show sufficiency in each task. Tutorials could be provided to assist survivors when preparing for the quiz. These aspects are further developed in the Self Education section. Proven steps toward sustainability, displayed through objective completion, could be rewarded with current gains to be sure that ending rewards and current gains are both achieved. This structure reinforces benefits of sustainability until those benefits can be seen by the survivors. After some initial guidance, survivors would inevitably determine the organizational structure of the new society.

Infrastructure Package

In Section 2, we concluded that modern agricultural systems cannot withstand a major disaster that would lead to the collapse of society and changes in the environment. A post-disaster society would require an agricultural system that is robust and independent of non-local resources. Furthermore, it must be based on a closed, self-sustaining system. An agricultural system similar to that used in Great Britain around 1800 seems to meet these criteria.

The British system used sustainable four-field crop rotation, allowing each crop to replace the nutrients used by the other crops. Locally maintained and produced mechanical devices were used to tend the crop. Some of these devices were Jethro Tull's seed drill, the Rotherham plough, and Andrew Meikle's threshing machine. These machines allowed the same land to be worked by a smaller group of people and only required human or animal power, so a completely self-sustaining system was created (Overton 2002 and Overton 1996).

To find similar agricultural systems, we need not go back in time. These systems are still being used in third world and developing countries like the People's Republic of China. During our work for this report we had the opportunity to talk with Huang Jianyong. He is a Chinese tour guide with knowledge about the agricultural systems of minority communities in southwestern China. He explained how these Chinese people still work their fields largely by hand and are self-sufficient with respect to their agricultural practices (Huang 2007). This is surprising considering the same farmers have mobile phones and satellite television plus small trucks powered by a single-cylinder engine. Although some of the farmers are starting to use these engines as part of mechanized plows (making the farming dependent on fuel), these Chinese southwestern areas are a good example of a robust agricultural system that can exist in modern times.

There are a few drawbacks to these sustainable agricultural systems. The crop yield per area is smaller than in the case of modern agriculture, and more people are required to work on the same piece of land. Because of the presumed lack of a fossil fuel supply and the expected changes in the environment, the modern agricultural system will no longer be an option after a disaster and a more stable and sustainable system must be used. This might result in a situation where there will not be enough food for every person to survive.

When we compare the different agricultural systems (UK 1800, China and third world), the common denominator has nothing to do with their culture or society, but rather with smart use of local, natural, independent resources. Another interesting hallmark of these robust cultures is their adaptability to change and shortfall. In his paper, Dreier (2005) gives an interesting view of this flexibility in the face of famine, explaining "that during the course of history Africans have developed an extensive set of strategies to cope with a broad spectrum of famine situations and they continued to invent new techniques that seemed appropriate to specific situations." Some examples of these techniques are resting, selfishness, mobility (going to other places with more food), and storing.

In this case, selfishness means not sharing food with other people. Here, the survival of enough individuals is more important than the survival of every single person in the group. During the Limpopo famine there were cases of individuals surviving by hiding food for their family and secretly eating it at night (Dreier 2005). Although this seems ethically wrong, it might be just such selfish people who will guarantee the survival of humanity.

Lack of flexibility and social/cultural robustness would be an unwanted characteristic for our post-disaster agricultural society. The survivors may have to cope with environmental changes such as dropping temperatures and lower light levels, thus societies must be adaptable. Groups may be forced to change the types of crops they grow or even turn from farming to fishing because of changing precipitation patterns. The Norse settlement in Greenland around 1400 is a good example of a collapsed society that used up its agricultural resources and died out. If they had looked at the Inuit (native), changed their diets to more fish and had started hunting seals in the winter, they would have had a chance to survive (Diamond 2005).

Since we are trying to create a flexible, robust society, the content of the archive should be chosen to take into account global differences. For example, an archive aimed at the survival of Indonesia should contain information about rice agriculture, while an archive aimed at Europe should specify knowledge about potatoes and grain. For both regions, other agricultural information and tools may be needed to help with adaptation to global environmental changes.

It is beyond scope of this report to describe the exact crops that are grown around the world, detail the required tools and practices, and predict the possible changes needed after the global catastrophe. We advise a regional agricultural analysis for future work on the Archive Program's development that will answer the following questions:

- What crops are grown in each region and what crops could be grown there should the temperature change? For example, sunflowers are now grown in France, but if the temperature drops they should be replaced by a more hardy winter crop like Brussels sprouts. This research is needed to determine what seeds should be stored in each repository.
- How are the aforementioned crops grown? This research should look at regional practices for each crop and identify those that are most suitable, so that relevant information is available in each repository.

- What kinds of tools are needed to grow these crops? One requirement for these tools is that they should be driven by humans or animals and not by fossil fuel. A second requirement is low maintenance with the help of local resources. This recommended study should indicate which tools should be kept in each repository.
- What kind of inventive technologies are available? Tools that can support the agricultural system without depending on fossil fuel will be indispensable after the disaster. An example is the desalinization device invented by the "Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek," which works on a temperature difference of 1-3K (Hanemaaijer 2006). This will show which innovations could increase the likelihood of rebuilding a healthy society.

At this moment we see three major factors needed for crops to grow in an area: soil, water (humidity), and temperature. With these three factors it is possible to create a multidimensional matrix for the different types of crops and seeds. The second step would be to determine/estimate the post disaster status of these factors. Using the matrix, the stability of the determined factors can be addressed. This is required to determine how small changes in disaster scenario impact the factors. We propose further research on this method for seed analysis. Otherwise the lunar archive would only account for a very specific disaster.

We would advise researchers to investigate possible seed enhancements, allowing seeds to grow in regions with poor conditions - areas so poor that without these seeds no agriculture would be possible. The Chinese space program has done some research involving seed enhancements. China has been launching and returning seeds to and from space since 1987. When exposed to microgravity environments and cosmic rays, some seeds mutate to produce much higher yield and improved quality. The Chinese program has resulted so far in large scale planting of 43 species of space seeds (China Daily 2006). The advantage of space seeds is that they are not a special strain, but are an entirely new, mutated, diverse species. Space seeds also do not have the disadvantages of a mono-culture crop and therefore might be useful in a post disaster system.

Other infrastructure demands pertain to buildings, water and in a later stage communication system. In the current scenario, many of the existing buildings would still be standing and could therefore be used. The archive should still contain information on how to build houses and other structures with the help of local resources, such as rammed-earth houses in southwest China. Water required for agricultural systems could be provided by rain. In some regions, however, the archive should provide information on how to dig a well or build an irrigation system.

The post cataclysm infrastructural system should be as simple as described above and its only aim should be to support the sustainable self-sufficient agricultural system.

3.2.2 Storage of Cultural Artifacts

Earth repositories are designed primarily to address the needs for immediate survival. However, recovering higher-living standards and reviving human civilization, creativity in particular, is a fundamental objective of the Lunar Archive Program. The storage of cultural artifacts would play a critical role to that respect. Other elements such as books, musical instruments, sculptures or paintings may need to be saved to address this very issue. Dedicated areas shall be designed in the Earth repositories to address this need. What to store and where are important issues. The content (what artifacts should be saved) can be determined by the management of the Lunar Archive Program. This is a similar issue to the need for finding information sources to save human knowledge and this aspect is covered in the Data Collection section. A good place to start the collection is with museums. Would a museum agree to have its most valuable artifacts stored in a place where no one could see them? This raises logistics problems when it comes to moving those artifacts back and forth from the museum to the repository. Where should we store those priceless artifacts? A first approach would be to store them according to their geographic origin. However, the biggest museums are located in coastal areas, more vulnerable to a global catastrophe than remote areas. Another approach would prioritize the safety of the artifacts and maximize their recovery capability. To avoid these problems being raised, one can think of storing only copies of original productions. Those issues would need to be addressed by the people in charge of the Lunar Archive project.

3.2.3 Revival of Earth's Ecosphere

After the catastrophe, the ecosystem will be badly damaged but not totally destroyed. Therefore, its capability of self-recovery and self-regulation (Sustain 2004) will still work and, given enough time, the structure and function of the ecosystem will rebuild itself. The revival of the ecosphere after the event can be separated into three phases: Phase A - effective microorganisms will grow and spread rapidly; Phase B - herbaceous plants will begin to bloom and insects and small animals will appear; Phase C - gradually, some woody plants will occupy most of the land surface and the number of large animals will continuously increase. An excellent new book on species succession is Weisman's (2007).

Figure 3-3: A bird (heron) representing the recovery of the ecosystem (photo courtesy of United States Geological Survey)

Fast-Forwarding is a tempting idea for ecological restoration, the idea that one can accelerate ecosystem development by controlling pathways, such as dispersal, colonization, and community assembly, to reduce the time required to create a functional or desired ecosystem (Hilderbrand et al. 2005). However, what the survivors need is basic knowledge and techniques to help them accelerate the process of environmental revival simply and naturally. Before the event, the standards for selecting keystone species and potential keystone species should be established based on, for example, pioneer communities/pioneer plants, food chain, and spatial niches.

We recommend creating a microbe storage, seed bank, zygote warehouse, stem cell bank, or gene facility to retain the maximum diversity of life-forms.

- Microbe storage: A storage facility with appropriate conditions to preserve different kinds of microbes in non-active forms.
- Seed bank: A place to sort and conserve resting seeds for all plants, similar as Svalbard Global Seed Vault, also called Norwegian Seed Bank and Svalbard International Seed Vault (2007).
- Zygote warehouse: A storage warehouse for embryos. It is not easy to keep frozen embryos, especially for a long period, but it is possible to keep some frozen zygotes for insects, fish, and animals, and easy to resuscitate them when necessary.

- Stem cell and gene facility: Stem cells from insects, fish, and animals (include human) can also be stored by freezing, and extracted genes can be saved for a long time.

Microbe storage and seed banks are mainly focused on conservation of different species and using them simply and naturally for remodeling environment. Zygote warehouses, or stem cell and gene facilities should also function for advanced study in life sciences and benefit improving medical treatment for survivors. So, zygote warehouse or stem cell and gene facility is somewhat like the biological factory or bio-laboratory, special instruments and equipments are required.

Also, grouping different species for each revival phase and making them into usable packages (called Bio-Revival Packages, which would include such environments as grassland, rain forest, highland, or wetland) would simplify the revival process. Therefore, it would be easy for the survivors to use these packages to rapidly achieve an appropriate ecological density. The most important consideration would be to ensure that all the species in the same package have positive co-evolutionary relationships and that there are no biological invaders (Perrow and Davy 2002).

Figure 3-4: "The Norwegian government will hollow out a cave on the ice-bound island, Spitsbergen to hold the seed bank. It will be designed to withstand global catastrophes like nuclear war or natural disasters that would destroy the planet's sources of food." (The Weblog BioTech 2006)

The basic knowledge for revival of the ecosphere to be preserved in the archive must include following information:

- How to use the Bio-Revival Packages and how to know it is time to use them
- How to be sensitive to the signals or feedback of the environment
- How to keep a balance (monitoring and controlling the population density of some very important species) and to maintain biodiversity
- How to reuse resources and minimize waste to reduce pollution

Also, advanced knowledge (Young et al. 2005) should be involved, such as:

- Ecological factors
- Models of community succession
- Diversity/function relationships (mechanisms of species coexistence)
- Environmental sustainability

3.3 Lunar Archive

3.3.1 User Interface

The main goal for the archive interface would be to show its vast contents to people who would be so shocked after the disaster that many might neither want nor be able to understand the content. Because the survivors would have different cultures and languages, a good interface should be carefully designed to be intuitive, easy to use, and interactive.

An interactive environment is the key to self-education techniques, because no teachers will be available to answer questions or to drive the learning process. To fulfill those requirements, we can distinguish between software and hardware interfaces, bearing in mind that hardware interfaces would be placed inside Earth repositories.

- Software: The best approach, to avoid problems with multicultural issues, is to use multimedia information as much as possible: didactic videos, audio files, interactive programs with voice recognition capabilities, and games to increase motivation and to make learning process easier. Using common symbols (e.g. fire 🕯, water 💧, poison ☠, radiation ☢) on the interface can bypass some of the language problems for simple tasks.
- Hardware: Software determines the hardware selection. Multimedia files need hardware support, such as computers, screens (touch screens), audio devices, and microphones. Future capabilities in digital systems would allow us to try Virtual Reality, in 3D environments, but only as an option. Future computers, using orders of magnitude less electrical power than present ones, could be powered by clockwork.

Between the hardware and the real contents, we would have a main program director (shell) that would display the contents in a structured fashion. The shell would allow programming of different tutorials and guides to drive the self-learning process; these would be developed by actual teachers. Last, as the shell program would take a small part of the archive's memory and interact with many people, it should be implemented in all languages.

Language Interface

Linguistic diversity is a two-sided coin. On one hand, its richness needs preservation; on the other hand, it is a complication for the lunar archive because people from many cultures and ethnicities will need to access the lunar archive and its Earth repositories. Human history has known several *lingua franca* – idioms adopted as a common means of interaction between people whose native tongues are different. From the "*Koine*" Greek of merchants to the Latin of medieval scholars, from the French of modern era diplomats to the Swahili of East Africans and the Russian of the former Soviet Republics, many languages have served this purpose. The establishment of the United Nations has brought to the forefront six official languages (Arabic, Chinese, English, French, Russian, Spanish), whereas globalization has placed English in first place.

While the Earth repositories can have an interface using local languages, the lunar archive has a greater linguistic challenge. The accessibility issue can be addressed several different ways. One suggestion is to store the essential content in English, making it thus available to a significant portion of humankind (native and non-native speakers). Another alternative is to expand it to include the principal languages by user population of the world, the top ranked languages being Mandarin Chinese, Hindi, Spanish and English (UNESCO 2007). If we adopt the latter approach, we increase the accessibility but data storage requirements increase. A final option is to store the basis of the information and provide machine translation locally. Altavista's "Babelfish" project (Altavista 2007) has proven to be a success in this respect, although improvements are needed for a fully functional machine translator. As machine translation technology improves, we expect that it will be a valuable resource for the Lunar Archive project.

3.3.2 Self-Education

There is a Chinese proverb: *"Tell me, I forget. Show me, I remember. Involve me, I understand."* This proverb illustrates the importance of getting learners mentally involved in learning activities, generating connections between what they already know and what they are being asked to learn, and constructing meaning from their experiences (Driscoll 2002).

After the disaster, survivors would find themselves in a far from optimal learning situation: no schools, no teachers, and no materials for study. They also probably would suffer from psychological problems since they would be in shock after the disaster. This would make them reluctant to start the hard process of learning for themselves. Bearing this in mind, one of the main tasks of the archive would be to maintain a very high level of motivation among the population that would be dedicated to the learning process.

To improve learning capabilities, it would be important to focus on creating teachers and researchers. Not all people should read the complete archive's content; many would only use the archive as a reference, to read and understand something in particular. Several people may show interest in specific subjects. This would improve specialization. After their training, some of those specialized people would be able to become teachers for the others. This would exponentially increase the learning capabilities of the new population. Finally, humans would show the ability to create new things as scientists and artists (see Figure 3-5).

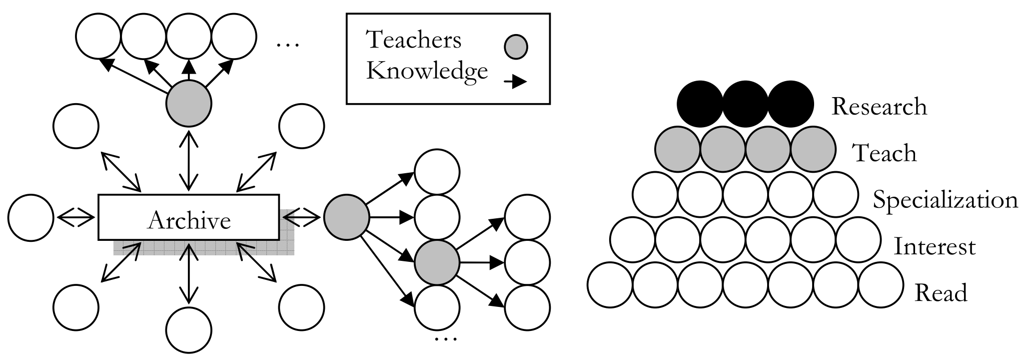

Figure 3-5: Network approach of self-education and knowledge hierarchy

The Earth repository network, with its reconstituted communication links, would eventually allow discussion groups, forums, and exchange of knowledge among different locations. This would also increase the exponential curve of learning.

Different studies and theories of learning have arisen during recent years:

- Behaviorism: based on behavioral changes. Focuses on a new behavioral pattern being repeated until it becomes automatic.
- Cognitivism: based on the thought process behind the behavior. Changes in behavior are observed, but only as an indicator of what is going on in the learner's head.
- Constructivism: based on the premise that we all construct our own perspective of the world, based on individual experiences and schema. Focuses on preparing the learner to problem-solve in ambiguous situations.
- (Mergel 1998)

Each theory has several self-learning methods, such as the "Supermemo®". This software uses repetitions (behaviorism theory) to help the student memorize a subject. The last two theories have the most modern techniques, based on computer-assisted instruction and Artificial Intelligence (AI). Computer-assisted instruction is often used in modern learning environments, with multimedia and interactive programs. Moreover, it is also used in self-learning environments with training programs, guides and tutorials, networks, and rings via the Internet, forums, and discussion groups.

AI could improve the process by substituting for teachers until they would be able to teach themselves. The AI program would be able to evaluate progress, create new challenges for the students, and propose different approaches to the contents.

The state of the art, by means of computer-assisted instruction and AI, is enough to consider both in the archive, led by the shell program and augmented by the knowledge classification.

3.3.3 Classification and Linguistic Aspects of Knowledge

Classification Aspects

From the beginning, humanity has been driven by curiosity and the need to understand. As a consequence, it has generated a tremendous amount of knowledge. The issue of organizing and storing this knowledge in an archive for future use after a global catastrophe is extremely important. Indeed, since the archive should be designed for use by any individual, regardless of culture or background, the knowledge should be presented in an intuitive way. This section discusses knowledge classification systems.

As far back as the Greeks and early Chinese, people have tried to classify and organize knowledge. Famous philosophers, such as Aristotle or Porphyry, have proposed theories to categorize concepts using different attributes. Later, other famous philosophers built on this idea. During the Enlightenment period in Europe, for instance, Diderot and d'Alembert developed the Enyclopédie, one of the first attempts to create a true encyclopedia. This current to categorizing human knowledge continues today, and the International Society for Knowledge Organization was created in 1989 (International Society for Knowledge Organization 2007) specifically to address issues related to knowledge organization.

Taxonomy is the science of classification and taxonomies are often hierarchical in structure. Other approaches are based on so-called faceted classification. Wynar gives the following definition for faceted classification (1992):

> "A faceted classification differs from a traditional one in that it does not assign fixed slots to subjects in sequence, but uses clearly defined, mutually exclusive, and collectively exhaustive aspects, properties, or characteristics of a class or specific subject. Such aspects, properties, or characteristics are called facets of a class or subject, a term introduced into classification theory and given this new meaning by the Indian librarian and classificationist S.R. Ranganathan and first used in his Colon Classification in the early 1930s."

In this scheme, a given object may be shown from different perspectives, according to the context.

The Dewey Decimal Classification (DDC) system is a very common classification system in the library world and serves as the basis for more complex systems. The First Summary divides knowledge into Ten Main Classes, numbered from 000 to 900 as shown in Figure 3-6 (Online Computer Library Center, Inc. 2003). Those Ten Main Classes are then further divided into the Second Summary, which contains the Hundreds Divisions. Then, the Third

Summary describes the Thousand Sections. The figure below highlights the first two levels (or Summaries) of the DDC system.

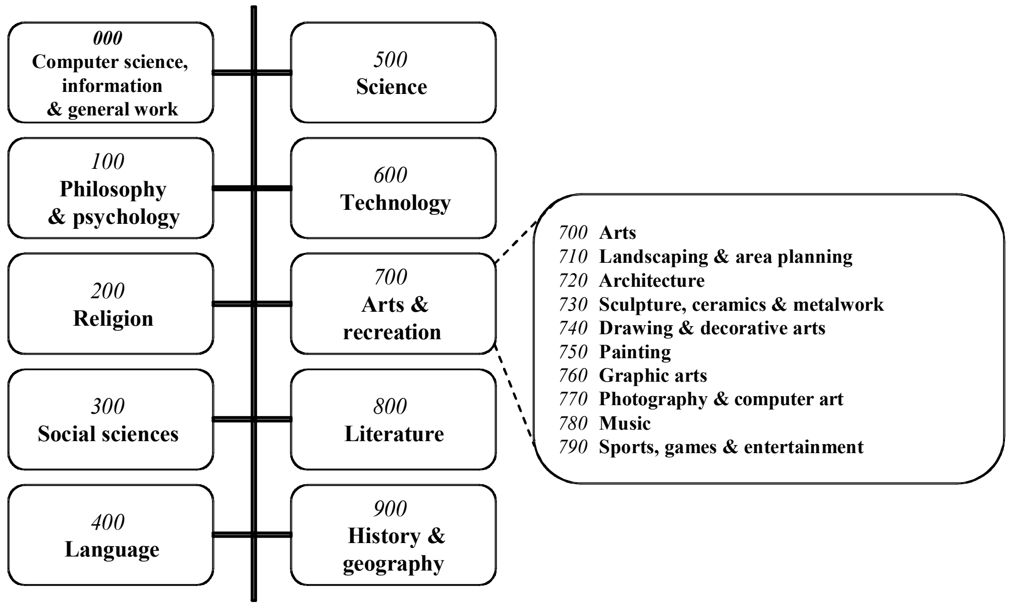

Figure 3-6: The Dewey Decimal Classification system (first two Summaries represented)

Another classification system is the so-called Colon Classification system. It is based on the faceted classification approach introduced by S.R. Ranganathan (defined above), but makes use of colons to separate facets. Also, other classification systems – the Universal Decimal Classification for instance – use punctuation to add logical links (addition or extension for instance) between different facets. In addition, a thesaurus based on the knowledge content may be developed and serve as an index. A thesaurus is a list of entries with the related items that derive from them. It can be seen as an index of all logical relations between the lowest-level topics of the classification system architecture. It would complete the approach of the faceted classification and add another level of organization.

Other important characteristics of the classification system of human knowledge include highlighting potential logical links among different disciplines: relevant for teaching and the design of tutorials; prioritized content for survival (described in previous sections); the updatability of the database (growing database, refreshed over time); and consideration of the diversity of cultures. In addition, the issue of having different versions of history, written by different cultures at different times, needs to be carefully addressed as it relates to the objectivity of the archive content.

The actual content of the archive would be determined using the chosen classification scheme. This scheme would highlight the topics for which sources of information need to be found. This aspect is covered further in the Data Collection section below.

Finally, the memory load needed to store human knowledge has to be estimated in some way. We based our reflection on Wikipedia. Its content (both text and images) may be estimated to 75 Gb for the English version of Wikipedia only (Wikipedia talk 2007). However, this does not take into account video media. With modern technologies, 1 minute of video represents 10 Mb. If we assume that for every ten images stored in Wikipedia one would generate a one-minute film, this makes between 500 and 1000 Gb video media. Therefore, 1000 Gb or 1 Tb is a very broad estimation for the storage needed to save the knowledge in one language. If we assume that the content of the archive would be stored in the six main languages the United Nations has highlighted (see Lunar Archive – User Interface), 6 Tb are needed.

Linguistic Aspects

According to the United Nations Educational, Scientific and Cultural Organization, the languages of the world represent a tremendous wealth of human creativity, containing and expressing the global pool of ideas cultivated throughout the ages through customs, local traditions, and heritage (UNESCO 2007). Preserving the diversity of languages and cultures is as important as preserving the diversity of ecosystems and species for the survival of humankind and life on Earth. For a post-catastrophe Earth, linguistic diversity may help to maintain a robust, sustainable living given that:

> "[i]n many cases the knowledge of natural cures and remedies for illnesses transmitted by languages through generations and linked to local plant life have [sic] been lost due to the abandonment of languages and cultures, and the destruction of natural habitat" (UNESCO 2007).

In the year 2000, almost 7,000 languages were in use (UNESCO 2007); however, even without a global catastrophe, the linguistic heritage of humankind is endangered by globalization. Within the next century, it is estimated that between 50 and 90% of the world's languages – many with no significant documentation – will be lost (Welcher 2007). Initiatives to preserve the linguistic diversity of the world exist. An example is the Rosetta Project, a "global collaboration of language specialists and native speakers working to build a publicly accessible digital library of human languages" (Welcher 2007). The Lunar Archive Program could cooperate with UNESCO (the United Nations Educational, Scientific and Cultural Organization) and the Rosetta Project to preserve humankind's linguistic diversity.

Chapter 4
Technical Design

4.1 Introduction

The lunar archive system has two main components: the Earth repositories and the lunar archive storage. Repository distribution, communications systems between Moon and Earth-survivors, the design of the facilities on the Earth and the Moon, and their use, maintenance, and upgrading are also described in this chapter. Communications is a key issue for the continued development of our society. Reliable communications after a catastrophe will be critical. Another important issue is preparing a safe storage area to help survivors to immediately recover and later rebuild society. The technology chapter addresses these topics.

4.2 Earth Repositories

4.2.1 Function

Here we investigate the technical function of the Earth repositories. The Earth repositories would provide immediate and long-term resources to the survivors of a catastrophe. The immediate survival needs should be addressed by low level, emergency response items that satisfy the three needs of immediate survival: food, water, and shelter. The facilities would contain the bulk knowledge of the archive and items needed for long-term survival and societal re-growth. We make a comparison with existing emergency systems, their functions, and how we can adapt those functions to the needs of the lunar archive.

4.2.2 Design

The three levels of terrestrial support include terminals, Tier 1 repositories, and Tier 2 repositories.

Terminal Access Points

Terminal access points are places that can send emergency communications to the lunar archive, receive unsecured data from the archive, and store Phase 1 survival information. They can be small enough for a home or small community.

One idea is to implement the terminals using the valuable amateur radio communications protocols that exist today to send and receive packet communications to and from the lunar archive. This way, survivors can communicate distress signals and get directions to the nearest repositories in the absence of all terrestrial communications networks. One lone survivor with a terminal link could find a safe haven and download any vital information from lunar archive from anywhere in the world.

Tier 1 Design Requirements

Since the content of the Tier 1 repositories would be relatively small and divided among the survivors, the ideal location of the repositories would be in available storage areas within communities. Suggested storage areas include civic centers, universities, libraries, and other public facilities. These facilities are landmarks within communities and people will remember their locations and know where to go in the event of a disaster.

Tier 2 Design Requirements

The Tier 2 repositories should be built to last at least 100 years, with periodic maintenance and continuous refreshment of content. As the repositories reach their maximum lifetime expectancy, their administrators must decide to remove, renovate, or rebuild each repository, depending upon a variety of factors. Such factors include new technologies, new building materials, the evolving need and function of the repositories, and the need for continuing survival strategy updates.

The repositories must withstand earthquakes and other disasters that may originate from the initial catastrophe. Their power sources should be self-sustaining, and communication capabilities with the Moon should survive with little structural maintenance, independent of the lifetime of the expendable supplies within the repository.

Power

Diesel fuel generators may be used in the immediate aftermath to produce electricity and heat. Diesel engines are reliable, and stored diesel fuel is relatively stable compared to alternatives such as gasoline. Diesel engines have been used in intercontinental ballistic missile (ICBM) silos around the world as backup generators for these reasons (Hartzer 1994). In rural China, the single-cylinder, 20 kW Changchai engine is widely used (Huang 2007).

Because fuel resources are limited, alternative sources of power should be used and stored in the repositories. Wind and water power, photovoltaic cells, and human and animal power are options for renewable, sustainable, small-scale power sources.

Large wind generators cost approximately $1500 per kilowatt. Small, individual and possibly portable units can cost as much as $3000 per kilowatt, but can be used for long periods for 24-hour power (CanREN 2006). Several small- or medium-scale generators can be stored inside the repositories and easily set up following a catastrophe.

Although the solar flux will have decreased because of the cloud cover, some areas will still be able to receive up to 1 kW/m^2 of solar power. With solar cells becoming more efficient, this is also an option to consider for power generation. In 2006, an efficiency of over 40% was achieved using solar cells, and future developments will see this figure rise (Blass 2006).

When all else fails, and temporary electrical power is necessary, human power is a possible last resort. There are flashlights already commercially available that rely on power provided by shaking a magnet over the center of a wire coil. A better source would be an exercise bike that has been converted into a generator. A person in good shape can generate bursts of power of over 700 watts and continuously produce around 150 watts (Butcher 1994 and Burke 1980).

Communications

The communications system will need to be sensitive enough to communicate with the Moon and be small enough to be stored within the repository and set up by a single person. A low power transceiver with a small aperture antenna can provide communication capability with the Moon. Automated trackers would greatly help with lunar communications, but they are not vital because someone can simply ensure that the antennas are pointed at the Moon and move them throughout the time the Moon is visible.

As the lunar archive payload evolves and a wider communications budget is available, the required antenna size will shrink. Storage, deployment, and use will become easier. Ideally, the antennas should be less than 1 m in diameter.

Ideal Facilities
Ideally, the Tier 2 repositories would be located underground; however, not all areas of the world will have the resources to build a large underground complex. The facility is required to have enough room to store all that is necessary for a given population as well as protecting it from the catastrophe itself and potential earthquakes that could result from a NEO strike or supervolcano. The repositories will also have to withstand the usual weathering and aging that all structures face.

Decommissioned ICBM silos should be considered for the repositories. They are strong structures, designed to survive near-misses from nuclear blasts and can store large volume. In the event of a power loss, the heavy doors of an ICBM silo can be opened manually. Decommissioned ICBM silos have been sold through eBay as large, underground mansions, many have selling for less than $2 million (Fenton 2004). Many of these sites are being destroyed as a result of the 1993 U.S.-Russia Strategic Arms Reduction Treaty (Flock 2000 and Matzko 2000). ICBM silos are dispersed far away from high-population areas, so they would be safer after the catastrophe during the madness and fight for scarce resources.

Another design solution for Tier 2 facilities is the underground tunnel infrastructures of modern cities. Cities around the world have plenty of volume tunneled out for subways and sewer systems. Many of these tunnels have been abandoned and can be modified or augmented to support both tiers of repositories. However, caution should be exercised when selecting this option because many tunnels may flood without continuous pumping.

The ultimate design of the repositories depends on the needs of the surrounding culture and geographical location. The specific designs are beyond the scope of this report and should be dealt with on a case-by-case basis.

4.2.3 Distribution
The distribution of the terminals and tiered facilities is important for the success of post-catastrophe human survival. The factors involved in estimating the optimum distribution of the centers include population density, terrain features, existing facilities (civil centers and old ICBM silos), and the economic health of individual areas. We will discuss the issues of worldwide and local distributions, and provide recommendations.

Population Density
As of 2007, the world population is 6.7 billion with an average population density of 48 people per km^2 (Nations Online Project 2007). Population densities are variable across the world depending on terrain, climate habitability, economic success, and access to vital resources. These variations must be taken into account when distributing the Earth repositories to maximize their effectiveness. The table below shows an example of the variability in the population density per country:

Table 4-1: Examples of population and density (Nations Online Project 2007)

Country/Region	Population	Area (km^2)	Density (Pop per km^2)
World (land only)	**6,727,508,082**	**134,682,000**	**48**
Bangladesh	158,822,300	143,998	985
United States	298,212,900	9,629,091	31
Spain	45,061,274	506,030	88

Forty-four percent of the world's population lives within 150 km of the coast, including eight of the top ten largest cities in the world (UN Atlas of the Oceans 2007). In China alone, where the urban population is expected to increase by over 125% in the next 25 years, over 400 million live on the coast. If a large NEO struck an ocean, a massive tsunami would almost certainly cause severe population loss and infrastructural damage to any coastal habitat; this needs to be considered when distributing facilities. Tier 2 facilities should be located away from coastal regions and at higher altitudes in areas where tsunamis would be less of a threat. Necessary Tier 1 facilities, for high density ocean coastal areas, would have to be positioned with respect both to the dangers of a tsunami wave, and ease of access for the population. It must be noted that in life-threatening situations people will have higher desires to reach such facilities and therefore the security of their location should, in some cases, be prioritized against their accessibility.

Terrain and Natural Resources

Drinking water will be a main priority for the disaster relief program. On this scale, the economics and engineering challenges of storing massive quantities of water are unrealistic. A natural water supply, such as a lake or river, along with purification systems could provide clean water for the surviving population. Earth facilities, especially in high-density zones, should be located in large open-land areas such as university and community playing fields.

Natural resources like woodlands or areas with extracted energy sources, such as coal mines, could become vital to keep the population alive. Higher level facilities should be placed near these locations. Woodlands could provide energy and materials for short and long term shelter re-building. Facilities in remote areas, such as abandoned missile silos, could be used as long-term storage facilities for grain, agricultural equipment, and fuel. These bunkers are generally concentrated in developed countries and similar robust, long-term facilities will need to be found or built in other regions.

Economics and Cultures

The distribution and quantity of the facilities will depend on the resources and budget provided by the corresponding country (assumed to be proportional to a government's available resources). Less developed countries will not be able to afford such facilities in every major population area; however, most of these countries are already prepared for regular large-scale natural disasters and have active supply centers. For example, data from such disaster relief programs as the 2005 tsunami can be used to provide a good placement model to locate resources. Civic centers, specifically universities, have been discussed as ideal locations for the Earth repositories because they are located across the world in populated areas. This is not the case for developing countries; Bangladesh has 20 times fewer universities compared to the United States per population figure (Universities Worldwide 2007). Other types of civic facilities such as religious centers or libraries can cover this deficit and, again, are generally proportional in quantity and size against the local population.

Recommendations

Human development around the world is complex and, because of the unknown location, devastation, and loss of human life occurring during and post-disaster, the exact distribution of the Earth facilities is beyond the scope of this report; however, some considerations for future studies will be discussed. The number of civic centers in any area across the globe will always be generally proportional to the local population, so this limits the distribution possibilities. Natural disasters, such as tsunamis, and other dangerous occurrences must also be considered when distributing and securing the facilities. The size and quantity of the facilities directly relates to existing infrastructure and availability of local resources, such as water and energy supplies. A detailed, localized study will need to be done to determine the best regional locations for these facilities. Sustainable Earth facilities are essential to successfully securing, stabilizing and re-building human civilizations

4.2.4 Maintenance

Following the generic design of the different Earth repositories, some basic maintenance needs to be performed on a regular basis, differing slightly for tier I and II repositories. This maintenance can be divided into two parts: contents maintenance and operational maintenance.

Contents Maintenance

The following table summarizes the maintenance requirements of the Earth repositories:

Table 4-2: Maintenance of archive contents

Item	Maintenance
Food	Replacement prior to their expiration date
Water treatment tablets	Replacement every five years (shelf life) (Butyl Product Ltd's Aid Equipment 2007)
Sanitation Equipment	Replacement prior to degradation
Medicine	Replacement prior to their expiration date (dependent on each kind of medicine)
Flashlights and matches	Requires waterproof containers
Seed deposits	Requires specific temperature and humidity conditions
Tools	Only applies where machinery is involved

Operational Maintenance

Because of the different repository designs throughout the world, maintenance requirements concerning their operability may differ from one to the other. The following must be maintained in all repositories:

- Structural integrity: Since the Earth repositories have life spans of at least 100 years, and must meet local building regulations, the structural health must be checked on a regular basis, as established in each government or country.
- Power system: As each repository has a stand-alone power generator for use in the event of an external power failure, the equipment needs to be kept in a functional state and serviced at appropriate time intervals.
- Electronics: The operability of electronic equipment in the Earth repositories must be inspected on a regular basis, and broken parts must be promptly replaced. At this point, upgrades of hardware or software may be considered according to changes in technology. Special attention must be paid when checking the status of the uplink to access the data on the lunar archive.

4.3 Lunar Facility

4.3.1 Function

Here we investigate the technical function of the lunar facility. The lunar archive will contain large amounts of information and should be accessible for many years after the disaster occurs. The lunar archive should be able communicate with the Earth repositories before and after the catastrophe. The archive should be self-reliant with as little maintenance as possible. Implementation of the lunar archive should be achieved in at least two phases with the possibility of a third phase if the current global political situation continues to push for permanent human settlement on the Moon.

4.3.2 Lunar Environment

The Moon is a natural satellite of the Earth having an age of 4.5 billion years. The lunar environment differs significantly from that of the Earth as it is a quiet and desolate celestial body. The main characteristics of the Moon are that it has no atmosphere, no fluids, and no tectonic activity. It is an ideal place to store any object in an unforeseeable future.

The lunar environment has many characteristics to consider when designing a lunar archive for the Moon. Several issues need to be addressed such as the gravitational, thermal, vacuum, and radiation environment. Furthermore, the lunar terrain and dust, and the continuous rain of micrometeoroid impacts should be considered.

Some of these issues such as thermal and radiation environment, and micrometeoroid impacts may be removed partially or entirely if the mission exploits a lunar subsurface location.

Gravitational Environment
The Moon is smaller and lighter than Earth, resulting in a gravitational environment of 1/6 of that on Earth. The lower gravity affects structures built on the Moon.

Thermal Environment
The thermal environment of the lunar surface is directly related to the incoming solar flux, the reflected lunar albedo flux, and the infrared radiation from the lunar surface. The lunar surface temperature varies according to latitude and time within the 14 day/night cycle of the Moon (Little 2003). The extreme temperature environment, that a man-made object finds itself in, varies depending primarily on the latitude of the landing site, see Figure 4-1 (Langseth and Keihm 1975), Burke (2002).

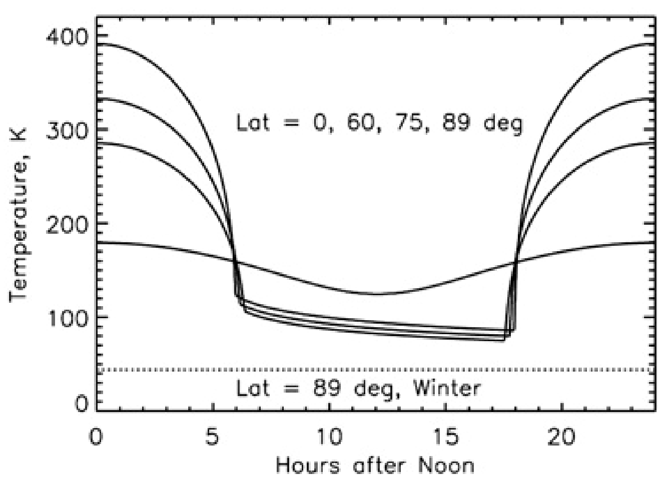

Figure 4-1: Lunar surface temperature profiles at different latitudes over a lunar day. (Langseth and Keihm 1975)

The subsurface lunar thermal environment differs significantly from the surface thermal environment due to the stable temperature. Table 4-2. The temperature 1m beneath the surface at the lunar equator is 232K ± 3K (Langseth and Keihm 1975).

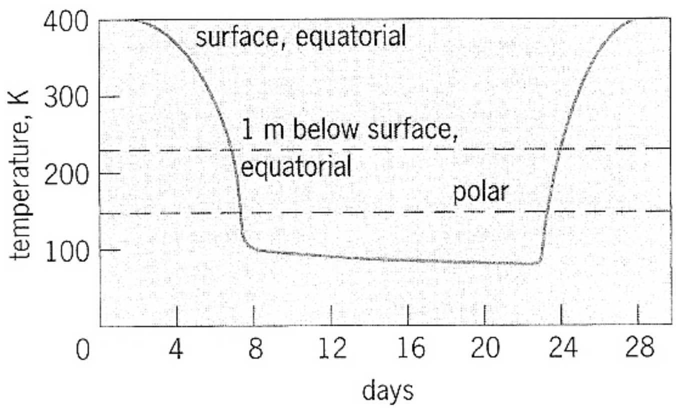

Figure 4-2: Lunar surface and subsurface temperature profiles. (Burke 2002)

Vacuum Environment
The lunar atmosphere is a hard vacuum with 2 orders of magnitude fewer particles per unit volume than in Low Earth Orbit (LEO). The hard vacuum excludes the use of many common plastics and rubbers whose strength and durability is reduced by outgassing of their volatile components. Polymers approved for use in LEO may not be suitable for use on the Moon.

Radiation Environment
Due to the lack of any substantial atmosphere surrounding the Moon, any spacecraft or structure on the Moon encounters a harsh ionizing radiation environment consisting of large fluxes of low-energy solar wind particles, smaller fluxes of high-energy galactic cosmic rays, and occasional intense particle fluxes emitted by solar flares. In addition to the ionizing radiation that reaches the lunar surface, soft x-rays and ultraviolet light are also significant hazards.

Dust Environment
Lunar dust is a large concern because of its specific properties. The particles are very fine, angular, and highly abrasive that can erode bearings, gears, and other mechanical mechanisms not properly sealed. Lunar dust carries an electrostatic charge enabling it to cling tenaciously to all non-grounded conductive surfaces.

Lunar Terrain and Micrometeoroids
The characteristic terrain of the lunar surface has been formed by impacts. The perpetual rain of micrometeoroid impacts has resulted in an extremely fine, loosely-compacted soil, the regolith (Greek: blanket rock) covering the entire Moon.

The lunar terrain has been well characterized around prior landing sites with the size distributions of boulders and craters having been mapped Figure 4-3 shows the results of a random simulation of lunar craters and boulders created using Apollo 11 landing site data, which is a moderately smooth area. Only craters larger than one-half meter (represented as circles) and boulders larger than one-quarter meter (depicted as filled rectangles) are displayed. The scale is given in the lower left corner of the plot.

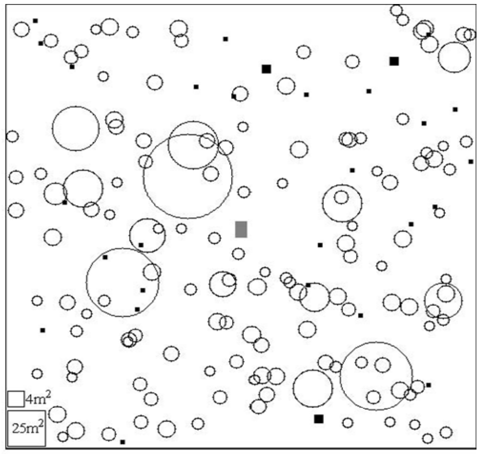

Figure 4-3: Lunar terrain, simulated from data gathered by Apollo 11

A concern for spacecrafts and structures on the surface of the Moon is micrometeoroid impacts. Micrometeorites with a mass larger 1 gram are capable of perforating structures causing severe damage. Even though the likelihood of an impact is very remote ($1/10^6 \sim 10^8$ per year), the consequences it may have should be considered.

4.3.3 Design

This report is not a preliminary design document. Here we intend to set forth the mission requirements, demonstrate that design solutions exist based on present and near-future technologies, and point towards needed further options studies and developments. We envision a phased technology program, with each phase building on the previous phase. The first phase shall be a technology demonstration mission, followed by the fully functioning archive, with the last phase being far future extensions of the archive. These phases are depicted in Figure 4-4.

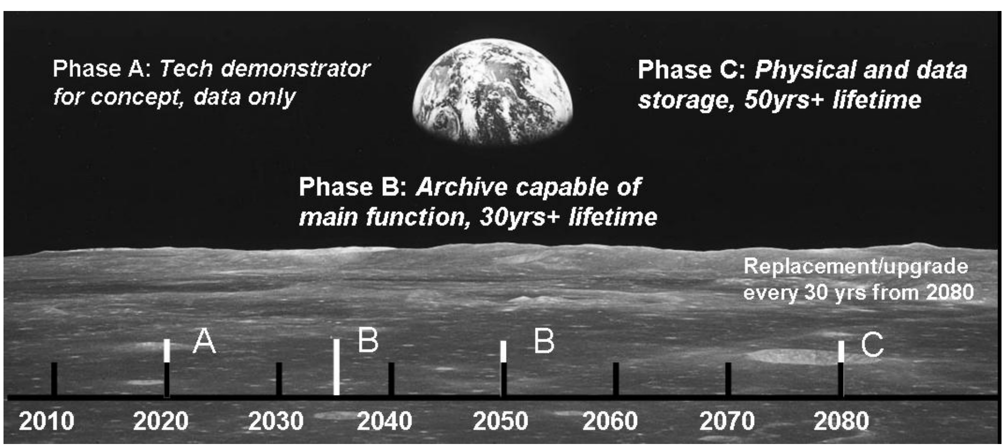

Figure 4-4: Lunar archive timeline

We have derived the following requirements for the different phases:

Phase 1:

- This phase shall demonstrate critical technology needed for the second phase, including:
  - Power system
  - Data storage below surface

- Drilling & burying
- Sending information to basic receiving stations on Earth

- The archive shall store hardware, including at least data storage, beneath a layer of regolith with a thickness of 10 cm or more.
- The archive shall be able to send basic information to a simple receiving system on Earth with an antenna of maximum 1 m^2.
- The archive shall have an operating lifetime of at least 15 years without maintenance.
- The archive shall be launched no later than 2020.

Built to meet these requirements, Phase 1 might also be used scientifically to broaden our knowledge about the environment beneath the regolith and about the regolith itself.

Phase 2:

- This phase will be the actual archive.
- The archive shall have a lifetime of at least 30 years without hardware maintenance (data updates would be possible at any time)
- The archive shall be launched no later than 2035.
- The archive shall have sensitive items beneath a regolith layer with a thickness of 1 meter or more.
- The archive shall be able to send basic information to a simple receiving system on Earth with an antenna of maximum 1 m2.
- The archive shall have a more advanced communication system (higher data rate and bandwidth) that allows multiple users to access and search the information available in the archive from the Earth repositories.
- The archive shall have a trigger function.

Phase 3:
In this phase the archive could be part of a human lunar base. It will have the same requirements as Phase 2, with the possibility of added physical information (e.g. cultural artifacts) and function as a library to the lunar base.

Design Considerations

Here is a list of a few of the issues that will arise when designing a data storage archive and communications platform, especially if some of the subsystems are buried underground to take advantage of the constant thermal conditions under the surface of the Moon.

Data Storage Systems
It shall be able to store data at least 6 terabytes in size, one terabyte for each of the six world languages (see the Classification and Linguistic Aspects of Knowledge section). There are several possibilities for storing this large amount of electronic data in the lunar archive.

- Hard disks: These have the advantage of proven technology and low price. They have reasonable data storage and lifetime. The disadvantages are relatively high power usage, relatively slow data access and the use and vulnerability of moving parts.
- Solid-state memories: These have fast data access, no moving parts, longer lifetime and low power usage. The disadvantages are higher cost, relatively new technology, and lower data storage, although this last part is changing rapidly.
- Possible future storage techniques include the IBM Millipede (IBM Zurich Research Laboratory 2005), optical storage, or quantum computing techniques. Some of these are nearer in the future than others, but none are currently available, so the advantages and disadvantages still have to be proven.

For the first and second phases, the lifetime and power usage of the data storage device are the critical parameters. Therefore our current baseline is to use solid-state memories for both phases.

Power Systems

There are a few viable options for the power system on the Moon:

- Radioisotope Thermal Generator (RTG): In such a generator a nuclear decay generates thermal energy, which is transformed into electrical energy by some means. This requires including thermocouples (no moving parts and proven technology, but less than 10% efficiency) and Stirling engines (moving parts and still under development, but up to 20% efficiency). The radioactive material can be any of a number of radioisotopes, but the most common used is Plutonium 238. Plutonium 238 has a half-life of 87.7 years and a modern RTG (such as the one onboard the Cassini probe) has a mass of 55.5 kgs, which can generate 300 W of electrical power and 4.4 kW of thermal energy at the beginning of life (Kelly and Klee 1997). Finally RTG's can be put below ground where they are less vulnerable to radiation, temperature changes, and meteorites. Removing thermal energy is a big issue.
- Solar power. On the surface of the Moon, the maximum power achieved with current technology solar panels is about 200 W per square meter. Except at the poles, during the 14-day night, no power can be obtained from the solar panels, and either power storage or some other power generation is necessary. Current technology solar panels only have a lifetime of about 20 years.
- Thermocouple (TC) Power: TCs are used by RTGs to convert heat energy into electrical power. Because of the constant subsurface temperature and changing surface temperature, multiple TC units could be buried or wedged into the regolith so that one end the exposed end acts as the hot side while the buried end acts as the heat sink during the day. At lunar night, the heat flow would reverse. No planetary probe has explored this option of power generation.

Since the first phase will have a limited lifetime, solar panels could be used for power generation. The second phase, however, will require a longer lifetime, so longer-term power options will be necessary. This means that the technology needs to be tested in the first phase and possibly other lunar missions, but solar panels can be used for redundancy in the first phase.

Communications

Communications with the Earth from the Moon will be one of the largest challenges faced for design of the first phase. Some of the criteria that must be considered for a communications system on the final design are:

- Antenna Size and Shape. How can we maximize the gain without sacrificing the lifetime?
- Antenna Location. Could the antenna itself serve as an energy flow path to the heat sink if placed above ground? Would it heat up too much if placed underground where the regolith cannot dissipate the heat?
- Free Space Loss. What frequency will be ideal for traveling so far yet still legally available for communications immediately when the archive is implemented?
- Power Use. Will the power system be able to provide enough power for continuous transmissions with an acceptable bit rate and bit error rate to all sides of the Earth?
- Receiving Antenna Size. The lunar communications system dictates ground antenna requirements.

If the antenna were placed beneath the surface at a depth of no more than 2 m, the signal scattering due to the regolith would be minimal because regolith is dry and does not absorb long-wavelength signals (Rossiter and Strangeway 1978).

Digging Systems
The advantages of storage systems beneath lunar regolith are constant temperature, protection from solar radiation, and shielding from micrometeorites. To exploit these conditions, we must explore a means placing a payload beneath the regolith. Lunar robotic drilling and digging has already been demonstrated on the Russian Luna 20 and 24 missions and the United States' Surveyor missions. A Mars Lander launched in 2006 that shares its name with this report has been sent to drill into Martian ice. Although no systems larger than measurement probes have been placed beneath the surface, current digging and digging technologies do not need massive development compared to the development of longer lasting power, data storage, and communication systems.

Figure 4-4: Trench dug by Surveyor 1 in lunar soil (Burke 2002)

Landing Site Selection:
It is of fundamental importance to situate the lunar archive in a suitable location to maximize its life-time and usability. There are several key differences that need to be understood between locating the lunar archive at an equatorial location or a polar location.

Polar Regions: Certain polar landing sites have the advantage of almost constant solar illumination and a more benign thermal environment with less extreme temperature swings. This allows a simplified approach to power management and thermal control for the archive and allows solar panels to provide the main source of power. However accurate localized mapping of the surface and further at landing will be needed as any error could lead to a landing within a crater in such a way to completely block the Sun's illumination rendering the spacecraft inoperable. A further disadvantage is that the communications antenna will need to be positioned at a very low angle from the horizon increasing the chances of a foreign obstacle (rock or crater wall) blocking the Moon-Earth line of sight.

Equatorial Regions: Equatorial regions are where the majority of the past Apollo and Lunar missions were situated and so accurate mapping and local terrain detail is at present all ready known about many areas. Communications will be simplified since the Earth will be positioned almost directly above the Lander allowing constant and secure data links. However the thermal environment is far more extreme will temperatures ranging from 110K to 390K over the 27-day lunar cycle. This along with the fact that the Sun is in shadow for half of this period means that power and thermal management is far more complex and dual-use systems will have to be emplaced. Below is an image taken from the Apollo 12 astronauts of Surveyor 3 at an equatorial location (notice also the shallow hole that has been dug by the lunar Lander).

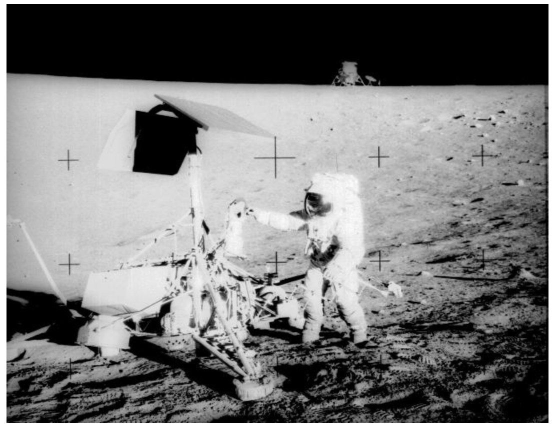

Figure 4-5: Apollo 12 astronaut examining Surveyor 3; lunar module intrepid in background

Both regions have their respective advantages and disadvantages however both can be accommodated with modern designs. By locating part or all of the archive below the lunar surface, some of these issues can be resolved (specifically thermal). In reality the first phase will piggyback on a lunar orbiter or landing and so the region of landing will already be fixed meaning both scenarios will have to be studied.

4.3.4 Maintenance

When planning the lunar archive maintenance, three main issues must be considered: on the hardware side, the in-situ maintenance of taking care of the power subsystem, thermal control subsystem, communication subsystem, and structure itself; and on the software side, software maintenance and periodic data updates.

Finally, the monitoring of several variables (temperatures, intensities, storage capacity, power etc.) is essential for the assessment of the workability of all the subsystems to be maintained. Monitoring shall operate in closed-loop mode except if one variable oversteps limits, then a warning message shall be sent to Earth.

In situ maintenance

A periodic review of all the subsystems is to be considered (Elbert 2001): no maintenance for the first phase and 30 years of periodic maintenance for the second phase. It could be either robotic or, in the future, human support. There might be scenarios in which external support coming from the Earth should be required in case unexpected events happen.

Power subsystem
Following the design of the lunar archive, both solar arrays and electric batteries will be installed to provide power to the different subsystems on board.

The current technology allows an expected life time of 20 years. Different events may cause earlier end of life, for example, dust deposits, erosion produced by dust or micrometeorites impacts (Erikson et al. 2004). Tele-operated support may be used for maintaining or replacing the solar arrays.

Battery durability depends on the load-unload cycles (with current technology, up to approximately 10000 cycles) (Bukley 2007), being determined at design time. No dedicated maintenance would be required during their lifetime, but after their life span has expired, replacement should be provided.

The RTG power system is meant to require no maintenance.

The power control and distribution subsystem may require maintenance, taking place each time tele-operated support is sent. Should power supply be missing (information coming from the monitoring survey), additional power generators should be sent and connected to the power subsystem.

Thermal control subsystem
Computer hardware requires specific temperature range both for operating and non-operating times. The temperature 1 meter beneath the equatorial surface equals -41ºC ± 3 ºC so cooler than normally required (Intel 2007). Software on board should, based on input from the temperature sensors, control the corresponding thermostats to activate subsystems such as radioactive heat units when required to maintain the temperature in specified design margins.
By monitoring the on board temperatures, the workability of this subsystem can be assessed.

Communication subsystem
Reliable antenna and electronics operation is essential for the health of the link. Test links may be used for monitoring the health of this subsystem, but only in-situ maintenance (periodic inspection and protective care) (Elbert 2001) can be performed on this subsystem and is dependant of the overall maintenance plan frequency.

Structural integrity
Only in-situ maintenance can be applied to this, should it be needed.

Hardware
The mean time between failure of the solid state memories is targeted to be more than 5 million hours or more than 500 years (Intel 2007). The hardware will not last that long: despite the knowledge shall be safe from time degradation, periodic maintenance missions will care of the hardware. Earlier replacement should occur should miss performance be observed.

Tele-maintenance

Some maintenance operations do not require any robotic or man presence in-situ. They may be operated from Earth via communications links.

Software maintenance/updates
Software updates may be required once the lunar archive is already installed (bug fixing, new features implementation, coping with new databases, etc). As archive data content is refreshed and augmented and software state of the art advances, new software uploads from Earth will be part of routine archive operations.

Data updates
Constant data update may be allowable on a periodic basis, to take into account the evolution of the contents of the archive, particularly, the knowledge from humankind.
New data may need to be added to cope with information either not considered at the time of the launch of the archive or non-existent at that time.

4.3.5 Transportation

The components of the lunar archive must be safely transported to the lunar surface by a launcher system. We will discuss past, present and near-future launcher systems and their limitations to understand the feasibility of specific launcher designs. By looking at these limitations, along with the economics, a set of transportation recommendations for the lunar archive system can be made.

Launcher Systems

Between 1959 and 2007, 65 lunar missions have been launched. NASA orbiters, Apollo Lunar Modules, and rovers were launched on now retired launch systems like early Atlas rockets and the Saturn family. The later Soviet missions were launched by the Proton launcher, which is still in service today. Other systems that successfully launched interplanetary or lunar missions include Titan 23B (obsolete), Delta II, Atlas V, Ariane 5, Proton and Soyuz-Fregat vehicles.

The most common method of transporting a craft to the Moon is splitting the trip into multiple steps and propulsion burns. A craft must exceed Earth's escape velocity from Low Earth Orbit and head towards the Moon before a burn(s) to be captured and circularize the lunar orbit. This is followed by a maneuver reducing the periselene down to a very low altitude before the final landing procedure. Most lunar missions have taken this approach; first reaching lunar orbit, thus allowing more precise landing decisions to be made.

It is only slightly more difficult to reach lunar orbit than a geostationary orbit (3.8 km/s from LEO compared to 4.1 km/s). This means that it is possible to put a significant payload into lunar orbit with present day launchers. The largest known robotic spacecraft to the lunar surface was the Russian sample-return mission Luna 24. It had a Lander mass of 1880 kg and an orbiter mass of 5600 kg (The Moon Station 2003). This was the approximate mass of the last seven Luna missions and so is assumed to be the largest possible lunar surface payload using the Proton-Blok D launcher system (Blok D rocket stages). This launcher is relatively unchanged since the 70's and is still classed as a heavy lifting rocket with similar payload launch characteristics to the Ariane 5, Delta IV, and Atlas V. By using present day launcher systems the largest payload that can make a soft-landing on the Moon's surface would have a mass of ~2000 kg and an orbiting mass of ~6000 kg. A lunar archive established before the availability of the next generation of launchers will have to follow these design constraints.

A further option is to use the example of ESA's SMART-1 spacecraft, which used a more fuel efficient propulsion system. This spacecraft took over six months to reach lunar orbit but used a fraction of the fuel and thus minimized the total mass, allowing a reduced launch cost. Landing procedures in the past used a descent chemical propulsion system that could get within a few meters of the surface before the spacecraft was left under its own mass.

Economics and Cost

All governmental or corporate agencies who own launcher systems give an estimated launch cost, however this is variable depending on the type of activity planned, the current market, the launching entity, the mass/dimensions of the spacecraft, and complexity of integration. Costs can be reduced by using piggy-back payload opportunities where there is excess room in the payload fairing for another smaller satellite (like the previous example of SMART-1). This could be an option for the first phase of the lunar archive system.

NASA's Exploration program along with other nations' recent lunar programs has once again highlighted the importance of space travel to the Moon. These visions will no doubt encourage further lunar orbiters, Landers, and rovers to explore and map the Moon's terrain and so there are likely to be many piggy-back opportunities in the next 15 years for a lunar archive. A dedicated heavy-lifting launcher however will be needed for the later phases, and so launch costs will be significant. Example costs are Delta IV or Atlas V derivatives, which as of 2004 cost in the region of $250 million USD (Astronautica). Since these missions are planned for 2030+, the precise launcher market and cost is difficult to predict. The cost of NASA's future manned lunar class launcher, Ares V, is unknown but expected to significantly above that of the present heavy lifting vehicles. The complexities of the later phases of the archive depend on the payload. Launcher insurance must also be considered.

4.4 Communications

A lunar archive system would not be complete without communication between the survivors and the archive. Here we will investigate the communication links needed from the Earth to the Moon to support a lunar archive. We will also look at terrestrial, Earth to Earth communications, for disaster response and communication between Earth repositories, as well as an interface between the terrestrial communications and the Earth to Moon communications.

4.4.1 Earth-Moon Communication Architecture

Pre-Disaster

Before the catastrophic event, a communication link will need to be established. This link would allow for data to be uploaded to the archive, updates to the content of the archive to be made through time, and a way to call the data back to Earth when required. A reliable, autonomous and on-demand system would enable the transfer of information from the lunar archive to the Earth. We believe this system should include a beacon, a trigger, and a transmission system. It can be assumed that current technologies will be available to establish the needed communication system before the global disaster. We will also explore the possibility of using the lunar archive as an international library before the catastrophe.

Post-Disaster

After a global disaster, the state of terrestrial and Earth to Moon communications systems will be unknown. Information could be sent on demand to Earth as required by the survivors. Satellite communications can only be relied upon for a short period of time, if at all, following the disaster. By creating a robust communication system before, post-disaster communication problems can be mitigated.

Communication Links

Earth - Moon Communications

Communication from Earth to the Moon and back is an essential part of the structure of the lunar archive. Different methods to communication between networks of earth repositories and the lunar archive have been researched on and are presented in this section. Depending on the amount of information transferred between the Earth and the Moon, its transmission speed, and other technical considerations, two major solutions are proposed:

- A Radio Frequency (RF) communication system
- A laser communication system

Laser systems have various advantages over RF systems including narrower beam widths, a brighter laser beam at the receiver due to the very narrow beam that exits the transmit telescope, it requires much less power to transmit data than the RF system for the same received power and finally it is capable of much higher data rates than the RF due to their differences on their wavelength. These particular characteristics allow a laser system to have a much smaller antenna than those of the RF systems. The main problems of the laser system are derived from how difficult it is to point correctly the telescope. An almost negligible error in its pointing direction will cause failures on the communication between the Earth and the Moon. Furthermore, due to the need for an accurate positioning mechanism, it makes the laser system expensive and very complex. These reasons show that the RF system may not have as high data rate as the laser system, but it is more reliable, simpler to design, and implement.

Uplink & Downlink Design

The communication architecture of this Earth-Moon-Earth link consists of a downlink in two categories: the low and high bandwidth characteristics, and an uplink that has a high bandwidth. The downlink refers to the communication link in the direction of the Moon to Earth, likewise the uplink is the communication link leaving the Earth towards the Moon. The uplink and the downlink have been designed to have the requirements shown in Table 4-3. The assumptions made here are the following: the required E_b/N_o (signal-to-noise) value has been considered based on a turbo coding and a bit error rate of 10^{-7}, the range was 400,000 km, and the thermal noise was set to 440K.

Table 4-3: An Earth-Moon communication link budget estimation

Characteristics	**Downlink**		**Uplink**
	Low data rate	High data rate	High data rate
Carrier Frequency (GHz)	0.40	2.0	2.0
Tx Antenna Dia. (m)	2.0^{M*}	2.0^{M}	4.0^{E**}
Tx Antenna Efficiency (%)	65^{M}	65^{M}	500^{E}
Tx Antenna Output (W)	10^{M}	10^{M}	100^{E}
Bandwidth (Kbps)	1.0	60	60
Rx Antenna Dia. (m)	0.80	0.80	2.0
Rx Antenna Efficiency (%)	65	65	65
Margin (dB)	7.80	4.00	17.9

*E: Earth, **M: Moon

The requirements for the antennas are based on the concept that the entire Earth shall be in the Field of View of the Moon antennas and vice versa. To this end the maximum diameter and consequently gain is limited by the view angle of the Earth from the Moon. Increasing the antenna gain the transmitted power is concentrated in a small fraction of the space and the consequent ratio between the power received and the background noise increases. Since the Earth view from the Moon covers an angle of about 2 degrees, the 3 dB angle of the Moon's antenna shall be bigger than 5 degrees considering margins. Since the 3 dB angle is given by Equation 4-1.

$$\theta = \frac{21}{f_{GHz} D}$$

Equation 4-1: Equation for half powered beam width.

where **θ** represents the angle in degrees, f_{GHz} is the carrier frequency in GHz and D is the antenna diameter in meters, the maximum diameter of the antenna for the 2 GHz carrier is 2.1 meters.

The downlink has a low bandwidth that is intended to reach simple radio receivers anywhere on the Earth after the disaster. These receivers may not be close to densely populated areas where Tier 1 or Tier 2 facilities are located and should be simple to use, inexpensive and portable. The high bandwidth communication link of the downlink has the purpose of provide with a faster source of information to the Tier 2 facilities.

Earth - Moon Communication Facility Distribution

The communication between the Earth and the Moon is one of the key elements in the survival of humankind to retrieve information. To keep this communication link working continuously it is suggested to locate multiple Tier 2 ground stations on the Earth. These ground stations should be built uniformly distributed around the Earth although not specifically at the equator. High and dry are the desired characteristics for the locations where these stations will be. Mountaintops are considered optimal sites. The control and communication among the different ground stations can be performed automatically with human intervention only on monitoring tasks.

Moon facilities could be distributed at high elevation, polar locations which have the potential to provide year-round continuous sunlight for power and a more benign thermal environment. A polar site also provides proximity for likely future human lunar bases. Besides location, other parameters should be considered such as elevation, terrain, and geology that allow the appropriate positioning of the antenna. The optimum landing location should have an altitude that guarantees sunlight all year around. The landing site terrain can present pronounced differences in the elevation which may lead to mechanical instability and poor signal reception. A central equatorial site meets these conditions, also providing a clear line of sight with the Earth. This area has been well documented, presenting places of flat terrains with diameters of up to 160 km.

Trigger System

The trigger is the system that initiates the broadcasts from the lunar archive, after a catastrophe has occurred and been confirmed. The lunar archive would broadcast to the Earth in a continuous and periodic basis. The system has two phases: pre-event and post-event. During the pre-event phase, there would be a communication between the Tier 1 facilities that comprise a given region. These facilities will have a redundant communication method that will pass a token to every facility as shown in Figure 4-5.

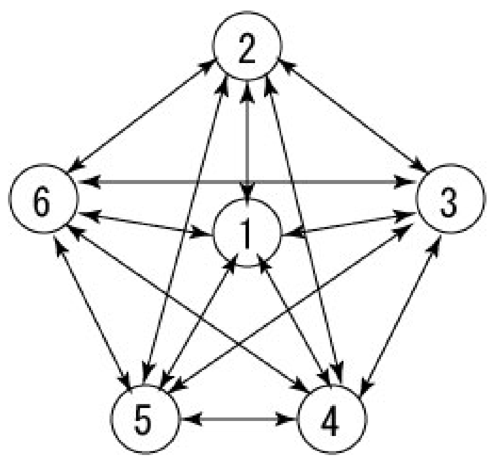

Figure 4-5: Communication mesh network

These tokens will include the status information of all the facilities, allowing every facility to store this data in the event that one or several of these locations are destroyed. Any facility could work as a direct link to the lunar archive. During normal operation, the tokens would pass between all the facilities including the designated, main communication point that would establish a connection with the lunar archive. This process will be performed on a daily basis.

After a disaster, when multiple Tier 1 facilities have been destroyed, the other members of that specific damaged region will follow a predetermined, hierarchical order deciding which facility would gather the others' status and upload it to the Moon. During this period, the lunar archive would register an anomaly, asking for confirmation of a possible disaster on the Earth. Upon confirmation, data packages (of immediate survival help) will start downloading to the Earth.

4.4.2 Earth-Earth Communication

Terrestrial communications are vital following a global catastrophe. The survivors of a global disaster need immediate disaster response communication systems, and a way to communicate with each other following a disaster. The after disaster effects on Earth to Earth communications will depend on the exact scenario. Earth to Earth communications via satellite, and low level, radio communications will be explored in this section as a means of first responder disaster communication, and communication between survivors.

Existing Satellite Communication Systems

Before we can propose recommendations for a communication system for Earth to Earth communications via satellite, we must examine our existing systems. By looking at existing satellite systems and making modifications, we will hopefully create a more robust system to withstand a global disaster. Here we will look at current technologies of global satellite communication systems, deciding if such technologies would work for lunar archive communication and how to modify these technologies.

Intelsat, and Inmarsat are well designed satellite communication systems. Intelsat has media and telecom services including video, broadcasting services, data file transfer, and voice over internet. Inmarsat provides similar services. NASA's Deep Space Network is an international communication system used to support interplanetary and selected Earth-orbiting space missions. Inmarsat's Broadband Global Area Network includes 10 satellites with three communication options, each with a range of data links.

The prohibiting characteristic of using existing satellite systems is the location of their ground stations. Intelsat places their ground stations near the coast. Intelsat has ground stations in Maryland (USA), California (USA), and Fuchsstadt, Germany (Intelsat 2007). With the high probability of a global disaster affecting coastlines, a costal ground station is unfeasible for the lunar archive system. Other systems such as Inmarsat have limited coverage, only providing service for the densely populated areas of Earth. These systems are also not viable because we cannot know in advance who will survive, and communication systems must be available to anyone.

Although current systems will not work for a post-disaster terrestrial communication system, their well-built design could be modified for use. By using existing ground stations from systems like Inmarsat and Intelsat, building similar stations away from coastal regions, and linking these ground stations together with the help of VSAT (very small aperture) terminal systems, we could develop a robust ground communication system for use following a catastrophe (assuming electric power has survived or could be reconstituted). VSAT terminals could be used as ground hubs, linking data from satellites to other terminals that are not directly connected to the satellite. VSAT systems have many benefits including small size, mounting location and options, direct line of communication to the satellite, and low cost.

Post-Disaster Communications

A global nuclear disaster would affect communications systems on the Earth, and could possibly affect the communication link between the Earth and the Moon. This section will examine the probable characteristics of Earth after a nuclear cataclysm, discussing robust communications networks to withstand these characteristics, immediate disaster response communications, and communication networks between ground repositories.

Nuclear explosions in the Earth's atmosphere create openings in the ionosphere and high electron-density gradients. These strong gradients can reflect incoming radio signals at high frequencies (about 300 MHz) and high altitudes (Arendt and Soicher 1964). Reflections harm satellite and radio communications. Blackouts in communication can also occur when the ion cloud is very dense. With the right frequency and altitude, we believe satellite and radio communication would be able to remain in operation after a global disaster.

Earth-to-satellite communications in conjunction with first responder technology is ideal for communicating among the survivors after the disaster. Satellite systems are able to survive most global disasters, although their post-disaster lifetimes are limited without operators. Satellite communications systems cover the majority of the Earth's surface, and new networks can be set up easily. First responders use satellite communications systems for satellite phones, push to talk radios, and help with establishing fixed terrestrial communications following a disaster, again assuming that electric power would be available. These technologies could calm, and guide the survivors.

Radio Communications

If the satellite network were to fail and the Earth repositories needed to communicate with each other, a lower level communications system would be required. This communications system would need to withstand the effects of the dust cloud following a global disaster by having a powerful transmission capability and a long life span. Amateur radios with a standard language such as Morse code or Teletype, could be used for ground communication. Amateur radios are basic short-wave radios. Operating these radios has remained a hobby for radio enthusiasts since their existence. Emergency networks of volunteer radio operators, such as ARES (a Canadian network) already exist and can be integrated into a global system for use with the lunar archive's communications system.

It is very likely that ground communication systems will be partly destroyed in the disaster. The Earth repositories should contain back-up systems such as antennae and VSAT terminals, as well as an instruction guide for how to repair the communications systems. The Tampere Convention on the Provision of Telecommunication Resources for Disaster Mitigation and Relief Operations has outlined a way for states to receive telecommunications assistance after a disaster. The Tampere Convention calls on states to facilitate the provision of prompt telecommunications assistance to mitigate the impact of a disaster, and covers both the installation and operation of reliable, flexible telecommunications services (International Telecommunication Union 2007). The Lunar Archive Program could establish a similar system to help rebuild communications systems after the global disaster.

Chapter 5

Program Implementation

5.1 Introduction

We now describe an implementation plan that would be instrumental in the success of the Lunar Archive Program. An international, structured, well-managed program, with support from a variety of stakeholders, is necessary to manage the construction of archive facilities, data collection, and the education and outreach to the public. This program must be robust and cost-effective. It must last for many years to ensure that the archive is continuously viable.

Planning for success, the program dedicates itself to these principles: longevity, growth, adaptability and flexibility. All aspects of the lunar archive and Earth repositories will continuously evolve as storage content is refreshed and augmented over time. As technology advances, more cost-effective tools will be employed to make the program more efficient. We outline concepts for managing the logistics, funding, and maintenance of the Lunar Archive Program.

5.2 Program Support

5.2.1 Gaining Program Support

Support from the world community is essential for implementing a Lunar Archive Program. We must identify the many different rationales for supporting the program. Rationales for support may include interest in space, desire to preserve the knowledge and culture of humanity, or simple financial benefit. The stakeholders that should be part of the process are: inter-governmental organizations (IGO), such as UNESCO; international non-governmental organizations, such as the International Committee of the Red Cross, religious associations, and those focused on environment and culture; local non-governmental organizations and foundations, such as the Bill & Melinda Gates Foundation or the Rockefeller Foundation; national governments; national government agencies, such as national space agencies or agencies for cultural conservation; private enterprises, whether involved in space or not (Boeing, Alcatel, Monsanto, Coca-Cola); and private citizens. Figure 5-1 shows the relationships between the different stakeholders. We can leverage these relationships to benefit the Lunar Archive Program.

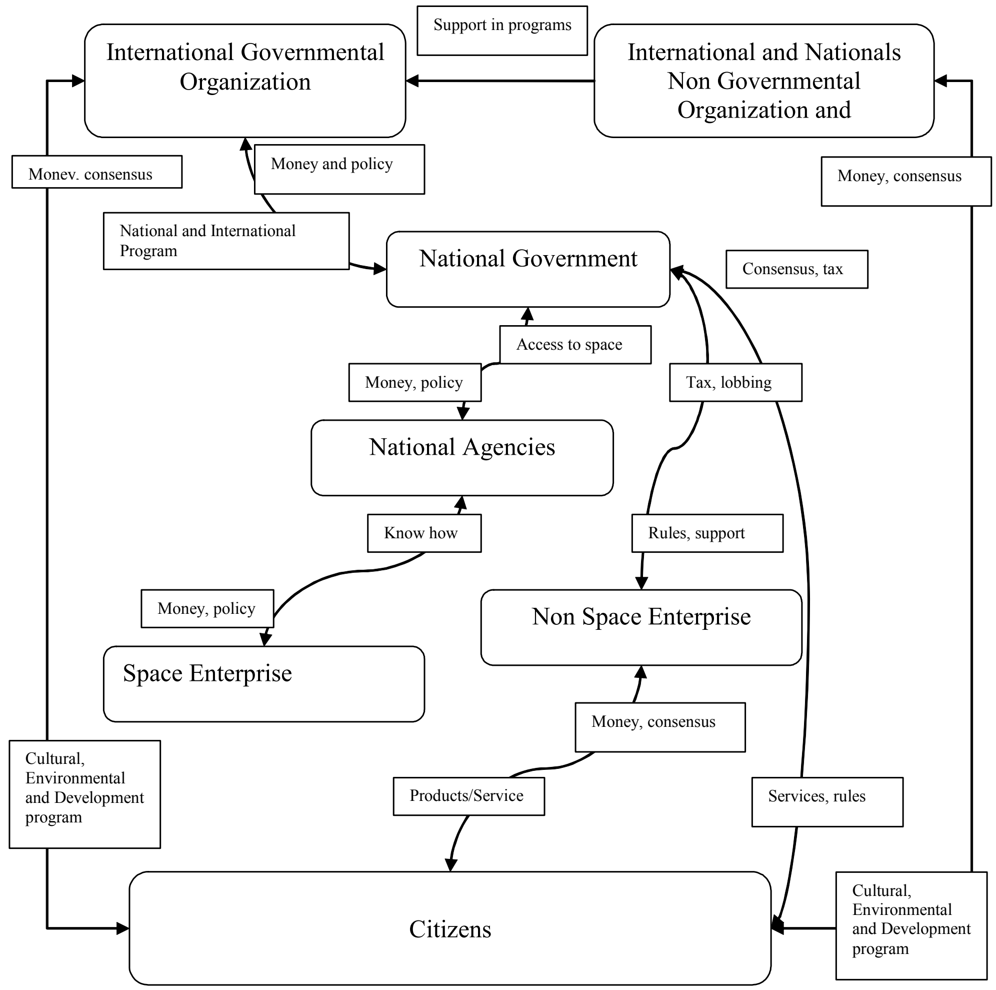

Figure 5-1: The stakeholders and their relationships

Legend: The rounded boxes represent the various stakeholders. The square boxes are the support and/or resources they can provide each other.

5.2.2 Sources of Support

According to the previous section, we will now describe the stakeholders' possible involvement with and use of the Lunar Archive Program, and determine their likely rationales. The hierarchy of the stakeholders is depicted in Figure 5-2.

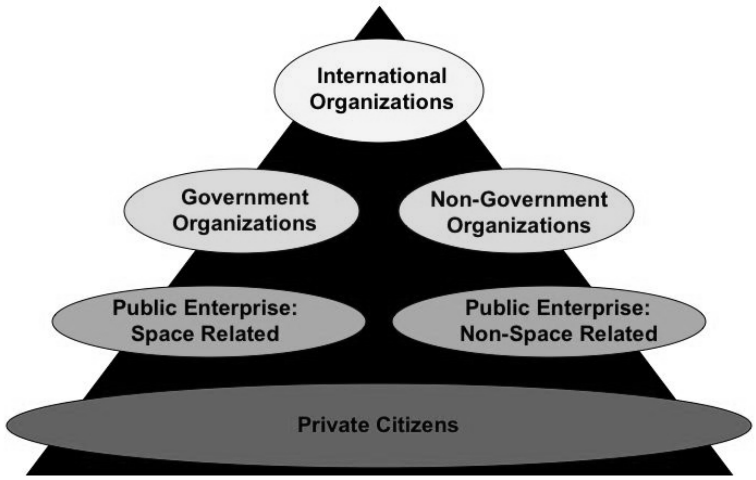

Figure 5-2: Hierarchy of stakeholders

International Governmental Organizations: Most international organizations work in fields that are related to the purpose of the Lunar Archive Program. Therefore, the Lunar Archive Program could be part of their strategy to fulfill their mission. The most appropriate organization is UNESCO, which is composed of 192 Member States in the fields of education, science, culture, and communication (UNESCO 2007). All of these fields are in agreement with or are functional to the Lunar Archive Program. For example, we can cite the Convention Concerning the Protection of the World Cultural and Natural Heritage (1972); the Lunar Archive Program could be placed under Article 5 of this Convention. The Lunar Archive Program is also in agreement with the Convention for the Safeguarding of the Intangible Cultural Heritage (2003). In such ways, IGOs could lend support by promoting international cooperation, providing general management, financing, and giving content from their cultural collections.

International and Local Non-Governmental Organizations: In this large category we can find organizations that support such Lunar Archive Program-related subjects as culture, languages, environmental defense and preservation, and international cooperation in a variety of fields. Religious organizations may also wish to participate in the Lunar Archive Program; their missions often include humanitarian programs that are consistent with the Archive Program goals and they would wish to preserve their systems of belief. Both secular and religious non-governmental organizations (NGOs) could be important for their outreach capabilities, lobbying capacity, and institutional support.

National Governments: Possible motivations for national governments to become involved with the Lunar Archive Program are numerous and variable. Some rationales might include: United States - to maintain political leadership by showing that it can promote a peaceful and globally useful action; European Union - a way to develop new knowledge useful for industrial activities (European Commission 2003); Russia - an occasion to play a central role in a geopolitical scenario with the use of its technology; China - to increase its international collaboration for development and acquisition of knowledge. Other governments, particularly those that do not have strong science and technology capacity, could find motivation in collaboration on a high tech program. The most important rationale for central governments, however, would be to show their citizens that they would be supported in case of a catastrophe and their national cultures, languages, and histories preserved.

National governments could provide support through their funding of the international governmental organizations and through the involvement of their national agencies.

Space Agencies: The main functions of national agencies (or trans-national, in the case of the European Space Agency [ESA]) are to develop space systems, construct space assets, and support the national and international policies of their governments. Presently, many of the space agencies have programs for lunar exploration, such as the National Aeronautics and Space Administration's (NASA) Vision for Space Exploration (NASA 2007) and ESA's Aurora Exploration Programme (ESA 2007). At the same time, new launch vehicles are being developed (such as NASA's Ares) and the cost of launching with existing rockets (Arianne family, Long March family, H2-A, etc.) is being reduced. These factors are in perfect agreement with Archive Project needs. For these reasons, space agencies could provide mission management and technological knowledge.

Other Government Agencies: Those government agencies involved with education, culture, agriculture, management and protection of the environment, or other missions compatible with the Lunar Archive Program would be invaluable participants. They could provide content, money, and outreach.

Space Enterprises: Although governments are sometimes shareholders in these enterprises, like all businesses, their main incentive for participation would be financial. Using their technical expertise, they could be the contractors that build the terrestrial and lunar components of the archive system.

Non-Space Enterprises: Non-space private enterprises may have two main rationales to participate in the project. The first would be social responsibility; including the Lunar Archive Program as part of their philanthropic programs would provide a positive public response to the company. The second rationale would be advertisement of their products through sponsorship. Private enterprises could directly purchase space in the archive, provide funds through sponsorship, and expand outreach through their advertisement.

Private Citizens: Public opinion is the most important factor necessary for support of the Archive Program. We must involve as much of the world population as possible, with particular reference people in countries with space capacity and high gross domestic products (GDP). There are many ways in which the public may be involved in the Lunar Archive Program. First, we can bring our message to the academic community through educational campaigns. Second, we can involve the public by partnering with enterprises for advertisement and outreach. Third, we can sell space in the archive to store personal information for posterity. Fourth, we can develop an Internet-based game, which will increase involvement and outreach, provide a simulation through which to get data about social rules and the needs of survivors, and be sold to players for Archive Program maintenance and support.

5.2.3 Sources of Funds

The first and most important source of funds would come from the national governments, separately or through specific IGOs like UNESCO, which has a budget of $611 million. By partnering with this organization, costs related to Program Administration (estimated at $25 million per year) could be paid for less than 5% of its annual budget, less if we use their resources. Education and Outreach costs (projected to be $50 million per year) could easily be covered by enterprises that wish to use the Lunar Archive Program to improve the image of their company and their products. Program Administration and Education and Outreach are classified as *Programmatic* in Table 5-2 of the Funding Profile section. International and local NGOs could provide subscription through associates and organize fund-raising. Their total annual contribution could amount to $30 million.

At the outset, before broad public comprehension and acceptance exist, it may be possible to get advocacy for a program started with a private donation. Costs at that stage are low enough to be covered by a single wealthy, altruistic person or a small foundation grant. Beyond private donations, we could sell space in the archive to enterprises or private citizens, over 15 years we could get as much as $100 million. The online game Second Life has 8.5 million players who pay $9.95 per month (Second Life 2007). If we suppose that we are more cost effective ($5 per month) and less successful (2 million players), we can aspect a net profit of $0.25 per players per month, we can get $6 million per year. Finally in consideration of the maintainability national governments could provide $35 billion over 85 years, or $411 million per year, which averages to less $2.5 million per year per government.

5.3 Program Structure

5.3.1 Program Participants

Program participants are previously discussed in the Sources of Support and Sources of Funds sections. These entities are distinguished based on their financial, resource, organizational, and international abilities. In addition to these qualities, the participants should wish to be represented in the Archive Program. Although preservation of culture, social structures, and information have traditionally fallen primarily - but not exclusively - to government organizations, any participating entities with similar motivations would be welcome to submit data for preservation in the archive. They should not, however, have control of archive management and operations without meeting criteria set up by the archive ownership and management structures. These are defined in subsequent sections of this report.

5.3.2 Participant Decision-Making Model

We envision a governing committee of participants representing the major contributors to the Archive consisting of delegates from the Sources of Support and Sources of Funds organizations. When discussing the Archive Program, we will use the term Stakeholder Board. This term is analogous to a standard business model Board of Directors. The delegates would form the core of the Stakeholder Board. This Board should have a balance of private and public representation to diversify expertise and interests; however, each represented organization should be subject to qualifying criteria relative to the interest vested in the Archive. Contributions to the archive content as well as the provision of other value items such as direct currency; or, through provision of real estate, technical infrastructure, services, facilities, personnel, and/or man-hours. Each of these contributions would be accepted for the purpose of relieving the Archive Program fiscal burden for beginning and on-going operational and maintenance costs. Minimum resource contributions are required to gain voting privileges on the Stakeholder Board. Standards for a minimum contribution for the governmental organizations would be based on a percentage of that country's GDP in combination with both funding and in-kind resources that could be offered to satisfy the Archive execution needs.

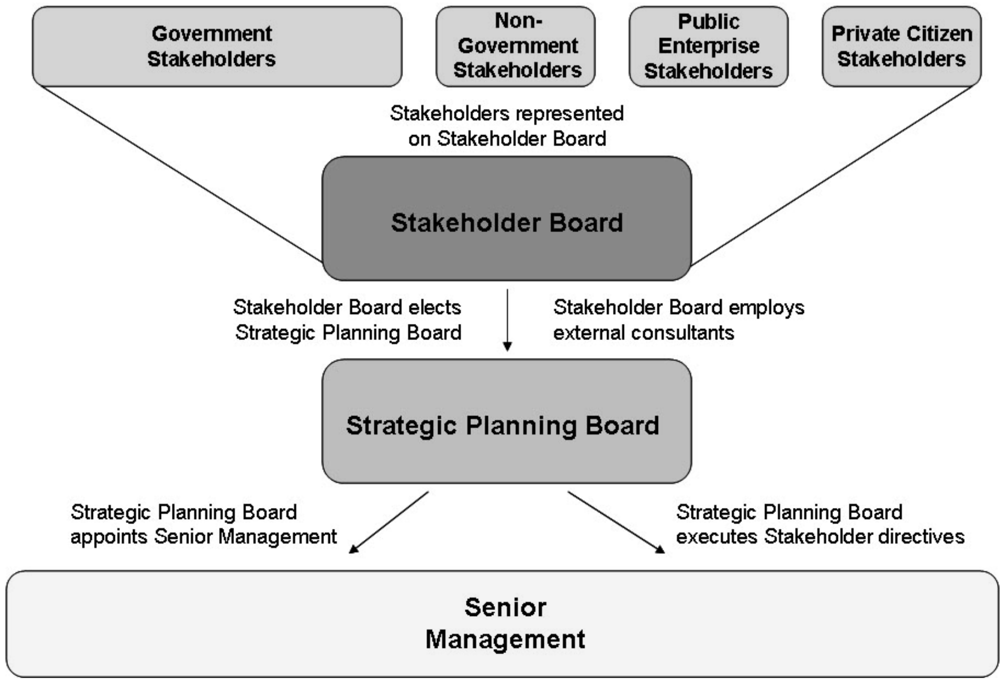

Figure 5-3: Lunar Archive Program structure

We recommend that the hierarchy of the Stakeholder Board resemble that of the United Nations organizational structure (Rao 1996) to take advantage of an established, long-term, proven medium for international and intercultural cooperation and decision-making. Stakeholder Board participants would appoint members to the Archive Strategic Planning Board (similar to business model, Executive Officers). The Stakeholder Board would organize its own rules of operation, standards, and criteria for selection and appointment to the Strategic Planning Board, as well as determine short- and long-term goals and objectives for the Archive Program. Initiatives would be approved based on the motions and resultant votes of the Stakeholder Board. The stakeholders would have the privilege of selecting experts to consult on challenges posed by the interdisciplinary nature of the Lunar Archive Program.

Selected advisors to the stakeholders should be organizations and consulting firms with recognized expertise in the appropriate fields. Consulting services and sub-contracts would be implemented to accomplish major milestone tasks on the Archive Project timeline. The Archive Project may need such international expertise for: disaster relief, emergency preparation and supplies, global social and educational programs, large scale technical engineering, system integration, information systems, policy, law, financial management and investments.

Similar representation guidelines would apply to other entities wishing to participate as voting members of the Archive Stakeholder Board. Examples include public-private partnerships, single or multiple private customers or contributors, public organizations, private individuals or public companies. Voting positions will be limited to those who achieve the minimum contribution standard. These voting members representing the smaller value classes would have less influence than the participating governmental organizations, due to the great importance of governmental widespread capability and influence.

5.3.3 Internal Management Model

The Archive Strategic Planning Board would be comparable to a business model Executive Management Team and would function as the top-level management structure for Archive operations. A combination of matrix and hierarchical management structures (Rao 1996) could be employed below the Strategic Planning Board to address the diverse technical, operational, and growth and maintenance needs. The management structure would be similar to those of existing large organizations that require international, interdisciplinary cooperation and coordination. We assume moderate changes to address unique, large-scale requirements specific to this undertaking, including global information systems and protection, launch vehicles, catastrophic scale disaster coordination, complex systems engineering and worldwide logistics.

The external purpose of the Strategic Planning Board would be to execute the Stakeholder Board decisions/directives and approved advisor recommendations. The Strategic Planning Board would formulate planning approaches to mitigate political, technical, financial and schedule risk. It would work to quell or avoid opposition from impacted international organizations and would consider possible recovery and back-up strategies in the event the baseline execution plan experiences any setback or delay.

Internally, the Strategic Planning Board would select the senior management structure. The structure would cover each of the major business and technical components of the Archive Program operational requirements and lay out the optimal format for the organization. The Board would retain the right to re-organize the structure and could remove or replace senior management team members.

Senior management would ensure execution of protocols and standards to enforce ethical, consistent business practices. Major functional roles within Senior Management would include standard business model parallels, such as Chief Executive Officer, Chief Financial Officer, Chief Engineer, and Operations Manager. Each of these management positions would require extensive organization at lower levels to integrate global operations. There should be representatives whose function would be forward thinking in matters of education and outreach, data refreshment and physical maintenance. A disaster awareness aspect perhaps integrated with existing management organizations such as the Disaster Monitoring Constellation would further strengthen the independence of the management structure.

5.4 Funding Profile

Initial funding and in-kind support are required to kick-off world wide advocacy, set up a skeleton programmatic organization, acquire (ideally, donated) offices or base of operations, communications, logistics planning, travel reimbursement, and personnel compensation. Previously identified funding sources, or possibly a private benefactor, will cover many if not all of these initial start-up costs. Innovation by the stakeholder board will be instrumental for decreasing costs. As an example, using the Student Space Exploration and Technology Initiative (SSETI) Program to design and build a demonstration model of the Moon-based technology would show early technical progress at reduced cost while also positively impacting outreach and education. Consistent with the SSETI format, consultation from participating national space organizations would ensure technical viability (Student Space Exploration and Technology Initiative 2007). The Stage I (piggyback) payload could be a derivative of this proof-of-concept demonstrator. Launching the main Stage II robotic lunar archive facility to the Moon and building the first Earth repositories (T0 – Terminals, T1- Tier I, T2 - Tier II) requires the budgets typical of other lunar programs. The figures in the table are intended to reflect our judgments as to the required scope and scale of each envisioned phase of the Lunar Archive Program. Of course, the real budget numbers would be produced in phased planning exercises done by the program organization and its contractors distributed over the world. Cost information in Table 5-1 has been estimated by comparison with previously successful programs wherever possible (European Space Agency 2003), adjusted to 2007 dollars.

Table 5-1: Projected initial program costs for the first 15 years

ITEM	NUMBER	PER UNIT (M$)	TOTAL COST (M$)
Programmatic	15 years	75	975
Lunar Mission	1	60	60
Launch	1	20	20
Earth Repositories	576 T0	0.001	<1
	192 TI	0.25	48
(Development Only)	0 T2	200	200
			TOTAL: ~1300

A sustained stream of funding is needed to maintain the Archive Program indefinitely. There will be a core of full-time personnel required for daily operations. Using the burden rate structure of similarly sized non-profit organizations, with additional assumptions for the requirements of an internationally coordinated organization, recurring cost figures are shown in Table 5-2. Facility maintenance, content updating, and public outreach must continue annually. Our estimates assume a 100 year program budget requirement, covering three additional launches for scheduled lunar facility upgrades and maintenance (Delta 7000 1999). Additional Earth repositories will be added as funding and resources are contributed.

Table 5-2: Projected program costs for the subsequent 85 years

ITEM	NUMBER	PER UNIT (M$)	TOTAL COST (M$)
Programmatic	85 years	75	6375
Lunar Mission	3	400	1200
Launch	3	100	300
Earth Repositories	2700 T0	0.001	2.7
	1400 TI	0.25	350
	24 T2	1000	24000
			TOTAL: ~32,300 (85 yrs)

Participating organizations may make in-kind contributions, reducing the planned Archive organization annual burden and infrastructure requirements. Earth repositories can be built in additional locations as funds become available. The cost to maintain the lunar facilities will change as technologies mature. The allocated cost will also be completely different (and completely unpredictable now) once there is a continuous human presence on the Moon. Advancing technologies are expected to decrease future costs and risk, making the program goals only more obtainable as time progresses.

5.5 Program Responsibilities

5.5.1 Sustaining Funding

The main goals of the Archive Program maintenance teams are to keep up indefinite economic support to ensure that adequate resources are available to add to the archive's content, update the technical hardware, maintain the facilities, and continue both public outreach and education campaigns about the archive. Continuous feedback with all stakeholders would be necessary to create stable support for the archive to maintain the funding flows required. More funds will come from bids of previous archive materials or from space qualified used parts to collectors, online donations, and organization of entertainment and cultural events. Public advertising would encourage bringing knowledge to the archive.

The channels used for advertising would be radio and TV, Internet and newspapers, student interdisciplinary contests (arts, engineering, business, consultants) (Dougherty 2007), affinity programs and school education. Every year there should be an international meeting to evaluate the best channels that are working in each culture to transmit the goals to the audience and especially, find ways of improving the outreach campaign and fund the next updates. Itinerant museums and expos, interactive websites, international exchange programs, TV series, and educational forums sustained through a structured organization with a well-defined public relations spokesman would help to spread the archive idea to the popular culture, creating a strong brand, present in the daily life of Earth's citizens.

New members would have the same rights and obligations as the founder countries. They would have to pay the fees to cover update campaigns twice per year and special launching campaigns every 30 years to upgrade the Moon hardware. Reports to the stakeholders would be based on the economic repercussion in case of disaster and recovery.

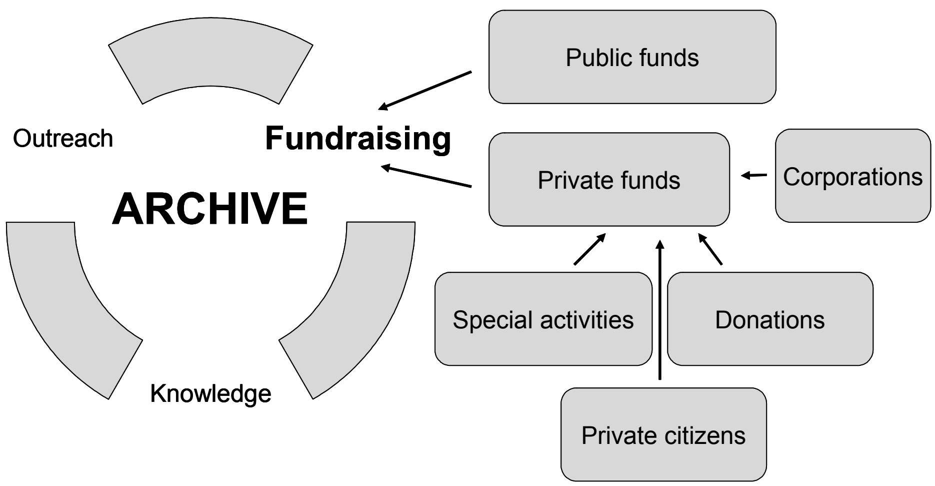

Figure 5-4: Ongoing fundraising efforts

5.5.2 Project Management

The internal organizational structure of the Lunar Archive Program, includes a project management division. This team will manage the implementation of the physical lunar archives and the Earth repositories. Instead of building space- or Earth- based hardware, the project will issue Requests for Proposals. The Lunar Archive management team will oversee the solicitation and selection process and direct the development. Separate Requests for Proposals will be issued for the lunar archive and the Earth repositories. Local workforces will build the Earth repositories across the planet. Using a local contractor and workforce significantly complicates the management of the Lunar Archive Program, but enhances the prospect of design and construction responding to local needs and consistent with local resources. Also it appreciably benefits the local economy, thus improving the quantity and quality of local support. The project management team has the further responsibility to communicate the ongoing development progress to the executives and board of directors.

5.5.3 Data Collection

The Lunar Archive Program must manage the data collection process, organize the data, and update the archive as appropriate. As was mentioned above, the lunar archive will be interdisciplinary, intercultural, and international. The Earth repositories would contain a subset of the data stored in the lunar archive. Thus we do not need separate consideration for Earth repository data collection. For the purposes of this discussion, we refer solely to the lunar archive portion of the project.

The process of data collection would require a coordinated online system with personnel dedicated to various concerns. Project representatives could be assigned to either a geographical region or a specific topical area. The two kinds of representatives would need to work closely together to balance the interests of the specific regions with the content needs for each topical area. For example, each culture will be welcome to submit its own history to the archive, but the topical and local representatives will work to present a consistent view of quantum mechanics.

For data in specific topical areas (e.g., physics, medicine), we will want to be sure that accurate, up to date information would be included. In these cases, we would have a topic representative who would coordinate with experts in that field to ensure that the data included in the archive are peer-reviewed and reasonably well-respected by that topical community. Wherever possible, we would like to include the research leading up to the final process or discovery, as well as the final product itself.

For each geographic region, someone familiar with the culture will be best suited to explain the archive, negotiate legal agreements, and collect the data. The local governments, corporations, non-governmental organizations, and citizens would be more likely to respond to someone of their own culture than to a foreigner. Depending on the staffing levels of the project, the same representative may be in charge of outreach as well as data collection.

For creative works such as art, literature, music, and video, the topical coordinators would be limited more by the availability of data storage in the archive than availability of content. The regional representatives and topical representatives would need to work together to select the content. In the early stages, the archive data storage capacity may be limited to survival data with very little room for cultural content. Later in the project, technological enhancements would enable us to include more cultural and media images.

Public data collection would be closely tied with the education and outreach effort and would entail multiple collection mechanisms. In addition to person-to-person data collection at public events, we would use a web-based system. Data collection from the public could be used as a revenue source via auction or outright sale. Beyond the money collected through fundraising, there would be content selected via competitions and lotteries.

Many different data content sources could simplify data identification, if not the final data selection process. The Internet has provided a surplus of information varying in quality and value. In addition, many other organizations have already begun the process of collecting interdisciplinary, international, and intercultural data. Wikipedia currently provides one of the largest sources of free content. "As of August 8, 2007 Wikipedia has approximately 7.9 million articles in 253 languages" (Wikipedia 2007). Wikipedia's strength is that anyone in the world can volunteer to contribute to its articles. This is also a weakness from the perspective of the lunar archive. Since anyone can edit the articles, it is very easy for someone to introduce errors or maliciously corrupt the encyclopedia. The Rosetta Project is an Internet based group that catalogs the world's languages and associated cultures. It incorporates written, audio, and video segments as part of its web site (Rosetta 2007). Another Internet-based source of information is the ongoing Google Books project. There are many groups working on digitizing the world's books, but Google is easily the biggest player. They have set out to use their proven search capabilities on the text of the world's books. After finding the book, the website directs the user where to buy or borrow the book (Google 2007). These are just a few examples of current knowledge and culture collection efforts. The Lunar Archive Project could partner with these groups to simplify data collection and provide project support.

Beyond the new media sources of information, the archive could also partner with organizations such as the United States Library of Congress and the various International

Patent Offices. In the long term, we would hope that as new content is created, copies of that content could be automatically forwarded to the Lunar Archive Program for inclusion in the next update to the archive.

Some of the identified data would be freely available in the public domain, but some would be protected or sensitive information. In such cases, archive representatives would need to convince the corporations, governments, and/or individuals to agree to include the data in the lunar archive. Such cases may need use a multi-faceted approach. First, provide the legal assurance through contractual obligation that intellectual property rights would be protected until the event of a global disaster. The legal section of this report has a further discussion of the legal protections regarding the archive data. The second facet would be assurance that the data would be technically protected. This technical protection would be provided by the implementation details of the lunar archive and Earth repositories themselves. The specifics of the technical implementation are still to be determined but may include encryption and isolation of archive data from the public domain.

The final facet is social and economic. We would appeal to the social responsibility of the intellectual property holder. For corporations, there is a significant social and economic pressure to contribute to a project like the Lunar Archive Program. Corporate social responsibility has become a major issue with business in the past decade. [It]". . . is the continuing commitment by business to behave ethically and contribute to economic development while improving the quality of life of the workforce and their families as well as the local community and society at large," (Holme 2000). Applying this concept to both individuals and corporations, we can make a convincing argument that participating in the archive would be in the best interests of the property holder.

Beyond mere social responsibility, corporations could use their participation in the lunar archive project in their marketing and publicity. This would benefit the corporation and would help the lunar archive project through maintained public consciousness of the project.

Finally, the intellectual property holders would want their creations and property preserved beyond a global disaster. By contributing to the lunar archive project, the contributors can be assured that their content would persist beyond the global catastrophe. They would have contributed to the ultimate legacy of humankind.

5.5.4 Legal Considerations

Introduction

The lunar archive raises important legal questions. Legal considerations include the use of the lunar surface or subsurface by the archive, the potential radioisotope thermal generator power source, and the need for a dedicated communications frequency. Equally important are the intellectual property issues raised by storing information in the archive.

Intellectual Property Law Aspects

The storage of data (be it on the Moon or Earth) raises important legal questions. Different issues come to play before and after an emergency.

Pre-Emergency

The most challenging legal problems posed by the establishment of a lunar archive arise from storage of information. Placing the lunar archive outside of a State's territory does not bring it outside the sphere of law. On the contrary, Article VIII of the 1967 "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies" (Outer Space Treaty) establishes that a State Party on whose registry a space object is carried retains jurisdiction and control over such object, and ownership of space objects and component parts is not affected by their presence in outer space or on a celestial body. Information is also unaffected by its passage through outer space – otherwise, anything broadcast by means of satellite would be copyright free.

Restoring human society and culture by means of a lunar archive would involve storing and retrieving information such as creative and artistic works, technical manuals, or blueprints. Most of these are subject to intellectual property entitlements such as copyright, patent, trademarks, and industrial design rights. A certain amount of information is in the public domain, i.e., the body of information and creativity whereby no entity can establish or maintain proprietary interests. This body of knowledge and innovation is considered to be part of a common intellectual and cultural heritage, and is free for use by anybody. Therefore, storage and retrieval of information pertaining to the public domain by means of a lunar archive would be lawful, whereas storage of information protected by intellectual property rights would need prior consent from the rights holders.

In practice, the lunar archive could be designed as a dual system, where public domain knowledge could be accessed before and after a catastrophe, while protected information would be retrieved only after a catastrophe, if rights holders consent in advance to the storage. Most of the information necessary for immediate survival belongs to the first tier. Open source initiatives such as Wikipedia and free software are laudable, and extremely useful. The second tier would involve obtaining the rights from the holders and protecting the information from unauthorized access. The Archive builders may encounter extreme difficulties when trying to obtain information subject to controls such as International Traffic in Arms Regulations (ITAR) and other similar schemes.

In 2007, The Planetary Society launched a glass DVD aboard NASA's "Phoenix" mission to Mars. The disk contains a 1.43 gigabyte digital library comprising 63 pieces of artwork, 161 novels and stories – such as H.G. Wells' War of the Worlds and Ray Bradbury's The Martian Chronicles - and four radio broadcasts related to Mars. One of the authors, Kim Stanley Robinson, declared the idea of being part of the first library on Mars "a fulfilling moment" (Mosher 2007). According to Jon Lomberg (2007), Project Director and Editor in Chief of "Visions of Mars", the legal issues for archives beyond Earth involve determining if the copyright is still in effect, finding the copyright holder, and negotiating terms for use in the archive. The terms needed to provide permission for world-wide use in the actual archive, replica versions of the archive, and use in media publications reporting on the archive. Lomberg considers that terms should be uniform for all copyright holders.

If adequate safeguards for protected information are in place, a case could be made for expanding the legal deposit- a well established institution in many jurisdictions. As early as 1537, King Francois I of France issued the "Ordonnance de Montpellier," a royal decree forbidding the sale of any book without first depositing a copy in the library of his castle. His aim was to have access to said books if other copies were lost from human memory or their text altered (Lariviere 2000). Legal deposit can be defined as –

> "a statutory obligation which requires that any organization, commercial or public, and any individual producing any type of documentation in multiple copies, be obliged to deposit one or more copies with a recognized national institution" (Lariviere 2000).

An "International Legal Deposit and Lunar Archive Convention" could support data collection and storage by obliging the publishers in the Member States to send an electronic copy of their publications for purpose of lunar storage.

Post-Emergency

Property (be it tangible or intangible) exists only insofar as there is a society to enforce it. According to Thomas Hobbes (1642),

> "the state of men without civil society (which state may be called the state of nature) is nothing but a war of all against all; and that in that war, all have a right to all things"

Collapse of society will mean collapse of the social contract. In practice, in the case of a global catastrophe as envisaged in this report's scenario, States will cease to exist. Intellectual property rights not only will lose their enforcer, but many of their holders will be dead. Using the information stored in the lunar archive will be, in practice, free. Even in case of lesser natural disasters, many legal systems allow for the defense of criminal necessity. In the United States, this defense allows an individual to use the property of another person without liability for trespass, provided that the user has sought to prevent a significant evil, had no adequate alternative, and the harm thus caused has not been disproportionate to the harm avoided (McMillan v. City of Jackson). In the area of intellectual property rights, the 1994 Agreement on Trade-Related Aspects of Intellectual Property Rights allows for use of a patent without the authorization of the right holder "in the case of a national emergency or other circumstances of extreme urgency" (art. 31.b).

Space Law Aspects

The location of the lunar archive on the Moon brings the legal questions under the international law of outer space. As a general rule, any space law discussion has to be started with the fundamental rule concerning freedom of space activities: "everything that is not, one way or another, prohibited or conditioned, is allowed" (Von der Dunk, 1999). This resonates with the "Lotus Principle", dictating that "under international law, every door is open unless it is closed by treaty or by established Custom" (Lotus Case).

Placement of the Archive on the Moon

A critical space law issue is the legal right to place the lunar archive on the Moon. Article I of the Outer Space Treaty declares space activities as "the province of all mankind" and directs the States Parties to perform these "for the benefit and in the interests of all countries". The aim of the lunar archive makes it an excellent example of such an activity benefiting all humankind. The same Article establishes the freedom of use of the celestial realms and the "free access to all areas of celestial bodies". The 1979 "Agreement Governing the Activities of States on the Moon and other Celestial Bodies" (Moon Agreement) builds upon this principle, allowing States Parties, on informing the public (art. 5.1), to pursue their activities in the use of the Moon "anywhere on or below its surface" (art. 8.1). In the execution these pursuits, *inter alia*, States Parties may place their "space vehicles, equipment, facilities, stations and installations anywhere on or below the surface of the Moon", and move them freely (art. 8.2). The placement of the archive ought not to interfere with the lunar activities of other States Parties. If such interference occurred, the parties involved should undertake consultations (art. 8.3). Article II of the Outer Space Treaty prohibits the national appropriation of the Moon, *inter alia*, by means of use. Art. 11.3 of the Moon Agreement builds upon this norm, proclaiming that the placement of space structures on or below the surface of the Moon shall not create a right of ownership over that location. The lack of property rights does not, however, preclude placement and operation of lunar installations, as seen from previous uses of the lunar surface by lunar landers. All the above norms support the conclusion that placing the lunar archive on the Moon is allowed by international law.

Powering of the Archive by RTG

It is likely that the lunar archive will be powered by a RTG and by solar power. Whereas the Outer Space Treaty prohibits, in Article IV, the installation of nuclear weapons on celestial bodies, the same article allows the "use of any equipment or facility necessary for peaceful exploration of the Moon". While the RTG powering the lunar archive is not used for the exploration of the Moon but for the analogous "use" of the Moon, it can be argued that it lawful because it is not a weapon of mass destruction. Other specific norms exist concerning use of radioactive materials that require States Parties to notify the UN General Secretary in advance of "all placements by them of radio-active materials on the Moon and of the purposes of such placements". The non-binding 1992 UNCOPUOS "Principles Relevant to the Use of Nuclear Power Sources in Outer Space" are directed primarily at free space, but are also of relevance to celestial bodies. The aim of Principle 3 is to "minimize the quantity of radioactive material in space and the risks involved"; therefore, "the use of nuclear power sources in outer space shall be restricted to those space missions that cannot be operated by non-nuclear energy sources in a reasonable way". Nonetheless, the Preamble of the same document recognizes that "for some missions in outer space nuclear power sources are particularly suited or even essential owing to their compactness, long life and other attributes". It can be argued that the lunar archive qualifies as such a mission. Principle 4 requires a Launching State to ensure that "a thorough and comprehensive safety assessment is conducted". From the above it can be seen that powering the lunar archive by means of an RTG is lawful, and it should not be difficult to comply with the constraints that the Secretary General be notified of its placement on the Moon, and that a safety assessment be conducted.

Radio Frequency Issues

Article IX of the Outer Space Treaty directs States Parties to conduct all their lunar activities "with due regard to the corresponding interests of all other States Parties to the Treaty". In order to successfully operate, the lunar archive needs a dedicated radio frequency band and protection from interference. The appropriate frequency and power requirements necessary for an operational link budget need to be coordinated with the International Telecommunications Union - the coordinating body in the area of frequency spectrum (Ribeiro 2003).

Conclusion

From our research, we see that international law of outer space is quite permissive, allowing placement and operation of the lunar archive hardware on the Moon. Current intellectual property law is not very proactive regarding the storage and retrieval of copyrighted information. Pending the establishment of an "International Legal Deposit and Lunar Archive Convention", the promoters of a lunar archive will be faced with the very laborious task of securing permission from individual right holders. Nonetheless, the information necessary for immediate survival resides in the public domain, so its storage and retrieval is lawful.

5.5.5 Public Engagement

A lunar archive will be of little value without public awareness and access. For this reason, a proactive and sustained public outreach campaign would be necessary to make the lunar archive program a success. The critical components of such a campaign include: initial public awareness to raise first generation knowledge about the archive; public education to teach potential survivors how to access the archive; and sustained public exposure ensuring that knowledge would not be lost over time.

Initial Public Outreach

An initial public outreach campaign will be necessary at the beginning of the lunar archive program. The goals of this campaign are twofold. First, the campaign must raise public awareness of the Archive Program, showing why an archive would be important to people's lives and the lives of future generations. Early support and understanding of the Archive Program could help raise initial program and funding support. Second, if the current generation knows about the lunar archive, they will instinctively pass some of their knowledge on to future generations, enabling future outreach efforts.

An aggressive public outreach program requires different methods depending on the target audience. A message to the highly developed world requires different tactics from those used to reach people in rural areas and in developing countries.

In the developed world, the majority of the population is already linked to mass media. An effective outreach campaign could use methods such as those employed by large corporations to reach global audiences. For instance, certain brands are known the world over because of their aggressive and pervasive advertising campaigns. The lunar archive could partner with globally branded companies to bring initial awareness of the archive to audiences worldwide.

A deeper understanding of the archive's utility requires outreach that goes beyond simple brand recognition. In this case, the outreach campaign would be most effective by exploiting already recognized information outlets. For instance, if a certain population relies on local news broadcasts for information, the lunar archive outreach campaign should be featured there. The general population relies more on the Internet as a source of information; thus, the Archive Program must ensure its information is linked to those websites receiving heavy traffic.

Specialized groups linked to the lunar archive's purpose could be used to pass more detailed information to their constituents. For instance, in the United States the American Library Association already has a captive audience of individuals and organizations committed to enhancing public access to information (American Library Association 2007). By partnering with organizations like the American Library Association, the lunar archive program could rapidly spread targeted, in-depth information to those groups likely to support it.

In rural areas and the developing world, outreach must serve those populations not touched by mass media. Distinctive cultures of these communities must be considered when conducting outreach campaigns. Cultural and ethnic history, traditions, and beliefs may require framing the concept of and reasoning for the lunar archive to complement local values (Huang 2007). Locally operating non-governmental organizations (NGOs) are well equipped to reach members of traditional societies through their experience of framing issues using non-western idioms, symbols, and metaphors (Abrams 2007). Grass-roots activities that gain the trust and understanding of isolated peoples would ensure that those communities are included.

Finally, a tangible opportunity may exist in the next year (2007-2008) to carry out a small precursor mission advancing the same goals as the Lunar Archive Program. The Japanese Aerospace Exploration Agency's Space Dictionary project will archive and broadcast from the International Space Station phrases from the world's 6500 native languages (Yamanaka 2007). In the process of executing this project, information about the potential value of a lunar archive could be conveyed to those cultural representatives providing language information. This activity could serve to kick off a campaign to get the public interested in and supportive of a full-scale lunar archive program.

Public Education

Once the Archive Program exists and facilities are installed on the Moon and on Earth, the public must understand how to access the survival materials and information available to them. The goals of public education would be to teach people the locations of the Earth-based repositories, how to use the archive facilities, and what to do in the event of either a local or global emergency.

One way to passively educate the public about its local repository would be to co-locate it with a university or other civic center. These facilities are well known, frequently visited, and logical shelters in a disaster. Universities, in particular, are already centers of knowledge, giving them a natural constituency for selection and maintenance, a population likely to use the archive before a disaster, and innovative funding opportunities through legacy giving. Additionally, every student who passes through the university would know of the location and existence of the repository, helping to sustain the public engagement effort.

Active engagement through traditional and non-traditional educational methods could also teach individuals how to react after a disaster. Traditional training and simulation could be conducted, just as current fire, earthquake, tornado, and other natural disaster drills are done today. Students in schools and adults at work could be required to perform a number of disaster drills, learning where the nearest emergency facilities are and how to access them. Making drills a part of the annual calendar would require cooperation with the local governments who currently mandate many such activities (Oregon Emergency Management 2001). A lunar archive and Earth repositories clearly augment such existing activities.

Outreach could also take advantage of new media outlets to create virtual simulations of disasters and allow individuals to act as if they were living in a post-catastrophe world. Computer and web-based simulations, similar to popular games such as SimCity and SecondLife, could allow individuals to practice finding archive locations, accessing information, and rebuilding society, all based on actual archive information. These types of virtual environments could be very successful at engaging the youth in learning about the lunar archive (Whitesides 2007), and perhaps shaping how the archive evolves, based on its simulated use. If successful, a game could even be sold to augment archive outreach funding.

Sustaining Public Knowledge Over Time

A public outreach program must sustain public knowledge about the archive over many generations. It is possible that thousands of years could pass from the inception of the Archive Program to a global disaster requiring its use. An outreach program must ensure that when disaster strikes, the future population knows about the archive and how to use it.

A public outreach campaign, such as the one described previously, could maintain awareness of the archive over a few generations, provided that the Archive Program continues to exist and be active in the public eye. As centuries or millennia pass, this campaign must transition to something more sustained and embedded within society.

An approach to long-term sustainability would be to create an international society, order, or fraternity dedicated to preserving knowledge about the archive and its use (Miller 1959). A society that requires an oath or the equivalent from its members could ensure their continuing loyalty to the order and its goals – in this case, the preservation of knowledge about the archive and a commitment to help survivors use it after a catastrophe. To be successful, this society must be international. Having members scattered across the globe would create a reasonable probability that some would be among the survivors.

A similar idea for passing lunar archive knowledge down over time would be to tie it with existing religious, cultural, and ethnic institutions and heritage. Religious institutions such as the Catholic Church are some of the longest-lasting organizations in our history. Because of their international network and strong community ties, they can be powerful allies in maintaining awareness of the lunar archive and understanding how to help survivors after a disaster. The Archive Program, however, must ensure that archive activities remain secular and are not tied to religious proselytizing.

Similarly, tying information about the lunar archive with existing cultural and ethnic heritage, especially in areas with native beliefs, will help ingrain information about the lunar archive in the minds of individuals. Care should be taken, however, to avoid making the archive so mythological as to be disbelieved, and not accessed during a crisis. By encouraging such cultural incorporation, the lunar archive system could be sustainable over the generations.

Finally, active use of the archive's content in universities, libraries, and even from individuals' homes and offices via the Internet, could be one of the easiest and most effective methods of maintaining awareness of the archive. By allowing the public to access the archive on a regular basis, it could become so ingrained in their daily lives and habits that they would not be likely to forget its existence. The main challenge is ensuring that the public remembers the deeper function of the archive beyond a casual daily information search.

Chapter 6
Recommendations

"An invasion of armies can be resisted but not an idea whose time has come."
强大的侵略者可以被抵御，但适时到来的好思想不能被忽略。
Victor Hugo
Chinese translation by Zhang Yuhua

This report is a call to action.

We have discussed the vulnerability of the Earth and the dire need for a biological and social archive. Our analysis has provided findings and recommendations as shown here:

- A lunar archive program should begin now. A catastrophe could happen at any time. Future events such as near misses with comets and asteroids will remind the public and political leaders of the need to safeguard civilization. The arrival of the asteroid Apophis in 2029 could serve as an appropriate worldwide experience to strengthen support for the archive program.

- Humanity must not wait until a global catastrophe to begin making our modern civilization more robust. We must acknowledge the vulnerabilities of our technological civilization and address them now − specifically our modern agriculture system and reliance on fossil fuels.

- The Moon should be used as a storage and broadcast location for the information contained in the lunar archive. Storing data off-Earth provides a back-up in case of a worldwide catastrophe. Subsurface lunar locations provide stable environmental conditions favorable to long-term storage of information.

- We recommend a phased implementation approach beginning with a worldwide public outreach campaign to call attention to these problems. This can begin now with the JAXA Space Dictionary mission to the Kibo ISS module and become successively more ambitious. An early step should be a demonstration mission to the Moon. This should be followed by successive missions that provide more functionality and store more content.

- We recommend that this Lunar Archive Program be synchronized with the existing lunar programs over the next twelve years.

- We advocate a multicultural, multidisciplinary archive organized in a way that is useful to survivors of the catastrophe. We recommend that the content in the archive expand beyond basic survival information.

- We recommend coordination of the Lunar Archive Program with current disaster mitigation efforts such as those identified by ISU Summer Session Program 2007 Team Tremor. The Earth repositories can be used before, during and after lesser disasters.

- A Lunar Archive Program must involve as many stakeholders as possible to ensure that the archive is representative of all humanity, not only selected nations, companies, or cultures. In particular, average citizens must be included through multiple means, as they are the ultimate user community. All potential survivors must be able to access the archive after a disaster and recover their cultural heritage.

- We recommend the creation of an international organization to promote, plan, manage, and maintain a Lunar Archive Program. The lunar archive system, including the Moon and Earth facilities, must be maintained indefinitely. A catastrophe critically requiring the use of the lunar archive may not occur for millennia, or it may occur tomorrow.

Chapter 7

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