Low-Activation Reinforced Concrete Design Methodology (1)
- Overview of the project -

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ABSTRACT

Design methodology for reinforced concrete of nuclear power plants to reduce radioactive wastes in decommission phase has been developed. To realize this purpose, (1) development of raw materials database of cements, aggregates and steel bars on concentration of radioactive target elements, (2) trial production of low activation cements and steel bars based on the material database developed in (1), and (3) development of tools for estimation and prediction of the amount of radioactive elements in reactor shielding walls have been carried out. Overview of backgrounds and results of this project is summarized in this paper.

INTRODUCTION

Most of the concrete shielding walls and structural components around pressure vessel of light water reactor become low level radioactive wastes at decommission time because they contain radioactive nuclides produced by thermal-neutron irradiation during operation. Disposal cost of these radioactive wastes becomes 100 to 3000 times higher than that of non-radioactive wastes. The disposal cost depends on the level of radioactivity, therefore, reduction of radioactivity and volume of wastes are necessary from the viewpoint of waste management. Recently, to classify the radioactive waste, clearance level (CL) of each radioactive nuclide (C_i [Bq/g]) was established by IAEA [1]. To classify radioactive/non-radioactive materials, $\Sigma(D_i/C_i)$ is calculated, where "D_i" indicates concentration of each residual radioisotope and "i" indicates each radioisotope. When the $\Sigma(D_i/C_i)$ of waste is less than 1, the waste can be treated as non-radioactive waste.

Previous work showed that the major radionuclides in reinforced concrete material at decommission time were Cobalt-60 (^{60}Co), Europium-152 (^{152}Eu) and Europium-154 (^{154}Eu) generated by ^{59}Co (n, γ) ^{60}Co, ^{151}Eu (n, γ) ^{152}Eu and ^{153}Eu (n, γ) ^{154}Eu [2], respectively. Therefore, it is important to select the low-Co and low-Eu raw materials to develop the low-activation reinforced concrete. In this work, these elements are called radioactive target elements. The results of trial calculation showed that the radioactivity of low-level radioactive wastes of nuclear power plant such as reinforced concrete is close to the clearance level [3]. It is very desirable in terms of life cycle cost reduction that the radioactivity of those low level radioactive wastes is decreased below clearance level. In case of light water reactor, however, methodology of low activation design has not been established yet because these reactors are large-scale facility and consists of various types of structural materials. To realize reduction of radioactivity of the waste of nuclear reactor components, selection of low activation material, calculation tools of radioactivity estimation and prediction in nuclear reactor systems and large-scale production technique of low activation structural materials such as cements and reinforced steel bars are required.

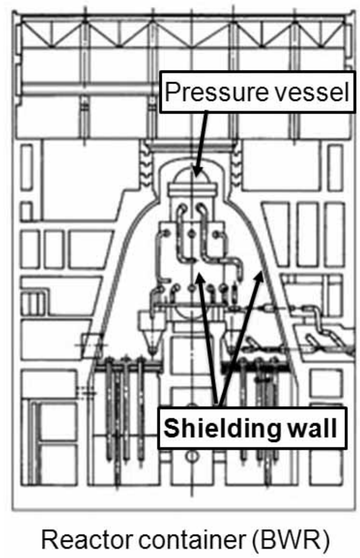

Figure 1 Schematic cross sectional view of BWR and shielding wall

In order to solve these problems, the project of "Development of Low Activation Design Method for Reduction of Radioactive Waste below Clearance Level" has started in 2005 to 2010 [4]. This project is being conducted under the collaboration of Tohoku University, Fujita Corp., Toshiba Corp., Hitachi Ltd., Mitsubishi Heavy Industry Ltd., Taiheiyo Cement Corp., Denki Kagaku Kogyo K.K., Nippon Steel Technoresearch Corp. and Tohoku Electric Power Co.. It was supported by a grant-in-aid of Innovative and Viable Nuclear Technology (IVNET) development project of Ministry of Economy, Trade and Industry, Japan. The objectives of this project are as follows;

(1) To develop a database on the content of target elements, which transform radioactive nuclides, in raw materials of reinforced concrete
(2) To develop calculation tools for estimation of residual radioactivity of plant components
(3) To develop low activation cements and reinforcing steel bars for structural components

This project is mainly aiming for reducing activation level of shielding wall of a new nuclear power reactor such as radiation shielding walls (RSW) and biological shielding walls (BSW) of a boiling water reactor (BWR) shown in figure 1, and primary shielding walls (PSW) of a pressurized water reactor (PWR) by selecting low activation materials before reactor construction. Additionally, to apply the newly developed calculation tools to predict radioactive level of current reactors, reduction of decommission cost and radioactive waste is also expected by improving the accuracy of radioactivity classification.

OVERALL SCHEME OF THE PROJECT

The work structure of this project to establish the Low Activation Reinforced Concrete (LARC) is shown in figure 2. To achieve the goal of this project, it is necessary to develop (1) the database of the chemical composition of raw materials to select low activation material, (2) the calculation tools to estimate residual radioactivity of nuclear plant, (3) the manufacturing technique of low activation concretes and reinforcing steels bars. There are two steps to the goal of this project.

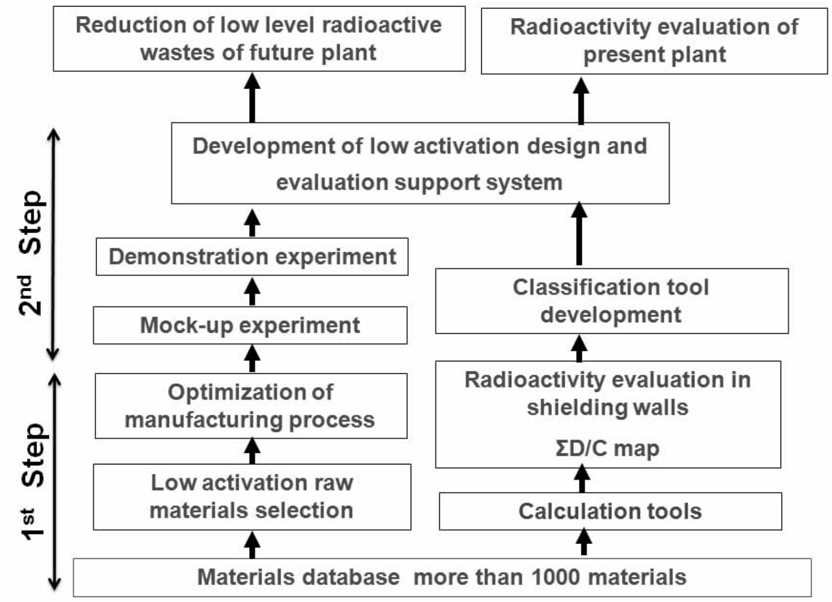

Figure 2 Structure and scheme of Low Activation Reinforced Concrete

The first step includes (1) investigation of chemical composition of target elements in typical component material and developing the framework of database, (2) radio-activation calculation tools for typical LWR conditions, (3) material design using low activation raw materials, and (4) optimization of production technique of low activation concretes.

The second step includes (1) fabrication and characterization of low activation concrete materials for nuclear power plants, (2) development of design method of nuclear power plants using the low activation materials, and (3) development of the material database for judging the activation classification. In order to apply these low activation materials to nuclear power plants, further confirmation experiments will be required. It is not included in this project, but we are planning to perform some tests at the final stage of this project to confirm whether those low activation materials can meet a requirement for structural materials of nuclear power plant.

OVERVIEW OF RESULTS

The numeral target of the reduction of the radioactive elements was clarified to get the materials' radioactivity below the CL for the RSW, BSW, and PSW. In consequence of this feasibility, it was indicated that the low activation concretes and reinforcing steels would be successfully manufactured using the currently existing raw materials. Development of the database of the major cement materials in Japan and optimization of the manufacturing process of the low activation steel reinforced concrete has proceeded and some results will be presented in this conference.

Figure 3 shows the material development scheme at 1st step of this project. Based on low activation material data, low activation cements and steels bars are manufactured in laboratory scale. The detail results will be presented the following papers [5-16]. Development of material database and supporting system for material selection are presented in references [7,15,16]. Instrumented neutron activation analysis (INAA) and ordinary quantitative chemical analysis (ICP-MS, XRF) were used to collect tracer level of radioactive target elements and major elements. Data of raw material of cements and steels and supporting system for material selection are shown in reference [7], and data of radioactivity of steel bars [15] and aggregates of cements [16] are also shown.

Calculation tools to estimate residual radioactivity distribution in shielding walls are reported in reference [5]. New cross section library that has multi-group structure in thermal energy was developed. These libraries are processed from evaluated cross section library JENDL3.3 by using NJOY 99.83. Number of neutron energy groups is 183 and number of nuclides processed is 337. Cross section library for S_n transport calculation and activation calculation are prepared. The libraries are tests by JPDR experiment and found to give better results than single thermal group treatment [5]. Using the cross section library, induced radioactivity of shielding walls of BWR made of several candidate of low activation concrete was calculated and showed that obtained radioactivity and total volume of radioactive were sufficiently lower than that of the ordinary concrete [6]. In order to estimate disposal classification easily, the calculation system indicating disposal classification with graphic representation was developed. Using this tool, we can research low activation materials for every location and every cooling time appropriately [7].

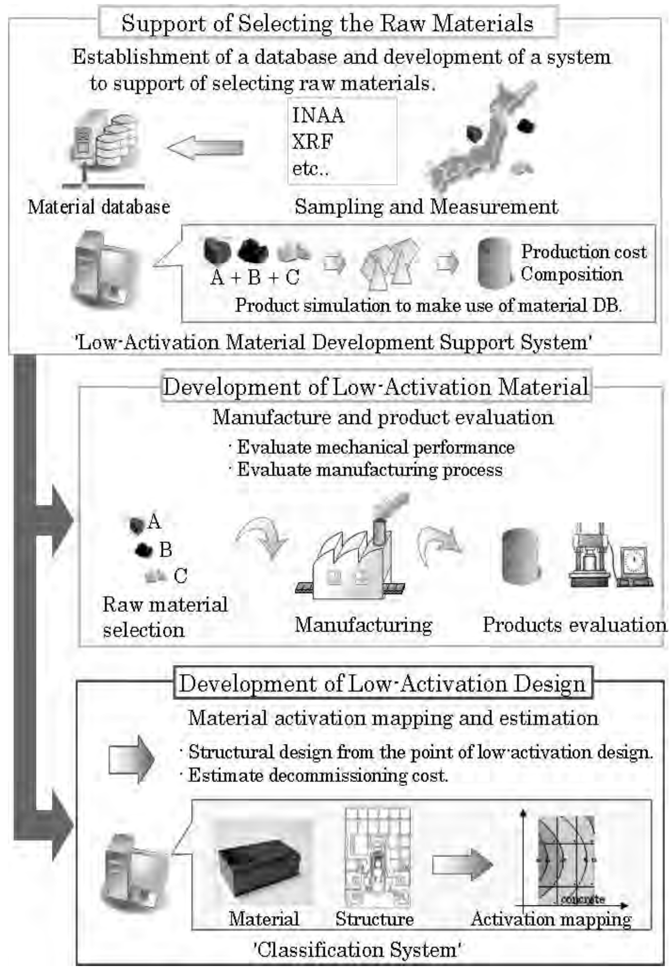

Figure 3 Scheme of Low Activation Material Development

Development of low activation cements is reported by reference [9]. Results of trial manufacturing of Portland cement using low Co and Eu containing materials showed that radioactive elements of low activation cement could be decreased to 1/2 (Eu) and 1/7(Co) of ordinary cement (JIS Cement) by controlling grinding process and selection of fuel of cement production process. Development of low activation high-alumina cement, which is used as radiation shielding wall of BWR, is presented in reference [10]. High alumina cement had excellent low-activation ability due to lower Co and Eu contents, however, the high alumina cement showed poor workability and high heat of hydration that caused reduction in long term compressive strength. In order to avoid these properties, new additive was developed. This is typical case of optimization of manufacturing process using new raw materials.

In the case of concrete, combination of several types of low activation aggregates [11] and cements [12,13] were examined to optimizing process conditions. Characterizations of these concretes and low activation properties are reported and show several types of low-activation concrete as neutron shielding material [13]. Optimization of construction conditions of concrete is also important because massive concrete is imposed thermal stress caused by heat of hydration of cement. It causes cracks and decrease strength of concrete. Thermal stress evaluation system of the mixed proportion design regarding the low activation concrete was established [14].

Analysis of radioactive elements in steel bars produced by electric-furnace or blast-furnace basic oxygen furnace process (BF-BOF) was conducted [15]. The lowest level of Co content of the steels was found to be approximately 20ppm. The analysis of material balance of Co in iron and steel making process was examined and the results showed that lower Co steel could be produced without Ni-containing scrap or ferro-alloys. Low-activation steel bars were produced in laboratory scale was performed using high purity iron materials. The evaluation of mechanical properties of the steel rods was carried out. The results showed that the mechanical properties of the low activation steel bars was almost the same as the SD345. Therefore, the prospect of development of the low activation reinforcing steel was obtained.

COCLUSIONS

MATERIAL ANALYSIS AND LOW ACTIVATION MATERIAL DESIGN

Radioactive analysis showed that Co and Eu were the major target elements which decide the radioactivity level of reinforced concreate. Material database for the contents of Co and Eu was developed based on the chemical analysis and radioactivation analysis. The correlation between the Co and Eu content was obtained for cement materials. Therefore it was clarified that the low activation cement would be successfully manufactured by adequate selection of raw materials.

DEVELOPMENT OF TOOLS FOR THE LARC DESIGN METHODOLOGY

It was claryfied that the accurcy of calculation results for the radioactivity evaluation was very high compared to available benchmark calculation for the JPDR. The specification of the mapping system for judging the activation classification was also developed by using the general-purpose radio activation calculation tool.

DEVELOPMENT OF THE LOW ACTIVATION MATERIALS

The prospect to produce the low-heat portland cement which would have a one-third radioactivity in comparison with conventioanl cements obtained by means of selection of limestone and natural gypsum. The prospect of manufacturing the low activation non-Portland cement was also obtained by selecting the silica materials.

An attempte was carried out to produece low activation heavy-mortar which would have radioactivity below the CL when using at the RSW of BWR. Characterization and optimization of consturction conditions with new additives have also been carried out.

For the development of the low activation reinforcing steel, the lower limit of the target elements in the blast furnace iron was obtained by chemical analysis of the raw materials used as the blast furnace feed and the blast furnace pig irons.

The content of Co in the blast furnace pig irons was about 20 ppm. The prospect of development for the 1/3 radioactive reinforcing steel by steel making without scrap irons was obtained.

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REFERENCES

1. International Atomic Energy Agency, *Application of the Concepts of Exclusion, Exemption and Clearance Safety Guide No.RS-G-1.7*, 2004.
2. Kinno M., Kimura K. and Nakamura T., “Raw Materials for Low-Activation Concrete Neutron Shields”, *Journal of Nuclear Science and Technology*, Vol. 39, No. 12, 2002, p.1275-1280.
3. Kimura K. et al., “Development of Low-Activation Design Method for Reduction of Radioactive Waste below Clearance Level; (4) Measurement of Residual Radionuclides in Irradiated Specimens after 18 years of cooling”, Proc. of 2005 Fall Meeting, Atomic Energy Society of Japan, 2005.
4. Hasegawa A. et al., “Materials Selection and Activity Evaluation System to Reduce Radioactive Waste from Steel Reinforced Concrete of Nuclear Plants”, *The Proc. of 15th Pacific Basin Nuclear Conference*”, Sydney, Australia (2006).
5. Hayashi K. et al., “Low-Activation Reinforced Concrete Design Methodology (2) - Multi-group X-Sec. Library for Precise Activation Analysis -, “*19th International Conference on Structural Mechanics in Reactor Technology*, Toronto, Canada, (2007), [submitted].
6. Uematsu M. et al., “Low-Activation Reinforced Concrete Design Methodology (3) - ΣD/C value reduction by utilizing Low-Activation Concrete -, “*19th International Conference on Structural Mechanics in Reactor Technology,* Toronto, Canada, (2007), [submitted].
7. Ogata T. et al., “Low-Activation Reinforced Concrete Design Methodology (4) - Classification System for Radioactive Waste Disposal -, “*19th International Conference on Structural Mechanics in Reactor Technology,* Toronto, Canada, (2007), [submitted].
8. Kakinuma N. et al., “Low-Activation Reinforced Concrete Design Methodology (5) - Low-Activation Material Development Support System -, “*19th International Conference on Structural Mechanics in Reactor Technology,* Toronto, Canada, (2007), [submitted].
9. Ichitsubo K. et al., “Low-Activation Reinforced Concrete Design Methodology (6) - Development of Low-Activation Cement -, “*19th International Conference on Structural Mechanics in Reactor Technology,* Toronto, Canada, (2007), [submitted].
10. Yoshino R. et al., “Low-Activation Reinforced Concrete Design Methodology (7) - Application of High Alumina Cement for Low-Activation mortar -, “*19th International Conference on Structural Mechanics in Reactor Technology*, Toronto, Canada, (2007), [submitted].

11. Kimura K. et al., "Low-Activation Reinforced Concrete Design Methodology (8) - Fundamental Investigation for Various Types of Low-Activation Concrete -, "*19th International Conference on Structural Mechanics in Reactor Technology*, Toronto, Canada, (2007), [submitted].
12. Katayose N. et al., "Low-Activation Reinforced Concrete Design Methodology (9) - Low-Activation Concrete Based on Limestone Aggregates and White Cement -, "*19th International Conference on Structural Mechanics in Reactor Technology,* Toronto, Canada, (2007), [submitted].
13. Nishida H. et al., "Low-Activation Reinforced Concrete Design Methodology (10) - Low-Activation Concrete Based on Fused Alumina Aggregates and High Alumina Cement -, "*19th International Conference on Structural Mechanics in Reactor Technology,* Toronto, Canada, (2007), [submitted].
14. Fujikura Y. et al., "Low-Activation Reinforced Concrete Design Methodology (11) - Preliminary FEM Analysis of Thermal Stress for Reference Low-Activation Concrete -, "*19th International Conference on Structural Mechanics in Reactor Technology,* Toronto, Canada, (2007), [submitted].
15. Kinno M. et al., "Low-Activation Reinforced Concrete Design Methodology (12) - Measurement of Residual Radionuclides in Irradiated Low-Activation Concrete -, "*19th International Conference on Structural Mechanics in Reactor Technology,* Toronto, Canada, (2007), [submitted].
16. Kitamura S. et al., "Low-Activation Reinforced Concrete Design Methodology (13) - Technology to Produce Low Activation Steel Reinforcing Bars -, "*19th International Conference on Structural Mechanics in Reactor Technology*, Toronto, Canada, (2007), [submitted].