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Record Preservation Study on Geological Disposal

- Significance and Technical Feasibility -

Kazutoshi Sugiyama, Hajime Takao, Jin Ohuchi, and Takao Tsuboya

2003 March

Radioactive Waste Management Funding and Research Center (RWMC)

This report is to summarize the results of a study which was conducted from 2000 to 2001 by the Radioactive Waste Management Funding and Research Center (RWMC) under the contract with the Ministry of Economy, Trade and Industry (METI)

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Summary

The geological disposal of high-level radioactive waste (HLW) is based on the passive safe system concept and its long-term safety should not rely on institutional control. On the other hand, institutional control has been discussed since the 1980s and accepted to be effective from the viewpoint of confidence-building in implementing geological disposal.

The record preservation system is regarded as an institutional control, and has already been implemented or formulated as concrete measures in some countries. For example, in the U.S. WIPP case, the implementing entity of repository is required to place markers and also preserve documentary records to reduce the possibility that future generations might come in contact with the repository (the US EPA Regulation 40CFR 194, 1998). In addition, from the ethical point of view that the future generations should be given the freedom to make their own decisions with regard to utilization of resources for safety and long-term protection (SKN, 1988), an approach has been conceived that records preservation should play a role towards making and preserving records for decision-making (Nordic Nuclear Safety Research Project KAN-1.3, 1993, etc.).

In Japan, The Specified Radioactive Waste Disposal Act (2000) requires that the Minister of Economy, Trade and Industry should preserve permanently all records of geological disposal. The Nuclear Safety Commission of Japan had reported in “The Basic Policy of Safety Regulations for the Disposal of High-Level Radioactive Waste (The First-Stage Report, 2000)” that institutional controls, such as record preservation, will be effective in reducing the possibility of future generations’ unpredictable contact with the repository.

Purpose of the Study

This study aims to provide information for the government, related bodies, and other organizations to utilize in formulating programs for building public confidence in geological disposal, by reviewing and investigating on the record preservation issues as

a component of institutional control concerning geological disposal.

Basic Significance and Objectives of Record Preservation

In order to build public confidence in geological disposal, it is considered that implementing measures designed from social and ethical points of view is vital, while providing scientific and technological theories and data concerning the safety of the disposal system. Preserving records regarding geological disposal would be of great significance in terms of intergenerational equity. In this study, we have formulated two objectives for record preservation: 1) preventing future generations from unintentional access to the repository, and 2) providing future generations with information necessary for decision making on the repository.

Future Time Frame to be Considered in Record Preservation

With regard to future time frame to be considered in examining the record preservation system for geological disposal, the following matters have been given consideration:

- Radioactivity of HLW deteriorates over time; for example, it deteriorates by several digits in the first one thousand years.
- Some of the uncertainties, which occur in site characterization and the safety assessment of geological disposal system, increase over time.
- Durability of media on which records will be stored varies according to the types of media to be used. Preservation technology should be examined according to the requirements for preservation period.

By studying the relationship between the above elements as well as the objectives of record preservation, this study has concluded that records to be preserved for future generations' decision-making would be most important during the first several hundreds to about one thousand years during which radioactivity concentration of the waste remains high. On the other hand, as the radioactivity of the waste will linger even after the first one thousand years, it has been concluded that a proper objective would be to communicate information required to prevent human intrusion of repositories by future generations as long as possible, by implementing methods which are expected to be more durable.

Design of a Record Preservation System to Provide information for Unpredictable Future Societies

Anticipating a wide range of technological and institutional issues concerning record preservation, this study examined several methods to communicate messages for future generations that are quite different from our own in terms of social systems, culture, values, languages, level of knowledge, etc. as well as for the future in which national systems for record preservation is maintained.

As the first step, we theorized five society models with different cultures, languages and level of knowledge. Next, methods of record preservation and communication of information, which could be effective in each model of society, were formulated into an appropriate combination, and then an examination was undertaken to determine the "robust" record preservation system.

A Case Study on a Record Preservation System

In considering requirements and issues concerning record preservation, a trial record preservation system was formulated. First, an examination was made on the contents of information to be preserved and methods of objectives based on the purposes of record preservation to ensure restriction of human intrusion and the provision of information for decision-making by future generations.

Next, an examination was made on the requirements for the record preservation system. As the basic requirements, records should be preserved for a long time period with uncertainties of future societies taken into consideration and robustness and flexibility being musts. The subordinate requirements ensure that record preservation would be entrusted both to the social relay system, and to a permanent media which would not require any human control.

Based on the results of these examinations, a record preservation system in the form of documentary records and markers/monuments are presented as examples.

Development of Durable Recording Media

Research on recording media has shown that progress has been made in the technological development of durable paper that ensures long-term preservation of documents. However, a quantitative assessment of the long-term durability of ink

materials has not been made, leaving room for future examination with regard to the assessment method.

In order to develop a long-term record preservation technology and engraving experiment on the selected artificial materials, such as metal and ceramics, was carried out by using laser technology. The results of the test show that lines, characters, patterns, and shading can be engraved to a certain level of quality, thereby showing the technical possibilities of those materials as the media for long-term record preservation. Among other things, silicon carbide, which was proposed by members of the committee scince Japan is a leader in the global market, is expected to be a promising material for long-term record preservation.

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Radioactive Waste Management Funding and Research Center (RWMC)
No.15, Mori Bldg, 2-8-10, Toranomon, Minato-ku, Tokyo 105-0001, Japan
TEL +81-3-3504-1081 FAX +81-3-3504-1297 http://www.rwmc.or.jp/

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We would like to thank the members of the Committee on the Geological Disposal Record Preservation System whose names are provided in Appendix-B. As the Committee consists of specialists from various fields, it look advantage of their up-to-date knowledge in each field and their useful advice.

Furthermore, we would like to thank the working group members listed in Appendix-C. They participated in some areas of this study and provided valuable advice and opinions in the course of discussions for drawing up this report.

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APPENDIX

Introduction

To build public confidence in geological disposal, significant and technical issues on record preservation(*) were discussed. Preserving records of geological disposal would be of significance in terms of intergenerational equity. This study aims to provide information on the record preservation issue for the related bodies of geological disposal.

The concept of geological disposal is based on the passive system and its long-term safety should not rely on the institutional control (IAEA, 1995a etc.). On the other hand, from experiences of western countries, the effectiveness of institutional control has been accepted from the viewpoint of confidence building in long-term safety, and issues have been discussed in international organizations since the 1980s (OECD/NEA, 1982 etc.). Moreover, recent discussions include the importance of a flexible development of a repository, such as the step-by-step approach, and the effectiveness of institutional control has been appreciated.

Record preservation, an item of institutional control, has an important meaning in that it would prevent the inadvertent intrusion by future generations into a repository. In addition, in considering the recent discussions on the ethical issues, it is thought that information of geological disposal should be communicated for the basis of future generation's decision-making in the area of the repository (KAN-1.3, 1993).

The Radioactive Waste Management Funding and Research Center (RWMC) has been studying on the issue of record preservation of HLW geologic disposal since 2000. The concepts, plans and conditions of record preservation in overseas countries and international organizations were studied and the basic information required for the record preservation system in Japan was arranged.

This report has been drawn up through discussions at a committee-level consisting of specialists from various fields related to this research theme (The Committee on Geological Disposal Record Preservation System: Appendix-B). This report was issued with the aim of asking for a review by experts in the field of geological disposal as well as other related fields.

(*) In this paper the term "record preservation" has the broad sense encompassing the keeping and retrieval of documents to communication by markers and monuments.

1. Purpose and Background

1.1 Purpose of This Study

This study aims to provide information for the government, related bodies, and other organizations to utilize in formulating programs for building public confidence in geological disposal, by reviewing and investigating the record preservation issues as a component of institutional control concerning geological disposal.

1.2 Background of Record Preservation for Geological Disposal

There is international consensus that the geological disposal system for high-level radioactive waste, which is under consideration both in Japan and in other countries, presents the most feasible method of safely isolating the waste safely from the human living environment for a long time period without relying on any human institutional control (OECD/NEA, 1995).

However, although institutional control is not an essential measure for securing safety, it is useful in terms of promoting the safety of geological disposal such as minimizing the possibilities of inadvertent human intrusion into the repository, and from an ethical viewpoint that future generations should be given room for their own decision-making.

Therefore, in recent years, more experts in this field have adopted the idea that incorporating institutional control to a certain extent would be effective in building public confidence in, and understanding of, the geological disposal program (e.g., IAEA, 1999).

Some of the discussions about the institutional control relating to geological disposal after the closure of repository by international organizations or other countries are given below:

> **Institutional Control.** Control of a waste site (for example, disposal site) by an authority or institution designated under the laws of a country or state. This control may be active (monitoring, surveillance, remedial work) or passive (land use control) and may be a factor in the design of a nuclear facility (for example, near surface disposal facility).
>
> ・・・IAEA (1995)

> During the institutional control phase, active and passive controls may be used.
> **Active measures** include controls such as exclusion of intruders by fences or other physical barriers, the maintenance of accessible barriers against migration of the radioactive inventory, and monitoring to verify that the continued and acceptable performance of the site are maintained after closure.
>
> **Passive measures** are those designed to maintain knowledge of the facility location within the institutions of society or are designed to limit land use for certain types of activities. Passive controls may be intended to survive beyond the institutional control period.
>
> ・・・IAEA (1999)

Passive Institutional Control Means: (1) Permanent markers placed at a disposal site, (2) public records and archives, (3) government ownership and regulations regarding land or resource use, and (4) other methods of preserving knowledge about the location, design, and contents of a disposal system.

'''The US EPA Regulation 40 CFR Part 191.12(e)

According to these discussions, institutional control to be implemented after the closure of the repository is classified into the following two categories:-

- Active Institutional Control

  Activities intended to provide certain concrete controls such as having security staff, construction and maintenance of fences, and various kinds of monitoring activities.

- Passive Institutional Control

  Preservation of documentary records as well as placement of permanent markers designed to maintain the knowledge of the location of a disposal system, whose effectiveness would continue without any permanent control activities.

The record preservation system, listed as one of the Passive Institutional Controls, is under consideration or examination in several countries and at some international organizations. For example, in the U.S., those who handle radioactive waste at the Waste Isolation Pilot Plant (WIPP) are obligated to preserve the knowledge of their operation by way of markers and documentary records, with the aim of lowering the possibility of human intrusion into the repository in the future (the US EPA Regulation 40CFR 194, 1998).

On the other hand, future generations might intend to repair the repository or to retrieve HLW for some reason. Based on the concept that the present generation should not hinder any decisions that future generations might make, the approach that records should be preserved with the aim of facilitating such decision-making by future generations has been conceived in recent years. This is intended to give active roles to record preservation (e.g. Nordic Nuclear Safety Research Project KAN 1.3, 1993).

In Japan, the Economic, Trade and Industry Minister (METI) had ordered, in The Specified Radioactive Waste Disposal Act (2000), that all records on geological disposal should be kept permanently. Also, the Nuclear Safety Commission had concluded that institutional controls, including a record preservation system, will be effective in reducing the possibility of future generations' access of the repository (Nuclear Safety Commission, 2000).

2. Basic Significance and Objectives of Record Preservation

2.1 Basic Significance of Record Preservation

As high-level radioactive waste contains long-life nuclides, there have been extensive discussions about the environmental and ethical grounds for geological disposal. For example, in 1995, OECD/NEA issued a report summarizing the opinions of experts, and expressed the achievement on interest focuses of ethical concerns. One of them was *"intergenerational equity" by choosing technologies and strategies which minimize the resource and risk burdens passed to future generations by current generations which produce the wastes*. It was also expressed that *our actions and decisions will be more acceptable if appropriate degrees of equity or justice are respected, and we do not unduly restrict the freedom of choice of future generations*.

Concerning the relation between science, technology and society, there have been arguments that science and technology form one part of human activities in a broad sense (KAN-1.3, 1993) and as science increases its presence in people's everyday life, it cannot remain scientific in its true sense (NRC, 1990).

Based on the above arguments, the basic significance of record preservation is illustrated in Fig. 2-1. It would be important to develop options formulated from social and ethical viewpoints, in order to build the public confidence in geological disposal, as well as providing scientific and technological theories and data relating to the safety of the disposal. Preservation of records relating to geological disposal would be vital from the viewpoint of the intergenerational ethics.(*)

(*) In the Committee on the Geological Disposal Record Preservation System, it was pointed out that record preservation is not only an item intended for future generations, but also a "meta signal" that plays an important role in the present generation's decision-making concerning the implementation of geological disposal.

2.2 Objectives of Record Preservation

In light of the above-mentioned basic significance, this study proposes the following two points as the objectives of record preservation;

Preventing future generations from unintentional access to the repository

Record preservation methods and the contents of information to be preserved are examined from the viewpoint of that record preservation would help minimize the possibility of unintentional access to the repository by future generations.

Providing future generations with information necessary for decision-making on the repository

Geological disposal entails the ethical aspect that future generations should be allowed to make their own decisions. If future generations plan the other more appropriate options than geological disposal chosen by our own generation, the burden for future generations accompanying the implementation of such options could be reduced by the provision of the necessary information. Such more appropriate options are, for example, the retrieval of waste due to some reason, the restoration of repository and the reassessment of the disposal system.

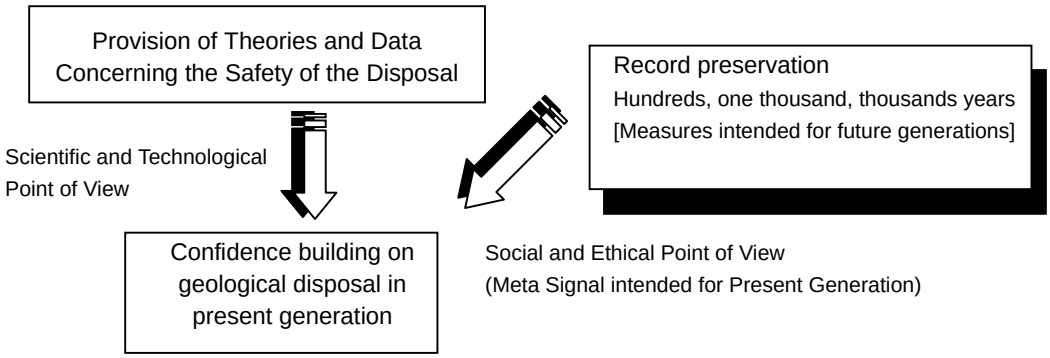

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Fig. 2-1 Basic Significance of Record Preservation for Geological Disposal

3. The period, target group, purpose, record type and methodology

In this chapter, the Committee examined the length of the period for preventing future generations' access and intrusion into the repository as well as information for facilitating future decision-making that should be preserved. The following items were given consideration in the Committee's discussion. Figure 3-1 conceptualizes the relation between the time-frame and each item.

- The radioactivity (potential danger) of HLW decreases with time. Records resulting from geological disposal are of significance, as the radioactivity of HLW is extremely high at the very beginning as compared to the natural environment. Therefore, the necessity for preserving records falls with time. (The radioactivity of high-level radioactive waste deteriorates to approximately one fifth in thirty years and to approximately one ten-thousandth in one thousand years.)
- Safety assessment, which verifies the long-term safety of a geological disposal system, depends on the understanding of the facilities of a repository, characteristics of the geological environment surrounding the site and the waste to be disposed, and actual conditions of events and processes. At the same time, it is an assessment system in which uncertainties have been taken into consideration (JNC, 1999). Such uncertainties within the safety assessment of geological disposal system increases over time.
- The long-term durability of media on which records will be stored varies according to the types of media and the environment in which the media is stored. For example, durable paper, at the present time can serve the purpose for several hundreds of years or one thousand years in an appropriate storage environment. However, to date, the quantitative assessment concerning the long-term durability of ink materials has not been confirmed. If a longer storage period of record is required, other material that are superior in long-term durability should be used.
- According to the present governmental program (Nuclear Safety Commission of Japan, 1998), the final disposal is scheduled to commence between 2030 and the mid-2040s, after the selection of the site and the construction of the repository. The operation of the repository is expected to continue for several decades, and then all the underground facilities will be buried to close the repository. After the closure of the repository, post-closure management at the disposal site may be implemented, if necessary in view of public requirement, and then finally the entire disposal program will come to an end. Thus, the geological disposal program will be carried out over a period with a time frame of more than a hundred years. A greater part of the records will be produced and record management will be necessary in the period up to the closure of the repository. In the post-closure management phase, records concerning administrative jobs will be produced.

In light of the above argument concerning the relationship between each of the items as well as the objectives of record preservation, we have concluded that the records to be preserved for future generations' decision-making would be of significance during the first several hundreds to thousand years in which the radioactivity concentration of waste is rather high. In such a time span, although documentary records in the form of paper can be preserved, the restriction of preservation

environments and the assessment of durable ink materials remain to be discussed. Therefore, appropriate media that have satisfactory durability and, at the same time, can accommodate a large volume of documentary records and other data have to be developed.

However, as the radioactivity of HLW will remain after the first one thousand years or so, it was concluded that an appropriate target would be that necessary information should be communicated to prevent future generations' unintentional access to the geological disposal repository, by way of more durable methods such as markers and monuments, as far as possible into the future.

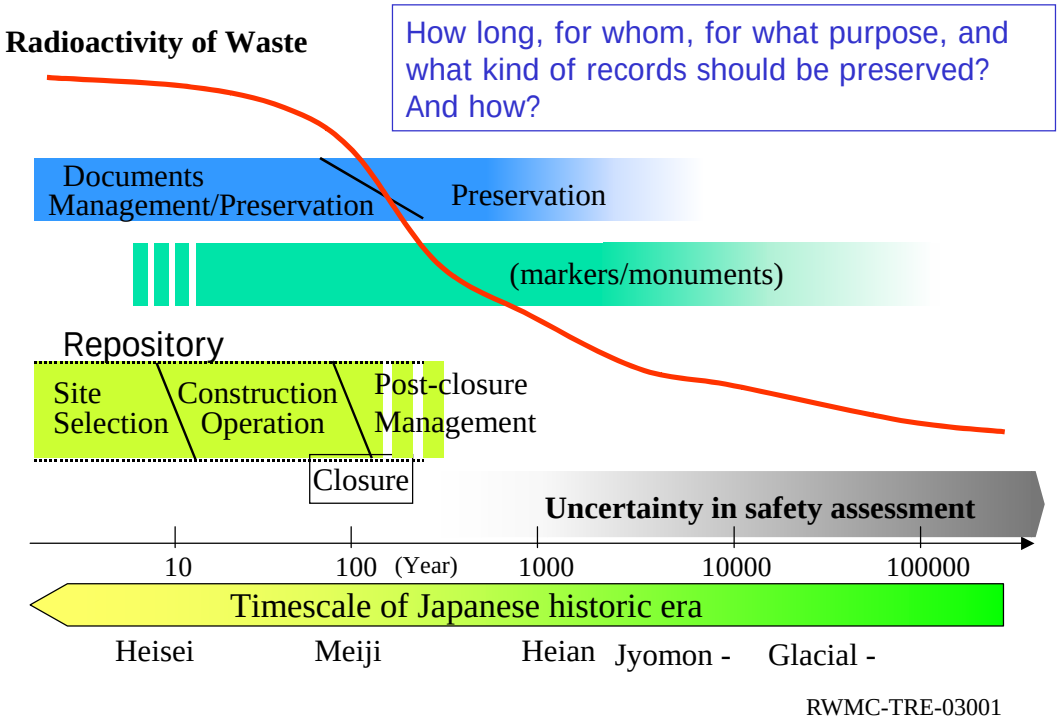

Fig. 3-1 Time Frame For future and Record Preservation

4. Design of a Record Preservation System to Provide for Future Societies

In this chapter, methods for preserving and communicating records or information to future generations are discussed.

4.1 Record Preservation Intended for Societies Different from Us

The Public Archives Law of Japan was enacted in 1987 in order to facilitate the preservation of public records, valuable historical sources, and others as public heritage. However, even in the case of public records and historical sources designated as archives, generally, there have not been in-depth discussions about how long they should be preserved. There has been tacit understanding that as long as the present national system is in effect, they would be preserved eternally.

It is still open to argument whether we should preserve and communicate records to future generations who might be quite different from us in national systems, cultures, values, languages and levels of knowledge. Moreover, there are many issues to be discussed whether the future generations could understand our messages correctly. This study adopts the basic position that a wide range of technological and institutional issues concerning record preservation will be addressed, thereby formulating state-of-the-art practices.

It would be ideal that records on geological disposal be preserved in the form of documentary records and be communicated to future generations. Assuming that the future society will be stable and will take over our values, such a preservation system would be the most reliable option. However, various forms of societies quite different from our own could emerge in the future. Regarding this point, the Nordic Nuclear Safety Research Project KAN-1.3 (1993) discusses as follows:

> A technique is to be developed for conservation of information in order to warn future generations over a long time period about the presence of and risks associated with a deeply buried waste repository. In this context, information conservation has two seemingly different goals. The first goal is to communicate to those future generations, that are still culturally similar to our own, the risks of the repository. The second goal is to communicate this warning to other future generations so culturally different from our own that no understanding of our language or level of knowledge is likely to exist. (KAN-1.3, 1993, Chapter 3.1)

4.2 Approach

It is quite difficult to predict culture, language, and knowledge in future societies. Moreover, these factors do not always change in the course of time. For example, in the ethnic and civil wars in East Europe, especially in the former Yugoslavian territory, the total collapse of the record preservation system within a very short period of time was reported (Ogawa, 2000) [(*)]. These indicate the possible sudden and unexpected changes of social systems and losses of current values, institutional control systems, and record preservation systems in any part of the world in the near

future.

(*) "Ethnic and civil wars in former Yugoslavia revealed a blind spot in international agreements made for the conservation and preservation of cultural heritages after the World War II. They taught us that the methodology for the preservation of cultural assets that UNESCO had envisaged was not at all a safe one. The outstanding example is "The International Committee of the Blue Shield Memorandum". This arrangement is based on the idea that cultural heritages could be protected from being destroyed in warfare by placing light blue, star-shaped marks on buildings designated as cultural assets such as historical buildings and libraries. However, these marks were used as a target to destroy cultural properties of the rival ethnic group in the ethnic cleansing .... Reports on similar tragedies are continuously made."（Ogawa, 2000）

In this context, based on the attitude that the state-of-the-art practices of record preservation should be attained, the following approach was adopted as a method to communicate information of geological disposal to future societies whose level of preservation, communication, and understanding of records can not be predicted precisely. As such, from the viewpoint of the ability to read (understand) records, we theorized five models of societies with different cultures, languages, levels of knowledge, etc., and then theorized on the preservation and communication methods that can be effective in each model of society which were then combined into a "robust" record preservation system.

A record preservation system formulated this way, can accommodate the possibilities of the destruction of records due to radical changes of social systems and values that can occur in the relatively near future. The models of future societies will be described in the next section.

4.3 Future Society Models

The following five models of future societies were proposed by taking into account the changes of scientific technologies, knowledge and cultures. Figure 4-1 conceptualizes these models of societies in terms of the level of understanding of these societies and the lapse of time from the present. These models would be divided into two cases in terms of continuity between civilization, the first case being one of a continuous society and the second, a discontinuous society.

In the case of a society continuous from our own

- **Model A**: a society with advanced technology that has succeeded, in spite of a certain degree of changes in cultural backgrounds including languages and values of our own.
- **Model B**: a society without remarkable advancement of technology that has succeeded, in spite of a certain degree of changes in cultural backgrounds including languages and values of our own.
- **Model C:** a society with retrograded technology that has succeeded, in spite of a certain degree of changes in cultural backgrounds including languages and values of our own.

In the case of a society discontinuous from our own

- **Model D:** a society discontinuous from our own with respect to civilization, and without advancement of scientific technology and cultural background.
- **Model E:** a society discontinuous from our own with respect to civilization, and with advancement of scientific technology and cultural background.

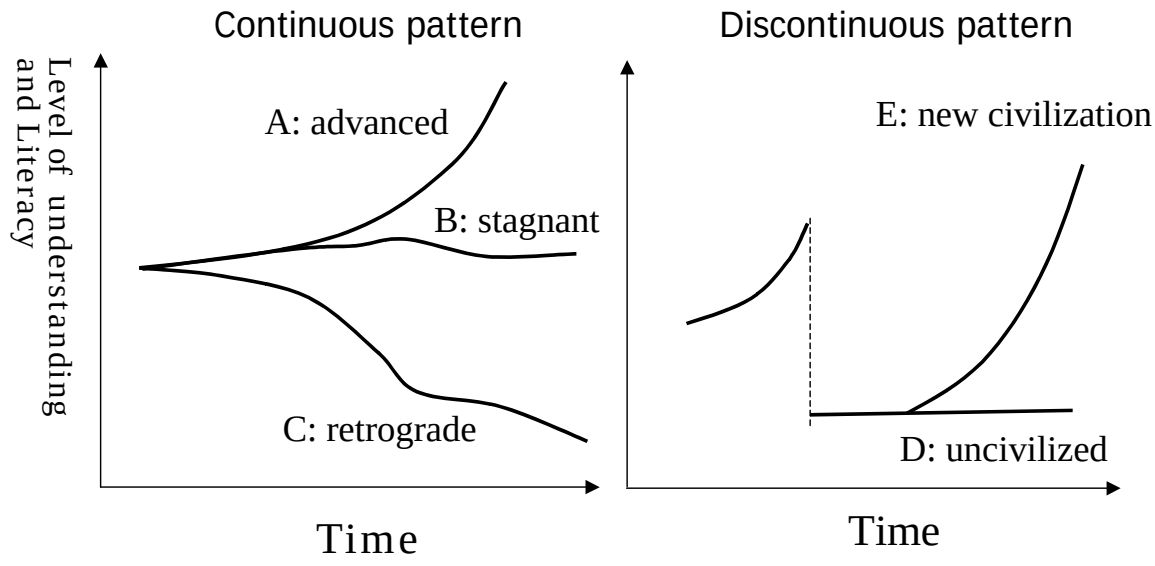

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Fig. 4-1 Concepts of Modeled Societies

Table 4-1 illustrates these society models based on the relationship between scientific technology, social system, level of knowledge, language and other cultural factors as aspects influencing the possibilities of preservation, communication and understanding of information.

Table 4-1　Characteristics of Modeled Societies

Society Model	Scientific Technology	Record Preservation in the Form of Social System	Knowledge Level and Language	Other Cultural Characteristics
A	・Advanced scientific technology and stable information network.	・Advanced management system for documentary records. ・Possible international management system.	・Advanced level of knowledge, and substantial capability of understanding our language in spite of its transformation.	・High level of awareness toward record preservation, but social metabolism is so active that possibilities of old things being replaced by new ones would be high.
B	・Similar level of scientific technology and information network.	・Similar social systems maintained and public records offices and other organizations in charge of management and preservation of records in place.	・Similar level of knowledge. ・In spite of a gradual transformation of languages, our languages could be understood.	・Similar level of awareness toward record preservation. ・Social metabolism is not so high as in Society A, and upgrading activities are not so active.
C	・Lower level of scientific technology, and less possibility of an information network.	・Less possibility of record management and preservation in the form of a social system.	・Lower level of knowledge. ・Due to a gradual transformation of languages, it is impossible to understand our languages.	・Lower level of awareness toward record preservation. ・Strong religious influence.
D	・Unsatisfactory level of scientific technology.	・Lack of record management and preservation in the form of a social system.	・No common language would exist. ・Our languages would not be understood.	・Similar to prehistoric society.
E	・Quite different scientific technology.	・Quite different social system.	・Less possibilities of understanding our language, but it would be possible to understand encoded messages.	・Quite different values.

4.4 Record Preservation methods According to the Five Models

In this section, effective methods were examined according to the above five models of future societies in order to preserve and communicate records and also to facilitate future generations' understanding of the messages.

In model A, with common values prevailing over a rather wide area, there would exist an advanced and stable information system. A social system for managing and preserving records would thus be in place. Therefore, it would be effective to preserve detailed information in the form of documentary records and digital media. In addition, preserving information concerning social and cultural backgrounds along with records of geological disposal would increase the possibilities of future generations' correct understanding of the meaning of the records (Fig. 4-2). Moreover, such a society would have superior cultural quality with some social system for succeeding and upgrading, as and when necessary, the communicated records through education and other means. In such society, markers and monuments would only serve as auxiliary functions in the system of record preservation.

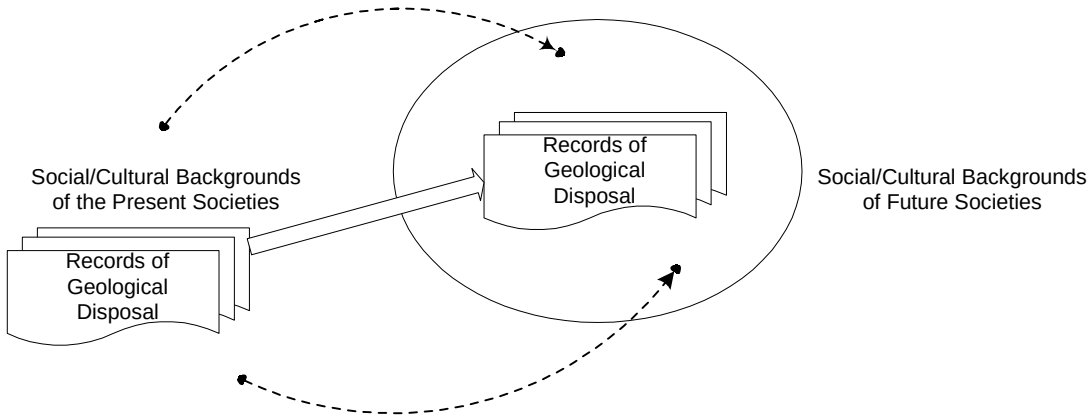

Fig. 4-2 Communication of Geological Disposal Records and Social/Cultural Backgrounds

In model B, there would exist a similar scientific technology, social system, and values as our own, and it would be effective to preserve the records as documents in the form of paper and others as well as digital media. Since it cannot be asserted that they would be engaged in record preservation, it would therefore also be effective to disperse the repositories of records. In such a society, social metabolism would be weaker than in model A, so that the possibilities of old things being replaced by new ones would be lower. Therefore, the possibilities that markers and monuments serve their original function would be high.

In model C, record preservation based on the digital media should not be expected, and it might be necessary to entrust documentary records in the form of paper, etc. to some strong social system such as religion. In addition, in such a society, our languages might not be understood.

Therefore, the importance of markers and monuments would be greater, and symbols and the same type of objects, which would warn future generations of danger would be effective for facilitating their understanding of the messages.

Model D is similar to prehistoric time, where scientific technology and a record preservation system in the form of documentary data would not be in place. Therefore, the possible option would be to communicate messages in the form of symbols which would warn people of danger. Model E is, as it were, quite a different society with different scientific technologies, languages and values. Therefore, they would not be able to translate our languages. In such a society, it would be a possible option to use markers and monuments utilizing nonverbal communication such as semiotics and information science in addition to psychological symbols.

Based on the above examination, Table 4-2 shows the possible effective options for record preservation according to models A through E. Each option is considered based on the results of research and examination of cases concerning existing record preservation, and similar examples, in history archaeology and related technologies, with general descriptions given in Appendix-A.

Table 4-2 Adaptabilities of Elemental Methods for Five Society Models

		Recording media						Repository location								Relay or permanent system						Expression method									Miscellaneous							
		Paper	Film	Electronic media/Optical media	Natural rocks and stones	Engineered materials	Future concerns	Authorization body	Geographical Survey Institute	District Legal Affairs Bureau	Domestic and foreign libraries and records office, and international bodies	Disposal site	Various parts of the world	Outer space	Future concerns	Institutional system concerning record preservation	Education system	Relay System	Preservation and improvement during post-closure management, etc.	Dependent on the robustness of physical media	Future concerns	Language presently used	Mathematical expression	Chart and Diagram	Drawing	Summarized message	Idiomatic symbol	Natural symbol	Nonverbal message	Future concerns	Hierarchical classification of records	Classification of warning information to exclude human intrusion	Dispersion of records	Advanced information system	Physical media as a monument	Physical media as communication media for critical information	Physical media as a warning marker	Future concerns
A	Documentary records	**	**	**	-	-	Preservation method, environment, period, etc.	**	**	**	**	**	-	-	Characteristics of existing organizations. Possibilities of new organizations.	**	**	**	-	-	Design of system	**	*	*	-	-	-	-	-	-	**	-	*	**	-	-	-	Clarification of information required for future generations' decision-making
	Markers and monuments	-	-	-	*	*	-	-	-	-	-	**	-	-	-	-	-	-	*	-	-	*	-	*	-	*	-	-	Existing symbols	-	-	-	-	*	-	-	-
B	Documentary records	**	**	**	-	-	Preservation method, environment, period, etc.	**	**	**	**	**	-	-	Characteristics of existing organizations. Possibilities of new organizations.	**	**	**	-	-	-	**	*	*	-	-	-	-	-	-	**	**	**	*	-	**	-	Clarification of information required for future generations' decision-making
	Markers and monuments	-	-	-	**	**	Durability of media	-	-	-	-	**	-	-	-	-	-	**	*	-	-	-	-	-	**	**	-	**	-	Contents of message	-	-	-	-	**	-	-	Classification of information subject to standards for disclosing records
C	Documentary records	*	*	-	-	-	Preservation method, environment, period, etc.	-	-	*	*	*	-	-	Characteristics of existing organizations	-	-	**	-	-	-	*	*	*	-	-	-	-	-	-	-	-	**	-	-	-	-	-
	Markers and monuments	-	-	-	**	**	Durability of media	-	-	-	-	**	-	-	-	-	-	**	-	**	-	-	-	-	**	**	-	**	-	Contents of message	-	**	-	-	-	-	**	Classification of information subject to standards for disclosing records
D	Documentary records	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Markers and monuments	-	-	-	**	**	Durability of media	-	-	-	-	**	-	-	-	-	-	-	-	**	-	-	-	-	**	-	-	**	-	Universal symbols	-	-	-	-	-	-	**	Marker system
E	Documentary records	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Markers and monuments	-	-	-	**	**	Durability of media	-	-	-	-	**	**	**	-	-	-	-	-	**	-	-	**	**	**	-	-	**	**	Nonverbal communication	-	-	**	-	-	-	-	Classification of information subject to standards for disclosing records

A: Advanced society continuous from our own B: Stagnant society continuous from our own C: Degraded society continuous from our own・
D: Society discontinuous from our own and without progress ・E: Society discontinuous from our own and with progress
(The mark ** means more effective than *)

5. A Case Study on a Record Preservation System

In this chapter, contents of information to be preserved and preservation methods are discussed with a viewpoint to restricting future generations' unintentional access to the repository and to facilitate their own decision-making. The requirements of a record preservation system are also discussed to preserve records for a long period of time. Based on these discussions, a trial record preservation system is formulated.

5.1 Contents of Information to be Preserved and Preservation Methods

The classification of information to be preserved and the preservation methods will be a key elements to keep redundancy of the record preservation system as well as the number and variation of the recording media. The study in U.S. WIPP (SNL, 1993) proposed the following classification of information to be preserved:

- Level I: Primary Level Information "Some artificial object exists"
- Level II: Warning Information "Some artificial object exists and it represents danger"
- Level III: Basic Information about the Repository (information about What, Why, When, Where, Who, and How)
- Level IV: General Information about the Repository (detailed description, figures and charts, diagrams, etc.)
- Level V: Further Detailed Information

Among these classified levels, information in Level I to Level III would be preserved in the form of markers and monuments. Furthermore, Information in Level IV would be recorded using some robust physical media and stored in the "information center" which is constructed above and around the repository. Level V information would be preserved in the form of documentary records at the national archives and other facilities.

By considering previous studies, it is proposed that information in Level I to Level III be preserved by way of markers and monuments made of robust physical material. Information in Levels IV and V would be preserved in the form of documentary records (Table 5-1). At the Level IV facilities, durable artificial materials would be used as recording media.

5.1.1 Information for Prevention of Unintentional Access to Repository (Level I to III)

Information to be encountered first (Level I and Level II)

According to the level classification of SNL (1933), if a future generation initiates some kind of action at or around a disposal site without knowing the existence of the underground repository, they would encounter the primary Level I information carried on markers and monuments describing that "something artificial exists here". Then, by encountering Level II information, they would learn "it is artificial and, at the same time, dangerous."

Assuming that future generations would have the same values as we have today, they would understand our messages in the above order. On the other hand, for example, archaeological and historical values might not be of importance or of value to them, and, therefore, they would conclude

that the geographical configuration, whether a natural landscape or artificial one, of the site they discovered is not of much value at that moment. In this case, records of Level I will lose their meaning and information in Level II or more might be disregarded. Therefore, it is ideal that information of Levels I and II should be communicated simultaneously.

Necessary Information After Perception of Danger (Level III)

After the danger is vaguely recognized, the future generation would need more practical information describing “what exists and where”. Therefore, Level III information would tell that “high-level radioactive waste exists” and “it is disposed deep within the ground near there”. In the case that the future generation has lost background knowledge of atomic energy, it might be difficult to understand the information based on simple messages. Therefore, information concerning “what is radioactive waste”, “why does it exist”, “when was it disposed of”, “who disposed it” and “how and where other additional information is preserved” should be added. For the purpose of preventing unintended intrusion into the repository by future generations, basically, it would be enough if information up to Level III has been correctly communicated. Level III information should describe existence of more detailed information for the purpose of information retrieval by future generations.

5.1.2 Information for Future Generations’ Decision-making (Levels IV to V)

The future generations’ decision-making efforts, such as in the retrieval of waste, the restoration of disposal sites and the review and reassessment of disposal programs, are projected in previous studies (e.g. KAN-1.3, 1993). In order to facilitate these decisions, detailed information about the repository would be required. Therefore, Level IV information should be preserved in the form of documentary records. More detailed records (Level V) concerning geological disposal would be preserved at national and/or international archives.

The Committee discussed the contents of future generations’ decision-making and required information, and agreed that the information to be preserved are as follows:

- Geology of disposal site
- Location and the depth of the repository
- Specifications of the facilities of the repository
- Characteristics of the HLW
- Safety assessment carried out by our generation
- Original data of the safety assessment carried out by our generation

Table 5-1 summarizes the level classification, contents and preservation methods of information.

Table 5-1 Classified Level, Contents and Preservation Methods of Information

Objective of Record Preservation	Level Classification and Contents(*)		Preservation Method
	Level	Contents	
Prevention of Unintensional Access to Repository	I/II	1. Information to be encountered first "Something artificial exists around here and it represents danger."	Marker and monument
	III	2. Information necessary after the danger is perceived "High-level radioactive waste exists" ・What is high-level radioactive waste? ・Why does it exist? ・When was it disposed of? ・Who disposed of the waste? ・How is the information preserved? "It exits deep under the ground nearby." ・Horizontal position and depth of underground facility "More detailed information exits" ・Structure of marker system, domestic and overseas archives.	
Future Generations' Decision-making	IV	3. Detailed information ・Geological information ・Geological location ・Geological environment conditions ・Location and the depth of repository ・Specifications of repository ・Characteristics of the waste ・Safety assessment carried out by our generation ・Original data of the safety assessment	Documentary record
	V	4. Further detailed information	

(*) Referred to SNL, 1993 etc.

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5.2 Requirements for a Record Preservation System

In the previous sections, it was suggested that both documentary records and markers/monuments should be adopted as record preservation methods. Furthermore, in Chapter 4, in order to communicate information to future societies, it was suggested that a combination of methods to preserve and communicate records would be the most appropriate in the sense of doing the best we could. Based on these, in this study, "basic requirements" for a record preservation system for geological disposal are defined as below:

"*Integration of several different methods would impart redundancy to the communication function of a record preservation system for geological disposal, and, at the same time, enable the system to retain robustness where the overall function would not be influenced by partial damage, thus resulting in a flexible system that can adapt to the changes of background conditions in the future.*"

The committee considered two categories of record preservation system. One is a "*relay system*", by which the records is kept, renewed and communicated through generations within a social system. Another is a "*permanent system*", by which the records and information are kept and communicated without human control by using durable recording media or methods such as markers and monuments.

In this study, further subordinate requirements were examined and the results are shown in Figure 5-1.

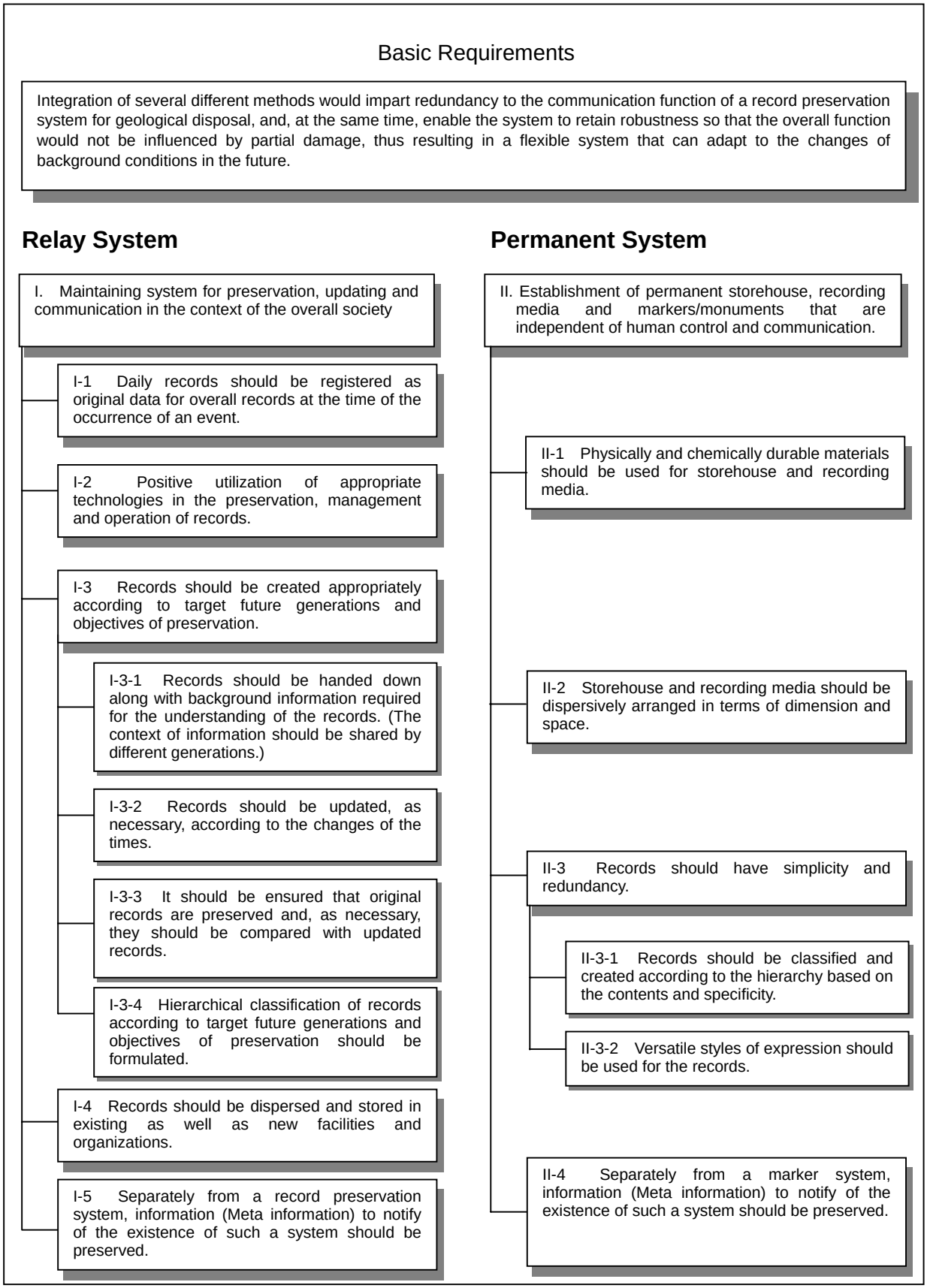

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Fig. 5-1 Hierarchical Construction of Requirements for Record Preservation

5.3 Scenario for Future Generations' Retrieval of Geological Disposal Information and Their Access to the Repository

Figure 5-2 illustrates the examples of the scenario for future generations' retrieval of information and their access to the repository.

5.3.1 Relay system

The upper part of Figure 5-2 illustrates the flows of events in the case that a *relay system* is maintained in society. This Figure shows not only the scenario for human actions but also the flow of information.

Organizations involved in record preservation as shown in this figure are those currently in place and are expected to continue to be in charge of record preservation as well as those organization yet unrealized but expected to be established in the future. More specifically, they are implementers of geological disposal, related administrative bodies, the Geographical Survey Institute, domestic record preservation organizations (libraries, archives, etc.), foreign and international organizations related to record preservation (foreign and international archives, IAEA, etc.) and newly established record preservation bodies.

Events that would lead to information retrieval concerning geological disposal by future generations are the acquisition of knowledge from the educational system, programs concerning resource investigation and development, actions relating to the ownership of disposal sites, as well as encounters with markers and monuments when entering a disposal site without knowing the existence of the repository. These events might lead to the retrieval activities of information by organizations as mentioned above. Through such retrieval activities, future generations would obtain detailed information about geological disposal, resulting in the cancellation of development activities over repositories or in decision-making on matters such as the retrieval of the waste.

It is impossible to project how long the *relay system* would be in place. However, it would be a useful approach to obtain supporting evidence, from record preservation examples seen in history, for the possibility of the systems' being successful in the future.

5.3.2 Permanent System

The lower part of Figure 5-2 illustrates the flow of human actions in the case that the *relay system* is lost but a permanent system survives. The Figure illustrates the flows of actions beginning from future generations' learning of the existence of the repository by encountering the information of Levels I to IV to the discontinuity of their access to the repository. Furthermore, the Figure also illustrates unfavorable scenarios (that should be eliminated) where markers and other facilities were lost or future generations would not understand the meaning of the messages, thereby resulting in an unintentional access to the repository. In order to avoid these unfavorable cases to the greatest extent possible, it was pointed out that further examination should be made on the arrangement of markers/monuments and storehouse of permanent records, as well as their durability and information

communication technologies such as languages, semiotic expressions and psychological communication means.

5.4 Trial Design of Permanent Record Preservation system

An examination was made on the materials and locations of markers/monuments and storehouse of documentary records to be constructed at or around a repository.

(Materials)

Natural rocks and engineered materials, such as metals and inorganic materials, are possible materials for markers, monuments and storehouse. From the point of view of long-term durability, materials should be selected by taking into consideration Japan's climate (humidity, rainfall, etc.) and the natural environment (geological and geographical features, etc.). It would be effective to make extensive reference to knowledge on history, archaeology, geography, geology as well as material science in selecting materials for markers, monuments and storehouse.

It would be ideal that media bearing Level I information describing the existence of artificial objects are as large as possible and, at the same time, hard enough not to be destroyed artificially. As an example, pyramids of ancient Egypt were made from limestone which is essentially not a robust material, but pyramids are large structures of simple shape which could be preserved for a long time period.

Level II information describing that the artificial object is dangerous would be expressed by way of languages or some kind of semiotic expressions. Monoliths bearing Level II information, which are made from natural rock and other materials could be erected near or on the structure bearing Level I information. Such Level II media would be much smaller than that of Level I, and it would be necessary that the material has superior durability in order to engrave messages on its surface.

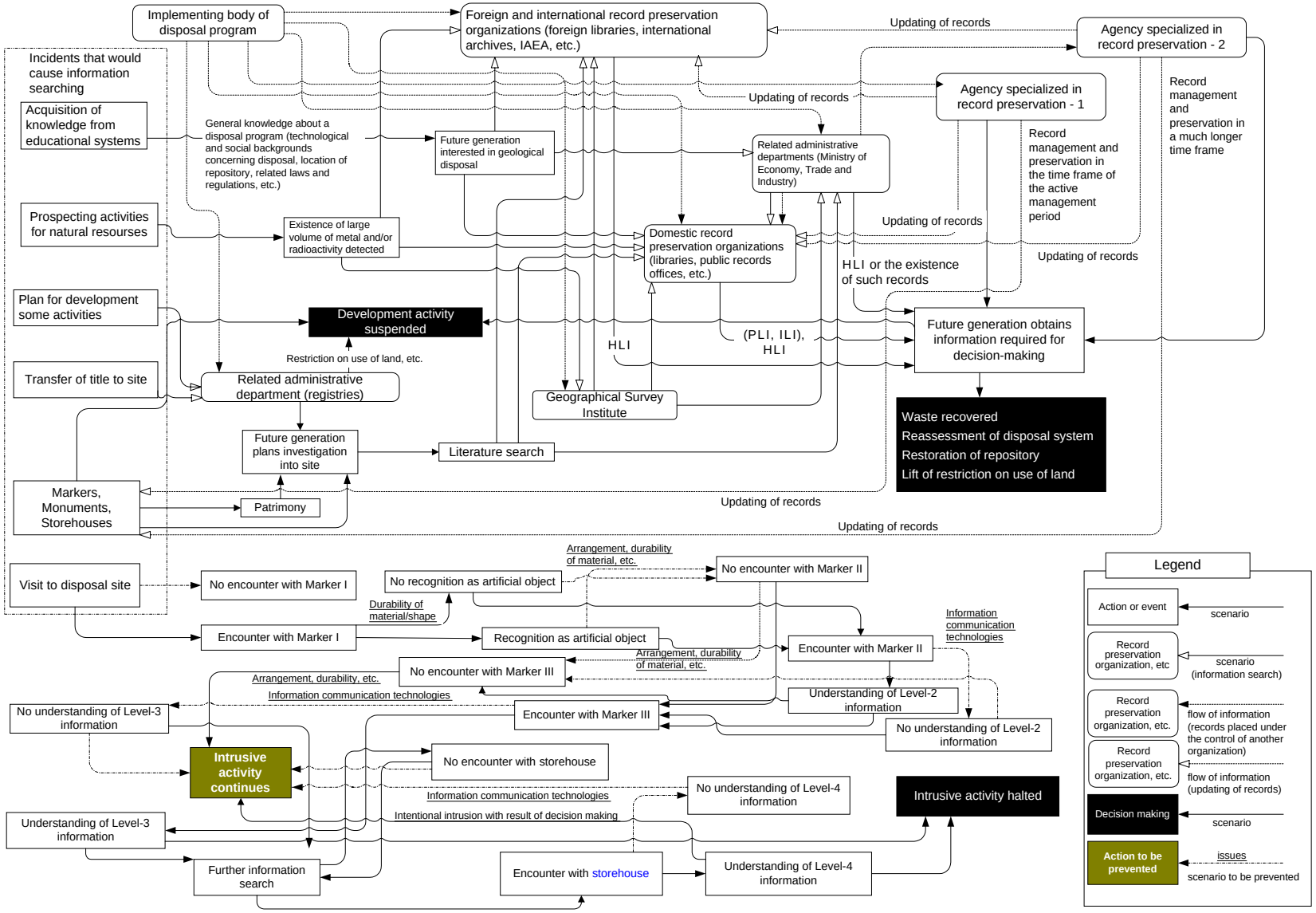
A study on the WIPP suggests the idea of a message kiosk (SNL, 1993). The idea is to have a message board made from granitic rocks on the ground, and surrounded by protective walls made from concrete or other materials. The recording media entrusted with Level III information would be made from hard natural rock like Level II media. Also, it would be possible to embed a tablet made from durable engineered material on a mount made from natural rock.

As for Level IV information, which would of detailed documentary records, it should be housed within some artificially-closed space, i.e. a storehouse. For example, a room surrounded by robust walls and a ceiling could be constructed to store documentary records. As for Level IV information, the recording media could be engineered material that resists various environmental changes and can preserve documentary records for a long time period. The results of this study show that ceramic material having superior strength, corrosion resistance, and wear resistance would be a promising material(Chapter 6). As the documentary records preserved in the storehouse are the most important information in the *permanent system*, it would be advisable that various preservation methods are tried. For example, other types of recording media (e.g., paper, microfilm, etc.) could be preserved simultaneously, and their durability could be tested.

(Arrangement)

In light of the above examination, the Committee discussed a trial design of markers, monuments and storehouse, erected on the grounds of the disposal site. The results are shown in Figure 5-3. In the Figure, Marker I communicating Level I information is a continuous structure with a trapezoidal section, and aisles are so arranged both around the repository and in radial directions that they connect to the center. This is one example of structures that would spontaneously lead future generations visiting the site to the next information. Markers II is arranged around Marker I, and they might be installed in shallow underground areas.

Markers III placed at the intersections of aisles extending to the center. From these markers, future generations would learn of the existence of further information and go farther into the center to find Level IV. As Markers III and the storehouse might be destroyed artificially, it is ideal that they have a dual structure that has aboveground and underground parts. Therefore, in the selection of the location of these facilities, consideration should be paid to the aboveground and underground temperatures, humidity of the environment, and other aspects.



PLI: **Primary Level Information** ILI: **Intermediate Level Information** HLI: **High Level Information (IAEA 1999)**

Fig. 5-2 A Scenario for Future Generations' Information Retrieval and decision-making

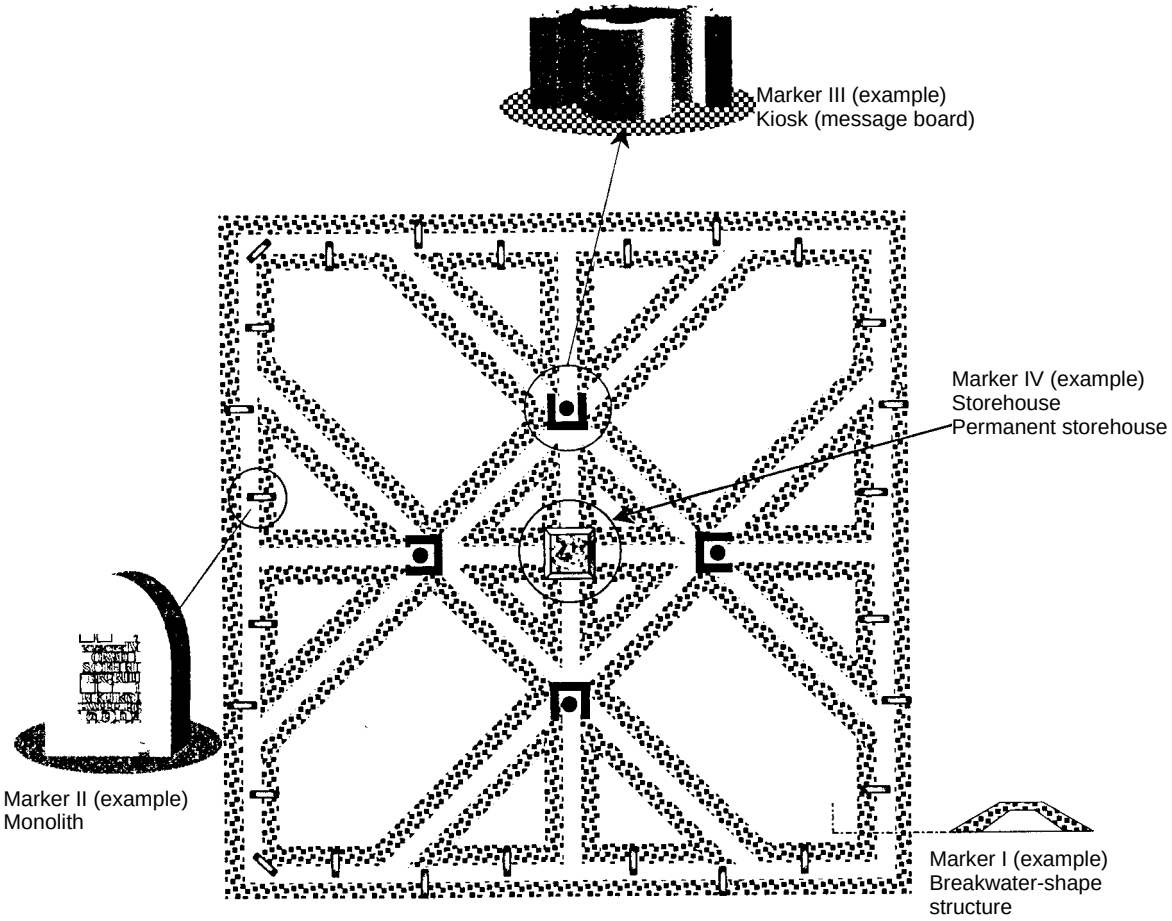


Fig. 5-3 Arrangement of Markers, Monuments, and Permanent store house

6. Development of Durable Recording Media

Paper, film and digital media are usually used as recording media for preserving documents in record management institutions such as the national and regional archives. Paper, most common for documents, could remain more than several hundreds years in an appropriate storage environment. However, a quantitative assessment concerning the long-term durability of written ink has not been made.

However, though the current technology is trying to strengthen the long-term durability of these media, human control would be needed for keeping a suitable environment such as temperature and humidity controls to preserve these documents. To preserve documents without human control for a thousand years or more, a physically durable recording media is desirable.

Engraving experiments on selected artificial materials such as metals and ceramics were carried out by laser technology to develop a long-term recording media.

6.1 Overall Plan

- **Selection of Materials**

Possible materials as recording media were selected from the viewpoint of long-term durability. The fineness of materials, surface finish specification, molding, etc., were considered in the selection process.

- **Examination of machining technology**

Lines, characters and graphics could be proposed as the targets to be engraved. In the case of characters, examination was made with regard to how complicated characters could be reproduced. Shading or gradation of graphics, possibility of reproducing photographs by means of engraving, and reproducibility of colors were also examined. As engraving methods, elimination machining, oxide film treatment, etching, physical deposition and chemical deposition are possible choices.

- **Engraving Experiments**

Engraving experiments were performed on the selected materials by using laser technologies.

- **Discussion**

Discussions were conducted on the following items: appropriate materials as recording media, types of records that can be engraved, precision, etc. Machining effectiveness (cost, time, etc.) was also considered.

6.2 Results of Engraving Experiment

From the overall plan mentioned above, the results of the engraving test of lines, characters and graphics on selected materials are given below.

6.2.1 Selection of Materials and Machining Methods

The selected materials were metals and inorganic materials. As for metallic materials, hastelloy was selected, and as inorganic materials, sintered compacts of alumina, zirconia and silicon carbide as well as CVD(Chemical Vapor Deposition) of silicon carbide were chosen. Table 6-1 presents a list of these materials. By considering the ease of procurement of specimens and implementation of experiments, plate materials of 100×100×5 mm were used in the case of hastelloy and ceramic sintered compacts, and, in the case of silicon carbide CVD, disc-shaped specimens of 12.5 cm diameter×1 mm thickness were used. Lines, characters and graphics were engraved on these materials. In addition, shading and gradation were also examined. The machining methods used were trench engraving and dot engraving by laser. The selected language characters to be engraved were Japanese characters, including Chinese characters, because of the great number of strokes and because they are ideographic characters superior in communicating information.

Table 6-1 List of Materials Used for Experiments

Material	Density (g/cm^3)	Hardness (MPa)
Hastelloy C22 (Ni-base alloy)	8.7	0.6
Alumina sintered compact (Al_2O_3 99.9%)	4.0	19
Zirconia sintered compact (ZrO_2 94.7%)	5.5-6.1	12-14
Silicon carbide sintered compact (α-SiC 98%)	3.2	25-31
Silicon carbide-CVD	3.2	34

6.2.2 Trench engraving

On hastelloy and sintered ceramics, simple graphics were trench-engraved by use of laser. The resulting groove depth and minimum intervals between grooved portions were examined. Simple characters were also engraved to check the stability of the projecting portions, so that the size of the font to be used in the trench engraving could be determined. Figure 6-1 shows the image of Laser/Water-Jet Hybrid Machining adopted in the present experiment. In this machining method, laser is enclosed within a water column, and condensed into a microscopic spot. The cutting sections are cooled off by water to eliminate effects and distortion due to heat, and chips are washed away by water jet to facilitate the engraving operation.

Fig. 6-1 Laser/Water Jet Hybrid Machining

The results of the preliminary experiment show that a promising accuracy can be obtained in the case of hastelloy and silicon carbide, and no major alteration of machined portions was detected. Lines were successfully engraved with promising accuracy at intervals of 0.3 mm and at a depth of 0.15 mm in the case of silicon carbide to 0.8 mm in the case of hastelloy.

As for alumina and zirconia, successful results have not been obtained with the method, and, therefore, the common laser (YAG fundamental wave) machining was used. After groove machining, the grooved portions were washed by water jet. No promising results could be obtained on these materials.

Based on the above results, sentences were engraved on hastelloy and silicon carbide (Fig. 6-2). Laser/Water Jet Hybrid Machining was adopted as the operation.

The results of the engraving shows that at parts where two lines overlap, the minimum interval is less than 0.3 mm and the groove widths are wider. However, these widened grooves occur only at small parts of the overall configuration, and, therefore, the influence on the machinability of characters is minor.

6.2.3 Dot Engraving

High-accuracy engraving using the Dot Matrix Method was performed on hastelloy, alumina, zirconia and silicon carbide (sintered compact) as well as on high-fineness silicon carbide manufactured by Chemical Vapor Deposition (CVD), in order to examine the accuracy of characters, the shading of graphics and the accuracy of gradation. Figure 6-3 shows the images of the dot engraving of Chinese characters and alphabets with sizes of 1 point to 12 points as well as the

machining to achieve gradation to express graphics. Figure 6-4 shows the results of dot engraving on sintered silicon carbide. The sizes of characters was gradually decreased from 12 points to 1 point. With all materials, characters of sizes down to 2 points (0.7mm) were readable by the naked eye or using a magnifying glass. With hastelloy, sintered silicon carbide, and silicon carbide CVD, characters of 1 point were especially readable. As shown in the picture(right-side) in Figure 6-4, patterns and graduation were also discernable.

Figure 6-5 shows 11-point characters engraved on different materials. As for alumina and zirconia, slight inconsistency of color and blurred profiles of marking portions were observed. By examining the machined portions on alumina and zirconia materials using a magnifying glass, it was confirmed that fine dots were not formed as with hastelloy and silicon carbide.

Figure 6-6 shows the results of dot engraving on sintered silicon carbide. The picture is a reproduction of Figure 3-1 in this report. The right-side shows the reproduction of 6 pages of sentences on A4 size page on a 10 cm×10 cm plate. In this case, the size of the characters is 2-point(0.7mm), and sentences were readable with the naked eye or using a magnifying glass (Fig. 6-7).

6.3 Discussion

Engraving experiments on durable artificial materials were carried out by applying laser technologies. By selecting appropriate materials and engraving methods, characters and patterns can be expressed along with shading and gradation. These technologies can be applied to not only documentary records but also to markers and monuments. Among the materials, silicon carbide, which has strong resistance against heat wear and chemical impacts, corrosion resistance and wear resistance, showed satisfactory results in terms of accuracy. Thus, it is expected to be a promising material for the long-term record preservation.

With respect to the density of characters in written records in the case of dot printing, it was estimated that, with 2-point characters, information totaling 6 to 8 pages of A-4 size can be engraved on a 10 cm×10 cm plate. When the a document that has 500 pages of A4 size paper is engraved on sintered silicon carbide plates, the total volume of recording media is evaluated as follows;

- Size of plate: 10cm × 10cm
- Size of character to be engraved: 2-points (0.7mm; of readable size by naked eye or using a magnifying glass)
- Number of pages of original document to be engraved on a plate: 8
- Number of pages of original document to be engraved on both sides of a plate: 16

- Number of plates needed for a series of document package: 500 / 16 = 32

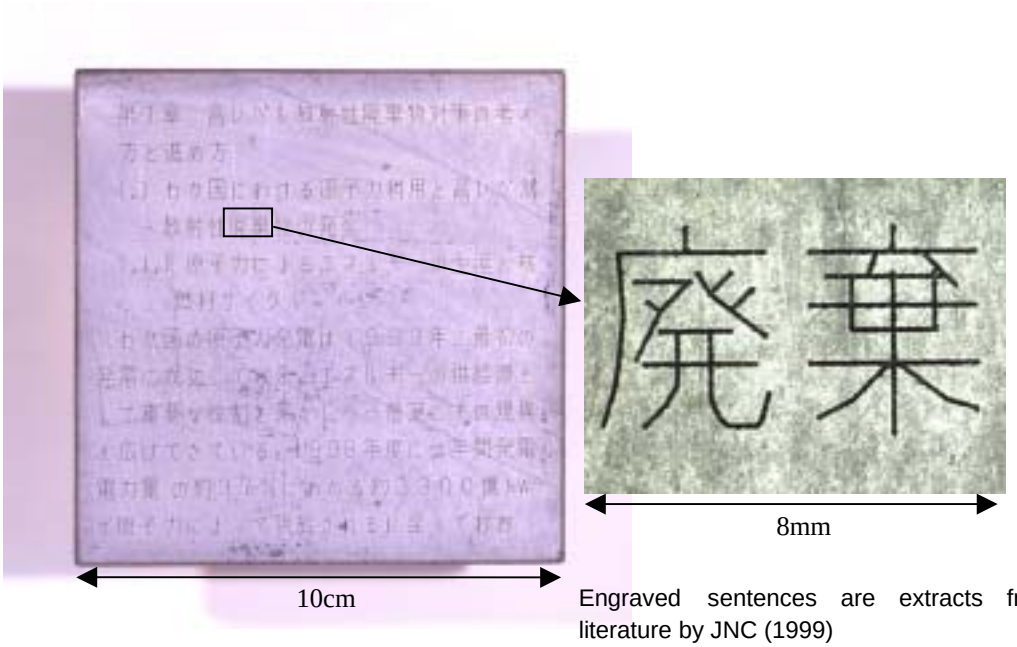
- The thickness of a plate: 1mm

- The total thickness of recording media: 32mm

- Bulk of recording media preserving 500 pages of document: 10cm × 10cm × 32cm

The examination has shown the possibility of long-term preservation of documentation records as a permanent system.

A further examination is suggested concerning the assessment of the durability of the sintered silicon carbide plate against wear and chemical impacts. Preserving color pictures and photographs for a long-term duration is also proposed.



Engraved sentences are extracts from literature by JNC (1999)

Fig. 6-2. Example of Results of Trench Engraving Test (Hastelloy)

Fig. 6-3. Images of High-Accuracy Engraving Test of Records

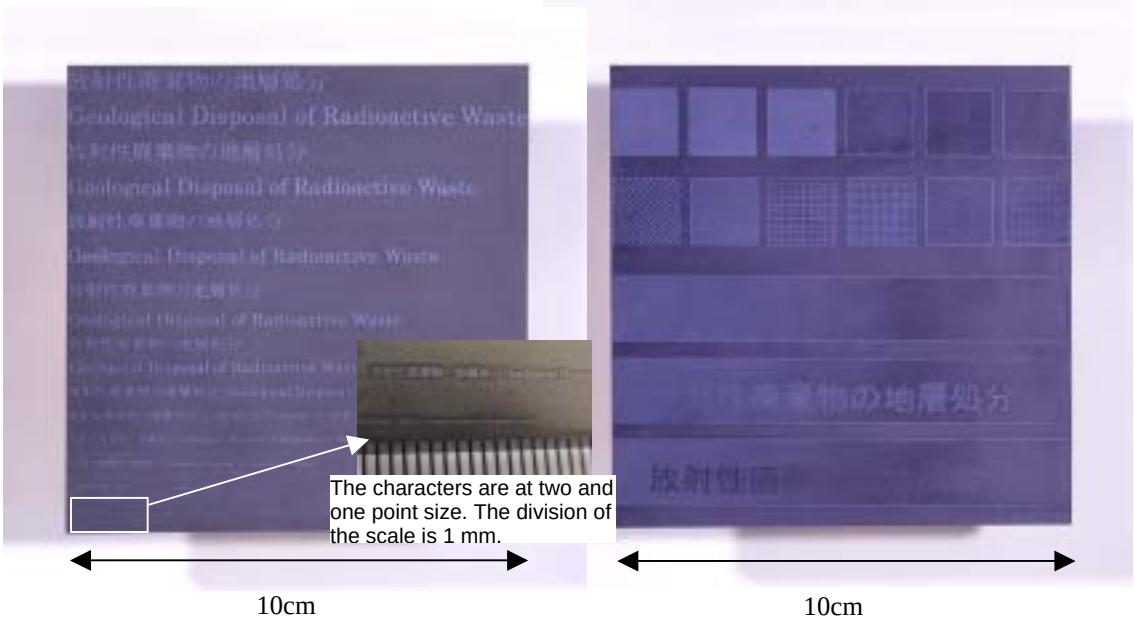


Fig. 6-4　Results of Dot Engraving Test (Sintered Silicon Carbide)

From above to bottom, hastelloy, alumina, zirconia, silicon carbide sintered compact, and silicon carbide (CVD). The size of character is 11 point

Fig. 6-5. Comparison of the Results of the Dot Engraving Test

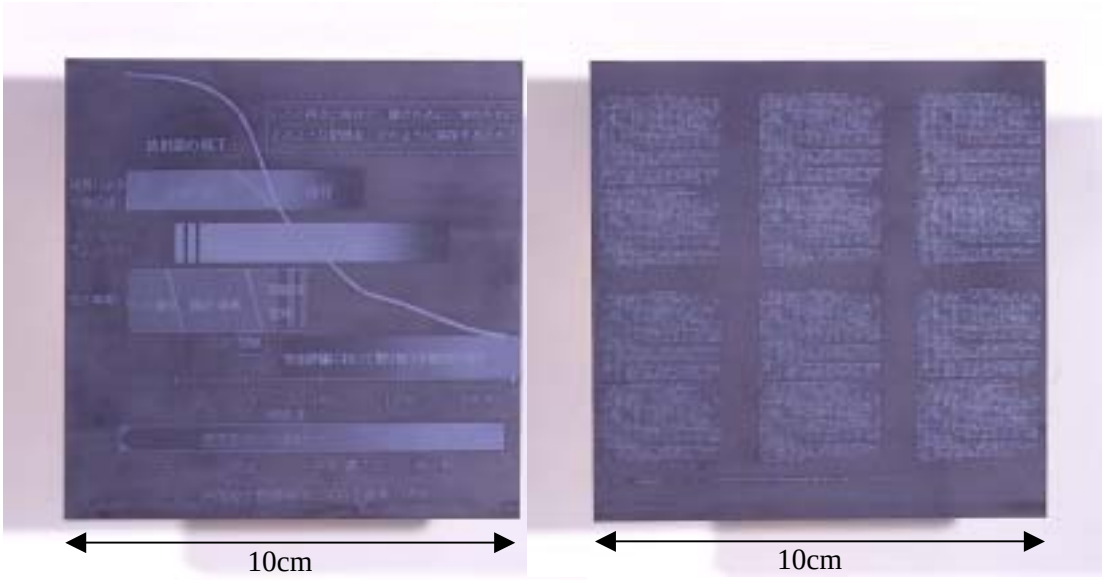
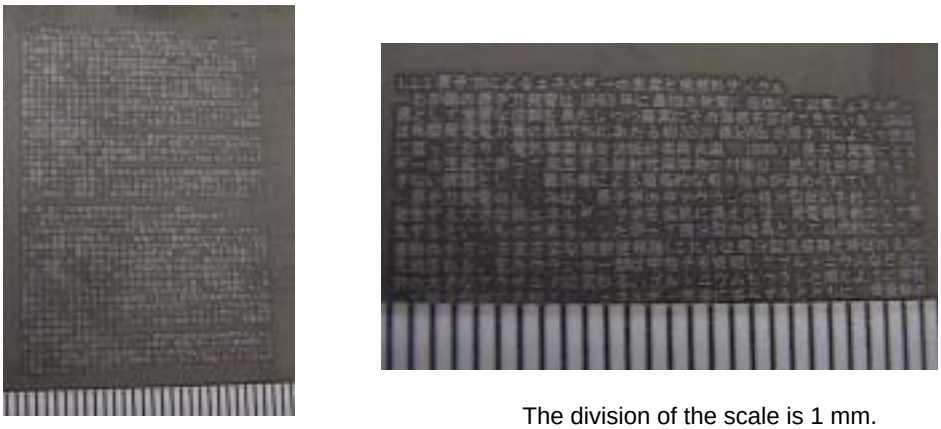


Fig. 6-6. Figures and Scaled Down Sentences Engraved on Silicon Carbide (Sintered Compact)



The division of the scale is 1 mm.

Fig. 6-7. Sentences Engraved in 2-point (right-side picture of Figure 6-6 enlarged)

7. Conclusions

Significance

- From social and ethical viewpoints, record preservation is important as a item for confidence building on geological disposal of HLW in a repository.

Purposes

- The purposes of record preservation is to prevent future generations from their unintentional access to a repository and also providing information necessary for future generations' own decision-making on the repository.

Methods

- Proposed concept of a record preservation system is the combination of several different methods in order to impart redundancy to the communication function. The system should be so robust that its overall function would not be influenced by partial damage, and also be flexible enough to adapt to the changes of background conditions in the future.
- Records and information should be preserved by way of both Relay System and Permanent System. The former would maintain record preservation and communication functions in the framework of social systems whereas the latter would consist of durable storehouse facilities, recording media and markers/monuments and be independent of any social systems and human control.

Technological Possibility

- As an appropriate approach to the survival of a record preservation system in the future, it is proposed that supporting evidence should be found for a long-term record preservation within historical and archaeological issues.
- High-quality paper has been developed with the durability of several hundreds to one thousand years under appropriate conditions. On the other hand, a durability assessment of ink material has not been investigated.
- Silicon carbide is expected to be the promising material for long-term recording media with its superior characteristics of resistance against heat, wear and chemical impacts, and of engraving accuracy.

The preceding research projects suggests that a major issue is the lack of a technical foundation such as recording media. However, our present study has shown the existence of promising recording media.

Our future task is to hold discussions on concrete issues to be dealt with for formulating a

record preservation system, including preparation of actual long-term record preservation prototypes using these materials, preservation place and method, markers and monuments, etc., that are best suited for the Japanese situations. Furthermore, it is important to assess the cost and effectiveness of the proposed record preservation system.

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Appendix-A

Examples of Record Preservation and Communication, and Related Technologies

In order to abstract useful information for the examination of long-term record preservation, research and analysis were made from various angles, on historical and archaeological examples, current record preservation system in society, and related technologies.

A.1 Historical and Archaeological Examples

The results of research and examination on historical and archaeological examples are organized according to documentary records (Table A-1) and physical media (Table A-2).

Documentary Records

For the purpose of research on documentary records, religious scriptures such as the Old Testament (Matsuoka, 1997; Arai, 1992; Old/New Testaments Great Dictionary Editorial Committee, 1989, etc.), which are the oldest documents in which a collection of information with clear messages is preserved, ancient literature (Fujinawa, 1996; Satoru, 1985, etc.) which have been handed down from the far past to the present generation while keeping the form of documents, and legends (Jiyukokuminsha, 1998, etc.) were researched. In addition, examples of historical manuscripts, which are abundantly available in Japan (Aida, 1959; Sato, 1997, etc.) and old records of the Korean Dynasty (Sangmin, 1997), which were prepared with a clear intention to convey the history of the dynasty to future generations were chosen.

As a result of the research and analysis on the reasons why the records were prepared and preserved, it wasconcluded that, in general, recording media and preservation environments play more important roles; that records have been handed down from one generation to another by way of manuscripts; that records have been preserved at several separate places; and, that the records themselves have been recognized to have value. At the same time, the change of social or national systems, or war damages, could be pointed out as reasons why some records were not preserved.

Physical Media and Constructions

Symbols and monuments (or historic remains), temples and shrines, castles and cities, and other ancient remains were taken up as items for research.

According to these examples, it was found that the recording media themselves are made from robust materials such as rock and brick, and they can be preserved in the environment where they were built without any human control. On the other hand, the reasons why these historic remains have not been preserved are due to destruction and robbery as a result of racial and religious confrontations and difference of values, reuse as resources, and the transfer of historic remains due to the construction of modern engineering works such as dams. Concerning the messages engraved on those physical media, the fact that they were written in ideograms (including Chinese characters) and that they were written in more than one language (as seen in the Rosetta stone) are pointed out as factors that contributed to

future generations' understanding of the messages.

A.2 Current Record Preservation System

Overseas record preservation research projects concerning radioactive waste disposal (Table A-3) and domestic and overseas social systems concerning general record preservation (Table A-4) were reviewed as items of research.

Overseas Record Preservation Research Projects Concerning Radioactive Waste Disposal

In other countries, there can be found several precedents concerning arguments and research on long-term record preservation of radioactive waste disposal. Among these precedents, as published documents, such as IAEA technical documents (IAEA, 1999), the WIPP marker system study by Sandia National Laboratories (SNL, 1993), and the Nordic Nuclear Safety Research Project (KAN-1.3, 1993) were reviewed.

The results of the review show that prevention and restriction of human intrusion as well as provision of information that would facilitate future generations' decision-making are the major objectives of record preservation, and that examination is being made on the contents of records to be preserved and preservation methods. As for documentary records, it is proposed that they be preserved at several domestic and overseas archives, and KAN-1.3 (1993) even proposes the establishment of an international archives.

The concept common among these studies is that information should be managed and preserved according to the level of importance. IAEA (1999) has presented the information strategy that information should be classified, based on the level of importance, into Primary-Level Information (PLI), Intermediate-Level Information (ILI), and High-Level Information (HLI). Also in WIPP, a marker monument system with a hierarchical structure is proposed, and even message communication methods from linguistic, semiotic and psychological viewpoints are discussed (SNL, 1993).

Record preservation in Social Systems

As for examples seen in domestic and overseas social systems, the Japanese census registry and other registration systems, cultural properties protection systems implemented in Japan and other countries, and record preservation systems at the level of public records offices were reviewed.

In the current census registry and other registration systems, in addition to paper and microfilm, electronic media are being used for purposes of preservation and management. Furthermore, decentralized preservation of records such as a duplicate copy system has been implemented (Tochiku, 1991, Tokyo Hokei Gakuin, 1993). In the field of cultural heritage protection in which originals should be preserved, succession programs of preservation and restoration techniques as well as educational programs through teachings at schools are being implemented (the Agency for Cultural Affairs, 1988).

To ensure record preservation at the level of national archives and other organizations, the

Public Archives Law of Japan was enacted in 1987, thereby developing the environment for preserving official documents as a national records heritage and historical records with historic value. In the U.S., the roles of administrative bodies with overall authority over records management as well as those of specialists (archivists) have been defined (Ando, 1998, Ogawa, 2000, etc.).

A.3 Related Technologies

For the purpose of research on current technologies, paper and microfilm, electronic information systems, metal and inorganic materials, and information communication methods (including psychological analyses) were reviewed(Table A-5).

Paper and Microfilm

Paper is the most fundamental media for preserving records. In this study, high-quality paper is generally used as recording paper. The use of Japanese paper as an example of paper that has been preserved through its long history, and papyruses as an example of the oldest writing paper was reviewed, and their characteristics and preservation technologies were examined among other aspects.

Concerning paper, progress has been made in technological development in order to enhance durability for the purpose of long-term preservation. In Japan, paper with durability of up to one thousand years according to the ASTM (Oji Paper Co., Ltd., 2001) has been developed. However, a quantitative assessment concerning the long-term durability of written ink has not been made.

Research was also undertaken on microfilm that is commonly used, at present, as a recording media from the viewpoint of preservation. Currently, microfilm is used in various fields such as in the national archives, museums, libraries, governmental agencies, corporations, and universities. While means of preserving information have been diversified, the advantages of microfilm as a recording media such as long durability and the possibility as legal evidence have been highlighted, giving rise to new applications such as preservation of large volumes of valuable cultural heritage and databases of image information.

Electronic Information System

Electronic information systems have become indispensable in many fields, in terms of management of records. However, innovation of electronic apparatus and software is moving so fast that it is uncertain whether future generations will be able to read the information, and the durability of the recording media cannot be expected to last. Therefore, for the purpose of long-term record preservation, many issues remain to be studied.

Metal and Inorganic Materials

Taking into consideration the development of recording media utilizing metal and inorganic materials, research was undertaken to find materials that are superior in corrosion resistance and stable under various environmental changes. The results show that among metal materials, titanium alloy and nickel alloy are superior in corrosion resistance. Among ceramic materials, silicon nitride and silicon

carbide are especially superior in durability even under conditions of high temperature and highly corrosive atmosphere.

Information Communication and Psychological Consideration

One of the issues to be solved concerning record preservation is the formulation of measures for future generations to understand recorded messages correctly. Research was therefore conducted into examples of linguistic and nonlinguistic technologies.

More particularly, hieroglyphic characters and nonverbal communication methods used in the SETI Program [(*)] by NASA (Gakken, 1993) as well as psychological knowledge (Takuma, 1989) were reviewed. The results of the research show that for the purpose of communication of linguistic information, ideographic characters, such as Chinese characters, are expected to be effective, and that there already exist many research findings on communication methods using logical expressions and figures. Research was also undertaken on basic facts about human instinct and depth psychology.

The committee believes that these element technologies could be presented as one methodology on record preservation for geological disposal of HLW. However, systematization of these technologies into information communication technology intended for future generations is a task that needs to be addressed in further research.

[(*)] SETI Program: “Search for Extra Terrestrial Intelligence” Program by NASA, the U.S. space agency

Table A-1 Research and Analysis on Preservation of Document Record Found in History and Archaeology

Factors to be considered	Old Testament	Relics	Legends	Japanese ancient writing	old records of the Korean Dynasty
Purpose of records (Why, for what purpose, and for whom)	Code of conducts governing people's life, and at the same time based on the clear intention that social pride should be inherited through generations.	For the purpose of relating stories and tragedies of their heroes to future generations. The target include other races.	Many theories such as traditional oral communication of historical facts, lessons for future generations, and an ideal nation. Targets are not limited to its own race.	In close interpretation, products of expression of intention to communicate information to specified targets.	Drawn up by emperors and royal families of the Choson Dynasty to hand down stories about events that happened during their reins and the ethnic history down to future generations.
Collection of data (who and how)	• Oral tradition of the Judaic people • Drafted, amended or altered by many writers consisting mainly of Jewish priests (P document, J document, E document and D document)	• Oral and documentary tradition of Sumer, Hittite, Akkad, Assyria, etc. (G) • Oral tradition from the Mycenae Civilization (H). • Dictation by admirers of poets (H). • Written by scholars of Alexandria Egypt (H).	• Patrimony from Sais flamines in Egypt to Sorong in Greece. (A) • Written by Plato in his work "Critias" (A).	• Correspondence between the Imperial Court or feudal governments and their retainers. • Construction of census registers and books according to laws.	• Drafted by appointed historians. • Drafts kept confidential in order to secure impartiality and independency among historians.
1. Factors that enabled record be preserved					
(1) Recording media	• Parchment/lithography • Paper	• Clay plate (G) • Paper	• Paper	• Japanese paper	• Paper
(2) Preservation environment	• Cave (Dead Sea Manuscript) • Ancient library • Church/abbey	• Royal archive (G) • Ancient library (H) • Abbey (H)	• Ancient library (A) • Abbey (A)	• Log house repository (Shosoin Storehouse) • Old samurai residence/shrine	• Repository built in mountainous terrain
(3) Preservation system	• Succession from one generation to another through traditional oral communication, manuscripts, etc. • Research by biblical scholar	• Succession from one generation to another through recitation (H) • Competitions at the time of ceremonies	• Succession from one generation to another through manuscripts, etc. (A)	• Succession from one generation to another	• Established system for preservation • Decentralized preservation
(4) Other factors		• Decentralized preservation (G) • Protection by other races (H)	• Manifold aspects of information (A) • Protection by other races (A)	• Succession due to essential value • Succession due to ancillary value	• Important historical records for the race
(4) -2 Self-assertion	• Religious devotion • Racial pride	• Racial pride		• Assertion of right to land and other assets	• Racial pride
(4) -3 Inherent value	• Historical and literary value	• Historical and literary value	• Paradise legend (A) • Possibilities as ancient historical facts (A)	• Academic value as historical data • Artistic value as bokuseki (scrolls of calligraphy by Zen priests)	• Academic value as historical data
2. Factors that enabled information to be communicated.		• Description by more than one language (G)	• Manifold aspects of information (A)		
3. Factors that prevented record or information from being communicated.				➢ Change of legal system and social system ➢ Change of national system ➢ War ➢ Fire and theft	➢ Change of national system ➢ War
4. Conclusions to be applied to the future study on a record preservation system	• Preservation environment --- closed space, library • Preservation system --- relay system	• Preservation environment --- library • Preservation system --- relay system, association for preservation • Others --- decentralized preservation, use of more than one language	• Preservation environment --- library • Preservation system --- relay system, association for preservation • Others --- decentralized preservation, use of more than one language	• Essential value and ancillary value according to laws and regulations • Relay system • Recording media – Japanese paper and Japanese ink	• Establishment of preservation system • Decentralized preservation • Relay system

G: Gilgamesh H: Relics by Homer A: Atlantis legend

Table A-2　Research and Analysis on Physical Media and Constructions Found in History and Archaeology

Factors to be considered	Monument/Symbol	Shrine/Temple	Castle/City	Others
Purpose of records (Why, for what purpose, and for whom)	Presumably, symbol of faith in the ruler, whose target was both the people under their control and different ethnic groups in surrounding areas. (P, S, O)	Presumably, symbol of faith in the ruler, whose target was both the people under their control and different ethnic groups in surrounding areas. (AB, AN) Buddhist symbol (B)	Excavated articles mainly consisted of bronze ware of priests' tools and grave goods (I) Also, possibility as a monument symbolic of the power of the city. (M)　Protection from foreign enemies (T)	
Collection of data (who and how)	• Ancient Egypt/Khufu (P) • Ancient Egypt/ Khafre (S) • Ancient Egypt/Ramesses II (O)	• Ancient Egypt/Ramesses II (AB) • Khmer Empire/ Suryavarman II (AN) • No record (B)	• Nothing known about the designers (I, M, T)	
1. Factors that enabled record to be preserved			•	
(1) Recording media	• Limestone (P, S) • Red granite (O)	• Sand conglomerate (AB) • Laterite (reddish soil) + Sand stone (AN)	• Bronze, tortoiseshell, animal bone (I) • Adobe brick/burned brick (M) • Unknown (T)	• Desert plateau (N) • Black whinstone (R)
(2) Preservation environment	• Desert climate (Libya Desert) (P, S, O)	• Desert climate (Libya Desert) (A, B) • Jungle in tropical monsoon climate area (AN) • Subtropical dry climate (B)	• Underground (I: excavated articles) • Tropical monsoon climate – heavy sand storm during summer season (M)	• Alpine climate, but rainfall, at the most, once a year (N)
(3) Preservation system	• None	• None (unknown)	• Restoration after destruction (M)	• None (N, R)
(4) Other factors	• Size and simple shape of the media (P, O) • Size of the media (S)	• Closed Space (Cave) (AB) Restoration by Buddhists who lived there? (AN)		• Size of the media (N)
(4) -2 Self-assertion				
(4) -3 Inherent value				• Curiosity toward the expression method of the records (study theme) (N, R)
2. Factors that enabled information to be communicated.			• The fact that the same records were made in several languages including ideogram contributed to the deciphering of the records (I).	• Description in more than one language (R)
3. Factors that prevented record or information from being communicated.	➢ Partial destruction due to difference of values from foreign enemy (S) ➢ Removal by foreign enemy (O)	➢ Transfer of all the facilities due to the construction of a dam (AB) ➢ Destruction by other religious groups (B).	➢ Reusable burnt bricks resulted in large scale destruction	
4. Conclusions to be applied to the future study on a record preservation system	• Quality of material (good quality limestone, granite) • Size and simple shape of media ➢ Shape of media might cause destruction or brigandage.	• Closed space (cave) • Maintenance and management system ➢ Could be moved if the purpose is not understood. ➢ Religious symbols are vulnerable to destruction.	• Versatility and redundancy of record expression method. • Size and shape of the media that could be reused should be given consideration.	• Size of media • Too large record media could be recognized only by an advanced civilization.

P: pyramid　AB: Abu Shimbel　I: Ruins of Yin　N: Nazca Lines　S: Sphinx　AN: Angcor Vat　M: Mohenjo-daro, Harappa　R: Rosetta Stone　O: Obelisk
B: Bamiyan　T: Troy

Table A-3　Research and Analysis on Record Preservation of Radioactive Waste Disposal in Other Countries

Factors to be considered	IAEA (IAEA, 1999)	U.S. WIPP (SNL, 1993)	Nordic countries (KAN 1.3, 1993)
Basic significance of record preservation	• Prevention of human intrusion • Provision of information that would contribute to future generations' decision-making.	• Prevention of human intrusion	• Prevention of human intrusion • Provision of information that would contribute to future generations' decision-making.
Time frame for record preservation		• For ten thousand years (preservation of markers)	• The initial period of one thousand years is important. • Possibilities of ice age should be considered.
Media for long-term preservation of documentary records	• Paper • Microfilm	• Paper • Microfilm	• Paper • Microfilm
Location of storehouse for documentary records	• Local and foreign public records offices	• Organizations of federal governments • Local and foreign public records offices and libraries • Other specialized agencies •	• Newly built repositories • International repository
Other record preservation measures	• Formulation of a record preservation system from the initial step	• Dictionaries, encyclopedias • School texts • Maps, etc.	• Records inscribed on the waste itself • Documentary records installed within the premises of disposal sites. • Education system, legends, myths
Contents of documentary records	• Primary-level information (PLI) All the information to be collected during the entire period of a disposal program. • Intermediate-level information (ILI) Information mainly necessary for fulfilling authorization and legal requirements. • High-level information (HLI) Concentrated information necessary for future generation's basic understanding of disposal sites (location of repositories, data on the site, information concerning waste, disposal system, etc.)	• Location of repositories (map) • Safety assessment, environmental effect evaluation and application documents for authorization • Environmental and ecological data • Information concerning the waste • Methods of waste disposal and demolition work of disposal sites. • Information on the design of institutional control	• Geographical location of disposal sites • Information concerning the waste • Design and barrier system of disposal sites • Data utilized in safety assessment and information on other backgrounds • Results of safety assessment • Information concerning general social backgrounds, etc.
Hierarchical classification of documentary records			• All the information (first level) • Abstract of the most important information (second level) • General description of the most important information and the location of other information (third level)

(Table A-3 Continues)

Factors to be considered	IAEA (IAEA, 1999)	U.S. WIPP (SNL, 1993)	Nordic countries (KAN 1.3, 1993)
Principle of arranging markers	In IAEA TECDOC1097, record management system (RMS) is examined by taking into account the active management period, which means advancement from the conventional stance that record preservation should be positioned as one part of passive management. While record preservation based on a marker system, etc., is positioned as one part of passive management in IAEA TECDOC1097, it is pointed out that such a measure should be intended to continue after the completion of institutional control.	• Notification of the existence of managed areas by a huge marker. • Marker system consisted of various elements.	• Install where the marker can draw people's attention.
Linguistic principle of markers		• Use of more than one language. • Redundancy and Simplicity	• Use of more than one language. • Redundancy (combination with figures and symbols)
Characteristic of materials for marker		• Durability • Responsiveness • Desirability	
Message Level		• Pattern informing about the existence of artificial objects • Hieroglyph warning • Information about what, why, when, where, who and how • Detailed multiple message	• Symbol information drawing people's attention. • One-sentence message serving as an alert. • Information about what, why, when, where, who and how (one sheet of paper or stone marker) •
Academic fields regarding the examination of markers		• Geomorphology, material science, engineering • Design, archeology • Archaeology, anthropology, linguistics, semiology • Astronomy, information science	• Historical science, archaeology • Seismology
Other aspects		• Announcement of an opposing opinion by the exploratory committee against the option without markers.	• The option without markers is practically impossible (The existence of a large volume of metal and radioactive waste themselves can serve as a permanent marker.)
Future concerns		• Durability of materials under present conditions • Mechanism for transcribing and engraving information. • Interaction between materials, wind, sand and water. • Hieroglyph independent of cultures. • Written message independent of cultures.	• Establishment of international guidelines concerning the levels of records. • Periodic review of records, and decrease in the volume over time. • Development of recording media. • Cost effectiveness of record preservation measures, etc.

Table A-4　Research and Analysis on Record Preservation Seen in Domestic and Overseas Social Systems

Factors to be considered	Census register/registration system (Japan)	Cultural properties protection system (Japan and other countries)	Documentary records preservation system at the level of public records offices
Legal requirements	• Preservation periods specified according to the types of documents. • Items for permanent preservation (registry book, map, etc.) • Removing out of specified departments is prohibited.	• Designation, selection and registration as cultural properties by national and municipal governments (Cultural Properties Protection Law).	• Responsibilities of national and municipal governments concerning the preservation of important government documents as historical data (Public Records Office Law, National Public Records Office Law).
Record preservation measures			
Recording media	• Paper (example: high-quality Mino Japanese paper – Census Registration Law 1916), microfilm. • Electronic media	• Original texts and originals of cultural properties are subject to preservation, whose material might be paper, ceramic, inorganic material, metallic material and others.	• Paper, microfilm
Location of storehouses	• Book boxes, storehouses, etc., that have key mechanisms and are able to resist fire.	• Owners' facilities • Facilities of management organization • Museum and art museum	• Book storeroom with temperature and moist control mechanisms and safeguard against fire.
Record preservation system	• Duplicate system (decentralized preservation) • Electronic information system based on distributed processing (recording system)	• Succession of preservation and restoration techniques based on a subsidy system. • Cultural properties protection panel • Enlightenment activities through school education • Protection based on private foundation – Britain, the U.S., etc.	• Management by governmental agencies with comprehensive authority over record management – the U.S. (National Public Records Management Office Agency) • Management by specialists (archivist) • Detailed catalogue for the purpose of management • Succession of preservation and restoration techniques
Other factors	• Census register system is based on human longevity. For example, it is stipulated that original documents can be abolished after microfilm texts have become authentic texts. The reason is because they are not intended for permanent preservation.	• Tangible assets include those such as arts and crafts that are, basically, stored and preserved at some facilities, those such as buildings that are repaired and preserved on their sites and those such as historical ruins and scenic beauties that are preserved according to environmental protection measures.	• Assessment and selection of preserved records according to assessment standards concerning importance of records – the U.S. • Existence of interim repositories (Records Management Center) – the U.S.
Conclusions to be applied to the future study on a record preservation system	• Decentralized preservation of records	• Succession of record preservation and restoration techniques • Establishment of a panel consisting of specialists. • Incorporation into education system.	• Preservation environment of records • Management by specialists • Implementation of assessment and selection standards of records.

Table A-5　Research and Analysis on Related Technologies

Factors to be considered	Information system	Paper and microfilm	Metallic and inorganic material	Communication and psychological considerations
Status of technologies (Obtained knowledge)	• AD conversion (Analogue data -> Digital data) • Database management system • Diversified use of SGML[1], GIS [2], a multimedia database and others. Integration of various data including pictures. • Decentralized administration of server • Security technology Realization of authentication, access control and data integrity • Data backup technology	• Current classification of paper and preservation technology • Manufacturing method and preservation technology concerning high quality paper, Japanese paper, and paperboard. • Long-term durability of Japanese ink • Storing conditions and durability of current microfilm. • AD conversion (Analogue data -> Digital data)	• Long-term durability of current engineered materials: ・Resistance to corrosion and heat, and mechanical characteristics of iron steel, stainless steel, copper, titanium, nickel and various types of alloys. ・Resistance to corrosion and heat, and mechanical characteristics of alumina, zirconia, silicon nitride and silicon carbide.	• The use of ideogram would facilitate the understanding of the messages by future generations. (Though Chinese characters are pronounced differently in each dialect, written characters have the same meaning.) • Nonverbal messages such as figures, drawings and sound were used as messages to life on other planets by the robot craft. • A space language was proposed by encoding basic concepts of mathematics and other fields, but has not come into practical use. • A picture message coded in binary form was used by the Arecibo Observatory as a message to outer space. • Warning symbol is effective irrespective of race. Taboo is based on culture, religion, and instinct from information accumulated in DNA. By analyzing these relations, common warning messages could be formulated.
Applicability of technologies	• Product manual, etc. (SGML) • Map database system (GIS) • Censor register system (character, image data and AD conversion) • Information system concerning a legal registration system (character, image data, AD conversion and decentralized administration) • Electronic library (character, image and sound data, etc.) • Digital museum (character, image and sound data, etc.)	• High-quality publications, commercial prints, etc. (high-quality paper) • Restoration of old documents, etc. (Japanese paper) • A picture scroll was put in the time capsule of Expo '70 (Naruko Japanese paper). • Duplication of various kinds of preserved documents (microfilm)	• Engine, pump, abrasive materials, etc. • Fire-resistant materials (Space shuttle, etc.)	•
Other factors	• Advantage of client-server system [3] • Strengthening of multimedia editing function [4]	• ASTM (the U. S.) and others as manufacturing standards for paper	• In the present situation, several promising materials such as silicon carbide could be pointed out. As for the function as recoding media on which records are duplicated and engraved, verification through future tests and research is required.	• Each has the possibility as a means of communication with future generations that could not understand our language. However, the effectiveness of these means for such purpose has not been verified yet, thus requiring further investigation.
Conclusions applied to the future study on a record preservation system	• The current technologies could be applied at the stages of management and operation of records. ★ In terms of readability of information and durability of recording media, there still are many problems to overcome for the purpose of long-term preservation.	• Durable printing paper for the purpose of long-term preservation has been developed. No research on the durability of ink has been confirmed as yet, leaving room for further research on the assessment method.		

1. SGML: Standard Generalized Markup Language = Expression format for the diversified utilization of documentary data and the interchange of data between different types of machines.
2. GIS: Geological Information System
3. AD conversion would be required at the time of record preservation. In connection to this, it would be effective to incorporate the server functions common into each client machine, and distribute the overall load over the entire system, thus constructing an optimized client-server system with superior scalability
4. It would be important to implement a multimedia editing function to facilitate editing operations in which isolated pieces of information are formulated into meaningful sets of information based on predetermined standards. The ultimate purpose is to improve assurance of data quality and transparency of the system

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APPENDIX-B

Members of The Committee on the Geological Disposal Record Preservation System

MATSUBARA Nozomu (Chairman) Professor, Graduate School of Frontier Sciences, Department of Environmental Studies, University of Tokyo

AKASAKA Hidenari (*1) Genaral Manager, Science and Technology Division, Nuclear Waste Management Organization of Japan (NUMO)

ADACHI Fumio Professor, Information System Division, National Museum of Japanese History)

GOTO Takashi Professor, Institute for Materials Research, Tohoku University

HOASHI Yosuke professor, Chief Librarian, Fuji Tokoha University

KITAYAMA Kazumi (*2) General Manager, Science and Technology Division, Nuclear Waste Management Organization of Japan (NUMO)

MIYAHARA Kaname Chief Researcher, Nuclear Cycle Backend Division, Japan Nuclear Cycle Development Institute (JNC)

MUROI Hisashi Associate Professor, Faculty of Education and Human Sciences, Yokohama National University

OGA Taeko Specialist for Archival Affairs, National Archives of Japan

TANAKA Satoru Professor, Faculty of Engineering, University of Tokyo

TANI Masakazu Associate Professor, Kyushu Institute of Design

UEDA Hiroyoshi Manager, Research and Development Science and Technology Division, Nuclear Waste Management Organization of Japan (NUMO)

(Observers to the Committee)

TAKAHASHI Yoshiaki Deputy Manager, Science and Technology Division, Nuclear Waste Management Organization of Japan (NUMO)

TAKEUCHI Mitsuo Group Manager, Science and Technology Division, Nuclear Waste Management Organization of Japan (NUMO)

TANUMA Susumu Assistant General Manager, Nuclear Power Division, The Kansai Electric Power Co., Inc.

APPENDIX-C

Members of working group (except RWMC)

KAGEYAMA Hitoshi	Mitsubishi Materials Corporation
SASAKI Ryoichi	Mitsubishi Materials Corporation
NODA Masaru	Obayashi Corporation
SATO Shoko	Obayashi Corporation
HIRUSAWA Shigenobu	Institute of Applied Energy (IAE)

Radioactive Waste Management Funding and Research Center (RWMC)
No.15. Mori Bldg, 2-8-10, Toranomon, Minato-ku, Tokyo, 105-0001, Japan
TEL +81-3-3504-1081 FAX +81-3-3504-1297 http://www.rwmc.or.jp

JPY. 2,500-