38. 環境と生物の試・資料を超長期保存する 環境タイムカプセル（ETCapsule 2001）構想について

ETCapsule 2001 PROJECT: ULTRALONG-TERM PRESERVATION OF ENVIRONMENTAL AND BIOLOGICAL SPECIMENS AND DATA

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ABSTRACT; An environmental time capsule or ET Capsule which will retain samples and data for an ultralong period is covered in this report. The samples will serve as fundamental data for researchers in the distant future. For this purpose, actual samples will be ideal to be preserved together with written records describing living things on the earth and their environments. We plan to seal the actual ET Capsule at 00:00, January 1, 2001, hoping it will be a good opportunity to leave the environment of 20th century earth for people in later centuries. This report discusses various aspects and problems associated with long-term storage of environmental and biological samples and describes the related studies we have made.
KEYWORDS; time capsule, environmental specimen, biological specimen, ultralong period, preservation

1. Introduction

This report introduces an environmental time capsule or ET Capsule which will retain samples and data for an ultralong period. The samples will serve as fundamental data for researchers in the distant future. For this purpose, it would be ideal if it were possible to preserve actual samples together with written records describing living things on the earth and their environments. We hope to seal the actual ET Capsule at 00:00, January 1, 2001 — at the end of the 20th century and the beginning of the 21st century. It will be a good opportunity to leave the environment of 20th century earth for people in later centuries.

Samples are stored for different periods and subject to different monitoring methods depending on the purpose. Some institutes and researchers have stored environmental samples and some public organizations have announced storage and monitoring plans (see Table 1). The longest period of 100 to 200 years is human liver storage by the National Institute of Standards and Technology, U.S.A., while the remaining plans are for several tens of years.

Preservation for terms exceeding hundreds of years is also important. Analysis of ice cores from the Antarctic helps us track changes in carbon dioxide concentration back over several tens of thousands of years. There is also a project to analyze DNA from mummies in Egypt. From looking at the results of long-term preservation in nature, and realizing what it offers us, we think it reasonable to take a natural step forward to intentionally preserve environmental samples (including living things) that describe the current earth environment for future generations of researchers.

This report covers various aspects and problems associated with such long-term storage and describes the related studies we have made.

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Table 1 Examples of long-term storage of environmental samples

Project	Organization	Purpose	Storage method	No. of samples
Liver bank	NIST (National Institute of Standards and Technology) U.S.A.	To hand down the earth's environmental data of the late 20th century to researchers of the 21st and 22nd centuries in the form of refrigerated human liver.	Freezing.	500 healthy livers.
Storage of fat of ocean-ranging fish and mammals such as shark and dolphin	Tatsukawa laboratory, Department of Agriculture, Ehime University (Japan)	To examine biological magnification and environmental diffusion of harmful chemical materials (PCB, DDT, etc.) by analyzing fats of animals ranging across less-contaminated oceans.	Freezing.	5000 heads.
System preservation of environmental microorganisms	National Institute for Environmental Studies, Environment Agency (Japan)	To collect and preserve systems of microorganisms that cause environmental contamination or contribute to the removal of pollution.	Successive cultivation and freeze-drying.	500 strains (as of 1985).
Earth environmental information center	National Institute for Environmental Studies, Environment Agency (Japan)	Environmental monitoring.		
MARC	London University, King's College	Monitoring and Assessment Research Centre (U.K.) Part of UNEP, worldwide environmental monitoring.		
Other preserved samples	Seawater, seabed samples (Kinki University, Japan); water of the Ishikari River (Hokkaido University, Japan); seed banks, blood sera of man and animals, pathogens, etc.			
Ultra-long preserved samples	Antarctic ice cores (by boring), seabed and lake bottom cores (by boring), Inuit ('Eskimo') corpse; in Sweden — 100-year-old foodstuff, egg shells of wild birds and feathers of stuffed white-tail eagles (these feathers prove that PCBs found in nature are an artificial product).			

2. Existing and Proposed Time Capsules

2.1. Comparison of existing time capsules

We have compared three scientific capsules: time capsules I and II buried by Westinghouse Electric & Manufacturing Company during the 1938 and 1965 New York World Fairs when the term "time capsule" was coined; and those buried during Osaka EXPO '70 by Matsushita Electric Industrial Co. Ltd. and The Mainichi Newspapers. Fortunately, we have official records of these capsules as well as related information on capsules I and II collected at the time of the New York World Fairs. We are also in contact with the persons responsible for the EXPO '70 time capsule to obtain unofficial, detailed information on discussions and studies which took place at that time.

Our comparison of these capsules is based mainly on the official records and the results have been listed in five tables which provide us with our primary data: what subjects were selected and studied during the planning phase of each time capsule, the background of each of these world fair years and the differences in technical levels between these times, and the changes in themes of these capsules. The five tables have specific titles; (1) General description, (2) Storage technique, (3) Selection of samples to be stored, (4) Burial site and (5) Official documents and follow-up system. Only two of the tables are shown (Tables 2 and 3).

2.2. Specific image of the ET Capsule

A) Background

(1) Theme

Placed beside the Beatles' record in the 1965 time capsule II are a Mercury heat shield after reentry and graphite from a Fermi reactor, symbols of the rapid progress of humankind since the burial of time capsule I in 1938, as can be known from Tables 2 and 3. Regarding the ET Capsule as the follow-up of the 1970 Matsushita-Mainichi time capsule, what are we to select as samples to represent human progress from 1970 to 2001? The most significant progress will be found in environmental and life sciences.

(2) Selection, collection, storage and preservation period of samples

Since the ET Capsule will be a monumental event at the beginning of the 21st century, suitable storage periods will be one thousand years (to the 31st century) or eight thousand years (the 101st century). Because the project will employ a natural storage method, and many samples will require low temperatures for storage, one possible burial location would be within a polar circle.

B) The proposed capsule

It is proposed, therefore, that the ET Capsule should be filled with environmental and biological specimens and data, and then buried somewhere in a polar region for retrieval in 1,000 or 8,000 years.

Table 2 Comparison of existing time capsules - (1) General description

	Time capsule I	Time capsule II	Time capsule EXPO '70
Triggering event	New York World Fair (1938-1939)	New York World Fair (1964-1965)	Osaka EXPO '70: 50th anniversary of Matsushita Electric Industrial Co., Ltd.
Sponsors	Westinghouse Electric & Manufacturing Company	Westinghouse Electric & Manufacturing Company	Matsushita Electric Industrial/Mainichi Newspapers
Date of burial	At noon, Sept. 23, 1938 (autumnal equinox) before the NY World Fair.	Oct. 16, 1965 after the NY World Fair II	Capsule No. 1: Jan 20, 1971 Capsule No. 2: Jan 28, 1971 (after EXPO '70)
Date of authorization	Early in 1938		Dec. 1, 1967
Planned preservation period	5,000 years	5,000 years	5,000 years
Reason for the period	Mankind has a 5000-year recorded history and the capsule is a monument buried at the midpoint of history as viewed from the 70th century.		Mankind has a 5000-year recorded history and the capsule is a monument buried at the midpoint of history as viewed from the 70th century.
Steering committee	Engineers of Westinghouse Electric & Manufacturing Company; scientists and researchers.	A committee comprising 14 experts in various fields. The chief of the committee was Dr. Leonard Carmichael (vice-president for research and exploration, National Geographic Society).	EXPO '70 time capsule committee and subcommittees: Technical committee – Seiji Kaya (chief) and 22 scientists and experts; Selection committee – Shiro Akabori (chief) and 28 members.
Major subjects studied	1) Means to ensure 5000-year preservation. 2) How to leave records showing the location of the capsule. 3) Selection of the contents.	Selection of the contents.	1) Selection of the contents. 2) Techniques for 5000-year storage.
Cost			Direct cost was approx. 0.2 billion yen (1.6 million US dollars).

Table 3 Comparison of existing time capsules -
(2) Selection of samples to be stored

	Time capsule I	Time capsule II	Time capsule EXPO '70
Selection criteria	Things representative of 20th century life	Things representing progress in civilization in the 25 years from the time of Time Capsule I.	Typical goods representing modern civilization and documents: up-to-date samples; Japan-based; actual items in preference to explanatory documents or pictures.
No. of contents	112 pcs (including 1 roll of microfilm containing 304 items, 1 newsreel containing 11 items).		2098 pcs
Major contents	Daily commodities, clothes, materials, seeds, books, money, microfilm (copy of documents), newsreel.	Microfilm, film, bikini, transistor radio, ball-point pen, automatic camera, electric toothbrush, electronic circuit.	Electronic devices, metal materials, new materials, papers, recording tapes, medical and biological samples, garments, contraceptives, materials recording manners and customs, photographs, microfilms.
No. of major items	The microfilm contains information the equivalent of 100 books (22,000 pages).	475 materials, the microfilm contains 117,000 pages.	Natural science: 742 pcs Social science: 686 pcs Art: 592 pcs Others: 78 pcs
Topics	Newsreel containing a speech by F.D. Roosevelt, fashion show in Miami.	A Beatles' album, graphite from the world's first nuclear reactor, a Mercury space capsule heat shield after reentry.	Pure iron.
Biological and environmental samples	Seeds (wheat, corn, oats, tobacco, cotton, flax, sugar beet, barley, rice, soy beans, alfalfa, carrots).	The microfilm descriptions include the discovery of DNA and RNA, new vaccines at that time, and organ transplants.	Phages, bacteria, DNA, enzymes, useful microorganisms, seeds, mosquitos and flies.
Instruments	None.	None.	Plutonium atomic clock, maximum/minimum thermometers.

* The reason for this difference is unknown.

3. Sampling and Storage of Samples

3.1. Biological samples

Freezing, freeze-drying (lyophilizing) and drying are all methods capable of preserving organisms or parts of them while retaining the life or biotic potential. Of these, freeze-drying and drying have been successfully applied only to bacteria, germs, fungi and some kinds of seeds, and the period of preservation is limited to at most several tens of years with increasing death rate. Freeze storage at –80°C and below can keep them alive for a very long time. So, to store life for ultralong periods, employment of freeze storage around -80°C under natural environmental conditions should be considered.

3.2. Environmental samples

First, we must determine the selection criteria of samples suitable for ultralong storage. Samples commonly studied in the environmental science field as listed in Table 4 are possible candidates. Generally, these can be divided into two groups: environmental and biological. Dead biological samples are regarded as environmental ones. Live biological samples that serve as index organisms also can be regarded as environmental samples because their habitat can be determined by their analysis; they can also be used as a contamination index.

Table 4 Typical environmental samples that may be preserved for ultra-long period

Air	Precipitation (rain, snow)	
	Fine grain (airborne, fallen)	
	Gas	
Water	Seawater (ocean, coastal)	
	Fresh water (lake, pond, river, underground)	
Soil	Soil (city, forest, arable land)	
Benthic soil	Benthic soil (marine, lake, river)	
Organism (dead sample) (Index organism)	Plants	Land (large, moss, seed)
		Water (large, lemnaceae, plankton)
	Animals	Air (birds, insects)
		Land (large, small, insects)
		Underground (small, insects)
		Water (fish, insects, plankton)
		Benthos
Human body	Body fluids (blood, urine)	
	Organs	
	Hair, nails, teeth	

3.3. Basic criteria for sample/information selection

We propose the concept of the optimum combination of samples and information, to maximize the density of information stored in the limited capacity of the environmental time capsule. The concept is explained below, taking DNA as an example of an essential biological sample.

The history of a creature is condensed in its DNA. In the distant future, it may be possible to produce clones using only the information contained and preserved in DNA. There is no man-made memory device that can carry such a huge amount of information as DNA. For example, the DNA contained in a single human genome has approximately 3 billion base pairs in a 0.01mm diameter cell nucleus.

According to the degree of processing of organic material, there are some alternative biological samples which could be stored: the whole body of a creature; a specific organ of the creature which may contain dense information; DNA, and a description of DNA sequences.

Among the alternatives, DNA may contain the maximum information per unit volume, since DNA is much smaller than any current artificial memory device which could record the whole description of its sequence. The explanation is conceptually depicted in Fig. 1. DNA has a further advantage — it is a chemically stable material. Consequently, it may be concluded that DNA is the best candidate to be selected as the core of living samples.

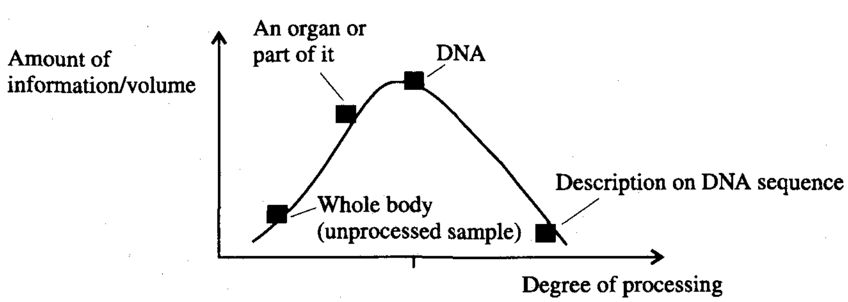

Figure 1 Relationship between degree of processing of samples and amount of information/volume

There are important messages that are not described in DNA. Among them is the life history of a creature; for example, physical deformations (crooked or broken bones, etc.) acquired during its life.

There are other organs that contain important information. One typical example is the brain whose molecular structure and composition could be used to play back memory and emotion when the ET Capsule is opened. These organs should be preserved directly.

To pack the maximum of information on a given organism into the limited space inside the time capsule, a set of materials should consist of DNA (the core sample) associated with samples of organisms themselves and supplementary documents. This concept may also be applied to environmental samples. It is important that selected environmental samples are representative in all respects. Both biological and environmental samples and data should be logically linked to reason the selection of a set of particular samples and data.

In addition to the above, documents, tables and drawings which have been included in conventional time capsules are effective media which preserve illustrative information for the future.

3.4. Worldwide simultaneous sampling

The environmental time capsule is to contain things that preserve the environmental state (such as sea water, air, land) of the 20th century. The selection of specific samples should be made after further results from related research. The means and locations of sampling are also under study. One preferable plan is to collect samples over the world in a standardized way and at the same time.

One-third of the simultaneous worldwide samples are to be immediately analyzed to describe the earth environment at the time of sampling. Another one-third are to be stocked under artificial management and analyzed as additional data becomes necessary (in time units of 10-100 years). Selected samples from the remaining one-third are stored in the environmental time capsule (1,000 years or 8,000 years).

Since the environmental time capsule will be recognized as an international event, quarantine barriers against the importation of materials (water, soil, etc.) could be lifted. Then the use of radiation or addition of chemicals for sterilization will not be required, and the preservation of the original state of the sampled materials can be assured which will be essential to accurate central analysis of all samples under the same conditions. In this way, the time capsule project will facilitate the advancement of science, not only for the purpose of the ultralong-term time capsule, but also for short- to long-term progress.

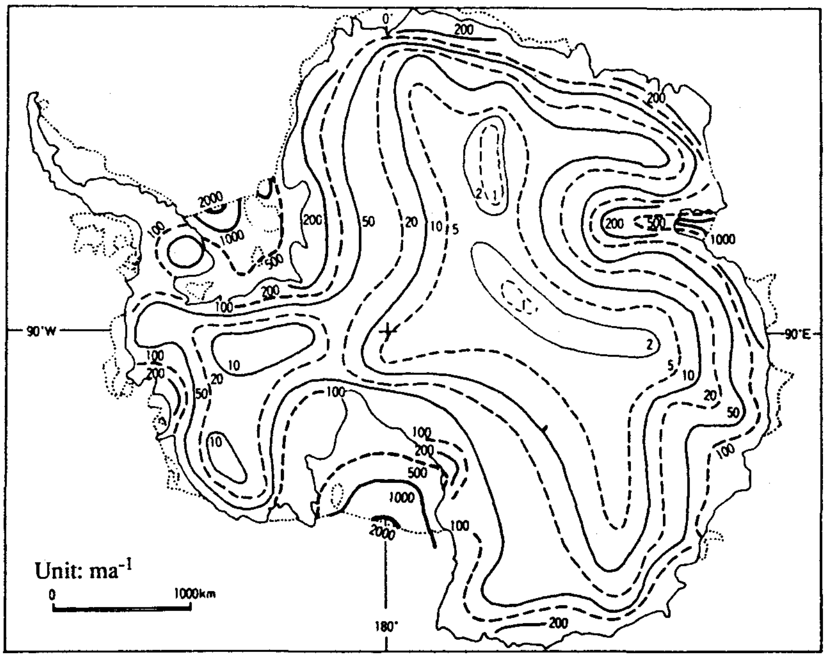

Figure 2 Balanced velocity distribution of the Antarctic ice cover (Budd, et al., 1971)

4. Preservation in polar regions

A) Ice cover movement

Thick ice abounds in Antarctica, Greenland, glaciers, and permafrost. The ice moves constantly at rates from 10 m to 2 – 3 km/year. Fortunately, at the domes near the south pole the movement is very slow in both horizontal and vertical directions (Fig. 2).[6] An ice-core borehole is currently being drilled at Dome Fuji (F) by a team headed by Professor Okitsugu Watanabe of the National Institute of Polar Regions of Japan, who is also on the ET Capsule committee to investigate long-term changes in the earth's atmosphere. Dome F is currently the best candidate storage site for one of the ET Capsules due to the reasons explained below.

B) Reasons for choosing Dome F

(1) Average temperature

At Dome F, the average temperature is below –60°C, close to –80°C, the critical level where living organisms could be kept frozen for a long time and remain viable. To our advantage, the annual temperature variation is negligible 10 meters below the ice cover surface.

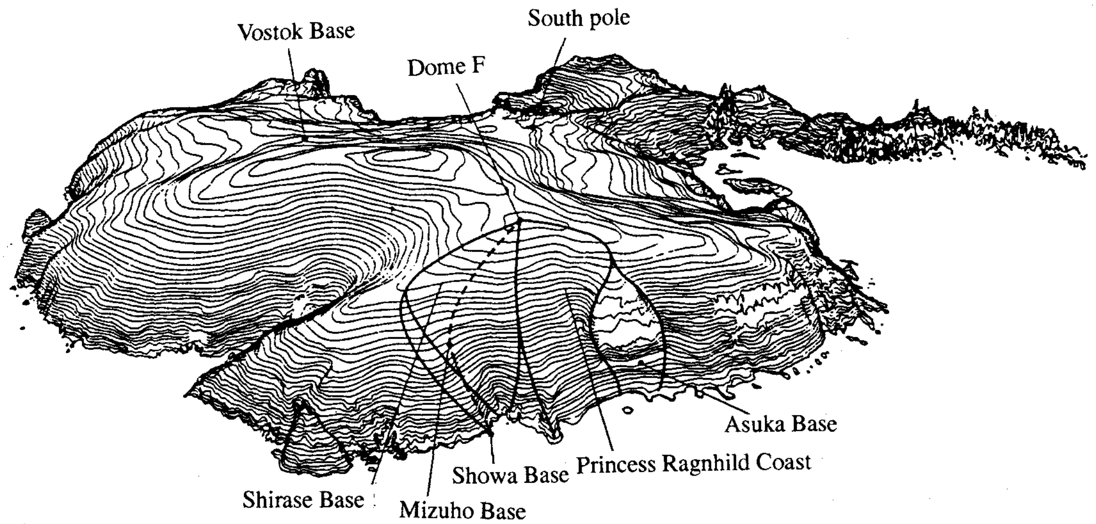

Figure 3 Bird's eye view of observation bases on Antarctica around Dome F [6]
(Distance : height above sea level = 1:1000)

(2) Ice movement

As can be seen from Figs. 2 and 3, at Dome F ice cover movement is negligibly slow, both horizonally and vertically with temperatures reaching –60°C. It would be possible, therefore, to use the borehole to bury the capsule a few tens of meters below the surface of the ice cover, in consideration of the possibility of the ice evaporation or melting.

(3) Precipitation

The annual average precipitation around Dome F is as low as 32 mm. This means anything buried in the ice would sink just 32 meters in 1,000 years.

(4) Transportation and accommodation

Transportation to Dome F already exists and accommodation is available thanks to the borehole drilling project, itself an international event.

(5) Legal approval

Permissions from and consensus among countries are also necessary to bury the capsule at the south pole.

5. International and Interdisciplinary Cooperation

The ET Capsule project cannot be implemented by a single academic institution but becomes possible only by cooperation between scientists from various fields, including biological and environmental sciences for sample collection, material science for material development for the container and recording media, and polar science for selection of the preservation site. The cooperation of social sciences and other academic fields is also essential for sample selection and the preparation of a follow-up monitoring methodology.

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* The ET Capsule Project was proposed by the second and the third authors. The first author initiated some basic studies on the project as a PhD student under the close supervision of the second and third authors. Text of Reference 1 was written by the third author and the data presented in the tables was gathered and analyzed by the first author.

This statement is made here as originality is most important in scientific research. The name of the first author was placed here because of the requirements for PhD dissertations of the Department of Civil Engineering, Kinki University.