Committee Report : JCI- TC 124A

Technical Committee on the Containment of Radioactive Contaminants and Safe Use of Concrete Materials

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Abstract

Following the accident at the Fukushima Daiichi Nuclear Power Plant (NPP) caused by the Tohoku-Pacific Ocean Earthquake, highly radioactive debris (melted nuclear fuel) is still left untouched in the containment vessel today. In addition, large amounts of contaminated water containing radioactive materials remain at the site including not only the cooling water supplied to the reactor core but also groundwater that has flowed into the site from the outside. This situation is posing critical challenges including the treatment, temporary storage and leakage prevention of the contaminated materials and water. Meanwhile, the radioactive materials released by the Fukushima Daiichi NPP dispersed and fell as airborne particulate matter such as aerosols, and caused widespread contamination of the environment including forests, agricultural lands, cities and towns, materials left outside, or rubble created by the earthquake and the tsunami. Technologies for the treatment, disposal and reuse of these contaminated concrete materials are in great need. This report summarizes the activities regarding this issue.

Keywords: Tohoku-Pacific Ocean Earthquake, Fukushima Daiichi Nuclear Power Plant, radioactive materials, contamination, leakage prevention, disaster waste, reuse

1. Introduction

Large amounts of radioactive materials were released into the environment from the accident at the Fukushima Daiichi NPP caused by the Tohoku-Pacific Ocean Earthquake, and highly radioactive debris (melted nuclear fuel) is still left untouched in the containment vessel today. Furthermore, large amounts of contaminated water containing radioactive materials remain at the site including not only the cooling water supplied to the reactor core but also groundwater that has flowed into the site from the outside. This situation is posing critical challenges including the treatment, temporary storage and leakage prevention of the contaminated materials and water. The establishment of a methods framework for reusing concrete materials and debris contaminated by radioactive materials, as well as the containment of waste and soil affected by radioactive materials are also critical challenges that must be dealt with. With the aim to make a technical contribution from the field of concrete engineering to these challenges, which are causing great public concern, the Technical Committee on the Containment of Radioactive Contaminants and Safe Use of Concrete Materials was established within the Japan Concrete Institute. The Committee took on the activities of the Energy Related Facilities Subcommittee and the Materials Production/Execution Subcommittee of the Tohoku-Pacific Ocean Earthquake Special Committee (FY2011 – FY2012), while focusing particularly on making detailed evaluations of radioactive materials containment and safe usage of concrete materials. Four Working Groups were setup within the Committee which implemented research activities of: 1) prevention of leakage from the power plant, 2) reduction of contaminated waste, 3) containment of contaminated waste, and 4) reuse technology. This paper reports the activities carried out by the Working Groups.

1.1 Committee activity period and committee members

The Committee implemented activities from April 2012 to March 2014.

2. Prevention of leakage from the power plant

2.1 Current status of leakage

The precipitation that fell on the grounds of the site and the vicinity of the Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPP almost entirely soaked into the ground, and has begun to flow as groundwater from the West side to the East side along the geological inclination and into the Pacific Ocean (see **Fig. 2.1**). While the amount of groundwater generated is approximately 800m^3/day (estimated to be 1,000m^3/day at the initial stage of the accident), approx. 400m^3/day flows into the ground under the reactor building, and the remaining approx. 400m^3/day runs off toward the ocean after contacting contamination sources in the underground trench.

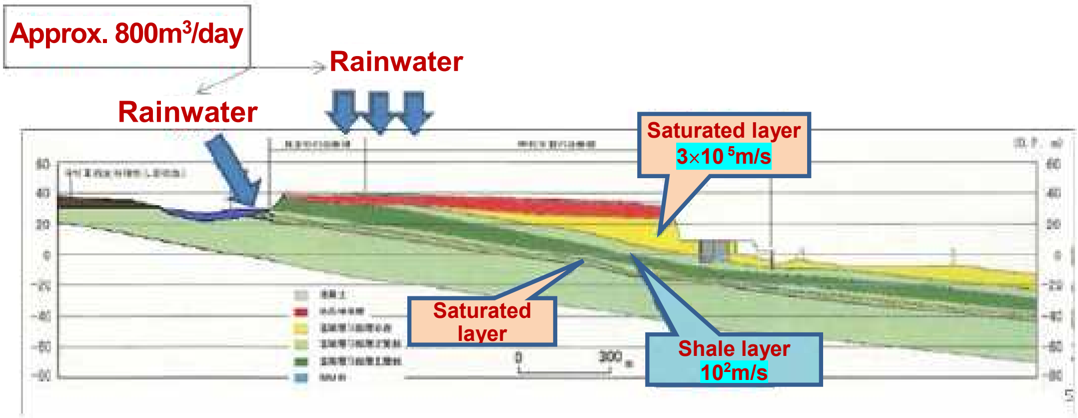

Fig. 2.1: Mechanism of groundwater generation and geological structure (Source: [1] with some addition by authors)

On the other hand, though the building was damaged by hydrogen explosions and other causes at the initial stage of the accident, it has been repaired. However, the interior floors have not been repaired following the accident.

Photo 2.1: Damage to Unit 4 (left) and Unit 4 after its repair (right) (Source: TEPCO)

2.2 Damage and durability of concrete after suffering impact pressure

In this section, we introduce an example in which we made an experimental evaluation of the destructiveness and the reduction of the compressive strength due to damage in concrete from contact with Composition C-4 explosive and from a nearby explosion. As shown in **Fig. 2.2**, it was found that the compressive strength of concrete is reduced when it suffers damage from an explosion [2].

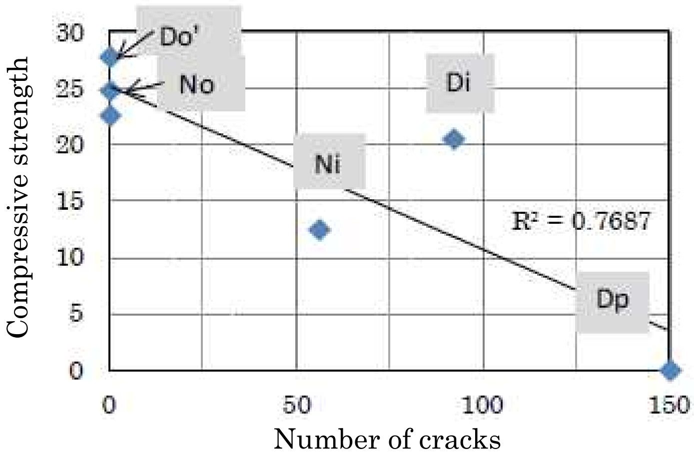

Fig. 2.2: Relation between the number of cracks and compressive strength [2]

Fig. 2.3 depicts the observation made on salt permeation in concrete damaged by hydrogen detonation [3]. It was clearly confirmed that salt permeated the concrete from the crack and that mass transfer was facilitated in response to the damage status of the crack.

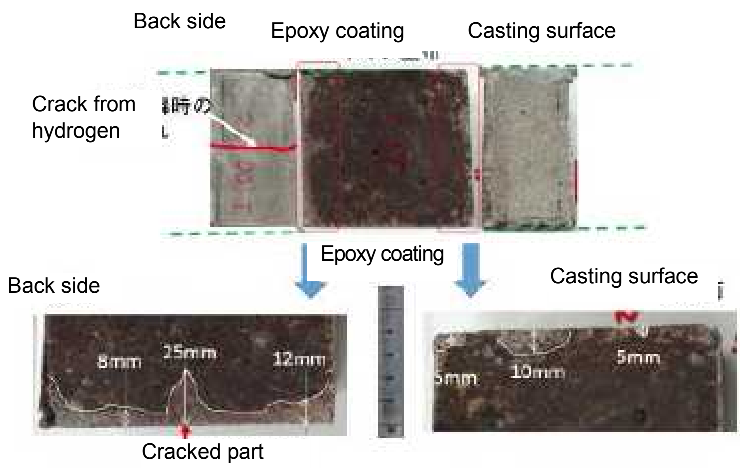

Fig. 2.3: Salt permeation in a test piece (with a crack)

2.3 Durability of concrete after high-temperature heating

Even after being affected by high-temperature heating from explosions and debris (heat source: approx. 2,700°C), the structures must subsist for the 30 years until removal is completed. In this section, we introduce the results from a basic research on the long term properties of concrete damaged by heat.

Fig. 2.4 shows the creep behavior of fly ash concrete after high-temperature heating. The compressive strength of concrete is reduced by heating; under 1/3 loading, the creep strain of the heated concrete was approx. 2.5 times higher than that of the unheated concrete. In addition, water absorption causes the creep strain to increase as time passed, demonstrating that the creep strain of heated concrete tends to increase slightly when it absorbs water in comparison to when it absorbs no water [4].

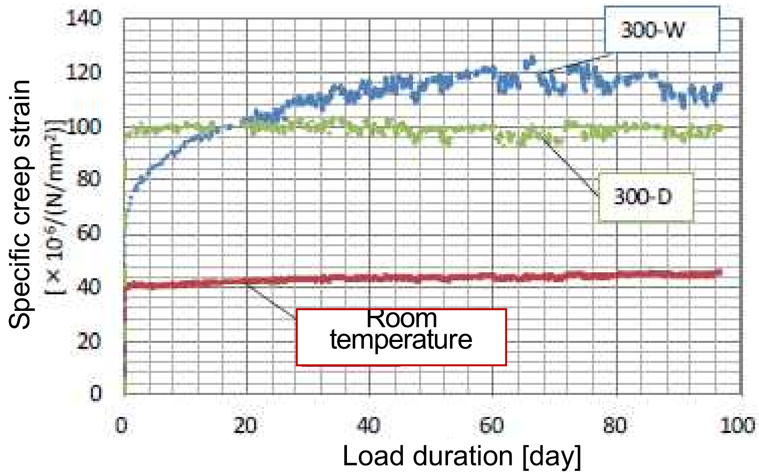

Fig. 2.4: Change in specific creep strain [4]

Meanwhile, it was also shown that the pore volume increases by heating in this type of concrete (**Fig. 2.5**). Furthermore, an experiment was conducted using regular concrete with compressive strength of 30N/mm^2 in which saltwater immersion test was conducted with 3%NaCL solution (equivalent to seawater) using an unheated concrete piece and concrete pieces heated at 100°C, 200°C and 500°C. As shown in **Fig. 2.6**, the depth of salt penetration in the unheated concrete piece and the piece heated at 200°C was only between 5 to 14mm, demonstrating no significant difference. On the other hand, salt completely penetrated the test piece heated at 500°C.

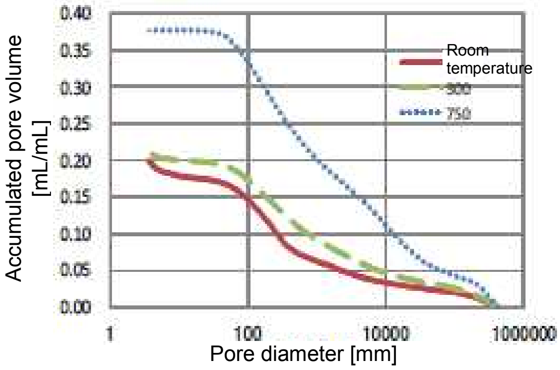

Fig. 2.5: Change in pore volume by heating [4]

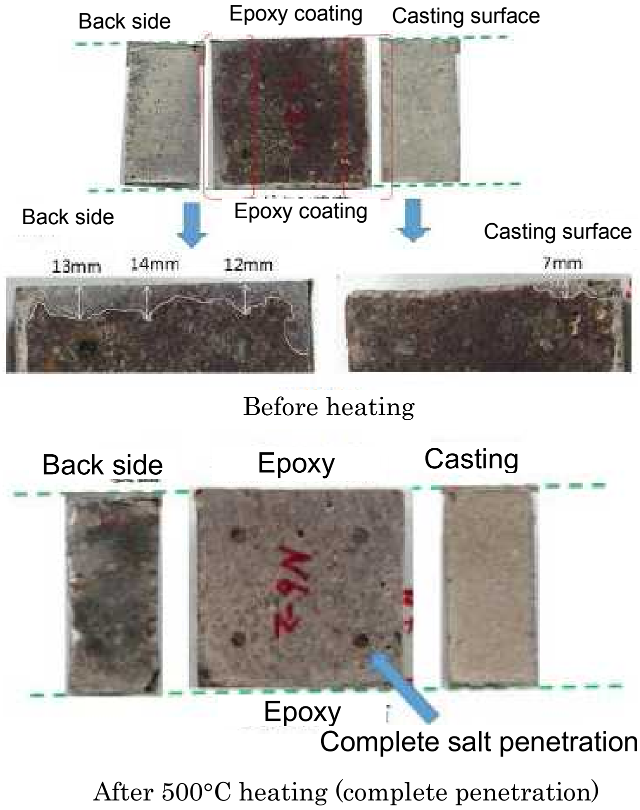

Fig. 2.6: Status of salt penetration by heating [5]

2.4 Technology regarding concrete materials for in-building water stops

The following performance characteristics are required for concrete materials that can be filled in any form and place, solidify even while water is running, and can be casted from above ground: underwater anti-washout properties, high fluidity, and unobstructed slump flow for wide-area filling.

The Committee has proposed a method for stopping water as shown in **Fig. 2.7** as a suggestion, and prepared documents such as committee reports outlining the below listed related issues:

- ✓ Underwater anti-washout concrete and high fluidity concrete [6], [7]
- ✓ Concrete crack control technology [8]-[11]
- ✓ Concrete spraying construction method technology [12]

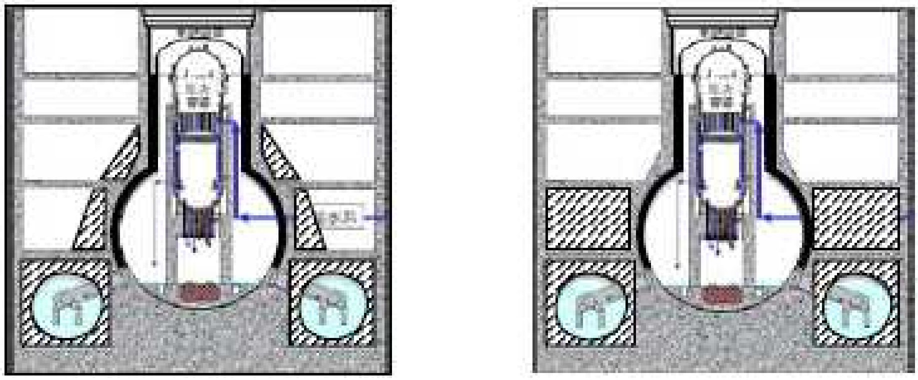

Fig. 2.7: Proposal from JCI on in-building water stops

2.5 Technology regarding concrete materials for water-shielding walls

Installation of land side water-shielding walls and other projects are planned as measures for controlling groundwater flow into the building. In order to reduce the risks of these measures not functioning sufficiently, it is expected that the amount of rainfall soaking into the ground is reduced at the site's mountain side (an area approx. 35m above sea level) where the on-site main source of groundwater supply is located, and that groundwater is cut off at the mountain side (to reduce the amount of water flow induced by groundwater to the north and south of the reactor building, etc). In this section, we propose a measure for controlling groundwater flow into the building as shown in **Fig. 2.8** as a suggestion, and compiled an outline of committee reports of related issues which are listed below.

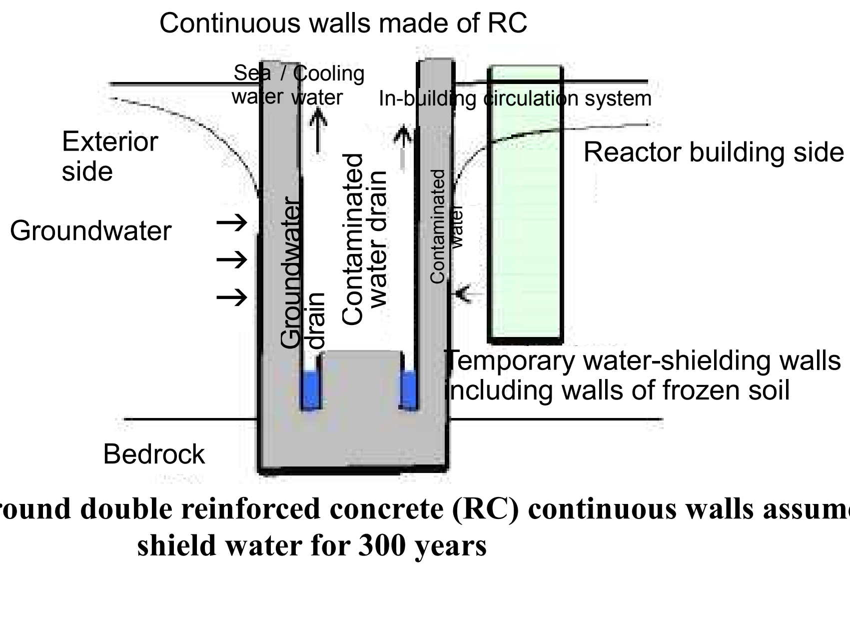

Fig. 2.8: Underground double reinforced concrete (RC) continuous walls assumed to shield water for 300 years

- ✓ Cement for injection [13]
- ✓ Underground continuous wall construction method [14]
- ✓ Crack control to prevent damage at the time of earthquake
- ✓ Concrete technology for ensuring long term durability and preservation / maintenance technology [15]-[18]

2.6 Containment of contaminated water

Various tanks have been installed to treat the daily generated contaminated water, and approx. 350,000m^3 of contaminated water is being stored at present (as of November 19, 2013). In a situation where one 1,000m^3 capacity tank is needed every other day, efforts for controlling leakage from the joints of steel tanks containing contaminated water have been unsuccessful. Here, the applicability of an all precast (PC) tank as a substitute for steel tanks was introduced, and a summary was presented on information regarding concrete tanks extracted from the submissions made to the International Research Institute for Nuclear Decommissioning (IRID) in response to the call for proposals on technologies for handling contaminated water [19].

3. Treatment and disposal of disaster waste contaminated by radioactive materials

3.1 Introduction

The working group on the reduction and containment of contaminated waste discussed decontamination as well as the treatment and disposal of various contaminated waste focusing on the areas where contamination by radioactive materials spread due to the accident at the Fukushima Daiichi NPP, excluding the interior of the NPP and its vicinity which is heavily contaminated.

3.2 Post-accident diffusion of radioactive materials and environmental contamination

Among the radioactive materials released by the accident, considering its half-life and the amount that was released, Cesium-137 (Cs-137) is expected to continue to cause problems. Hence, the reasons for concerns, the movement following the release, and deposition conditions of Cs-137 were first explained. The Cs released into the environment by the accident spread with the air through advection diffusion, and fell on the ground in part by rainfall. Most of the released Cs captured by soil and plants has immobilized stably, but some of the Cs was transferred again by human activities, and has ultimately collected in sewage sludge and general refuse incineration ash.

Next, legal aspects of the treatment of disaster waste contaminated by radioactive materials were explained. Regarding the treatment and disposal of radioactive waste, the handling of radioactive waste generated within NPPs are regulated based on the Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors. However, since these regulations do not apply to the radioactive materials released by the Fukushima accident, the Act on Special Measures Concerning the Handling of Environmental Pollution by Radioactive Materials Discharged by the Nuclear Power Station Accident Associated with the Tohoku District Off the Pacific Ocean Earthquake that Occurred on 11 March 2011 was established, and regulations were stipulated for the treatment of disaster waste contaminated by radioactive materials which exist outside the NPP site.

3.3 Decontamination of concrete

Since contamination of concrete by radioactive Cs is limited to the surface, such concrete can be decontaminated by grinding the contaminated portion. However, it is not an easy task to grind the surface of concrete material crashed in earthquakes or by tsunami. Here, a decontamination method employing pulverization was introduced.

Ogawa et al. developed a recycled aggregate production technology which limits the generation of fine particles, a byproduct of this process, to about half the amount of that generated by conventional methods by selectively removing fragile defective portions (cracks, voids, air bubbles) in the paste that attaches to recycled aggregates when producing this material. Furthermore, they applied this technology for the decontamination of the surface of crushed concrete pieces to which radioactive materials had attached [20]. It was reported that in an experiment using a mock contaminated concrete piece created by spraying stable CsCl solution onto a recycled roadbed material (RC-40), the Cs residual rate was reduced to 56% by one time grinding using a granulator, and after the second time grinding, the residual rate was reduced to 46% (**Fig. 3.1**).

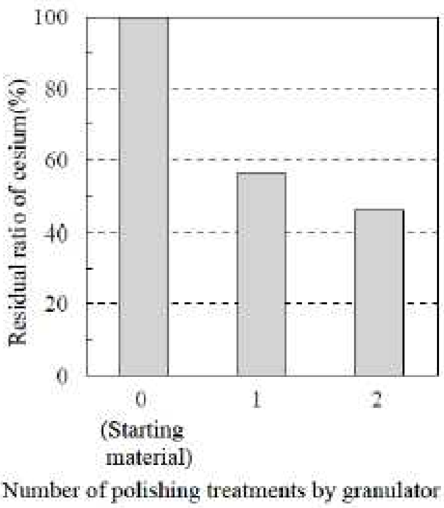

Fig. 3.1: Change in the Cs residual rate of mock contaminated concrete piece crushed by granulator

3.4 Shielding by concrete

First, a detailed explanation was given on the concrete shielding design including theoretical shielding calculation methods. Radioactive Cs is regarded as one of the typical radionuclides that emit gamma rays. Gamma radiation, or gamma rays, is a type of radiation. It has an extremely high amount of energy, and is mainly produced by the decay of radionuclides. Because of the permeating quality of gamma rays, light materials including paper and aluminum plates do not provide sufficient shielding. However, gamma rays can be efficiently shielded by dense lead or thick iron plates. Thus, since it is thought that protection against gamma rays is more difficult compared to other types of radiation, views on gamma ray decay in a collimated case and in case of isotropic scattering were presented. On that basis, the shielding effectiveness of concrete was analyzed using the Monte Carlo method as a tool to assess the reduction in radiation doses by shielding.

In the next step, information on concrete vessels for storing disaster waste contaminated by radioactive materials was collected and organized. Performance characteristics required for the vessels are, in addition to radiation shielding and material leakage prevention, easy handling and efficient storage by stacking. While the details on the radiation shielding properties are as described above, since in general the density and thickness of concrete are able to meet the required performance characteristics, high density aggregates are used including iron ore, iron powder, iron sand, copper slag, ferronickel slag, barite and lead glass. Meanwhile, since high durability concrete is necessary to meet the required material leakage prevention property, concrete vessels with resin lining such as internal coating of epoxy or vessels with waterproof sheets are available.

3.5 Disposal of disaster waste contaminated by radioactive materials

(1) Properties of incineration fly ash which is subject for disposal

Most of the radioactive Cs in massive amounts of soil is insoluble and stable. At issue here is the fly ash that is generated when combustible waste is burnt for volume reduction. While little soluble Cs is contained in the main ash, most of the Cs contained in fly ash is soluble, and particular caution is needed when disposing of the material. An example of the composition of incineration fly ash is shown in **Table 3.2**. The composition of incineration fly ash depends on the characteristics of the general waste; it includes 5 to 30% $CaCl_2$ and approx. 5% each of NaCl and KCl, while the amount of stable Cs contained is approx. 0.1 to 10ppm.

Table 3.2: Example of incineration fly ash composition

	Stoker incinerator fly ash	Fluid bed incinerator fly ash
Element	Weight% (of which, % of soluble components)	Weight% (of which, % of soluble components)
Ca	23.3 (8.5, 23.6 as $CaCl_2$)	21.3 (1.8, 5.0 as $CaCl_2$)
K	4.0 (3.6, 6.8 as KCl)	3.1 (1.8, 3.4 as KCl)
Na	3.2 (2.3, 5.8 as NaCl)	4.1 (1.9, 5.8 as NaCl)
Cs	2.7ppm (1.7ppm)	?
Cl	25.2 (19.5)	10.7 (7.0)
Al	2.3	5.5
Si	7.7	9.2

(2) Ash cleansing

Incineration fly ash contaminated by radioactive Cs with concentration above 8,000Bq/kg has been designated as specified waste, and is being stored in incineration facilities with no disposal plan. As such, shortage of storage space and other issues have arisen. In light of this situation, fly ash cleansing technology is being evaluated with the aim to reduce the stored amount by cleansing and treating the incineration fly ash contaminated by radioactive Cs down to concentration levels lower than 8,000Bq/kg to enable burying at a regular controlled final disposal site [21].

(3) Insolubilization treatment

Because the individual ionic radius of Cs is large, its hydrated ionic radius is in effect small. Its coefficient of selectivity against ion exchangers is large and as such, this ion is readily absorbed. However, since fly ash includes large amounts of K which has a relatively small hydrated ionic radius, this inhibits the absorption of Cs ions. While Prussian blue is well known as an ion exchanger capable of absorbing without being inhibited by K, it is decomposed by calcium hydroxide in incineration fly ash. For this reason, the conventional method used for absorption was to neutralize the cleansing solution for fly ash and then absorb Cs by putting it through Prussian blue material.

As an alternative, a method for the insolubilization treatment of radioactive Cs in fly ash and subsequent solidification with cement by using nickel ferrocyanide (NiFeCN) by substituting the Fe^{3+} of Prussian blue to Ni^{2+} [22] was presented here. The Cs removal rate after the addition of NiFeCN suspension as well as the relation between the removal rate and the concentration level of NiFeCN are shown in **Fig. 3.2**. The figure demonstrates that high removal rate was achieved.

Further research activities are implemented including the following evaluations: an evaluation of technology for reducing the volume of incineration ash and producing safe and firm solidified blocks/beds by solidifying high density ashes employing the superfluid construction method using high-frequency oscillation after adding a solidifying agent and a small amount of water to the incineration ash [23], an evaluation of the behavior of cesium in the incineration fly ash of woody biomass to which cement and bentonite have been added, assuming a solidification treatment using cement for the fly ash generated by the incineration of woody biomass including cut grass and branches contaminated by radioactive Cs [24], an evaluation of the radioactive Cs elution prevention performance of a solidified form created by solidifying fly ash containing radioactive Cs with cement using naturally-derived fine mineral particles mainly consisting of bentonite [25].

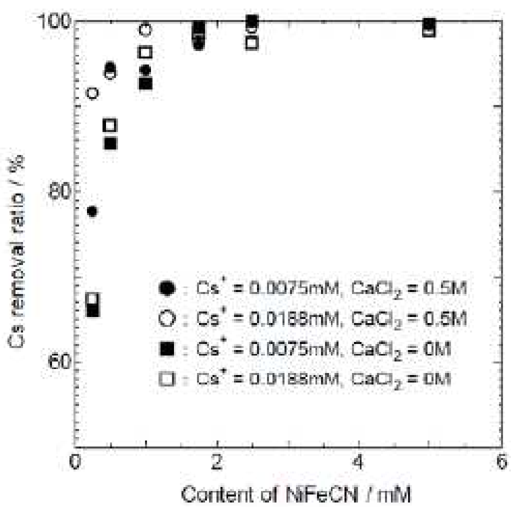

Fig. 3.2: Effect of NiFeCN concentration on Cs decontamination performance [22] (Solution: saturated Ca $(OH)_2$, concentration of NaCl and KCl = 0.25M)

Regarding the burying of waste with relatively low concentrations of radioactive materials among the low level radioactive waste generated by NPPs (pit disposal), such waste is treated on-site at the NPP by solidification using cement, asphalt, plastic and other materials for the purpose of reducing the volume of the waste and stabilizing it. An outline of this treatment was presented as reference material.

(4) Final disposal site and concrete

For the final disposal of designated waste with concentration levels above 100,000Bq/kg, water shielding becomes significant in order to prevent leakage caused by water. A shielding type disposal site which covers an RC structure with bentonite mixed soil and soil is presented [26]. **Fig. 3.3** depicts the image of the first monitoring period after burial completion.

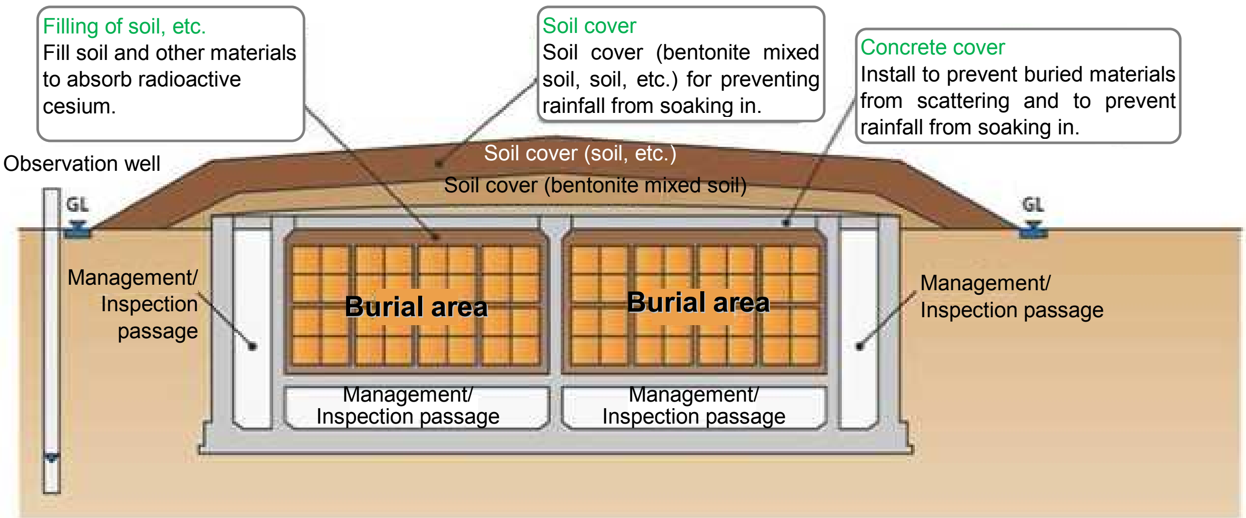

Fig. 2: Image of the first monitoring period after burial completion

Fig. 3.3: Image of the first monitoring period after burial completion at a shielding type disposal site for designated waste [26]

Taking into account the effects of the particular waste containing fly ash contaminated by radioactive materials on reinforced concrete and the possible occurrence of a severe accident, technical views for the disposal at a final disposal site equivalent to a shielding type disposal site were presented, and based on these views, the designing of RC structure materials was discussed from various viewpoints [27]. Though shielding type disposal site has a multilayer protection system to prevent exposure to water, a case where the corrosion countermeasure construction on the concrete surface is damaged and materials are exposed to concentrated salt water was presumed. In this case, assumed damages include cracks caused by temperature as well as dryness, and through these cracks, damage to the RC structure (salt damage) by concentrated salt water. Furthermore, it is possible that the situation would lead to cracking and embrittlement caused by alkali-silica reaction (ASR) and expansive minerals (3CaO, $CaCl_2$, and $15H_2O$). Views on the design and control concerning these problems were presented.

In relation to the above mentioned information, analysis examples of concrete cracks caused by temperature stress and dry environment, as well as penetration of Cs into concrete were also introduced.

4. Reuse technology

The working group for reuse technology evaluated the technology for reusing contaminated concrete debris. First of all, to provide reference for when contaminated concrete debris reuse will be evaluated while establishing specific reference values and standards, previous cases of establishment with backgrounds of changes within the concrete engineering field were introduced. Subsequently, for the purposes of grasping the materials subject for reuse and collecting information on producing ideas for reuse technology, the actual status related to concrete and radiation was researched. On this basis, regardless of its possibility of implementation, as many as possible ideas for the reuse of concrete debris contaminated by radioactive materials were proposed.

4.1 Reference values and standards regarding concrete

Reference values and standards concerning salt damage and ASR relate to the durability of a structure, and as such, its content is mostly based on genuine technical discussions. On the other hand, for matters that directly relate to human health such as environmental safety, the reference values and standards must be established not only to ensure safety but also with consideration to ensure public reassurance. Here, as an example of such cases, the adoption of environmental safety and quality assurance for slug aggregates is introduced.

In 1997, quality standards for aggregates including iron and steel slug aggregates, copper slug aggregates, and oxidized slug aggregates from electric furnaces were established within the Japanese Industrial Standards (JIS). Since these aggregates are used for concrete, density in oven-dry condition, water absorption rate, granularity, bulk density, etc. were standardized. Among the chemical components included in aggregates, quality standards were set up for calcium oxide, sulfur, and iron to ensure the quality of aggregates for concrete; i.e., with the intention to prevent solidification during storage, expansion in the concrete, or rusting. In other words, environmental safety was not included in the items for quality assurance at this point.

Meanwhile, a standard report on fine aggregates for concrete utilizing molten solids made of general waste, sewage sludge and other materials, TR A 0016, was established in 2002, and was adopted as JIS in 2006. While this JIS for molten slug aggregates is a standard for concrete aggregates, environmental safety was added to the items for quality assurance as such aggregates are made of incineration ashes of general waste, sewage sludge, etc., and standards were set up on permissible content/amount of elution of hazardous substances. Since the need arose for testing methods to ensure that materials conform to those standards, JIS K 0058 was established in advance in 2005.

As described so far, while quality standards regarding environmental safety were set up for some slug aggregates, such standards were not established for other slug aggregates. This situation called for harmonization of the quality standards. Consequently, an evaluation committee was set up for the adoption of chemical substance assessment methods for the category of concrete aggregate slug, and the basic views on environmental safety quality assurance and on the adoption of its testing methods were consolidated [28]. In other words, the reference values and standards were to be established on the basis of taking into account the life cycle of circulated materials, and especially exposure conditions which require particularly careful consideration. For example, even if it is used as concrete aggregate, if there is a possibility that the part will be dismantled and be reused as back-fill material, the reference values and standards will be established to meet the environmental and countermeasure standards that apply to that condition. On the other hand, if it is going to remain as part of a concrete structure which will not be dismantled, the exposure environment will be regarded in terms of the condition of a concrete structure; establishment of standards is necessary only for the amount of elution, and no standards are set up for the permissible content.

Basic principles for ensuring environmental safety, as described above, were established, and reflecting these principles, Slug Aggregate for Concrete Part 1: Blast Furnace Slug Aggregate (JIS A 5011-1) and Slug Aggregate for Concrete Part 4: Oxidized Slug Aggregate from Electric Furnace (JIS A 5011-4) were amended to include quality assurance for environmental safety. Furthermore, Slug Aggregate for Concrete Part 2: Ferronickel Slug Aggregate (JIS A 5011-2) and Slug Aggregate for Concrete Part 3: Copper Slug Aggregate (JIS A 5011-3) are planned to be amended in the near future to include quality assurance for environmental safety.

In any case, establishment and amendment of technical standards can be affected not only by "tangible" aspects such as technical innovation, but also by social aspects. Especially, not only safety but public reassurance plays an important role in the establishment of reference values and standards for items of quality assurance that have direct impact on human health.

4.2 Research on concrete and radiation

As shown in **Table 4.1**, high radiation doses were measured at an apartment in Nihonmatsu City, Fukushima Prefecture which was completed in July 2011. Initially, it was indicated that the use of crushed rocks from Namie Town, designated at the time as one of the planned evacuation zones, in the concrete used for the foundation of the apartment was the main cause of the high doses. After the contamination was discovered, as shown in **Photo 4.1**, concrete of 15cm thickness was additionally placed on the floor of the entrance at the first floor and as a result, the doses at the corridor leading to the upper floors were reduced. However, concrete could not be added to the corridor leading to the entrance and the rooms of the first floor, and the residents of the first floor evacuated.

Table 4.1: Radiation doses at an apartment in Nihonmatsu City

Measurement time	Measurement point	Dose (μSv/h)
Jan. 2012	Indoor / 2nd and 3rd floor	0.1 - 0.38 [29]
	Indoor / 1st floor	0.9 - 1.24 [29]
	Outdoor	0.7 - 1.0 [29]
Nov. 2013		0.375
	Measurement point 1 in the photo below	0.391
	Measurement point 2 in the photo below	0.740

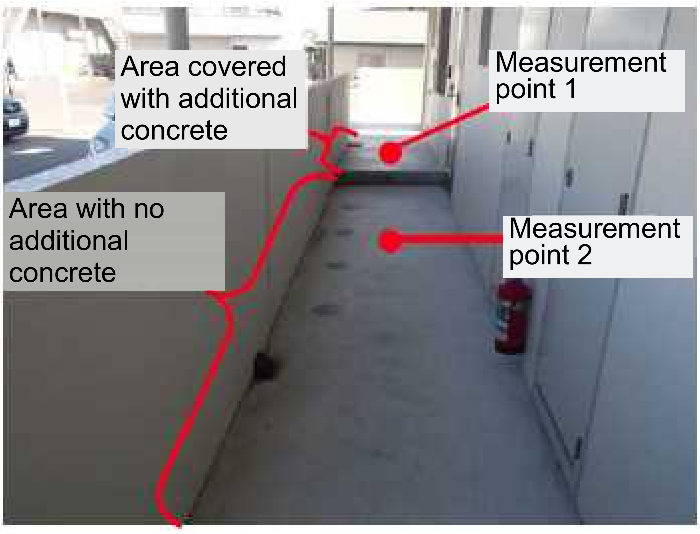

Photo 4.1: Status of countermeasure at an apartment in Nihonmatsu City

The rock crushing plant in Namie Town is located approx. 22km northwest of Fukushima Daiichi NPP. At the time of the accident, the air dose rate at the crushing plant was 300μSv/h. Even at the time in January 2012 when it was found that the apartment was contaminated, the air dose rate at the plant was 100μSv/h. In 2011 from March 14 through April 22, this plant shipped 1,987t of crushed rocks to two fresh concrete manufacturers, and subsequently, the fresh concrete was delivered to 940 construction sites. It was found by an investigation that among those 940 sites, high radiation doses were measured at 118 sites. **Table 4.2** shows the results from the on-site inspection of the crushing plant implemented by the Fukushima Prefecture Disaster Response Headquarter on January 20, 2012. According to these results, it is assumed that crushed rocks stored outside at the stockyard and portions that were exposed to the air at the time of the accident had high doses. However, it was impossible to determine which parts of crushed rocks were used for the concrete which had high radiation dose measurements.

Table 4.2: Results of the analysis of nuclides at the rock crushing plant (Bq/kg)

Measuring point		Cs-134	Cs-137
Plant yard with roof	South side	2,780	3,760
	North side	2,740	3,630
	Center	2,670	3,640
Stockyard with no roof	Crushed rocks for fresh concrete	29,800	39,500
	Crushed rocks for roadbed	63,900	85,700
Quarries		170,000	226,000
Residual soil treatment area		840,500	114,000

As mentioned earlier, it was announced that the main cause of the contamination at the apartment was the usage of contaminated crushed rocks. However, when taking into account that cement hardenings have shielding properties against radiation, it seems from an engineering point of view that contaminated crushed rocks are not the sole cause. The foundation of the apartment was built in April 2011. At this time, the air dose rate was 10μSv/h or higher. Since radioactive materials tend to attach to clay and mud, it can also be assumed that radioactive materials in the air were absorbed while the concrete was in the state of fresh concrete, and then surfaced together with the laitance at the top surface of the foundation. It is also possible that dust and dirt containing radioactive materials floated toward the foundation immediately after the concrete was casted, and were absorbed. By all means, it is critical that the causes of the contamination are elucidated by conducting investigations such as testing the apartment's concrete core. Moreover, such investigations should have been implemented at an early stage after the contamination was discovered.

4.3 Reuse technology proposal

Considering not only the current situation of Fukushima Prefecture but also taking into account the possibility of the occurrence of another accident in the future, ideas for effective utilization of contaminated concrete debris and aggregates are presented in **Table 4.3**. However, it must be noted that, as in the case of reuse for foundation materials [30], appropriate handling is a major prerequisite since the properties of contaminated materials differ from those of regular concrete. In other words, when reusing concrete debris and aggregates which have passed clearance tests, the material must be assessed in terms of safety and public reassurance as described in **4.1**. When those conditions are met, reuse of a material should be permit

Table 4.3: Reuse technology ideas

1. Reuse of contaminated concrete in a state of a structure ・ Cover the exterior of the construction with shielding material ・ Replace the exterior finish material ・ Decontaminate the concrete surface
2. Reuse of concrete debris contaminated after a structure is destroyed by an earthquake or tsunami / concrete debris contaminated in a state of a structure ・ Place contaminated debris only in the inner parts of a structure, and cover the vicinity with non-contaminated concrete ・ Crush after decontaminating the surface and reuse as aggregate ・ Mix with non-contaminated aggregate to achieve reduced overall concentration ・ Specify production and in-service locations
3. Reuse of aggregate contaminated in a state of raw material ・ Use as earthwork material for areas of higher contamination, concrete for the restoration of contamination sources, burial, etc.

5. Conclusion

While three years have already passed since the accident at the Fukushima Daiichi NPP, there is still much confusion regarding the controlling of radioactive materials. Challenges related to concrete technology include finding the most effective measures for preventing diffusion and leakage of radioactive materials, decontaminating concrete debris, and safely returning the materials to the society for use in structural foundations. We hope that this report will play a role in contributing to solving these issues. Finally, the authors would like to express their deepest gratitude to all the people who actively participated in the activities of our Committee despite their busy schedules.