DOI: 10.15669/pnst.7.168

Progress in Nuclear Science and Technology
Volume 7 (2025) pp. 168-174

ARTICLE

Achievements and status of the STRAD project for radioactive liquid waste management

Yoichi Arai, Sou Watanabe*, Masaumi Nakahara, Tomomasa Funakoshi, Takanori Hoshino, Yoko Takahatake,
Atsushi Sakamoto, Haruka Aihara, Kenta Hasegawa, Toshiki Yoshida, Toshihiro Iwamoto, Takeshi Ohsugi,
Takumi Taniguchi, Junya Sato and Masayuki Watanabe

Nuclear Fuel Cycle Engineering Laboratories, Japan Atomic Energy Agency,
4-33 Muramatsu, Tokai-mura, Ibaraki 319-1194, Japan

The Japan Atomic Energy Agency (JAEA) has been conducting a project named "Systematic Treatment of RAdioactive liquid waste for Decommissioning (STRAD) project" since 2018 for fundamental and practical studies for treating radioactive liquid wastes with complicated compositions. Fundamental studies have been conducted using genuine liquid wastes accumulated in a hot laboratory of the JAEA called the Chemical Processing Facility (CPF), and treatment procedures for all liquid wastes in CPF were successfully designed on the results obtained. As the next phase of the project, new fundamental and practical studies on primarily organic liquid wastes accumulated in different facilities of JAEA are in progress. This paper reviews the representative achievements of the STRAD project and introduces an overview of ongoing studies.

Keywords: liquid waste management; STRAD project; organic liquid waste

1. Introduction

Radioactive liquid waste generated in laboratories of the Japan Atomic Energy Agency (JAEA) frequently contains various hazardous chemicals and is stored inside laboratories without treatments due to the challenges in their handling. If the history of those liquids is lost during long-time storage, their treatment would be extremely challenging. These so-called legacy wastes might derail the decommissioning of facilities. Although several studies for removing radioactivity from aqueous and organic liquid wastes have been conducted [1-12], only a few reports exist on treating the hazardous chemicals contained in the wastes.

The JAEA is conducting a project named "Systematic Treatment of RAdioactive liquid waste for Decommissioning (STRAD) project" to develop technologies to treat the legacy liquid wastes [13]. The project comprises several collaborative studies with universities, a national institute and private companies, and each study conducts a fundamental research to establish an appropriate treatment technology for radioactive liquid waste containing reactive or hazardous chemicals. Most of the studies have used genuine liquid wastes accumulated in a hot laboratory of the JAEA called the Chemical Processing Facility (CPF).

In CPF, advanced reprocessing experiments on irradiated mixed-oxide (MOX) fuels have been performed for approximately 40 years [14-18]. After the Fukushima Daiichi Nuclear Power Station accident in 2011, various analyses of radioactive samples taken at the site were conducted in CPF [19]. Those activities have generated numerous radioactive liquid wastes, which have been stored in closed stainless steel bottles in CPF. Due to the systematic studies performed in the STRAD project, treatment procedures for all liquid wastes in CPF have been successfully designed, and the practical treatment is underway [20]. As the next phase of the project, new studies on treatment of liquid waste accumulated in different facilities of the JAEA are in progress. In this phase, the primary targets are organic liquid wastes, such as spent solvents loading radioactive elements, and treatment technologies for solidification or decomposition are being experimentally examined. The studies in the project should produce various treatment options for many kinds of liquid wastes, and the achievements will contribute to decommissioning existing facilities and designing liquid waste treatment systems in near future nuclear plants or facilities. Future nuclear fuel cycle facilities, such as MOX fuel fabrication and reprocessing plants, will employ these new technologies, and the experience of the STRAD project must be effective for developing these facilities. This paper reviews the representative achievements of the STRAD project and provides an overview of ongoing studies.

2. Achievements of the STRAD project in 2018–2021

Liquid wastes stored in the CPF were categorized into 4types; type 1 is aqueous wastes generated by reprocessing experiments of irradiated MOX fuel, type 2 is aqueous wastes generated by analyses on the experimental samples,

---

*Corresponding author. E-mail: watanabe.sou@jaea.go.jp type 3 is spent solvent generated by the reprocessing experiments and type 4 is organic liquid wastes generated by the analyses. Liquid wastes generated in experiments have reasonably simple compositions. However, many chemically reactive reagents coexist in the wastes generated by analyses. Various technologies have been proposed to treat these liquid wastes by systematic investigations considering the operational limitations in controlled area of the facility. Inside the hot cells of the CPF, decomposition of water-soluble organic compounds, precipitation recovery of nuclear fuel materials from spent solvents, concentration of aqueous liquid waste without heating and solidification of some compounds have been successfully performed by remote handling. Several chemically reactive nitrogen compounds have been treated inside the glove box. Through those activities, treatment procedures for all liquid wastes accumulated in the CPF have been designed [21]. Here, remarkable achievements obtained through the studies in the CPF are reviewed.

2.1. NH_4^+ decomposition in aqueous liquid waste

These liquid wastes are categorized to the type 2. Ammonium salts are often added to solutions for masking of Pu or valence adjustment of cations as pretreatments in analyses. Removing ammonium ions from the solution is essential to prevent the formation of hazardous ammonium nitrate compounds. We focused on the decomposition of ammonium ions in the solution containing various chemicals by ozone oxidization because the process can proceed under mild temperature/pressure conditions.

Our study has shown that Co^{2+} and Cl^- can be combined to work as catalysts, and ammonium ions in nitric acid solutions can be decomposed into N_2 gas through NH_2Cl [22,23]. Coexisting chemical species influence the efficiency of the reaction, and separating NH_4^+ is essential for efficient decomposition with catalysis. Selective NH_4^+ recovery from liquid waste is possible by zeolite adsorption/desorption reactions [24] or vaporization [25]. Those procedures require an additional setup and operation; therefore, simplifying the process is essential. The following step examines simplifying of the NH_4^+ decomposition by ozone oxidation.

Ammonium ions in an alkaline solution can be decomposed by ozone oxidation without a catalyst by chemical reactions (1) – (3).

$$NH_4^+ \rightleftarrows NH_3(aq) + H^+ \tag{1}$$

$$NH_3(aq) + O_3 \rightarrow NO_2^- + 3O_2 + H^+ + 2H_2O \tag{2}$$

$$NO_2^- + NH_4^+ \rightarrow N_2 + 2H_2O \tag{3}$$

The decomposition performance can be depressed due to the pH decrease caused by the ozone and water reactions [26]. The solution pH must be controlled to maintain the decomposition performance. Based on the article [27], the excess MgO dissolved into the solution can maintain a pH of 8–10 when H^+ is released from the decomposition reaction. Consequently, ammonium ion decomposition could be continued by consuming MgO in the solution.

Figure 1. Experimental apparatus of NH_4^+ decomposition set in a glove box.

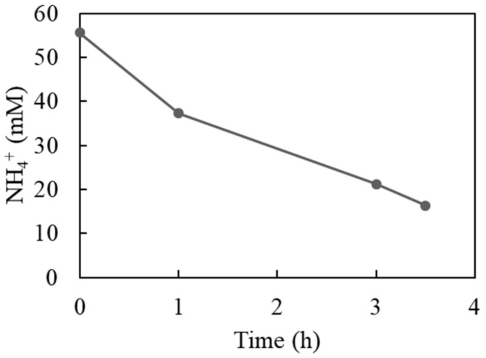


Figure 2. Concentrations of ammonium ion of the solution during the operation.

Ammonium ion decomposition experiments were performed on simulated waste solutions containing ammonium sulfate, ammonium persulfate, sodium hydroxide, and sulfamic acid. After adding the MgO powder, 5 vol% O_3 in air gas was supplied into the solution. The solution pH was almost constant during the operation, and more than 70% of NH_4^+ was converted into other nitrogen compounds after 5 h operation.

Ammonium ion decomposition demonstration in genuine liquid wastes of the CPF was also conducted in a glove box (**Figure 1**). Ozone gas was generated from O_2 in the air by an ozonizer and supplied into the target solution with excess MgO powder in a separable flask. The unreacted ozone was trapped and decomposed to prevent instrument corrosion. Pretreatment of beta-ray analysis on samples from reprocessing experiments generated the target liquid wastes containing ammonia water, tri-ammonium citrate, hydrogen peroxide, and nitric acid. **Figure 2** shows the ammonium ion concentration of the solution during the operation. The NH_4^+ concentration decreased by more than 70% despite the glovebox environment. Since the decomposition reaction rate is exponentially decreased with the reaction time, residual NH_4^+ can be efficiently decomposed after condensation by the reserves osmosis filtering system. Simplifying the ammonium decomposition process is achieved due to the MgO buffer. Since the solution pH range in the demonstration procedures differs from that in the simplified procedure, an appropriate procedure must be selected depending on the composition of a target liquid waste.

2.2. Removal of radioactive elements from organic liquid wastes

One of the challenging tasks of the STRAD project is treating spent organic liquids involving spent solvent loading radioactive nuclides. Degradation products of the solvent sometimes obstruct the efficient stripping of the radioactive elements. Removing the radioactivity from the organic solvent is the principal task of the treatment for safety reasons. The following subject must be enhancements in the chemical stability of the solvent for disposal or long-time storage. Spent TRUEX solvent comprising octyl(phenyl)-N, N-diisobutylcarbamoyl methylphosphine oxide (CMPO), tributyl phosphate (TBP), and normal dodecane, which has been used for trivalent minor actinide recovery experiments in the hot cell of the CPF [28], was selected as a target. Radioactive elements were recovered as precipitation by multiple stages of lavage with an alkaline solution. Fundamental experiments on a simulated spent TRUEX solvent loading Zr as a simulant of Pu have shown that several batch-wise operations can recover most Zr loading in the solvent as precipitation [29]. U and Pu recovery operation on a genuine spent TRUEX solvent were performed inside the hot cell using a special devise for batch-wise shaking (**Figure 3**), and U and Pu in the solvent were successfully recovered as $Na_2U_2O_7$ and $Pu(OH)_4$ with recovery ratios of more than 99% for both elements.

The precipitation procedure requires several steps (Figure 3); thus, a more straightforward procedure is required for practical hot cell operations. Our group focuses on developing an adsorbent to recover radioactive elements from organic liquid wastes, and fundamental studies have been conducted in the STRAD project. The screening of functional groups has shown that the iminodiacetic acid (IDA) group is promising for the complexation with tetravalent cations that form complexes in organic liquid wastes [30, 31].

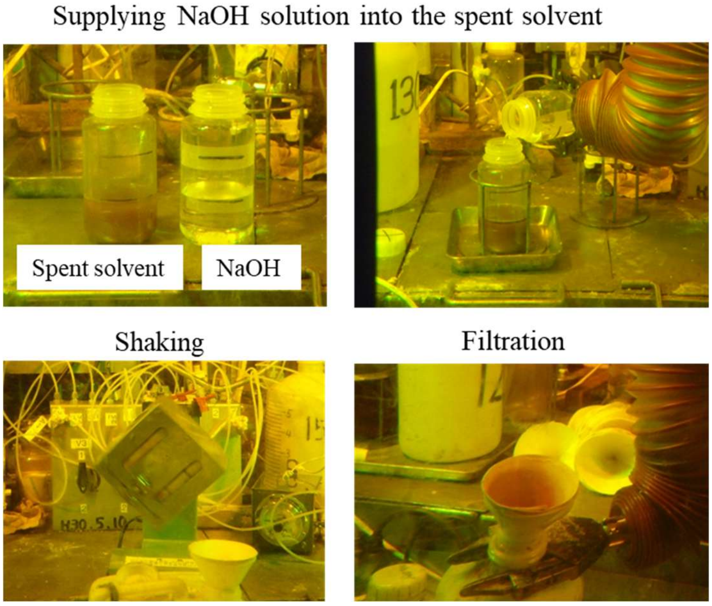
Currently, we are developing hydrophilic support for the adsorbent bearing the IDA group. One promising support is a graft polymerization-type adsorbent synthesized by the graft polymerization reaction of the glycidyl methacrylate emulsion solution and the polymer coating around the porous silica particles. The IDA was chemically introduced on the support. The newly synthesized adsorbents showed excellent Zr adsorption performance. Particle Induced X-ray Emission (PIXE) and Extended X-ray Absorption Fine Structure (EXAFS) analyses on Zr adsorbed on the new adsorbent from simulated spent solvent show that Zr is uniformly distributed inside the adsorbent. The adsorption reaction can be expressed by the following reactions [32], where dibutyl phosphate (DBP) is one of the representative degradation products of TBP.

$$\begin{aligned}&\mathrm{Zr(NO_3)_4 + NH(CH_2COOH)_2}\\&\quad\rightarrow \mathrm{Zr(NO_3)_2[NH(CH_2COO)_2\,] + 2HNO_3}\end{aligned}\tag{4}$$

$$\begin{aligned}&\mathrm{[Zr(NO_3)_4{\cdot}2TBP]org + 2NH(CH_2COOH)_2}\\&\quad\rightarrow \mathrm{Zr[NH(CH_2COO)_2]_2 + 4HNO_3 + 2(TBP)org}\end{aligned}\tag{5}$$

$$\begin{aligned}&\mathrm{[Zr(NO_3)_2{\cdot}2DBP]org + 2NH(CH_2COOH)_2}\\&\quad\rightarrow \mathrm{Zr[NH(CH_2COO)_2]_2 + 2HNO_3 + 2(HDBP)org}\end{aligned}\tag{6}$$

Improvement of the adsorbent to increase its hydrophobic property for larger adsorption capacity are underway to apply the adsorbent for treating genuine waste solvents. The synthesis procedures will also be revised to improve its adsorption performance.


Supplying NaOH solution into the spent solvent

Shaking

Filtration

Figure 3. Precipitation recovery of U and Pu from spent TRUEX solvent inside hot-cell.

3. New challenges from 2022

Design of treatment procedures for the wastes in CPF was completed in 2021, and the targets of the STRAD project were moved to those in other facilities. Investigations and fundamental studies for treating the wastes stored in chemical analysis laboratories A, B and Engineering Demonstration Facility-1 (EDF-1) in Nuclear Fuel Cycle Engineering Laboratories of the JAEA were started as the next project phase in 2022. These laboratories will be decommissioned in near future, and their wastes must be treated and/or transferred to other facilities as soon as possible. In this phase, the project goal is to complete the actual treatment of wastes beyond the designing of procedures. The wastes targeted in this phase are spent solvent loading radioactive elements, contaminated oils, vermiculite loading spent solvent, aqueous solutions containing hazardous chemicals, and spent salt used for pyroprocess experiments. The design of adsorbents for hazardous chemicals removal is in progress. Studies for the salt treatment have already been started from the previous phase, and combining purification and solidification of the salts is a promising procedure [33]. Here, an overview of the laboratories and study programs for organic wastes treatment are shown.

3.1. Overview of chemical analysis laboratories and EDF-I

The chemical analysis laboratories A and B have been operational since 1958 and 1962, respectively. U, Th, and radioisotopes were used in these facilities to study advanced aqueous reprocessing technologies. Pu was also used in the chemical analysis laboratory B. EDF-1 has been operational since 1980, and engineering scale apparatus for advanced reprocessing have been developed and demonstrated on simulated solutions containing U [34-37]. Actinides of Th, ^{241}Am, and ^{237}Np were also used in the facility.

Through many studies on reprocessing technologies for more than 30 years of operation of the facilities, various radioactive liquid wastes have been generated and accumulated. For example, a few hundreds of liters of spent solvents containing various extractants such as TBP, 2-thenoyltrifluoroacetone (TTA), Bis(2-ethylhexyl) hydrogen phosphate (D2EHPA) loading U, ^{241}Am, and ^{237}Np are representative organic liquid wastes, and must be treated before the decommissioning the facilities. Radioactive element removal should be performed using the achievements in the previous phase of the STRAD project. This phase aims to complete the organic liquid treatment after removing most radioactive elements.

3.2. Decomposition of organic liquid wastes

Organic compound mineralization is one of the most favorable treatments for organic liquid waste. Complete organic compound mineralization would reduce the amount and management load of wastes for disposal. In order to mineralize the organic compounds, decomposition of the molecules by oxidation might be one of the promising and practical technologies. Currently, we are developing different oxidization technologies for liquid organic compound mineralization through using Ag^{2+} ions, subcritical water and plasma. Electrochemical oxidation by Ag^{2+} ions, and oxidation by activated species generated in the subcritical water or the plasma are expected to contribute to the decomposition reaction. These technologies have already been examined to decompose organic compounds and have shown their potential for organic waste treatment [38-40]. However, oxidation processes and/or apparatus must be improved for efficiency, safety, and the reduction in total wastes. In the STRAD project, improvements in these technologies are ongoing for practical use in nuclear facilities.

Ag^{2+} is a strong oxidant, and it worked successfully for simulated spent solvent decomposition [41]. The oxidation reaction progresses through the boundary between organic and aqueous phases, and the boundary area should be kept large for efficient decomposition. Ultrasonic irradiation is a promising option to enhance the mixing of the two phases although it requires additional apparatus and electricity. In this project, an apparatus for continuously forming an emulsion of the organic liquid wastes with a solution containing Ag^{2+} is under development to achieve effective mixing with a simple setup. A decomposition demonstration with a prototype apparatus on a simulated waste liquid will be performed soon.

Supercritical and subcritical waters effectively oxidize material due to the reactive radicals generated under high temperature and pressure environment. To apply these technologies to radioactive material treatment, a reactor for the decomposition reaction must be completely closed and shielded. Furthermore, continuous operation is required for efficient treatment. This project is developing an apparatus where the organic liquid wastes can be in continuous contact subcritical water. The development will also consider a leakage-preventing structure and the appropriate shielding of the apparatus.

Nonthermal plasmas have successfully decomposed organic compounds in aqueous solutions, and degradation the behavior depends on the discharge type [42]. If this technology is applied to organic liquid waste management, various chemical species, including hazardous species, must be generated as byproducts. Trapping and treating these products will safety and secondary waste management. To achieve efficient and safe treatment of organic liquid wastes by plasma oxidation, a liquid waste treatment system comprising a discharge chamber, traps for solids and gas, and instrumentation is currently under development. Optimization in operational conditions for practical application will be performed in the future.

3.3. Solidification of organic liquid waste

Confining of the organic liquid wastes into a chemically stable matrix might be appropriate for organic compounds that are challenging to be mineralized or release hazardous compounds by decomposition operation. We focus on organic liquid waste solidification with a geopolymer [43], and the feasibility of geopolymer solidification for spent solvents is evaluated using a simulated spent solvent.

Simulated spent TRUEX solvent comprising CMPO, TBP, and normal dodecane was mixed with the same volume of paste comprising liquid glass (Nippon Chemical Industrial Co., Ltd.), metakaolin (BASF Corporation) and NaOH (FUJIFILM Wako Pure Chemical Corporation). Main components of the metakaolin are SiO_2 and Al_2O_3, and Si/Al molar ratios of 1.0 was used in this study. Detail experimental conditions and procedure are described in previous reports [44, 45]. The mixture has been stored inside a temperature-controlled room with 293 K for 1 year.

The simulated spent TRUEX solvent was successfully solidified with the geopolymer, and significant damages such as cracks were not found on the surface of the solid, even after several months of solidification. The solidification of the geopolymer progresses using silicate polymerization through dehydration–condensation reactions, and droplets of organic liquids are dispersed inside the amorphous polymer. Although liquid was not observed explicitly in the cross-section of the solid, TG/DTA analysis on the solid indicated that the organic compounds exist inside the matrix. XRD analysis on the amorphous solid showed that the organic compounds weaken the interionic correlations of the matrix, and the result indicates the existence of organic compounds inside the network structure of the matrix. Leaching tests are currently underway to evaluate the chemical stability of the organic compounds inside the geopolymer. Feasibility of the solidification technology will be evaluated based on the chemical stability of the compounds in the matrix.

3.4. Vermiculite absorbing spent solvent

Organic liquid waste treatment procedures should be applied to treat vermiculite-absorbing spent solvent, which is one of the wastes stored in the chemical analysis laboratory B. Vermiculite is soil with a porous structure used to absorb the spent solvent after experiments in the facility. During the storage of the spent vermiculite with the organic compounds for more than 50 years, the absorbed spent solvent leaked from the vermiculite. The leaked liquid and remaining organic compounds must be removed from the solid to dispose the vermiculite safely. Currently, we are developing removal technology for organic compounds from vermiculite, and washing with several diluents proved promising for removal. Decomposition or solidification is a candidate procedure for treating organic effluent. The treatment of genuine vermiculite wastes will start in 2023.

4. Summary

The JAEA conducted the STRAD project since 2018 for fundamental and practical studies to treat accumulated radioactive liquid waste. Systematic studies using genuine liquid waste accumulated in the CPF facility of the JAEA were performed, and the treatment procedures for the liquid wastes in the CPF were designed at the end of 2021. New challenges for wastes accumulated in different facilities in JAEA were started from 2022. Current principal targets are organic liquid wastes with various compositions, and various decomposition and solidification technologies are currently being developed.

References

[1] International Atomic Energy Agency (IAEA), Advanced in Technologies for the Treatment of Low and Intermediate Level Radioactive Liquid Waste, *Technical Reports Series* No. 370 (1994), IAEA, Vienna.

[2] International Atomic Energy Agency (IAEA), Chemical Precipitation Processes for the Treatment of Aqueous Radioactive Waste, *Technical Reports Series* No. 337 (1992), IAEA, Vienna.

[3] International Atomic Energy Agency (IAEA), Application of Ion Exchange Processes for the Treatment of Radioactive Waste and Management of Spent Ion Exchangers, *Technical Reports Series* No. 408 (2002), IAEA, Vienna.

[4] International Atomic Energy Agency (IAEA), Combined method for liquid radioactive waste teratment, *IAEA-TECDOC-1336*, (2003), IAEA, Vienna.

[5] V.M. Efremenkov, Radioactive waste management at nuclear power plants, *IAEA BULLETIN*, 4/1989, (1989), pp. 37-42.

[6] International Atomic Energy Agency (IAEA), Management of Discharge of Low Level Liquid Radioactive Waste Generation in Medical, Educational, Research and Industrial Facilities, *IAEA-TECHDOC-1714* (2013), IAEA, Vienna.

[7] International Atomic Energy Agency (IAEA), Treatment of Liquid Effluent from Uranium Mines and Mills, *IAEA-TECDOC-1419* (2004), IAEA, Vienna.

[8] R.O. Abdel Rahman, A.M. El Kamash, H.F. Ali and Yung-Tse Hung, Overview on Recent Trends and Developments in Radioactive Liquid Waste Treatment Part 1: Sorption/Ion Exchange Technique, *International Journal of Environmental Engineering Science* 2 (2011), pp. 1-16.

[9] R.O. Abdel Hahman, H.A. Ibrahium and Yung-Tse Hung, Liquid Radioactive Wastes Treatment: A Review, *Water* 3 (2011), pp. 551-565.

[10] Treatment of radioactive liquid waste by sorption on natural zeolite in Turkey, *Journal of Hazardous Materials*, 137 (2006), pp. 332-335.

[11] International Atomic Energy Agency (IAEA), Treatment and conditioning of radioactive organic liquids, *IAEA-TECDOC-656* (1992), IAEA, Vienna.

[12] International Atomic Energy Agency (IAEA), Predisposal Management of Organic Radioactive Waste, *Technical Reports Series* No. 427 (2004), IAEA, Vienna.

[13] S. Watanabe et al., *Progress in Nuclear Energy* 117 (2019), 103090.

[14] H. Ikeuchi, A. Shibata, Y. Sano and T. Koizumi, Dissolution behavior of irradiated mixed-oxide fuels with different plutonium contents, *Procedia Chemistry* 7 (2012), pp. 77-83.

[15] H. Aihara, Y. Arai, A. Shibata, K. Nomura and M. Takeuchi, Characterization of the insoluble sludge

from the dissolution of irradiated fast breeder reactor fuel, *Procedia Chemistry* 21 (2016), pp. 279-284.

[16] K. Yano, A. Shibata, K. Nomura, T. Koizumi and T. Koyama, Uranium crystallization test with dissolver solution of irradiated fuel, *J. Nucl. Sci. Technol.*, 44 (2007), pp. 344-348.

[17] M. Nakahara, Y. Sano, K. Nomura and M. Takeuchi, Partitioning of Plutonium by Acid Split Method with Dissolver Solution Derived from Irradiated Fast Reactor Fuel with High Concentration of Plutonium, *Journal of Chemical Engineering of Japan*, 51 (2018), pp. 237-242.

[18] S. Watanabe, K. Nomura, S. Kitawaki, A. Shibata, H. Kofuji, Y. Sano and M. Takeuchi, Flow-sheet study of MA recovery by extraction chromatography for SmART cycle project, *Procedia Chemistry* 21 (2018), pp. 101-108.

[19] Y. Takahatake, S. Watanabe, A. Shibata, K. Nomura and Y. Koma, Decontamination of Radioactive Liquid Waste with Hexacyanoferrate(II), *Procedia Chemistry* 7 (2012), pp. 610-615.

[20] M. Nakahara et al., *Proc. Global 2022*, No. 000053, 6-8, July 2022, Remis, France.

[21] H. Ogi, Y. Arai, H. Aihara, S. Watanabe, A. Shibata and K. Nomura., Comprehensive Treatment of Radioactive Liquid Wastes of Chemical Processing Facility, *JAEA-Technology 2021-007* (2021) [in Japanese].

[22] H. Aihara, S. Watanabe, K. Nomura and Y. Kamiya, Development of treatment method for analyt-ical waste solutions in STRAD project (1) Oxidative decomposition of ammonium ion with catalyst, *Proc. DEM2018* (2018), Avignon, France.

[23] H. Aihara, S. Watanabe, A. Shibata, L. Mahardiani, R. Otomo and Y. Kamiya, Oxidative decom-position of ammonium ion with ozone in the presence of cobalt and chloride ions for the treatment of radioactive liquid waste, *Progress in Nuclear Energy* 139 (2021), 103872.

[24] N. Asamuna, R. Miyano, H. Aihara, S. Watanabe and K. Nomura, Development of treatment method for analytical waste solutions in STRAD project (2) Ammonium ion adsorption onto zeolites, *Proc. DEM 2018* (2018), Avignon, France.

[25] H. Matsuura, A. Kobayashi, M. Miyoshi, H. Aihara, S. Watanabe and K. Nomura, Development of treatment method for analytical waste solutions in STRAD project (3) Separation of ammonia by vaporization, *Proc. DEM 2018* (2018), Avignon, France.

[26] B. Kasprzyk-Hordern, M. Ziółek and J. Nawrocki, Catalytic ozonation and methods of enhancing molecular ozone reactions in water treatment, *Applied Catalysis B: Environmental* 46 (2003), pp. 639-669.

[27] P.A. Krisbiantoro, T. Togawa, L. Mahardiani, H. Aihara, R. Otomo and Y. Kamiya, The role of cobalt oxide or magnesium oxide in ozonation of ammonia nitrogen in water, *Applied Catalysis A*, General, 596 (2020), 117515.

[28] Y. Koma, M. Watanabe, S. Nemoto and Y. Tanaka, A counter current experiment for the separa-tion of trivalent actinides and lanthanides by the SETFICS process, *Solv. Extr. Ion Exchange* 16 (1998), pp. 1357-1367.

[29] Y. Arai, S. Watanabe, T. Kubota and K. Nomura, Radioactive nuclides recovery from spent sol-vent in STRAD project (1) Zr recovered by alkaline solutions, *Proc. DEM 2018* (2018), Avignon, France.

[30] F. Nakamura, R. Abe, T. Arai, N. Seko, Y. Arai, S. Watanabe and K. Nomura, Radioactive nu-clides recovery from spent solvent in STRAD project (2) Zr adsorption onto ion exchange resins, *Proc. DEM 2018* (2018), Avignon, France.

[31] Y. Arai, S. Watanabe, S. Ohno, K. Nomura, F. Nakamura, T. Arai, N. Seko, H. Hoshina, N. Hagura and T. Kubota, Microscopic analyses on Zr adsorbed IDA chelating resin by PIXE and EX-AFS, *Nucl. Instr. Methods in Phys. Res. B*, 477 (2020), p. 54.

[32] Y. Arai, S. Watanabe, S. Ohno, M. Nakamura, A. Shibata, F. Nakamura, T. Arai, N. Seko, H. Hoshina, N. Hagura and T. Kubota, Analysis on Adsorbent for Spent Solvent Treatment by Micro-PIXE and EXAFS, *International Journal of PIXE* 29 (2019), p. 17.

[33] Y. Takahatake, S. Watanabe, K. Irisawa, H. Shiwaku and M. Watanabe, Structural characterization by X-ray analytical techniques of calcium aluminate cement modified with sodium polyphosphate containing cesium chloride, *J. Nucl. Mater.*, 556 (2021), 153170.

[34] T. Washiya, M. Takeuchi, H. Ogino and S. Aose, Development of Centrifugal Contactor System in JNC, *Proc. Global 2005* (2005), Oct9-13, 2005, Tsukuba Japan, Paper No. 305.

[35] M. Takeuchi, H. Ogino, H. Nakabayashi, Y. Arai, T. Washiya, T. Kase and Y. Nakajima, Extraction and Stripping Tests of Engineering-Scale Centrifugal Contactor Cascade System for Spent Nuclear Fuel Reprocessing, *J. Nucl. Sci. Technol.*, 46 (2009), pp. 217-225.

[36] Y. Koma, H. Ogino, A. Sakamoto, H. Nakabayashi, A. Shibata, M. Nakahara and T. Washiya, FaCT Phase-I Evaluation on the Advanced Reprocessing Process (4) Solvent Extraction Simplified for FBR Fuel Reprocessing, *Proc. Global 2011* (2011), Dec11-16, 2011, Makuhari, Japan, Paper No. 391547.

[37] A. Sakamoto, Y. Sano and M. Takeuchi, Effect of sludge behavior on performance of centrifugal contactor, *Procedia Chemistry*, 21 (2016), pp. 495-502.

[38] G.S. Singh, D. Banerjee and C. Srinivas, *SN Applied Sciences*, 2 (2020), p. 2149.

[39] A. Ikhlaq, R. Javaid and U.Y. Qazi, Subcritical and supercritical water oxidation for dye decomposition, *J. Environmental Management*, 290 (2021), 112605.

[40] C. Du, X. Gong and Y. Lin, Decomposition of volatile organic compounds using corona discharge plasma technology, *J. Air & Waste Management Association* 69 (2019), pp.879-899.

[41] F. Kobayashi, J. Ishii, K. Shirahashi, M. Umeda and K. Sakuraba, Basic study on the mineralization of organic solvents by the silver mediated electrochemical oxidation process with the ultrasound agitation,

JAEA-Technology 2009-056 (2009). [in Japanese].

[42] A.T. Sugiarto and M. Sato, Pulsed plasma processing of organic compounds in aqueous solution, *Thin Solid Films*, 386 (2001), pp. 295-299.

[43] S. Watanabe, Y. Takahatake, H. Ogi, T. Osugi, T. Taniguchi, J. Sato, T. Arai and A. Kajinami, Decontamination and solidification treatment on spent liquid scintillation cocktail, *J. Nucl. Mater* 585 (2023), 154610.

[44] S. Onutai, J. Sato and T. Osugi, Possible pathway of zeolite formation through alkali activation chemistry of metakaolin for geopolymer-zeolite composite materials: ATR-FTIR study, *Journal of Solid State Chemistry*, 319 (2023).

[45] S. Onutai, T. Osugi and T. Sone, Alumino-Silicate Structural Formation during Alkali-Activation of Metakaolin: In-Situ and Ex-Situ ATR-FTIR Studies, *Materials*, 16 (2023), p. 985.