Committee Report: JCI-TC-181A

Technical Committee on the Application of Cement and Concrete Technologies to Disposal of Hazardous and Radioactive Wastes

Kazuo YAMADA [*1], Kazuko HAGA [*2], Isao KURASHIGE [*3], Toru INUI [*4], Kenichiro NAKARAI [*5], Kazuhito NIWASE [*6]

Abstract

The safe and rational disposal of waste is an important social issue supporting sustainable economic activities. Until now, cooperation between this waste management area and the cement/concrete field has not been very active. However, in recent years, the necessity and importance of addressing the above waste management by integrating knowledge and technologies, not only across those own fields but also in many related interdisciplinary areas, have been recognized. Considering this background, this paper reports the relationships between the treatment and disposal of hazardous wastes containing toxic/heavy metals/substances, etc., and the radioactive wastes generated by nuclear power generation and radiological accident, etc., with the knowledge and technology in the cement and concrete fields, and additionally discusses the research and technologies that will be necessary in the future.

Keywords: Hazardous waste, radioactive waste, cement solidification, disposal facility, cementitious engineered barrier, long-term durability

1. Introduction

1.1 Purpose of the committee

In recent years, interdisciplinary research across research areas has been actively conducted for various topics. Concrete engineering is deeply related to the construction field and also to the

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disposal of hazardous wastes and radioactive wastes. For example, in foreign countries, a large-scale research group called Nanocem has been active since 2004, incorporating various knowledge and techniques of physical chemistry and materials science[1)]. The expansion of the conventional research areas has dramatically increased the level of research, which also applies to the radioactive waste disposal field. However, in Japan, the latest advances in cement chemistry and concrete engineering have not been fully reflected in relevant fields.

Therefore, in view of this background, based on the basic knowledge in the fields of cement chemistry and concrete engineering, and considering waste disposal, we have established a Technical Committee, JCI-TC-181A (committee chair: Kazuo Yamada, Fukushima Regional Collaborative Research Center of the National Institute for Environmental Studies) for the application of cement and concrete technology to hazardous waste and radioactive waste disposal, in cooperation with various fields deeply related to the disposal of hazardous waste and radioactive waste, such as geotechnical engineering, nuclear engineering, environmental engineering, and materials science.

Through the participation of experts in the above fields, the Technical Committee has conducted activities with the aim of matching practical needs with technologies and knowledge in the fields of cement chemistry and concrete engineering, as well as extracting technologies and knowledge expected to be applied in the future. Multiple organizations have been involved with regard to radioactive waste disposal, and each of these has been conducting large-scale research for a long time, whose findings are summarized in this paper. In addition, this paper summarizes research tendencies on radioactive waste in foreign countries and treatment of typical radionuclides by the phase equilibrium mass transport model (reaction transport model), which will become a standardized tool in the future.

In this paper, we introduce an outline of the activity results of this Technical Committee from the viewpoint of the relationship between waste and cement and concrete for the two years from fiscal 2018 following the FS committee of fiscal 2017. Due to the impact of COVID-19, the seminar reporting our activity that was originally scheduled to be held in fiscal 2019 was postponed to December 2020. Although the activity results were presented at the 2020 JCI Annual Convention, this report was also presented with a delay of one year.

1.2 Activity structure of the committee and structure of this report

As shown in **Table 1**, this committee consisted of 17 experts and two working groups (WGs): WG1 for cement solidification treatment technologies for hazardous wastes and WG2 for disposal technologies for radioactive wastes (**Figure 1**).

The committee's report also outlines the disposal of hazardous wastes and radioactive wastes in Chapter 2. Chapter 3 discusses the cement solidification treatment of hazardous wastes, which is the activity theme of WG1. Chapter 4 details the disposal of radioactive wastes of WG2 by summarizing the results of each activity. Finally, prospects and expectations are presented.

Table 1: Committee Activity Structure

Chairman: Kazuo YAMADA (National Institute for Environmental Studies) Vice Chair: Kazuko HAGA (Taiheiyo Consultant) Secretary: Isao KURASHIGE (Central Research Institute of Electric Power Industry)
[WG1: Cement-solidification Working Group] Director: Toru INUI (Osaka University) Members: Fumitake TAKAHASHI (Tokyo Institute of Technology) Yuya TAKAHASHI (University of Tokyo) Takahito NOZAKI (Taiheiyo Cement) [WG2: Radioactive Waste Disposal Working Group] Directors: Kenichiro NAKARAI (Hiroshima University) Kazuhito NIWASE (National Institute of Technology, Hachinohe College) Members: Go IGARASHI (University of Tokyo) Kazuto ENDO (National Institute for Environmental Studies) Eiji OWAKI (Taisei Corporation) Takuma SAWAGUCHI (Japan Atomic Energy Agency) Masakazu CHIJIMATSU (Hazama Ando Corporation) Takashi HAMAMOTO (Nuclear Waste Management Organization of Japan) Daisuke HAYASHI (Radioactive Waste Management Funding and Research Center) Shintaro MIYAMOTO (Tohoku University)

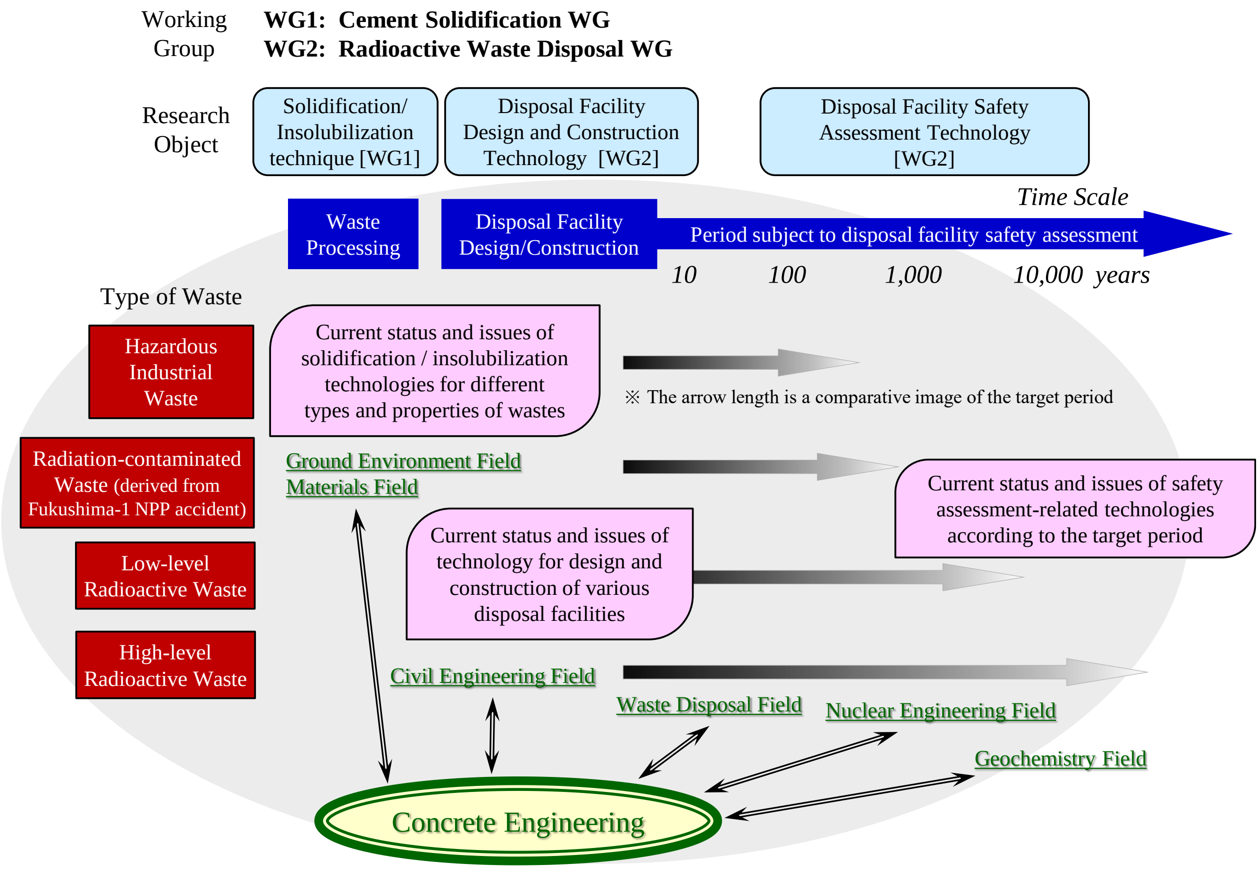

Fig. 1: Outline of Activity Structure and Study Themes in this Technical Committee

2. Outline of Waste Disposal

2.1 Disposal of hazardous waste

The Waste Management and Public Cleansing Act (hereinafter referred to as the Waste Management Act) in Japan does not include the term "hazardous waste," rather the terms “specially-controlled municipal solid waste” and “specially-controlled industrial waste” are used. Criteria have been established to judge whether the wastes need to be "specially-controlled" or not. Specially-controlled industrial or municipal solid waste is defined as the wastes with leaching concentrations of hazardous substances in excess of the criteria. Specially-controlled industrial waste that has been processed properly and meets the criteria is recategorized as “industrial waste” and can be disposed in controlled-type landfills. Waste that does not meet the criteria even after treatment is disposed in hazardous landfill sites. **Figure 2** shows the categorization of municipal and industrial wastes, in terms of final disposal options. The notification on "Partial Revision of the Enforcement Order of the Waste Management and Public

Cleansing Act (July 16, 1998, Environment and Water Planning No. 299)" states that "it is desirable to avoid disposal of waste materials in a hazardous landfill site, by detoxified treatment using suitable technologies." Thus, detoxification is usually performed for the wastes whose leaching concentrations of hazardous substances exceed the criteria.

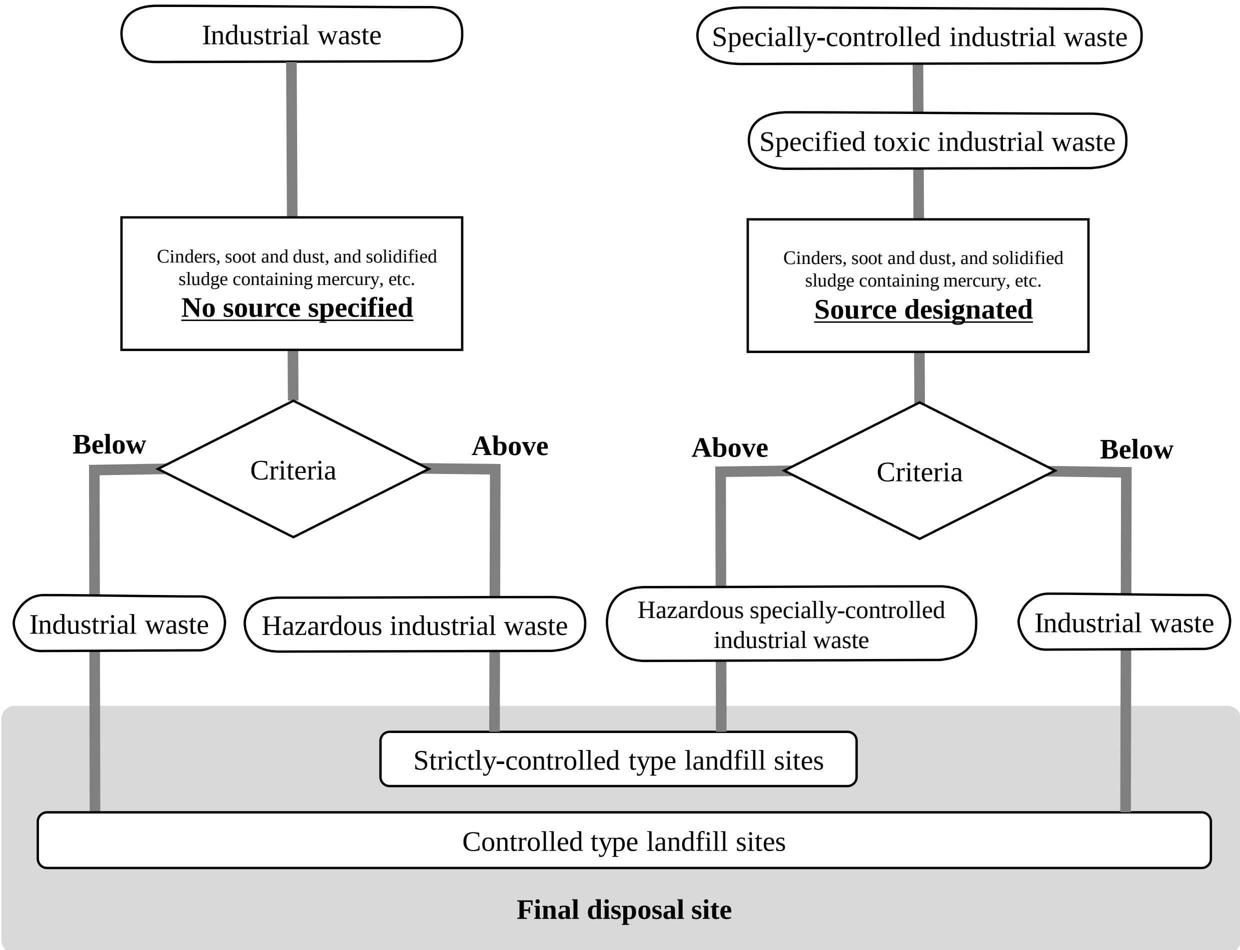

Fig. 2: Final Disposal Options of Hazardous Waste in Japan

Cement and concrete technologies applied to the disposal of hazardous wastes can be largely divided into cement solidification, solidification/insolubilization treatment, and containment using concrete barriers at hazardous landfill sites. As cement solidification is one of the essential technologies for detoxification of hazardous waste, the Technical Committee surveyed the state of cement solidification and solidification/insolubilization treatments. Details are described in Chapter 3.

In 1977, the Prime Minister's Office and the Ministry of Health and Welfare of Japan released general concepts for strictly controlled disposal sites as well as main technical points and examples on design of partitioning facilities for strict containment, and concluded that reinforced concrete was considered to be the most appropriate material for these facilities. In this document, the unconfined compressive strength required for reinforced concrete used for the peripheral partition facilities was determined to be 24.5 N/mm^2. Referring to the present JIS A 5308 on ready-mixed concrete, such strength can be realized by employing the ready-mixed concrete with a proper mixing design. In addition to the compressive strength, hydraulic barrier performance against temperature cracking and cracking due to drying shrinkage and alkali-silica reactions should be considered in the mixing design. Moreover, Endo and Yamada[2)] indicated that, in addition to cracking in such concrete materials, corrosion of internal reinforcement caused by the higher Chloride concentrations in the fly ash disposed of in hazardous landfill disposal sites poses another major issue.

For the designated radioactively contaminated wastes generated in the accident at Fukushima Daiichi Nuclear Power Plant, during landfill disposal for radioactive Cs concentrations of 0.1 million Bq/kg or higher, the structural standards of the partitioning facilities were required to be equivalent to those of hazardous landfill. Other technical requirements were provided by the National Institute for Environmental Studies [3),4)].

2.2 Disposal of radioactive waste

Radioactive waste includes: (1) radioactive waste generated in the nuclear fuel cycle, (2) radioactive waste generated by the decommissioning and demolition of nuclear power plants, and (3) other radioactive waste generated in research institutions, medical institutions, etc. The nuclear fuel cycle is a system in which fuel processing, power generation, and reprocessing of fuel are made to be one loop, and the radioactive waste can be high-level and low-level radioactive waste. The geological disposal of high-level radioactive waste and some low-level radioactive waste is under consideration by the Nuclear Waste Management Organization of Japan (NUMO). The burial disposal of low-level radioactive waste and (2) low-level radioactive waste generated by the decommissioning and demolition of nuclear power plants into relatively shallow ground has been considered by Japan Nuclear Fuel Limited, and some projects have been implemented. Burial disposal of (3) is under study by the Japan Atomic Energy Agency (JAEA). **Figure 3** summarizes the sources of radioactive waste, the types of waste to be disposed, and the prime entities implementing the disposal.

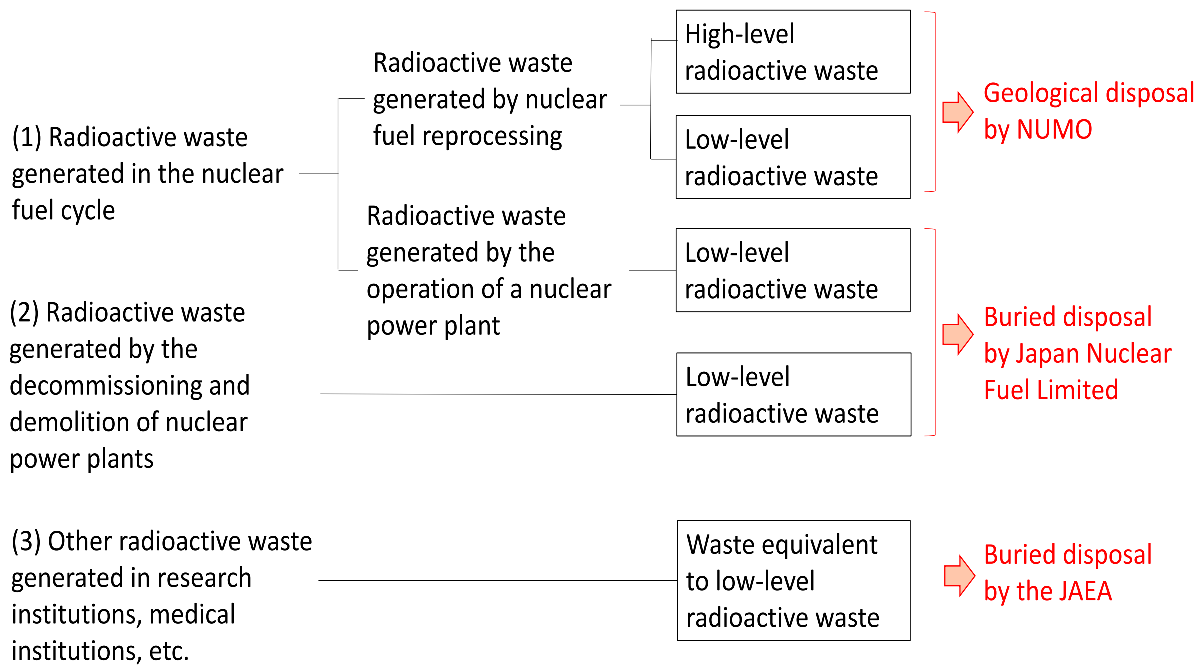

Fig. 3: Radioactive Waste Disposal System in Japan

Research on radioactive waste disposal involves researchers and engineers in many fields such as geology, geochemistry, materials science, and civil engineering, with a focus on experts in nuclear engineering, and several studies have been conducted in fields related to cement and concrete. In this Technical Committee, it was decided to systematize the knowledge on a time axis by arranging the transition of technology development in timeline form, such as that it can serve as an "index" for understanding the related technology. Details are described in Chapter 4.

3. Cement solidification technology for hazardous waste

"WG1: Cement solidification" was organized by researchers in fields of concrete engineering, cement chemistry, environmental engineering, geotechnical engineering, which are related to the treatment of hazardous wastes using inorganic minerals and binders such as cement, lime, cement-based stabilizers, neutral stabilizers, etc. (hereinafter, cement, etc.). A literature survey was performed on the present state and technical issues on treatments of hazardous wastes using cement, which are conducted prior to the final disposal and recycling, and the recent research achievements to solve the technical issues were summarized in the technical report. The structure of the report is shown in **Figure 4**.

The treatment concepts and the contents of the related laws and standards, that are the basis of design and construction, considerably vary depending on the types and properties of the hazardous wastes. This can be seen from the fact that the treatment of mixing the waste and cement for the purpose of limiting the mobility of harmful substances in the waste has several terminologies, such as "cement solidification," "cement stabilization," and "solidification and insolubilization." In the technical report, first, we concisely presented the definitions and the basic concepts of treatments such as "cement solidification" and "cement stabilization", related laws and standards, case histories, and technical problems of each waste material of concern based on the literature review. Next, the recent research status was reviewed on two primary technical issues on cement solidification of the hazardous wastes: 1) adverse effects of chemical and mineralogical properties of the waste on insolubilization performance of heavy metals and strength development, and 2) effects on integrity of the solidified waste due to expansion, from the viewpoint of clarifying the dominant influencing factors and the degrees of influence. Finally, as a new technological trend in the field of hazardous waste treatment, the recent achievements on application of geopolymerization technology to the hazardous waste treatment were summarized by focusing on the immobilization mechanisms of hazardous substances, as well as the relevance of immobilization effects and mixing composition. The short summary of the report are outlined below.

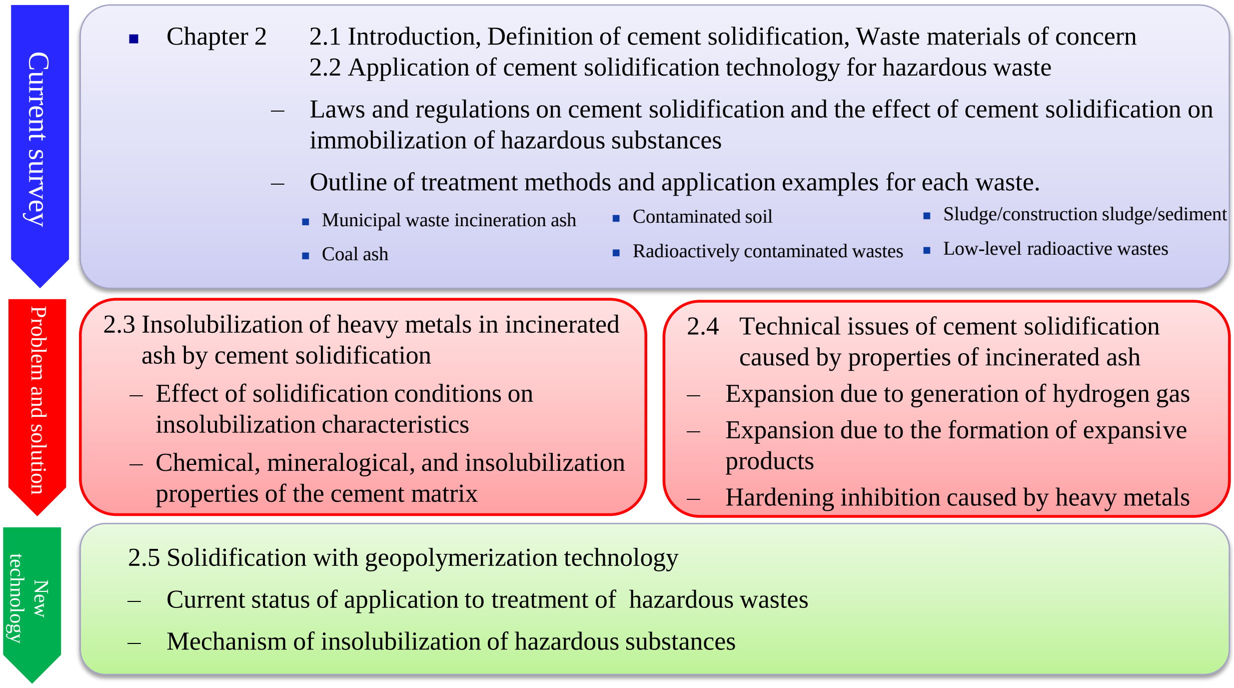

Fig. 4: Structure of Chapter 2 of the Report

3.1 Definition and scope of hazardous waste treatment using cement and concrete technology

In the Enforcement Order of the Waste Management and Public Cleansing Act, cement solidification is positioned as a treatment, which is necessary for incinerated ash and sludge that do not meet the judgment criteria to be disposed of in controlled landfills, as described in 2.1. Its dominant mechanism for reducing the leaching of the harmful substances is to lowering the water permeability by reducing the effective porosity of semi-solid wastes and fine-grained fly ash with a large specific surface area by cement solidification. Therefore, the uniaxial compressive strength and the size (specific surface area) of the solidified waste are set as treatment standards in the standards for solidification treatment of waste containing metals. (Notification No. 5 of the Environmental Agency on March 14, 1977). Therefore, leaching of radioactive substances, which are not chemically insolubilized by cement, is expected to be reduced by cement solidification[5)]. In contrast, "cement stabilization" is defined in the Ministry of Health and Welfare Notification No. 194 of July 3, 1992 as "a method for treating the waste in granulated or monolithic form by homogeneously mixing with a sufficient amount of cement to chemically stabilize the heavy metals of concerns" Therefore, the dominant mechanism for reducing the leaching of the harmful substances is considered as chemical insolubilization.

"Cement solidification" and "cement stabilization" are widely applied as intermediate treatments for effective utilization and final disposal of various wastes such as bottom and fly ash, coal ash, sludge and contaminated sediment, radioactively contaminated wastes, and low-level radioactive wastes. Although detailed descriptions are omitted in this paper, the report outlined the basic purpose and principle of treatment using cement and concrete technology, related laws and regulations, standards, examples of work, and technical problems for the wastes shown in **Figure 5**.

Among the wastes shown in **Figure 5**, “designated radioactively contaminated waste” refer to 1) wastes from specified sources discharged from specified areas with radioactivity exceeding 8,000 Bq/kg, among the wastes contaminated by radioactive materials released into the environment by the accident at TEPCO's Fukushima Daiichi Nuclear Power Station, and 2) "wastes generated in countermeasure areas," which were discharged from contaminated waste control areas (all areas of Naraha-machi, Tomioka-machi, Okuma-machi, Futaba-machi, Namie-machi, Katsurao-village, and Iitate-village, as well as areas of Tamura-city, Minamisoma-city, Kawamata-city, and Kawauchi-village, which were former caution areas and planned evacuation areas). Of these, cement solidification treatment must be performed:

1) If incinerated ash generated when combustible materials of waste in the controlled areas are incinerated, wherein the radioactive Cs content is 0.1 million Bq/kg or less and the leaching concentration of Cs-137 is 150 Bq/L or more, is disposed of in a landfill;
2) If designated waste with a radioactive Cs concentration of 0.1 million or less is disposed of in a controlled industrial waste disposal site or a municipal waste disposal site.

Fig. 5: Wastes Subject to Cement Solidification Treatment and Related Laws and Regulations

3.2 Technical issues in cement-type solidification of incinerated ash

(1) Effects of mineralogical characteristics of incinerated ash on insolubilization performance and hardening characteristics

Leaching of heavy metals from cement-solidified incinerated ash is largely dominated by the following three factors:

・Specific surface area and structural strength of the solidified product;

・Leaching test conditions, particularly pH;

・Properties and forms of heavy metals incorporated into the cement phase.

Incorporation of heavy metals into the cement phase is caused by the hydration reaction of the cement components. Factors affecting the hydration reaction and the consequent strengh development (curing or solidification) are as summarized in **Figure 6**.

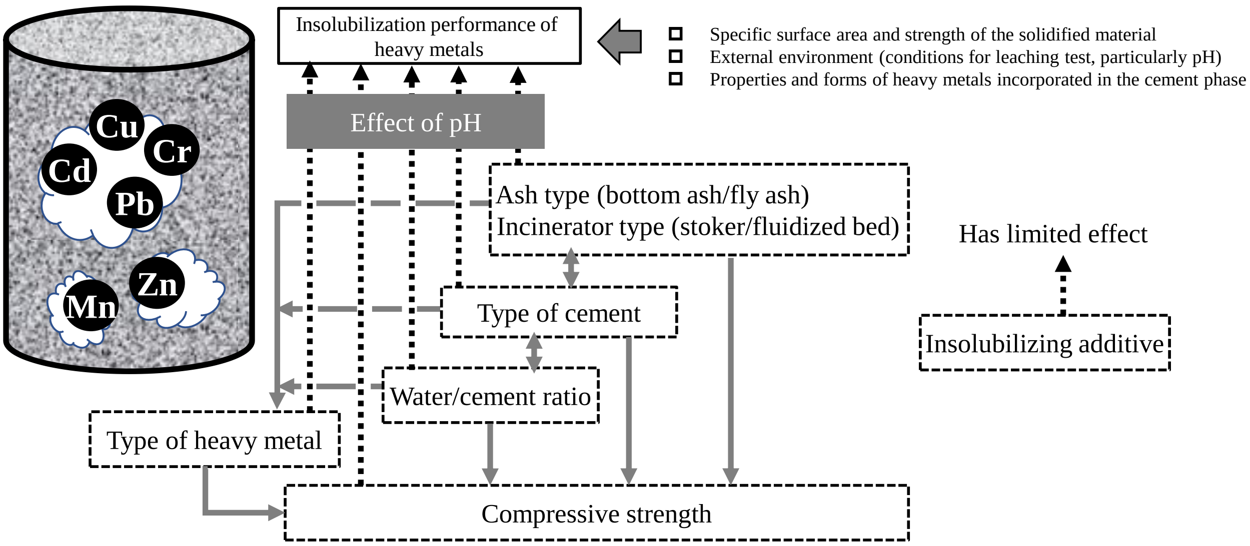

Fig. 6: Factors Affecting the Insolubilization Properties of Heavy Metals

For example, the main components leached from incinerated ash are calcium, sodium, chlorine, etc., regardless of the type of ash (bottom ash, fly ash) or the type of incinerator (stoker, fluidized bed). These components soluble in pore water accelerate the hardening of cement. In contrast, heavy metals such as Zn and Pb retard the hardening of cement[7)]. In particular, Zn is reported to retard the C_3S ($3CaO \cdot SiO_2$) hydration reaction[8)]. At this time, the formation of ettringite accompanying the reaction of anhydrous aluminate C_3A ($3CaO \cdot Al_2O_3$) and dihydrate gypsum ($CaSO_4 \cdot 2H_2O$) is relatively promoted, particularly in the presence of sulfate ions, and the structural strength (compressive strength, etc.) of the cement-solidified products is reduced[9). Thus, incinerated ash and fly ash contain the components that exhibit both accelerating and retarding effects on the hardening of cement, and the predominant effect is strongly dependent on the ash types. In addition, based on the literature survey, the report concluded that it is difficult to establish a systematic mixing design method for incinerator ash, because the insolubilization performance considerably differs depending on the type of cement, the water/cement ratio, the use of an insolubilization agent, and the mineralogy of hydration products.

(2) Effects of expansion of the cement-solidified ash

When cement solidification is applied to incinerated ash, it is necessary to consider the volume expansion of the solidified material derived from the chemical composition of the incinerated ash and the cracking and collapse associated with volume expansion.

The expansion mechanisms are roughly divided into two: one is hydrogen gas generation by the reduction of metallic Al and Zn contained in incinerated ash in alkaline pore water[10)], which results in volume expansion and porous structure several hours after mixing. The other is the formation of expansive minerals and gels, as shown in (1), which occurs over a long period of several tens of days or more. In particular, the former is a phenomenon peculiar to the treatment of incinerated ash. The literature investigation has clarified that there is a correlation between the content of metallic Al and the degree of expansion, and also that reducing the Al prior to the treatment by water washing and form and passivating the Al by formation of an oxide film on the metallic Al surface by use of an expansion inhibiting agent, are effective in suppressing hydrogen gas generation.

3.3 Insolubilization of hazardous substances by geopolymerization technology

As shown in 3.2, there are cases in which insolubilization of heavy metals has been stably maintained in geopolymer solidified bodies, even against the wastes containing components that inhibit the progress of cement hydration and in the environments aggressive to the cement-stabilized wastes. Application of geopolymerization technology to treatment of hazardous waste such as radioactive waste has been examined in recent years. “Geopolymer” is a generic term for structures produced by the polycondensation and polymerization of alumina silica powder and an alkali solution. A solid aluminosilicate material (e.g., metakaolin or fly ash) is mixed with an alkaline solution such as water glass or an NaOH solution, and cured in room temperature or high temperature. The mechanisms for immobilization of hazardous substances by geopolymerization are shown in **Table 2**. The report presents some research to examine the immobilization mechanisms of hazardous substance, and the effects of mixing design parameters, such as the Si/Al ratio and NaOH concentration, and treatment temperatures on the insolubilization performance of hazardous substances.

Table 2: Fixation Mechanisms of Hazardous Substances by Geopolymerization

Ion exchange	・Ion-Exchange with Na^+, K^+ needed for charge-compensation of four-coordinate Al in tetrahedral structures in geopolymers ・Ion exchange by zeolite pore structure
Chemical bonding and physical containment	・Covalent bond within the aluminosilicate structure ・Chemical coordination of terminal non-cross-linked oxygen with heavy metal ions ・Physical containment
Formation of insoluble salts	・Formation of heavy metal hydroxides, carbonates, silicates, and aluminate salts

4. Cement and concrete technologies related to radioactive waste disposal

Radioactive waste disposal is a special business that requires a long time to construct and operate facilities, and also long-term evaluation after closure. Consequently, it is particularly important to conduct studies based on the latest scientific knowledge and to ensure explanatory power and transparency. Several research results and study content are published in the reports of individual vendors and research institutes. However, it is not easy to systematically understand the vast amount of public information from the various types of information pervading modern society, and to achieve a comprehensive understanding.

Therefore, the aim of "WG2: Radioactive Waste Disposal" is to provide researchers and engineers of cement/concrete a comprehensive understanding of the history of research and technological development in the field of radioactive waste disposal.

4.1 Past projects and technical development tendencies related to radioactive waste disposal

(1) Explanation of the purpose and survey subjects

In this study, related business and technology development tendencies were arranged in a timeline to provide a clear historical course of research and technology development in the field of radioactive waste disposal. First, the organizations related to radioactive waste disposal as its primary object of investigation are described. Next, the tendencies in the concrete business and technology development related to radioactive waste disposal are presented in a timeline for each organization, and can be utilized as an index of related technologies. Explanatory articles regarding important events on this timeline are discussed. In addition to an outline of the event, the location of the original source is shown in the explanatory article such that readers can confirm the details if necessary.

Here, the collection and arrangement of the information on radioactive waste disposal were conducted for each enterprise and research institute to facilitate the arrangement of information on a time axis. However, as the flow of information between timelines became unclear, important events in the flow of the radioactive waste business were included at the bottom of the timeline for clarity. Note that not all relevant organizations could be covered because the companies and research organizations were investigated based on the affiliations of the committee members and the ease of information collection. For example, the Secretariat of the Nuclear Regulation Authority has implemented a commissioned project related to the disposal of radioactive waste and has disclosed the results on its website[11)]. However, we were unable to organize the data at this time.

(2) Main entries in each timeline

(I) Project commissioned by the Agency for Natural Resources and Energy that was conducted by the JAEA and the Radioactive Waste Management Funding and Research Center (RWMC)

This paper presents the genealogy of research on cementitious materials mainly conducted as a combined effort of the Ministry of Economy, Trade and Industry, the Agency for Natural Resources and Energy in the JAEA, and the RWMC (**Figure 7**).

The JAEA is the only institute in Japan for comprehensive research and development (R&D) related to nuclear energy, and the RWMC is specialized in research related to radioactive waste disposal. The revision and renaming of these organizations are shown in the lower part of the timeline.

The content introduced in the timelines is the research on the long-term behavior evaluation of underground disposal facilities (engineered barriers) for radioactive wastes, such as transuranic radioactive waste (TRU), in geological disposal. In addition, research on disposal technologies based on package containers storing the waste, the effect of saline groundwater, research mainly on the construction of underground facilities for medium-depth disposal, and the confirmation of their performance, etc., in the disposal of low-level radioactive wastes is also included. For the long-term behavior evaluation research, we have also introduced the related research as a reference.

(II) Commissioned project on geological disposal conducted at the JAEA Safety Research Centre

The JAEA Safety Research Centre is an organization established with the aim of implementing technical support to the Nuclear Safety Regulatory Administration and safety studies. Therefore, it does not participate in projects commissioned by the Agency for Natural Resources and Energy, but primarily implements projects commissioned by regulatory authorities (Nuclear and Industrial Safety Agency, Secretariat of the Nuclear Regulation Authority, etc.).

The content introduced in the timelines is related to the performance (low permeability) degradation of the bentonite buffer material due to contact with cementitious materials, which is a concern in the geological disposal of high-level radioactive waste. Moreover, studies on cementitious materials and a study on bentonite material were conducted in fiscal years 2001–2014. In both studies, the evaluation model was prepared based on the data and knowledge obtained through testing.

(III) Research and development on engineered barriers for low-level radioactive waste disposal at Japan Nuclear Fuel Limited (Project for implementation of low-level radioactive waste disposal)

Japan Nuclear Fuel Limited is an unlisted company with the purpose of establishing the nuclear fuel cycle, mainly by the investment of electric power companies, and is the responsible organization for business in relation to the operation of the nuclear fuel cycle facilities.

Among nuclear fuel cycle projects, the Low-Level Radioactive Waste Burial Center conducts burial disposal of low-level radioactive wastes emitted from nuclear power plants nationwide, and investigations and research on the feasibility of disposal of wastes (wastes with relatively high radioactivity levels) with higher radioactivity levels than the current wastes (wastes with relatively lower radioactivity levels) are underway.

The timeline introduces the studies on the design and evaluation of low-level radioactive waste burial facilities conducted by Japan Nuclear Fuel until now. Outlines of the research conducted on engineered barriers are described considering the materials utilized: cement-based materials and bentonite-based materials; the subject wastes were roughly divided into shallow underground pit disposal (L2) and middle-depth disposal (L1), which are wastes with relatively low and high radioactivity levels, respectively. In addition, in L1, as the effect of metal corrosion on the function of the engineered barrier is large, the effect of metal corrosion expansion is also discussed.

(IV) Technological developments related to the Nuclear Waste Management Organization of Japan (NUMO) (geological disposal of high-level radioactive waste, TRU, etc.)

NUMO is the main organization for the implementation of geological disposal of high-level radioactive waste and equivalent low-level radioactive waste (TRUs, etc.). In addition to fundamental R&D related to geological disposal technology conducted in relevant research organizations such as the JAEA and RWMC, since its establishment, NUMO has developed technologies to further enhance the reliability of individual geological disposal technologies, aiming at safer and more practical technologies.

In the timeline, engineering techniques related to the cement/concrete field for geological disposal sites and performance assessment techniques conducted by NUMO are also indicated. Regarding engineering technologies, the results of examinations on the applicability of low alkaline cement to cement-based materials of geological disposal sites, and design examinations on cement-based material utilization are presented. Regarding performance evaluation technologies, the results of technology development related to the evaluation of the effects of cement-based materials on the long-term barrier performance of bentonite-based buffer materials used in disposal sites are indicated.

(V) A case study of a cement-solidified waste by the JAEA

The commercial operation of Tokai Power Station Unit 1 of the Japan Atomic Power Company started in 1966, and in the 1970s, the establishment of safe and economical methods for the treatment and disposal of radioactive waste was an urgent problem. Solid waste and concentrated waste liquid, which are low-level radioactive wastes emitted from power plants, were solidified in drums using cement and dumped into the ocean. For this reason, the technology development at that time proceeded on the assumption that the waste bodies would be dumped in the ocean. Ocean dumping was subsequently suspended in 1985 (the 9th session of the Conference of the Parties to the London Convention), and was banned in 1993 (the 16th session of the Conference of the Parties to the London Convention). This report summarizes the so-called early research tendencies from the time of the change from marine disposal to land disposal mainly conducted by JAEA (formerly, Japan Atomic Energy Research Institute, Japan Power Reactor and Nuclear Fuel Development Corporation, Japan Nuclear Cycle Development Institute).

(VI) Research on cement and concrete for radioactive waste processing and disposal at the Central Research Institute of Electric Power Industry

The Central Research Institute of Electric Power Industry is a research institute jointly established in 1951 for the electric utility industry. It conducts research in a wide range of fields such as science, engineering, and social science, and provides technical support to the electric utility industry. The Central Research Institute of Electric Power Industry has conducted research on treatment and disposal technologies for all radioactive wastes, which is not focused on specific wastes. Therefore, it was decided that a timeline should be arranged for each research topic, and that the subjects of the investigations pertaining to radioactive waste disposal should be extracted from "Central Research Institute of Electric Power Industry Report", which is open to the public.

4.2 Research tendencies related to radioactive waste disposal

To understand the technical information from the past to the present, and discuss the future, the timelines arranged in the preceding section focused on the latest tendencies in R&D. The research tendencies on cement and concrete in the field of radioactive waste disposal can be understood from research announcements in international conferences and academic journals, but several of these announcements differ from those in general international conferences and academic journals for cement and concrete in the civil engineering and architectural fields. Therefore, an outline of the international conferences and academic journals in foreign countries and research tendencies related to radioactive waste disposal in each country are presented.

Among the international conferences in the radioactive waste disposal field, two meetings (the Scientific Basis for Nuclear Waste Management Symposium and the WM Symposium) in the United States are well-known. A search on the study announcements on cement and concrete in the WM Symposium revealed that research on cement and concrete increased since 1985, and that the content was roughly divided into 29% for cement solidification, 27% for waste body conversion (including containers), 16% for transfer control (related to engineered barriers), 16% for concrete waste, 5% for facility structure, 5% for durability (effects of drying, cracking, and radiation exposure), and 3% for insolubilization.

Recently, international conferences including themes related to cement utilization in radioactive waste disposal have been regularly held mainly in Europe, particularly in France and Switzerland, and a wide range of study presentations, including research not directly targeted on radioactive waste disposal, have been conducted, thus becoming a place for information exchange. Of these, NUWCEM 2018[12)] and the 5th International Workshop on Mechanisms and Modelling of Waste/Cement Interactions[13)] included several relevant academic papers regarding research tendencies related to radioactive waste disposal in each country.

In addition, as research on C-S-H, etc., has attracted attention even in the radioactive waste disposal field, case studies using thermodynamic phase equilibrium computation regarding the immobilization of radioactive materials such as cesium), strontium, and uranium in C-S-H are also provided.

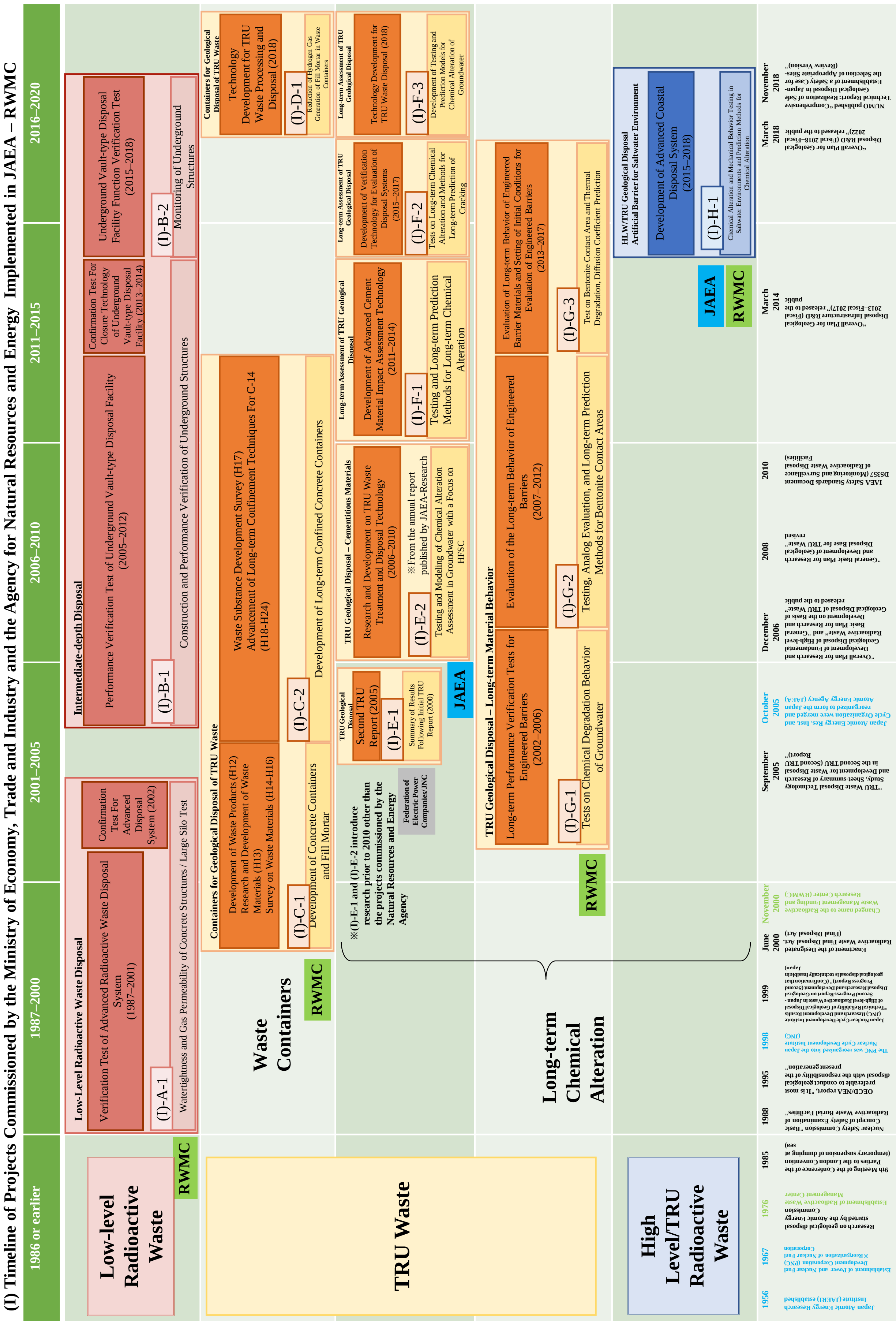

Fig. 7: Timeline (example timetable) of Projects Commissioned by the Agency for Natural Resources and Energy and implemented by the JAEA/RWMC

5. Conclusion

As this committee was interdisciplinary, one third of the members were composed of outside academic societies from JCI. There was a strong motivation for this collaboration in various technological fields. Ten years have passed since the nuclear power plant accident caused by the Great East Japan Earthquake, and resulting environmental pollution. Countermeasures against environmental pollution by radioactive materials require a fusion of knowledge of fields related to the environment and nuclear power. In addition, cement solidification processing and construction of disposal facilities must reflect the latest cement and concrete technologies. Although studies related to environmental restoration after the accident have been conducted by the National Institute for Environmental Studies, this Technical Committee has focused on restoring the environment and nuclear power with cement/concrete and reorganizing the technologies. One of the major points of the Technical Committee was the understanding of the academic societies and experts outside of the committee members who had participated in activities.

In the FS phase, we considered activities focusing on the construction of disposal facilities and safety assessment, including material transport prediction for radioactive waste disposal, but it was difficult to separate these two aspects because they were related.

This committee has also compiled a vast review of the literature, as shown in Chapter 4. Until now, such summarization did not exist, and it can be said to be a meaningful summary of the technological history.

In addition, considering the current situation in which terms are used ambiguously in waste treatment and disposal, we clarified the terms such that they could be related to the technical contents. Reporting of results will provide guidance on the use of appropriate technical terms.

Finally, this paper presented international research tendencies. In particular, from the viewpoint of materials, this paper described a phase equilibrium model in which ion distribution between solids and liquids can be calculated in arbitrary conditions, at least in concrete, for the "partition coefficients" used in radioactive waste disposal. Although controversy remains on the means to express the elemental distribution between solids and liquids, the issue can be raised in the future from the viewpoint of each limit and engineering role.

Although these items for consideration were largely the result of the chairman's awareness of the issues raised by the Great East Japan Earthquake, they were also the result of the extremely energetic work of the executive committee in controlling the direction and compiling the information based on the enormous effort of all the committee members. These considerations are expected to be utilized for future research and development activities in related fields.

References

1) Nanocem, https://www.nanocem.org/about-us

2) K. Endo and M. Yamada: Performance and Preservation of Containment for Landfilled Solid Waste, Material Cycles and Waste Management Research, Vol.27, No. 1, pp.18-26, 2016

3) National Institute for Environmental Studies: Technical Data on Concrete Used for Final Disposal Sites (Blocking-type Construction) for Contaminated Incinerated Fly Ash Waste, etc., https://www.nies.go.jp/whatsnew/2014/20141203/20141203.html, browsed on October 15, 2020

4) National Institute for Environmental Studies: Concrete Containers for Radioactive Pollutant Wastes, http://www.nies.go.jp/whatsnew/2017/201703XX/201703XX-1.html, browsed October 15, 2020

5) K. Endo: Landfill of Radioactively Contaminated Waste, Current Situation and Future Perspectives, Material Cycles and Waste Management Research, Vol.30, No.1, pp.39-48, 2019

6) S. Oyama, T. Tachibana, K. Kamimura, T. Mizomi: Confirmation of the Performance of Cement Solidification Facilities for Specified Waste, Proceedings of the 8th Annual Meeting of the Society for Remediation of Radioactive Contamination in the Environment, p.53, 2019

7) O. I. Fernandez, E. Chacon, A. Irabien: Influence of Lead, Zinc, Iron (III) and Chromium (III) Oxides on the Setting Time and Strength Development of Portland Cement, Cement and Concrete Research, 31, 1213-1219, 2001

8) I. Kolářová, P. Šiler, F. Šoukal: The Influence of Zinc on the Hydration and Compressive Strength of Portland Cement, Advanced Materials Research, 1000, 43-46, 2014

9) N. Alba, E. Vazquez, S. Gasso, J. M. Baldasano: Stabilization/Solidification of MSW Incineration Residues from Facilities with Different Air Pollution Control Systems. Durability of Matrices versus Carbonation, Waste Management, 21, 313-323, 2001

10) T. Nakayama et al.: User's Guide of Cement Solidification Test for Incinerated Ash, Japan Atomic Energy Agency, 2015

11) Nuclear Regulation Authority: Publication of 2019 Results Related to Expenses for Commissioned Surveys https://www.nsr.go.jp/nra/chotatsu/yosayosansh/itaku_houkoku_r1.html

12) Proceedings of NUWCEM 2018 – International Symposium on Cement-based Materials for Nuclear Wastes, Avignon, France, 2018

13) Book of Abstracts of 5th International Workshop on Mechanisms and Modelling of Waste/Cement Interactions, Karlsruhe, Germany, 2019