ROBUST RECORD PRESERVATION SYSTEM ON GEOLOGICAL REPOSITORY*

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Abstract. Long-term record preservation system on geological disposal of High Level Radioactive Wastes (HLW) has been investigated as the institutional control by RWMC, Japan. Geological disposal of HLW, being based on the passive safe concept, has been considered not to necessitate the human controls to maintain its long-term safety. However how to complement the safety case on geological disposal is an important issue in each countries to progress the repository program with the step-wise decisions process during the long-term period up to several hundreds years. Although we cannot predict the future society, we need to realize the robust and redundant system for preserving records, which should be accessible, retrievable and understandable for the unpredicted future generations. First of all, we held a Rome workshop in January 2003 to exchange views on the matter, resulted in the suggestion directing the discussion on the record management and long-term preservation and retrieval of information regarding radioactive waste. Second, we considered the balance of active and passive system to strengthen the robustness. Another significance of long-term record preservation is to send current generation an implicit message,"doing our best for future generations", in addition to aiming at both warning and their own decision-making. We call it "meta-signal" to current generation. Thirdly, we demonstrated the laser-engraving technology to have converted five hundreds pages of an A4 sized report with human readable font sizes to 42 square silicon carbide plates, 10cm x10cm and 1mm in thickness. Silicon carbide would be an alternative to paper and might be possible to be an alternative to microfilm utilized as digital recording media. Another case study is the future generations' accessibility to the preserved records.

1. Introduction

Geological disposal of High Level Radioactive Wastes (HLW), being based on the passive safe concept both of the engineered and natural barrier, has been considered in principle not to require active monitoring, maintenance and institutional controls such as record preservation to maintain its long-term safety. However recently, given the longevity of safety concerns of HLW, the long-term record preservation for the future generations concerning the safety of HLW repository should be a fundamental element of implementing repository programme with step-wise decisions process during the long-term period up to several hundreds years. These decisions require a clear and traceable presentation of technical arguments that will help in gaining confidence in the feasibility and safety of a proposed disposal concept. The safety case is a key input to support the decisions. [1-3]

Future generations will need information about the repository and wastes so that they are aware of the potential hazards involved to make informed decisions concerning the safety of the repository during the implementation of the programme. They can minimize the risk of unintentional access to the repository, and can make decisions on the safety re-assessment, removal of HLW and the possible reuse of the site and surrounding areas. As we cannot predict the future generations in the future society, so for transferring the information to them we need to realize the robust and redundant system. The system should be transferred in

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generation-to-generation and be accessible, retrievable and understandable for them in the unpredicted future societies. The core information should be preserved to the future generations by highly durable recording media.

Figure 1 shows the scope of our study on the long-term records preservation. In the previous report, [4, 5] we re-considered the objectives and significance of long-term record preservation on geological disposal of HLW, and clarified the requirements for strengthening robustness and redundancy, and formulated the adaptable elements to the unpredicted future society for attaining the long-term record preservation system with robustness and redundancy. Furthermore, we discussed the technical feasibility of laser engraving technology on silicon carbide plate for long-term record preservation (hereinafter we call “Laser-glyph”), independent of human control. Laser-glyph is the promising technology both for active and passive systems.

FIG.1. Scope

In this paper, first of all, we describe the efforts of Rome workshop held in January 2003 to exchange views on record management and long-term preservation and retrieval of information regarding radioactive waste. [6] Second, we considered the balance of active and passive system to strengthen the robustness. Another significance is to send current generation an implicit message, “doing our best for future generations”, in addition to aiming at both warning and their own decision-making. Thirdly, we demonstrated the Laser-glyph, and conducted case studies on the long-term record preservation system for future generations to access, retrieve and understand the preserved information.

2. Rome Workshop

In January 2003, we held the workshop in Rome to inform each other of the present status concerning record preservation. Twenty-three experts from 12 countries, IAEA and OECD/NEA participated in the workshop and discussed this issue. The objective of the workshop was not to reach official consensus but to understand the current activities in each country. As we had an ongoing discussion on the comprehensive issues regarding long-term record preservation, and developed Laser-glyph using durable silicon carbide plate which might give a possibility to preserve records for more than thousand years. Since we knew that a number of countries have been discussing the topic of long-term preservation and retrieval of information, it might be very timely to have a joint discussion on the issue of long-term record preservation and retrieval of information.

Main discussions were as follows. Knowledge management is an important field for all programs and needs further attention. However, regulations regarding knowledge management have not yet fully developed in most countries. Motives and key issues are slightly different between the programs. Systems for identifying important knowledge, records and documents are under development and are in some countries in the stage of implementation. The development on technical media also continues. What kind of records and information should be preserved and transferred to the future generations is a main point of the future agenda with responsibility and system design. We considered that open network is the most suitable system to transfer the information related to the safety concerns of the repository in the contextual framework based on the international standards by the International Organization for Standardization (ISO) and the International Council on Archives (ICA). Many computers with hard disks and isolated media such as optical disks and USB memories would support the open network, which would be backed-up by paper and microfilm. Silicon carbide has the possibility to enhance the durability of these back-up media.

We raised the question on the need of international archives and expressed several views. This question has to be discussed on a regulatory basis since repositories for Low- and Intermediate-Level Radioactive Wastes have been already implemented and repositories for HLW are well under way in some countries. Early actions on knowledge management issues will improve the possibilities for future generations to make informed decisions regarding radioactive waste issues.

To within a year or two have an international expert meeting for compiling the progress from the current established baseline as presented at the Rome workshop, such a meeting should be preferably anticipated to be held by an international organization such as IAEA and OECD/NEA. Clarification of remaining issues would be another task for such a meeting. At the next meeting, it might be considered to broaden the discussion by inviting also other stakeholders. Views from other industrial fields might also be a good approach to get a perspective on relevant measures for the future.

3. Additional considerations on robustness

3.1. Classification and preservation of information

In the previous studies, Nordic countries, Sandia laboratory and IAEA considered how to classify the information related to geological disposal programme [7,8], which we re-classified and combined with the preserving methods as shown in Figure 2. For example, recording media bearing Level-I information, the existence of artificial objects, should be as large as possible and at the same time hard enough not to be destroyed, as demonstrated by pyramids of ancient Egypt. Despite being made of essentially not robust limestone, they have been preserved as large and simple in shape as what they were until today for a long time.

Level-II information, describing the existence of artificial object and danger, should be expressed by various methods such as plural languages, ideograms, pictures, some kind of semiotic expressions and psychological communication means. Monoliths bearing Level-II information, made of natural rock and other materials, should be dispersed to the structure bearing Level-I information. Such Level-II media would be much smaller than that of Level-I, and be necessitated to be superiorly durable in order to keep the engraved messages.

Objectives	Level	Level-Classification and Contents(*) Contents	Preservation method
Preventing unintentional access	I/II	Information to be encountered first "something artificial exists around here and it represents danger."	markers, monuments
	III	Information after the danger is perceived "High-level radioactive waste exists." "It exists deep underground nearby." "More detailed information exists."	markers, monuments / documentary record
Future generations' decision-making	IV	Detailed description on the repository geography, geology, design, safety assessment, waste, etc.	documentary record
	V	Further detailed information	documentary record

(*) Referred to KAN-1.3 & SAND92-1382

FIG.2. Level classification & preserving methods

The study on WIPP suggests the concept of "message kiosk" to preserve Level-II and III information, which consists of message boards made of granite on the ground, and surrounding protective walls made of concrete or other materials. The message board would have another possibility to embed tablets to the boards, which are made of engineered materials that are more durable to bear Level-III information.

Level-IV information, detailed documents, should be housed within some artificially closed space, i.e. a storehouse, surrounded by robust walls and ceiling. The recording media could be chosen from engineered material that resist various environmental changes and can preserve documents for a long time. Ceramics having superior strength, corrosion resistance, and wear resistance would be promising. As the documents preserved in the storehouse are the most important information in the permanent system, various preservation methods should be anticipated. For example, conventional types of recording media such as paper and microfilm could be preserved up to several hundreds years under appropriate storing conditions.

Silicon carbide will enhance the longevity of information in the documents, and enhance the durability and precision of inscribing the classified contents on the markers and monuments into the level of documents.

3.2. Relay and permanent system

Both documentary records, and markers and monuments should be adopted as record preservation media. In our previous report, we clarified the adaptable elements to the robust and redundant long-term record preservation system and pointed out that integration of several different methods is the most appropriate in practical. Integration of several different methods would impart redundancy of communicating function of the system, and at the same time enable the system to retain robustness where the overall function would not be influenced by partial damages, thus resulting in a flexible system that would be adaptable to the unpredicted changes of future societies.

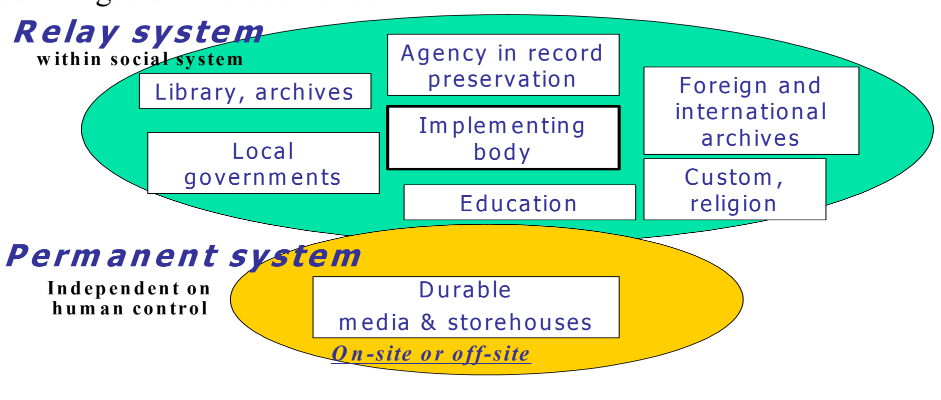

FIG.3. Relay & Permanent system

Figure 3 shows our consideration on two categories of record preservation system. One is a "relay system", by which the records is kept, migrated and communicated by active mechanism through generations within a social system. Another is a "permanent system", by which the records and information are kept and communicated passively without human control by using durable recording media or methods such as markers and monuments.
In the relay system, requirements are as follows.

1) Records should be registered as originals when being documented.
2) Records should be classified according to the objectives and preserving period, and transferred in contextual framework. Original records should be stored and, as necessary, updated in comparison with originals according to the time passed.
3) Records should be stored in the designated and distributed facilities and organizations.
4) Meta-information showing the existence of the system should be kept outside the system.
5) Appropriate technologies should be utilized at any time.

In the permanent system, requirements are as follows.

1) Durable materials should be used for storehouse and recording media.
2) Storehouse and recording media should be dispersively arranged.
3) Records should be simple and redundant with hierarchical classification and diverse expressional methods.
4) Meta-information showing the existence of the system should be kept outside the system.

As above mentioned, information can be transferred to future generations by the combination of relay and permanent system. Relay system requires human activity or intervention. The use of active information transfer systems would ensure the safety of the repository for future generations by providing of access to adequate information, especially information from dispersed or otherwise isolated sources. Permanent system such as the creation of long-lasting markers and monuments would contribute to safety by minimizing the risk of unintentional access to the repository, and support the active systems especially under any scenario where active systems have failed. We should balance the combination of relay and permanent system for robustness according to each country's properties such as praxis, regulations, and climatic and natural environments. Some additional considerations to strengthen the robustness are as follows.

3.3. Meta-signal to current generation

The ethical basis of implementing the robust long-term record preservation and information transfer system for the future generations is that each succeeding generation should be able to make its own decisions with regard to the continuing safety of the repository. In human communications various communicational modes are used such as play, non-play, fantasy, sacrament and metaphor. Human communication consists of transferring both explicit and implicit message. The latter is the mode-identifying signal of the communication, [9] which we call meta-signal in this paper.

To transfer the information to the future generations through the robust system, we need to preserve both contents and contexts, and furthermore meta-signals to be accompanied with. A meta-signal implies that current generation, responsible for the repository programme, had done its best to implement the robust record preservation system, so the information transferred through the system should be true concerning the safety of the repository. On the other hand, to current generation the meta-signal might identify the different mode that implementing group of the repository is willing to do its best for the future generations as well as in compliance with regulations. This might have resulted in the understanding and confidence of current generation that the implementers of repository programme will have the robust record preservation system with the state of the art technology. Thus, the meta-signal

might identify the mode of the actions being done to do its best for implementing the robust system, and provide current generation with an implicit message for their own conscious decision-making to progress the repository programme, for example, acceptance of repository site in their backyard as the contribution to the society.
Therefore, current generation might be able to understand that the implementing group of the repository will have a proper technology of the robust system and is obliged to decide doing its best for the future generations. Each generation is obliged to do its best for future generations within the context of the scientific knowledge, technology and resources available at the time. Therefore, we can say the actions doing our best would send a meta-signal to current generation that we are sending the future generations an implicit message of doing our best for them. The importance of the robust system is premised on not only the safety concerns of the waste itself, but also sending a meta-signal to current generation, who is responsible for implementing waste disposal programme.

4. Case studies

4.1. Demonstration of Laser-glyph

Laser-glyph is the computer-controlled laser-engraving technology onto silicon carbide plate in a similar way with a laser printer. We use a thin silicon carbide plate instead of paper. Robustness of information transfer system would be attained by utilizing an open network system and be further enhanced by preserving the core information onto silicon carbide plates.

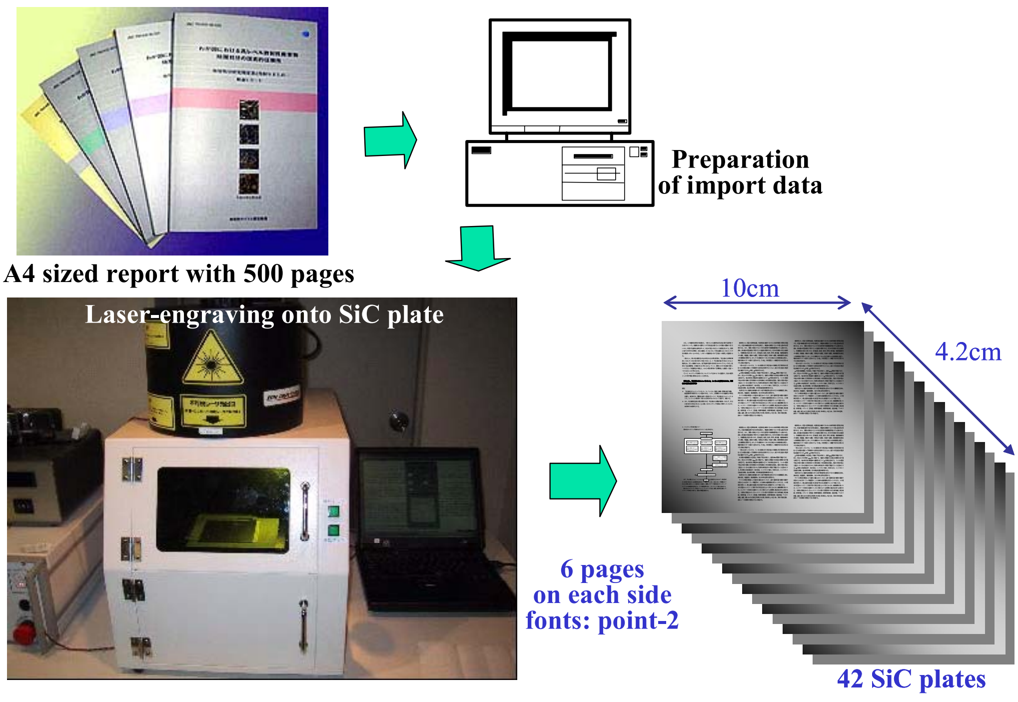

FIG.4.Demonstration of Laser-glyph technology

As shown in Figure 4, we demonstrated the technology to convert five hundreds pages of an A4 sized report to 42 pieces of silicon carbide plates, 10cm square and 1mm thick. We migrated a digital file of twelve A4 pages-records onto a dual sided silicon carbide plate within 30 minutes. In this demonstration, we used minimum point-2 fonts to be human readable with naked eyes and needed approximately 20 thousands dollars, which is anticipated to be decreased to reasonable level for practical use. As silicon carbide is the most durable artificial material in the world from a viewpoint of heat and corrosion resistance and wear due to abrasion, Laser-glyph could enable to preserve documents without the need for sophisticated preservation environment controls and without the need for human intervention to initiate a duplication program for over 1,000 years. Silicon carbide would be an excellent alternative of paper.

Digital records in the open network would be transferred to the isolated media such as hard disks, optical disks, floppy disks, and flash memories. To enhance the robustness of open network, digital records might be transferred to paper and microfiche. As they still need the dependency on the long-term storing environment, they might be lost by some incidents such as fire and flooding. Silicone carbide is possible to replace these conventional media.

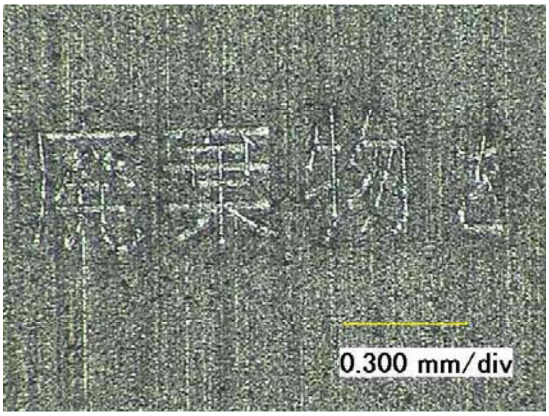

FIG.5. Smaller fonts for alternating microfiche

We have been undertaking further work to inscribe smaller fonts as shown in Figure 5. Digital information, converted to an analogue form, can be engraved onto the silicon carbide plate as an alternative to microfiche. Thus, digital records in the open networks could be converted to an analogue form such as a portable document format, PDF and isolated onto durable media such as microfilm, which might be replaced by durable media such as silicon carbide plate. Perhaps, a transcription of the digital file (in binary code) as well as the human readable form on the same plate could represent the best use of this technology.

It has been suggested that an all-embracing set of strategies covering information transfer should include the utilization of permanent monuments and markers on the sites of the repositories. Stone and earth-based monuments and markers designed to withstand tens of thousands of years of natural erosion have been proposed to inscribe entirely symbols and be suggestive and not mostly based on language. However, such strategies are designed to address a future where there has been a significant collapse of the socio-technical society, as we know it. Rock-based inscriptions of essential core information in multiple languages, as in the Rosetta stone, are deemed possible. Laser-glyph can attain markers and monuments made of silicone carbide with finer inscriptions and longer durability.

4.2. Future generations' accessibility and their decision-making

Figure 6 illustrates the examples of the scenario for future generations' retrieval of information and their decision whether to access or not to the repository. This figure shows both the scenario for human actions and the flow of information. Organizations involved in record preservation in the future might be implementers of geological disposal, related administrative bodies, the geographical surveying bodies, domestic record preserving organizations such as libraries and archives, foreign and international archives, IAEA, and newly established record preserving bodies.

The upper part illustrates the flows of events in the case that a relay system is maintained in society. The beginning of retrieving information on the repository by future generations might be the acquisition of knowledge from the educational system, programs concerning resource investigation and development, actions relating to the ownership of repository sites, as well as encounters with markers and monuments when entering a repository site without recognizing the existence of the radioactive wastes. 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 the repository, resulting in the cancellation of development programs on the repository or decision-making on the matters such as the retrieval of waste.

The lower part illustrates the flow of human actions in the case that the relay system is lost but a permanent system survives. Human actions would cover from the beginning of future generations' learning of the existence of the repository by encountering the information of Level-I to -IV to their

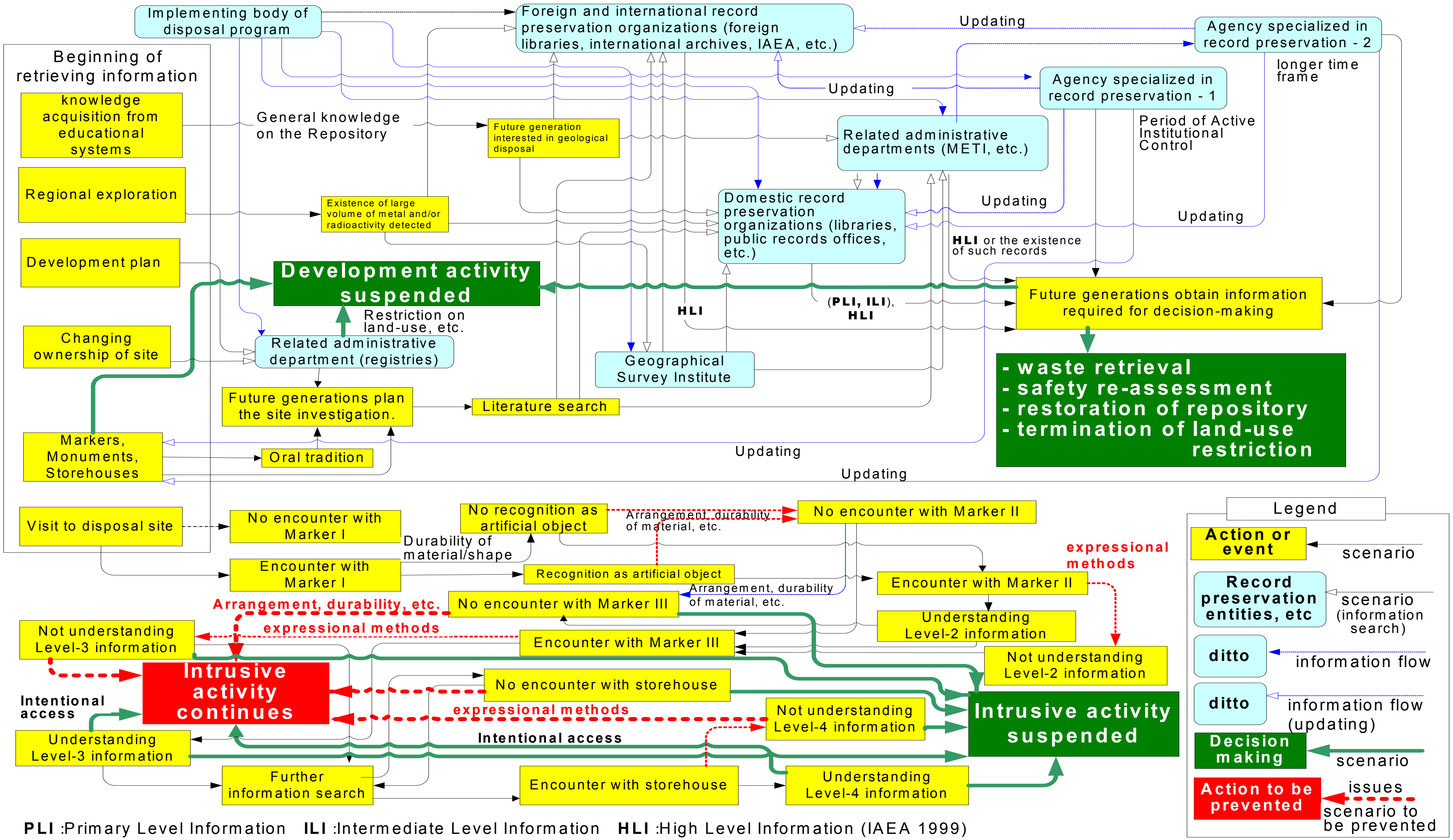

FIG.6. Scenario of future generations' accessibility

decision-makings such as the discontinuity of their access to the repository. Furthermore, the figure illustrates an unfavourable scenario to be eliminated, where markers and other facilities were lost or future generations would not understand the meaning of the information, thereby resulting in an unintentional access to the repository. In order to avoid the unfavourable case to the greatest extent possible, we pointed out that we should furthermore examine the arrangement of markers, monuments and storehouse of permanent records, as well as their durability and expression methods such as plural languages, semiotic expressions and psychological communication means.

4.3. Arrangement of permanent system

We examined the materials and locations of markers, monuments and storehouse of documentary records on the site of the repository. From the viewpoint of long-term durability, we should select materials by taking into consideration Japanese climate such as high humidity and rainfall, and the geological and geographical environments. 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 storehouses.

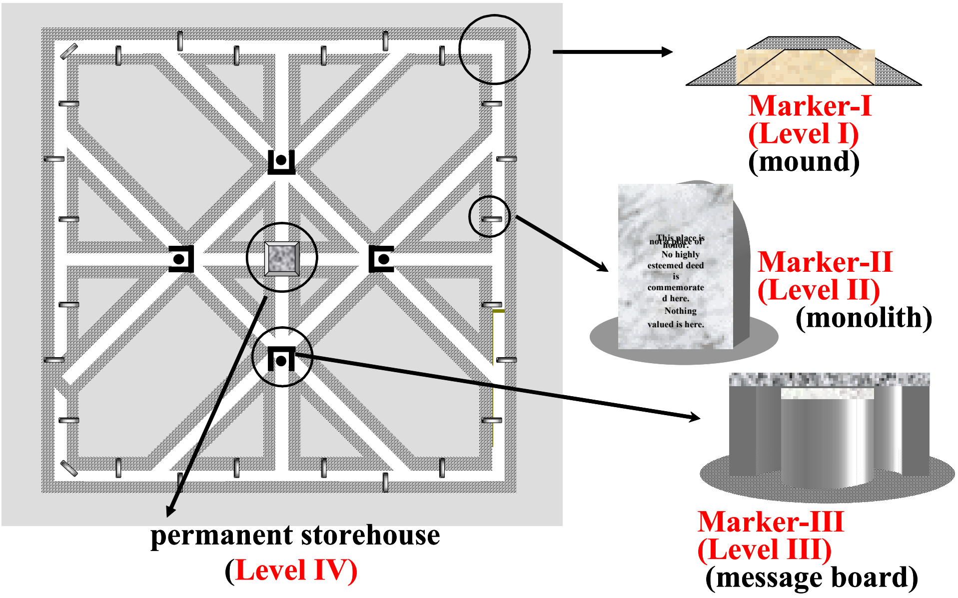

FIG.7. Example of permanent system

We designed in trial markers, monuments and storehouses to be erected on the grounds of the repository site. As shown in Figure 7, Marker I communicating Level-I information is an assembly of mounds with a trapezoidal cross section as aisles, and arranged both around the repository site and in radial directions that they connect to the centre. This is an example of structures that would spontaneously lead future generations to visit the further information. Markers II is arranged both at the roadsides and in the shallow earth of Marker I.

Markers III, placed at the intersections of aisles extending to the centre, might indicate the existence of further information and lead the visitors to the centre, where they can find the storehouse of Level-IV information. To meet the artificial destruction, Markers III and the storehouse might have a dual structure of aboveground and underground. Therefore, in the selection of the location, we should consider environmental conditions of the aboveground and underground regarding temperatures, humidity and other aspects.

5. Conclusions

Rome workshop confirmed the importance of knowledge management, indicated the main topics on record preservation and information transfer to the future generations, and suggested the future agenda. The question on future international archive systems should also be discussed further.

Additional considerations are the decisions on the balance between active system on one hand and passive system such as long-term durable marker and storehouses on the other hand. This must be taken in each country based on their praxis, regulations, climatic and natural environmental properties etc. We demonstrated Laser-glyph as an example of development of different technical long-term durable media. Furthermore, we conducted case studies on the future generations' accessibility from a viewpoint of combination of relay and permanent system and accessing scenario. These measures will send a meta-signal to all stakeholders and decision makers that we are today doing our best to transmit the necessary information to the future generations.

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