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German-Japanese Symposium on Technological and Educational Resources for the Decommissioning of Nuclear Facilities

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GREETINGS

The decommissioning of nuclear facilities, primarily nuclear power plants, is one of the urgent challenges of the 21st century. With many old reactors reaching the limit of their operational time, nuclear engineers and other experts from politics, administration, science and industry need to find solutions of how to minimise the cost and time for decommissioning and how to pass on the acquired expertise to the next generation.

On 21 April 2015, the German-Japanese Symposium of the German Research and Innovation Forum Tokyo together with the co-organisers University of Fukui, Technische Universität Dresden and the Japanese-German Center Berlin provided a platform for Japanese and German experts to meet and exchange views on cutting-edge technology as well as the current state of education and R&D in the field of nuclear decommissioning and decontamination.

The Japanese and German experts discussed the role of knowledge management systems and the use of robots and innovative cutting tools in successful and cost-effective decommissioning projects. Furthermore, German experts presented their practical experience with large-scale decommissioning projects, while Japanese experts highlighted the current state of the ongoing decommissioning efforts at the site of the crippled Fukushima No. 1 nuclear power plant.

We are pleased to present the Symposium's proceedings to you in the hope that this will help to make its outcomes known to the wider academic community and the general public.

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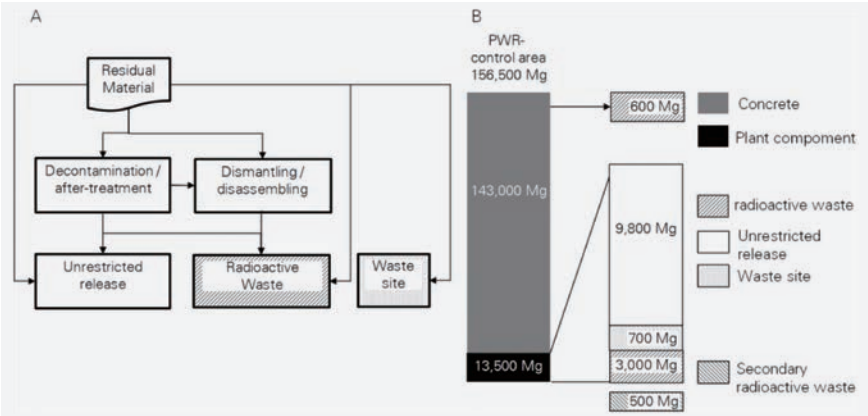
Decommissioning and Dismantling of Nuclear Facilities – Future Challenge for Technology and Education

Dr. Anton Philipp Anthofer and Prof. Dr. Antonio Hurtado

Nuclear Decommissioning and Dismantling (D&D)

There are three phases involved in the peaceful use of nuclear energy: set up, operation and decommissioning and dismantling (D&D). D&D is relevant to all nuclear facilities where nuclear fuel has been used at any time. In 2014, 434 reactors were in operation around the world and 72 new construction projects are planned [1]. Nuclear dismantling owes its complexity to the radioactive material which has been activated or contaminated during reactor operation. The objective of nuclear dismantling is to minimise radioactive waste, maximise the amount of recycled material and minimise the personal exposure. Activation of metal materials by neutron radiation can be minimised by selection of suitable metal. Contamination can be minimised by ensuring that safety barriers at the nuclear facility are secure. In both cases however, nuclear waste and the necessity of decontamination procedures is unavoidable. Moreover, damage to fuel rods, minor leaks, nuclear incidents or even accidents increase the complexity of nuclear dismantling. Figure 1 shows the possible treatment route of residual materials from nuclear dismantling and an example of the generated amounts. A simplified decision-making tree is shown in Figure 1 A. Decontamination or after-treatment of the building structures is normally necessary before the dismantling work starts. Large components or components that are difficult to reach can be dismantled and disassembled before decontamination. The residual material can be assigned to a particular disposal route based on its characteristics: unrestricted release of residual materials, disposal as radioactive waste or – depending on the material and radioactivity – landfilling. Contaminated or activated material can be decontaminated in order to reduce the activity to below permissible limits. If a single decontamination process is not able to achieve the required dose limit for an unrestricted release, it is possible to continue the decontamination process if is technologically, economically and ecologically feasible to do so.

Figure 1: Residual material from nuclear D&D and its disposal objectives



A: Decision-making tree for the separation into disposal objectives and treatment of residual material [2]
B: Example of separation of residual material of a pressurized water reactor (PWR) [3]

According to the data of VGB [3], Figure 1 B shows the compounds of a typical control area of a pressurized water reactor (PWR) with an overall mass of 156,500 Mg. This total mass is divided into 143,000 Mg of concrete and 13,500 Mg of metallic plant components. Metallic plant components are split into different disposal routes: 9,800 Mg can be released without restriction, 700 Mg are provided for landfilling and 3,000 Mg must be disposed of as radioactive waste. After the treatment of concrete structures, only 600 Mg of radioactive waste remains. The decontamination and dismantling procedures cause 500 Mg of secondary waste - including tools, personal safety equipment and secondary material such as abrasive materials [3].
The costs of D&D are covered by the nuclear plant operators. The Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) [2] estimates that the cost of D&D for a PWR is € 700 m. The IAEA [4] on the other hand estimates that the cost per nuclear power plant is between € 0.5 and € 1.0 billion. The cost of D&D of research and prototype reactors is covered by the public administration – in Germany the total costs amount to € 10 to 15 billion [2].

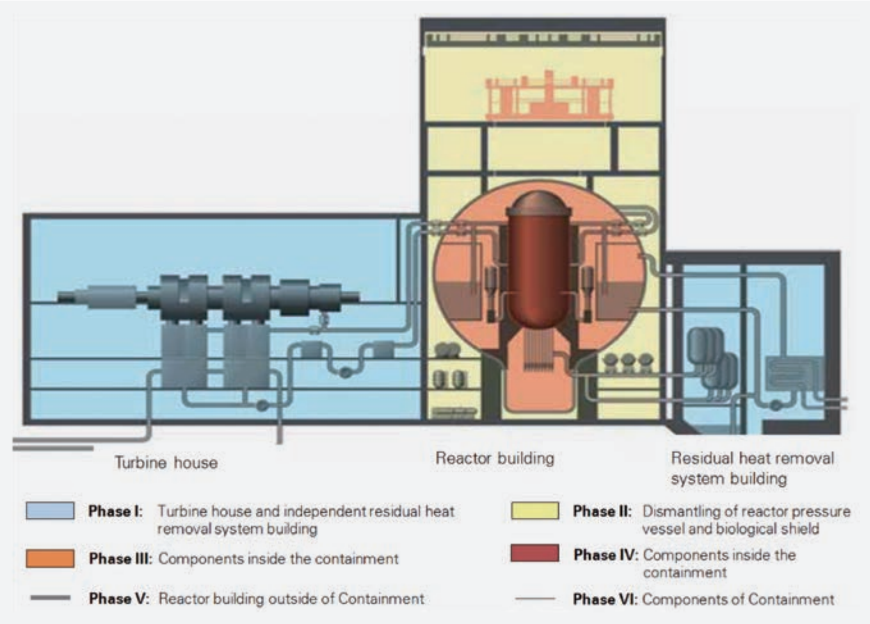
State of the Art and R&D on Dismantling and Decommissioning (D&D)

According to Noyes [5], the total D&D process includes the following five steps:

1) Facility shutdown and strategic planning of D&D.
2) Surveillance and maintenance.
3) Sampling, imaging and characterisation.
4) Decontamination and dismantling.
5) Recycling and disposal.

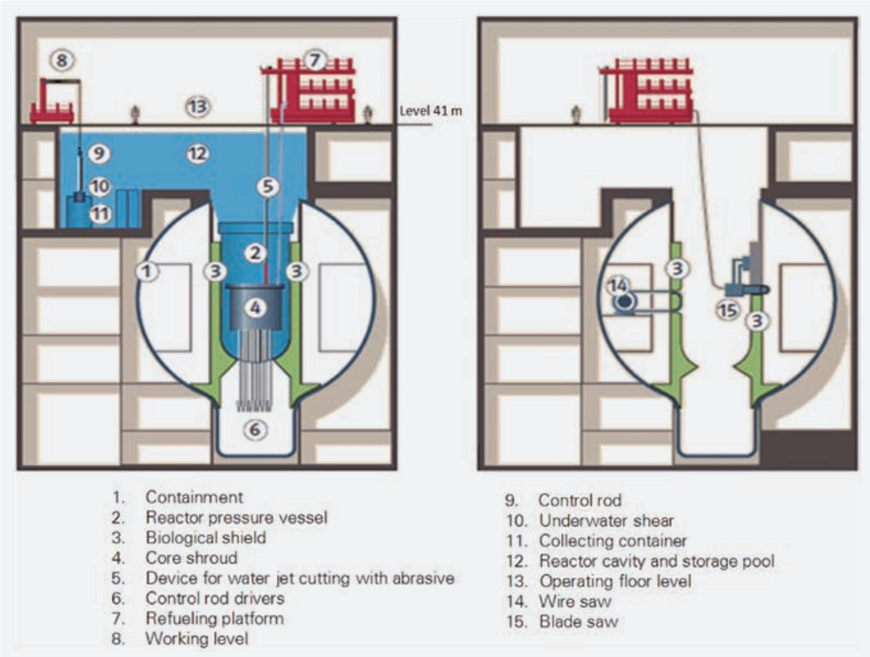
Strategic planning includes the decision as to whether the plant should be dismantled directly or if a safe enclosure over 30 years is more advantageous. A decision is taken on the basis of technological, economic and socio-economic criteria. Objectives of R&D activities are the enhancement of strategic planning of D&D by optimising the sequences of operations and reducing the D&D costs caused by the design phases and the selection of technologies. Furthermore, R&D activities focus on the development of new technologies for decontamination and dismantling in order to minimise primary and secondary radioactive waste. The development of manipulated or automated technologies in particular helps to optimise the D&D activities, as the staff can work remotely.
Possible fields of action are demonstrated here using D&D of the German BWR Nuclear Power Plant (NPP) in Würgassen as an example. Figure 2 shows the phases of D&D at the Würgassen NPP [6].

Figure 2: Phases of D&D at the Würgassen NPP [6]



In the case of BWR, space for storage and working can be created by the clearance of the turbine house in Phase I. The PWR presents challenges in relation to creating working space in the containment. Phase II involves the dismantling of the reactor pressure vessel and the biological shield around it, which is explained in detail in Figure 3. The main task of Phase III and IV is the demolition, decontamination and dismantling of components inside the containment. The complexity of these operations is caused by a high activity and contamination of material inside the containment.
Owing to this special complexity, the reactor pressure vessel of phase IV must be disassembled due to the activation of the high-alloyed steel and its geometric dimensions. Figure 3 shows the manipulated dismantling procedure of the reactor pressure vessel and the biological shield of NPP Würgassen [7], which is dealt with in Phase II.

Figure 3: Dismantling of the reactor pressure vessel of the Würgassen NPP [7]



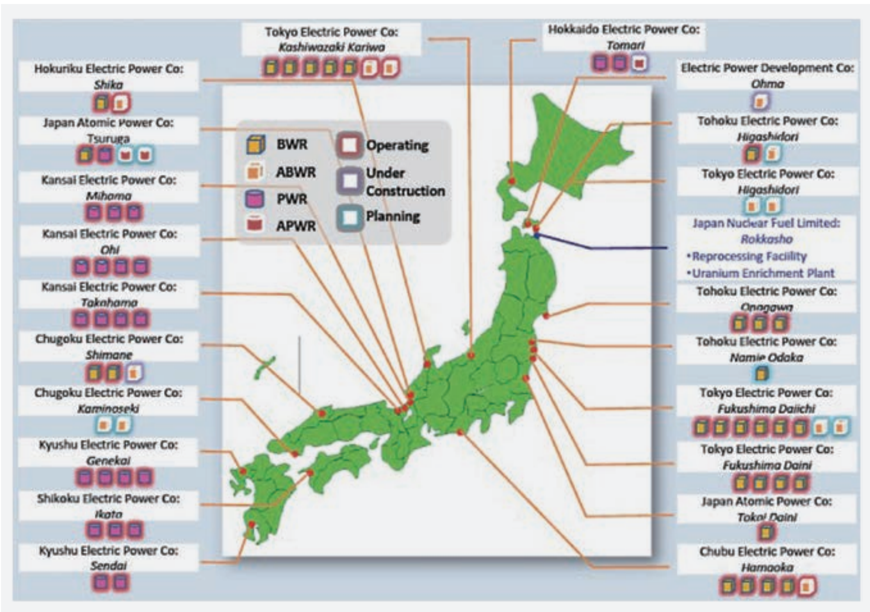
In this case, water jet cutting with added abrasive is used to cut the high-alloyed steel of the pressure vessel. This procedure works well under water. The single segments can be taken and stored in the reactor pool. As shown in Figure 3, the biological shield is cut using heavy-duty wire and blade saws.

Due to the high amount of dust and secondary waste caused by mechanical cutting, thermal cutting technologies are to be used in future D&D projects for the segmentation of the reactor pressure vessel. To reduce primary and secondary waste, the decontamination technologies have been developed further. In particular, a change from chemical-abrasive and mechanical decontamination technologies to laser-based thermal decontamination has been made, as is the case with Anthofer [8] and [9].

Situation in Germany and Japan

As a reaction to the accident at the Fukushima Dai-ichi Nuclear Power Plant in March 2011, the governments of Japan and Germany decided to shut down their nuclear plants. According to media reports from January 2015, five Japanese nuclear power reactors will remain shut down [10] indefinitely. The extent to which the remaining nuclear power plants will be used still remains unclear. Figure 4 provides an overview of Japanese nuclear plants, and their links to utility companies and reactor types such as BWR, advanced BWR (ABWR), PWR and advanced PWR (APWR).

Figure 4: Nuclear Plants in Japan [10]



In Germany, the seven oldest nuclear reactors and the nuclear power plant Krümmel were shut down immediately after the Fukushima accident. Moreover, the German government decided to shut down all German nuclear plants successively until 2022. Table 1 lists the German nuclear power plants, by type, BWR and PWR, electrical power, operator and start of commercial operation. Furthermore, Table 1 shows the scheduled date of the shut down. The timetable indicates that from 2022 onwards, Germany has to manage 17 dismantling projects.

Table 1: Overview of German nuclear power plants [11]

Plant	Type	MWel	Commercial operation	Operator	Provisionally scheduled shut-down 2001	2010 agreed shut-down	March 2011 shutdown & May 2011 closure plan
Biblis A	PWR	1,167	Feb 75	RWE	2008	2016	Shut-down
Neckarwestheim 1	PWR	785	Dez 76	EnBW	2009	2017	Shut-down
Brunsbüttel	BWR	771	Feb 77	Vattenfall	2009	2018	Shut-down
Biblis B	PWR	1,240	Jan 77	RWE	2011	2018	Shut-down
Isar 1	BWR	878	Mrz 79	E.ON	2011	2019	Shut-down
Unterweser	PWR	1,345	Sep 79	E.ON	2012	2020	Shut-down
Phillipsburg 1	BWR	890	Mrz 80	EnBW	2012	2026	Shut-down
Krümmel	BWR	1,260	Mrz 84	Vattenfall	2016	2030	Shut-down
Total shut down (8)		**8,336**					
Grafenrheinfeld	PWR	1,275	Jun 82	E.ON	2014	2028	May 2015
Gundremmingen B	BWR	1,284	Apr 84	RWE	2016	2030	end 2017
Gundremmingen C	BWR	1,288	Jan 85	RWE	2016	2030	2021
Grohnde	PWR	1,360	Feb 85	E.ON	2017	2031	2021
Phillipsburg 2	PWR	1,392	Apr 85	EnBW	2018	2032	2019
Brokdorf	PWR	1,370	Dez 86	E.ON	2019	2033	2021
Isar 2	PWR	1,400	Apr 88	E.ON	2020	2034	2022
Emsland	PWR	1,329	Jun 88	RWE	2021	2035	2022
Neckarwestheim 2	PWR	1,305	Apr 89	EnBW	2022	2036	2022
Total operating (9)		**12,003**					
Total (17)		**20,339**					

The plants which were shut down in 2011 are now awaiting the start of the D&D process. At the moment, D&D projects for small NPPs are scheduled, e. g. Stade, Würgassen or Gundremmingen. Table 1 shows the planned shutdown and the electric power of the NPPs. This illustrates that D&D for the big plants with high-capacities will start from now on. The number of plants, and the residual masses to be treated, will increase significantly.
Due to several projects running parallel, Germany and Japan must combine their efforts in an integral project management and exchange their technological developments and research results in order to handle the residual materials and to produce a maximum of recycled material.

Future Challenge for Technology and Education

There are several ways to optimise the D&D process in order to fulfill the challenges of waste reduction, especially in terms of minimising secondary waste. Potential lies mainly within the economical, ecological and technological fields. Moreover, social challenges of interim and final storage must also be considered.
German federal research on D&D is financed by the German Federal Ministry of Education and Research. The federal research strategy for development of D&D technologies is administrated by the Project Management Agency Karlsruhe (PTKA), which is part of Karlsruhe Institute of Technology.
State of the art D&D technologies are applied at the Stade and Würgassen NPPs, which were operated by E.ON [6] and [7]. In addition to the D&D of NPPs, research and pilot reactors have to be dismantled as well. One example is the Rossendorf Research Reactor. An examination of the operational D&D projects of research reactors highlights initial aspects of strategic planning, including technology application and development, radiation protection concepts and measurement instrumentation.
Reduction of secondary waste is also possible by an advanced treatment of the suspension material when using water jet abrasive technology, which is developed by Brandauer [12]. An example of an innovative technology in the field of ablation of heavily-reinforced concrete structures is made by Hess [13]. Assemblies that are very difficult to access, such as pipes of steam generators, can be decontaminated by high-pressure water, as demonstrated by Finkenberg of RST GmbH [14].
To reduce the personal exposure of the staff engaged in such decommissioning projects, further advances in robotic and manipulator systems are required. Scientists at the Karlsruhe Institute of Technology (KIT), Kern [15] and Mende [16], designed a path-optimised manipulator-system, which can be combined with laser technology. The dismantling of

compounds in high radiation areas is only possible by using manipulator technology. For operational handling, Wälischmiller develops manipulator-based dismantling solutions, as demonstrated by Metzger [17]. IABG realised a remote-controlled manipulator unit for intervention in nuclear disasters, which is able to work in high-radiation fields [18].

A major focus of D&D is on the conditioning and final storage of radioactive waste. The Forschungszentrum Jülich is running several research projects concerning the treatment of radioactive waste and its safe final storage [19], [20].

Several German decommissioning-projects, such as the Stade, Würgassen, and Rossendorf Research Reactor NPPs, are offering initial insights into the area of D&D. The first iteration of steps to optimise technologies and rationalise operational procedures could be implemented. A resource-optimised D&D using sophisticated technologies in order to reduce radioactive waste and increase the recycling rate is a challenge for the international nuclear community. As a consequence, an international exchange of technological experiences, know-how and nuclear education between Germany and Japan is necessary. The goal of future D&D research and development is to create a coherent and systematic material cycle taking technological, economic, ecologic and social aspects into account.

Competence and Education in Nuclear Technology in Germany

Professor Dr. Antonio Hurtado and Dr. Anton Anthofer

The accident at the Fukushima Dai-ichi Nuclear Power Plant in March 2011 had worldwide consequences for energy supply strategies, even in Germany. The seven oldest Nuclear Power Plants (NPPs) as well as the NPP Krümmel as a boiling water reactor were shut down immediately as a consequence of the events in Japan. As a further consequence, the decision of the German government to gradually phase out operation of nuclear power plants until 2022 was adopted by the legislature of the country.
Despite the German decision: to secure the safe operation of all German NPPs, to handle future challenges in the decommissioning of these facilities and to dispose of nuclear waste, maintaining and advancing nuclear competence is required. In addition, radiation protection also remains an important issue for medicine and measurement instrumentation. Nuclear strategies of Germany's neighbouring countries require, among other things, a preservation of nuclear competence in order to maintain a level playing field when discussing and supporting new reactor concepts and performing safety analyses. Owing to these challenges, German Education and Research came to the conclusion that in order to make a substantial contribution to nuclear safety it is necessary to adapt to these boundary conditions which came about quite by chance. The major focus of education will be shifted continuously from GEN II and GEN III reactor safety technologies to future reactor safety technologies of GEN IV reactors, nuclear dismantling technologies and the field of final disposal. However, to preserve competences in all fields of nuclear technologies, international cooperation must be intensified in the next few years.

Energy Policy of Japan and the Decommissioning of Fukushima Dai-ichi Nuclear Power Station

Professor Dr. Hajimu Yamana

Four years have passed since the nuclear accident in 2011. In these four years, the conditions of Fukushima Dai-ichi nuclear power station have been greatly improved.
The emergency situation caused by the accident had settled down by the end of 2011 and the measures based on the mid-and-long-term roadmap defined by the Japanese government subsequently carried out. Implementing these measures, the removal of spent fuels from Unit 4 has already been completed, most of the rubble accumulated on the operating floor of Unit 3 has been cleaned up, and radiation levels on the site have drastically

improved. On the other hand, challenging issues, such as the treatment of contaminated water, are still being worked on each day, and at the same time the preparation for the decommissioning work which is due to be carried out in the mid- and long-term future is currently underway.

Since last year, an organisational structure was formed to contribute to the decommissioning of Fukushima Dai-ichi by the four parties including the Government, NDF, International Research Institute for Nuclear Decommissioning (IRID), and TEPCO's Decontamination & Decommissioning Engineering Company. NDF developed the decommissioning technological strategy on the request of the Government, and plays a role in establishing a plan for necessary R&D. Now, "The strategic plan", the first version of the decommissioning strategy, is being prepared. The decommissioning strategy is developed from the viewpoint of optimising the risk reduction strategy which focuses on the retrieval of fuel debris from the reactors and radioactive waste management. Also, it is essential to develop the various types of technologies required for decommissioning as in the case of fuel debris retrieval, and this development has been promoted by IRID and is subsidised by the government.

After the nuclear accident, there was confusion surrounding the Japanese energy policy. At first, there was a large-scale political movement away from nuclear energy because of the impact of the accident. Owing to the renewal of the Nuclear Safety Regulations, the critical condition where no nuclear power is generated continued for two years.

Then, driven by the change of administration in Japan, the energy policy started to be deliberated again and a new basic energy policy was established last April. This new policy focuses on the promotion of renewable energy and maximum reduction of dependency on nuclear power. Also, the purpose of nuclear power generation as an important base load power was acknowledged in the policy. The Government is promoting a new energy mix and cost re-evaluation for each type of power source based on this new energy plan. The new targets of energy composition and carbon dioxide emission reduction in Japan, including nuclear power and renewable energy, were established in May 2015.

The Strategies of Research and Education on Decommissioning of Nuclear Facilities in the University of Fukui

Professor Dr. Satoshi Yanagihara

There are 15 nuclear power plants in Fukui prefecture where the University of Fukui is located. The university has been running a nuclear energy and safety course for 10 years by taking advantage of its location. The university's research institute of nuclear engineering located at Tsuruga city has played the role of regional research and education centre in the wake of the Fukushima accident, focusing on nuclear engineering, nuclear disaster prevention and risk management and nuclear decommissioning in collaboration with the private sector and local communities.

The organisation of the special nuclear decommissioning group set up at the university's institute is geared towards systemisation of the decommissioning and radioactive waste management process using the experience and lessons learned at the ongoing Fugen decommissioning project in order to minimise the environmental burden. The study includes methodology for optimising the decommissioning and waste treatment process, development of computer systems for decision making, radioactive inventory estimation, computer simulation of decommissioning work activities, knowledge management on nuclear decommissioning, etc.

In terms of the optimisation study, a decommissioning process is characterised by precise estimation of project parameters such as cost, accumulation of waste and radiation dosage of workers, for which computer systems have been developed for calculating the project parameters taking the technology and working conditions to be applied to the decommissioning project into account. The study also includes research on optimisation of a decommissioning plan and the optimum combination of the technologies deployed using multi-criteria decision analysis.

The university has also developed an education program on nuclear decommissioning to cope with expanding demand of the nuclear industry. In addition, the main focus of dismantling and decontamination activities is on remediation of the Fukushima Daiichi plant. The university is making an effort to measure the remediation throughout the long project period in cooperation with several universities. Its program includes project management, characterisation of debris caused by the accident, laser decontamination, etc. as well as education and training in nuclear decommissioning.

While decontamination and decommissioning might be possible using current technology, efficient deployment of current technology is necessary for cost-saving and safety reasons. In cooperation with local industry and research organisations, the university will contribute to improving knowledge management and technology deployment in upcoming decommissioning projects. Education and training on nuclear decommissioning is important for young people studying and developing a career in this area. The goal of the university in this field is to serve as a regional centre for the promotion of safe and efficient nuclear decommissioning.

German Federal Research on Technologies for Decommissioning and Dismantling of Nuclear Facilities

Dr. Michael Weigl

Since 1956, nuclear research and development (R&D) in Germany has been supported by the Federal Government. The goal was to help German industry to become competitive in all fields of nuclear technology. National research centres were established and demonstration plants were built. In the meantime, all these facilities were shut down and are currently being decommissioned and dismantled (D&D).
Meanwhile, Germany is one of the leading countries in the world in the field of D&D. Two big demonstration plants, the Niederaichbach Nuclear Power Plant (KKN), a heavy-water cooled pressure tube reactor with carbon-dioxide cooling and the Karlstein Superheated Steam Reactor (HDR), a boiling light water reactor with a thermal power of 100 MW, have been totally dismantled and a "green field" status reached. Another big project was finished in 2008. The Forschungs-Reaktor Jülich 1 (FRJ1), a research reactor with a thermal power of 10 MW was completely dismantled and in September 2008 an oak tree was planted on a green field at the site where the FRJ1 previously stood. This is another example for German success in the field of D&D.
Within these projects, many new solutions and innovative techniques were tested. These were developed at German universities and small and medium-sized companies mostly funded by the Federal Ministry of Education and Research (BMBF). Some examples are underwater-cutting technologies like plasma arc cutting and contact arc metal cutting. This clearly shows that research on the field of D&D is important for the future. Moreover, these research activities are important for preserving nuclear engineering know-how in Germany and will enable enterprises to compete in the expanding market of D&D services.

Challenges in Nuclear Decommissioning for E.ON – Focus on Decontamination Technologies

Dr. Steffen Pankow

Decontamination technologies – with a focus on decommissioning and dismantling (D&D) of nuclear power plants (NPP) in particular – were the subject of extensive research and development activities over the last decade and mostly driven by practical activities on D&D sites.
The main aspect from E.ON's point of view is the selection and planning of the best decontamination strategy in respect to radiation protection and cost optimisation many years in advance of practical on-site implementation.

Three aspects have to be considered in particular:

- Decontamination for radiation protection reasons (ALARA)
- Decontamination for the reduction of nuclear waste
- Decontamination of equipment for reuse

The presentation provided a short overview on E.ON's experiences in determination and realisation of decontamination strategies – i.e. the lessons learned from previous D&D projects (NPP Würgassen and NPP Stade) as well as the transfer of knowledge to sites where the D&D process is due to start shortly.
Although E.ON has gained a wealth of experience from decommissioning projects in the last decade, ultimately the decision-making matrix must still be developed and evaluated for each plant individually. Therefore the spotlight of the presentation was directed on typical questions and possible answers in such a decision-making process.

Radiation Protection during Decommissioning of the Rossendorf Research Reactor

Professor Dr. Peter Sahre

After obtaining the first licence for decommissioning of the Rossendorf Research Reactor in 1998, the spent fuel of the reactor was removed from the reactor building in 1998. In 2001 the dismantling of the reactor was started and we anticipate the decommissioning work will be finished in 2018.
The first step was the analysis of the radiological situation. For this we developed together with a company a system which is able to scan a room or a hot cell automatically by measuring the dose rate and Gamma ray spectrum of each point. Furthermore, in situ Gamma ray spectrometry and sample analysis measurements have been used to explore the radiological situation. The same methods have been used for clearance measurements. A cross gamma chamber was only used for clearance measurements. The clearance procedure comprises unrestricted clearance, restricted clearance for demolition of buildings and material for deposit.
The exhausted air of the reactor building was also measured. The resulting effective committed dose for individual members of the general public was lower than 0.1 µSy in each year.
In relation to occupational exposure, the collective dose of the staff during the whole decommissioning time was less than 20 mmanSv and was primarily made up of the internal dose. In order to reduce the internal dose when destroying the shield of the reactor, a stable tent including exhaust air was erected.
The decommissioning further included the dismantling of the cask for reactor water storage, remote-controlled recovery of solid waste and the management of radioactive waste.

Planning of Knowledge Management System for Decommissioning of Nuclear Facilities

Dr. Yukihiro Iguchi

The decommissioning of a nuclear facility is a long term project, and involves the handling of information, starting with the design of the project, followed by its execution and the deconstruction of the facility. Moreover, the decommissioning project is likely to be prolonged because of the lack of a waste disposal site.

In Japan, the decommissioning projects of the power plants Tokai, Fugen and Hamaoka 1&2 are currently in progress based on past experience with the Power Demonstration Reactor of the Japan Atomic Energy Agency (JPDR). Moreover, 6 units of Fukushima Dai-ichi Nuclear Power Plant and 5 normal LWRs will be decommissioned after the accident caused by the Great East Japan Earthquake.

Because of the social and political circumstances after the accident, the outcome of the decommissioning is unforeseeable, i.e. the location of the destination of spent fuel and radioactive waste has not been decided. This makes the projects longer and also more difficult, since the employees with enough experience and knowledge are about to retire.

This situation forces us to seriously consider "Knowledge Management", such as knowledge preservation, knowledge transfer and education.

IAEA recommended the importance of the "Nuclear Knowledge Management (NKM)" and has organised international meetings and prepared documents related to knowledge management (KM) since 2002. They are mainly for the commissioning and operation of nuclear facilities. Studying KM for decommissioning is recommended.

Because the transfer of knowledge to and education of the next generation is a crucial issue, integration and implementation of a system for knowledge management is necessary.

On the other hand, the knowledge required for decommissioning is different from the knowledge required for construction or operation. Knowledge of the design of the plant is undoubtedly necessary, but not of the entire plant.

Moreover, because the decommissioning is a long term project; the project lasts several decades from the start of the deconstruction phase. Consequently, knowledge transfer from one generation to the next generation is necessary.

We have to arrange, organise and systematise the data and information of the plant design, maintenance history, trouble events, waste management records, etc. The collected data, information and records should be organised by a computer support system, e.g. database system, which becomes a base of explicit knowledge.

Moreover, measures for acquiring tacit knowledge from retiring employees are necessary.

The experience of the retirees should be documented as much as possible through an effective questionnaire or interview process.

The integrated knowledge mentioned above should be used for the planning and implementation of dismantling or education of the future generation.

In conclusion, a comprehensive knowledge management system (KMS) should be well planned in advance for a decommissioning project.

Remote Control Manipulator Systems for Nuclear Intervention and Decommissioning

Dr. Ahmed Abou-El-Ela and Dr. Guido Kremer

In the event of a nuclear accident or during the dismantling of nuclear installations, most operations generally have to be controlled remotely. Highly-specialised equipment technology is required for this. The technical demands are as multifaceted as the intended spectrum of use and also the work to be carried out – for example, easy to handle sampling systems are just as necessary as heavy demolition machines, or even double-arm force-feedback manipulators for precision work.

The requirements regarding radiation resistance, intervention capabilities, decontaminability, etc. are very heterogeneous for each case. In the past, a wide variety of systems were designed that were adapted specifically to the respective task at hand, particularly the task of dismantling nuclear installations. Usually, these were prototypes as they were used only for one singular mission. The development expenditure was generally high, and time-consuming and costly tests had to be carried out to ensure sufficient reliability with these prototypes.

However, tools and systems are readily available on the market for nearly all tasks related to nuclear accidents or nuclear decommissioning, but these were originally designed for operation in a conventional working environment. To control these systems remotely in contaminated surroundings, they must be converted accordingly – for example, replacement of functions that are normally operated manually with remotely-controlled functions, and/or hardening of the electronics against ionising radiation. The necessary concepts and components of this conversion are largely independent of the type of the respective device or tool itself, and are listed below:

- Measurement and control technology
- Remote control systems
- Video techniques
- Data transmission
- Visualisation
- Control room technology
- Enclosures (radiation protection)
- etc.

Based on more than 20 years of experience in the conception, specification and testing of remotely-controlled systems acquired in various client projects in the field of nuclear decommissioning, we have developed a modular concept for converting specialised vehicles for remotely-controlled operation in contaminated environments. Based on this concept, it is possible to retrofit virtually any industrially proven vehicle and therefore adapt it to the specific requirements in the nuclear field.
With this, development duration and costs can be significantly reduced, while at the same time improving reliability and availability. The example of the 2014 project “Development of a highly flexible manipulator system (HMS)” demonstrates the conceptual approach, practical implementation and the achievable performance.

Remote Controlled Manipulator Systems for Decommissioning Process

Jan Hedtstück

Decommissioning of nuclear power plants (NPP) is a complex and long-lasting task with high requirements in terms of personnel safety and precise execution of any given work step. In order to minimise exposure of workers to unsafe and/or radioactive areas, remote-controlled manipulator systems that are able to perform a variety of tasks instead of human workers are needed. These tasks include but are not limited to handling of heavy loads, packing of active waste, handling of tools for cutting, welding etc., or carrying out maintenance on other vital equipment.
For these applications, Wälischmiller Engineering GmbH (HWM) from Markdorf, Germany is offering a variety of different radiation-resistant master-slave and power manipulators that are customised for each individual usage site.
The heavy duty A1000 power manipulator, of which almost 100 units have been delivered worldwide since 1979, is suited best for manipulating heavy loads up to 500kg in the gripper and lifting even heavier loads of up to 4t with its load hook.
The robotic power manipulator Telbot offers superior precision and robotic functionality like moving in a Cartesian coordinate frame and the ability to repeat pre-programmed moving patterns while still being strong enough to manipulate objects of up to 120kg with its gripper. An equally high radiation resistance of 1MGy can be achieved and all electrical parts like motors and sensors are located in a gearbox outside of the manipulator arm, whereas the arm itself consists only of mechanical parts like torque tubes, links and joints.

With dozens of NPPs due to reach the end of their service life in the next decade, the political decision in Germany to phase out nuclear energy and the triple disaster in Japan on 3/11, the need for viable decommissioning solutions, field experience of personnel and decommissioning equipment has increased.
After being used in the successful decommissioning work under the supervision of Energiewerke Nord GmbH (EWN) at Greifswald NPP and Rheinsberg NPP, a manipulator system consisting of one A1000 packing manipulator and one Telbot tool-handling manipulator was moved to its next usage site at Obrigheim NPP.
At Obrigheim, both manipulators were given the task to first cut and then pack the upper core structure of the PWR reactor in the wet cutting area. By using different cutting tools, both manipulators successfully cut the complete upper core structure and safely packed the pieces into Konrad containers for storage while also gathering samples during this process to determine radioactivity.

Robot Technology for Nuclear Decommissioning of Fukushima Dai-ichi NPS

Kiyoshi Oikawa

The International Research Institute for Nuclear Decommissioning (IRID) is a technology research association consisting of 18 member corporations that focus on R&D required for the decommissioning of the Fukushima Dai-ichi Nuclear Power Station (NPS). We have teamed up with TEPCO's Fukushima Dai-ichi Decontamination and Decommissioning (D&D) Engineering Company to identify the needs of the Fukushima Dai-ichi NPS site and are engaged in the development of various decommissioning technologies within an integrated management process. The integrated management of R&D being carried out by IRID follows the Mid-and-Long-Term Roadmap for the Decommissioning of TEPCO's Fukushima Dai-ichi NPS Units 1-4 (Mid-and-Long-Term Roadmap).

Total loss of all power sources at Units 1-3 of the Fukushima Dai-ichi NPS disabled the circulation pumps, thus preventing the flow of water into the Reactor Pressure Vessels (RPVs). Without the necessary water to cool them down, the inside of the RPVs overheated, leading to the melting of the fuel along with control rods and other structural components. It is assumed that the melted material solidified again after reaching the bottom of the RPVs, and partially at the bottom of the Primary Containment Vessels (PCVs). This solidified material is called "fuel debris."

The fuel debris retrieval project plans to use the "submersion method", an approach whereby fuel debris is fully covered with water. The submersion method helps reduce unnecessary exposure of workers since water is effective in blocking radiation and preventing dust dispersion during the machining of the debris for its collection. For implementation of the submersion method, water leakage from the PCV walls needs to be stopped. To do so, the work areas and access routes need to be decontaminated to allow access by workers, and leakage points must be detected.

Tremendously high radiation levels in and around the PCVs are preventing access by workers and require the use of remotely-controlled robots. Up until now, IRID has developed various remotely-controlled robots for decontamination and water leakage investigation and has conducted tests at the Fukushima Dai-ichi NPS site. In order to assess the damage situation inside the PCVs, and the location and condition of the fuel debris, IRID currently plans to develop remotely-controlled shape-deformation type robots that can enter the PCVs via a narrow access port. First testing was conducted at the Fukushima Dai-ichi NPS site in April 2015.

For the submersion method, IRID will develop technology for cutting and collecting of the fuel debris using the tools on the tip of a retractable manipulator which descends from the operation floor into the RPV/PCV. Remotely-controlled robot technology is also required in this case. Meanwhile, considering that fuel debris retrieval may not proceed smoothly by using the submersion method alone, IRID plans to study alternative methods including in-air work alongside the submersion method.
In order to progress the decommissioning of the Fukushima Dai-ichi NPS, remotely-controlled robots capable of conducting various operations for the workers must be built and technological innovations developed on the basis of knowledge from around the world.

Innovative Technologies for the Decommissioning of Nuclear Facilities

Martin Brandauer

As part of the German energy transition program, the decision to completely phase-out nuclear power generation was made abruptly in 2011, after the incident in Fukushima. As a consequence, eight running facilities were immediately shut-down by law. These facilities were undergoing life-extension procedures at that time and at no point had been considered for decommissioning. This circumstance resulted in a very long transition phase that is still ongoing. The remaining nine facilities still in operation will be shut down in the coming years, while a complete phase-out and final shutdown of all facilities is mandatory by the end of 2022. The final phase-out of nuclear power will, however, only be possible once all the remaining facilities have been decommissioned.
As a result of the current situation and due to the operators' decision to opt for a direct decommissioning strategy, many large scale facilities will be decommissioned simultaneously in Germany in the coming decades; which represents a considerable challenge. The subject of decommissioning is, however, not a new topic in Germany. There are a substantial number of facilities which are already in an advanced decommissioning state. To date, three facilities in Germany have also been completely decommissioned and returned to the so called "green-field" state, i.e. complete demolition of the facility and reforestation of the former site.
For this reason, decommissioning of nuclear facilities has already proven to be feasible. Nevertheless, many problems have occurred over the past decades and many lessons had to be learned. Furthermore, some of the applied techniques are still rudimentary and usually taken from other application fields, without adapting them for the new tasks. The

field of research and education for the decommissioning of nuclear facilities established in 2008 at Karlsruhe Institute of Technology (KIT) addresses these technical problems and advances the development of new technologies and contributes to the education of new professionals for the industry.

One technology currently being developed at KIT is related to the fast and efficient decontamination of concrete surfaces. This is an important step in guaranteeing the removal of all possible contamination from a nuclear facility before releasing it from the atomic law for complete dismantling. This technology is being addressed in two parallel research projects. The first one is a fully remote-controlled and semi-autonomous manipulator for deployment in radioactively contaminated sites. A virtual model of the site is created using 2D and 3D laser scanners. Specially developed algorithms process this data for optimised and efficient decontamination [21].

This manipulator assists the operator in fulfilling the intended task and prevents the staff from working in contaminated areas. Since this is still a prototype, a follow-up research project has been set up to develop a very fast and highly efficient decontamination unit in close cooperation with the industry. This unit is also controlled remotely, can be deployed and moved by a crawling chassis and has a very high mechanical decontamination rate of about 10 m^2/h [22].

Another technology that is currently being developed deals with the secondary waste produced during the water abrasive suspension cutting of activated steel components. This method has already proven to be highly suitable for application with underwater manipulators, cutting complex geometries like pressure vessel internals. The main drawback, however, is the concurrent generation of large quantities of secondary waste. For this reason a physical separation process is being developed, reducing the amount of waste by 90 % (essentially the comprised activated steel chips) [23].

The WAK Decommissioning and Dismantling Project

Dr. Marco Klipfel and Christian Held

The Wiederaufarbeitungsanlage Karlsruhe (WAK) was a pilot nuclear reprocessing plant for subsequent commercial reprocessing. Nuclear fuels from various experimental and commercial reactors were reprocessed at the plant. Uranium and plutonium were reused in new fuel elements and the High Active Waste Concentrate left in storage buildings on the site. In 1991, the reprocessing operation was terminated, and the decommissioning of the plant started.
As part of the restructuring, the WAK Rückbau- und Entsorgungs-GmbH (WAK Decommissioning and Waste Management Company) was committed to all activities related to the decommissioning of experimental and prototype nuclear facilities, including waste management at the Karlsruhe site.

The following facilities are being decommissioned:

- Karlsruhe Reprocessing Plant, including the Vitrification Facility
- Compact Sodium-cooled Nuclear Reactor
- Multi-purpose Research Reactor
- Research Reactor 2
- Hot Cells (shut-down sections)
- Smaller nuclear research facilities of the KIT after shutdown

The presentation provided a summary of current decommissioning activities. It focussed on the various concepts for techniques in relation to the remote dismantling of highly radioactive components.

Approach to the Decommissioning of Large Components utilizing Decontamination and Segmentation Technologies for the Use of Available Disposal Options

Andreas Roth

The approach for decommissioning of large components, e.g. steam generators, reactor pressure vessel and its internals, etc., is determined based on overall optimisation which takes regulatory and licensing, technical and operational, safety and ALARA, economic and scheduling as well as public-acceptance and stakeholder issues into account.

The main pathways for this material are recycling, clearance or disposal. These options require different levels of effort at the segmentation, decontamination, waste processing and packaging and transportation process steps. This presentation focussed on the segmentation process step. During an overall assessment of the most relevant management mode for large component decommissioning, the feasibility of segmenting on the decommissioning site and storage or disposal in standard containers or removal of the component from the site in one piece, followed by processing or storage offsite is also considered. However, especially at a damaged site like the Fukushima Dai-ichi site, segmentation technologies have to be used on site to dismantle the damaged equipment and offsite segmentation is not an alternative.

There are various tried-an-tested segmentation technologies on the market that offer different advantages and disadvantages. There is no best technology, but a toolbox to support a segmentation strategy specific to each project. Thermal segmentation methods, e.g. autogenous cutting, plasma arc cutting etc., offer high cutting rates, but require very precise guidance, can often not be used for multiple materials and produce difficult secondary waste like aerosols. A range of heavy-duty conventional mechanical segmentation equipment such as wire saws, disc saws, nippers, grinders, etc. is available. Such tools have to be designed to manage strong forces due to the direct contact with the component and consequently need strong and heavy supports and guidance systems.

Water Abrasive Suspension (WAS) jet cutting represents an alternative remote-controlled mechanical segmentation technology which can be used in hazardous environments and has a proven track record in nuclear, demilitarisation as well as off-shore applications. WAS can be operated in water or air. With this technology, a small and flexible cutting lance can be operated up to a distance of 1,000 m from the high pressure pumping and suspension mixing units. Intelligent use of sensors, hydrophones and cameras allows the cutting results to be efficiently evaluated remotely. These features and the robust cutting process itself make WAS particularly suitable for application at damaged sites, where access is limited due to a hazardous environment and no precise knowledge on the geometries and positions of components as well as available space for the cutting operations can be obtained. Disadvantages of WAS are the secondary waste generation from the abraded material and a relatively low cutting rate due to the batch operating mode. Research and development on continuously-operated nozzles as well as various efficient capturing systems for the abraded material (e.g. cascades, filters etc.) is being carried out to minimise these disadvantages.

Decontamination by High Pressure Water Jetting Systems

Matthias Finkenberg

During decommissioning of nuclear power plants (NPP), decontamination of low and medium radioactive waste reduces costs and exposure of the personnel.

Well known companies that are already involved in the decommissioning of NPPs generally use four methods of decontamination: electrolytic decontamination, chemical decontamination, dry blasting, and high-pressure water jetting. The general aim of decontamination is the reduction of measurable radioactivity so that the material is no longer considered to be radioactive in a legal sense.

High-pressure water treatment has been found to be an ideal method for cleaning or decoating contaminated parts. The advantage is that, compared to other mechanical cleaning methods, much less dust is produced and used water, the cleaning medium, can be circulated and filtered, which means that no new waste is generated.

The decontamination process for low-level waste by high-pressure water jetting can either be done manually under full protection of the worker or can be remote-controlled. The cleaning process is done in a special handling cabin with appropriate systems for admission of contaminated parts and discharge of cleaned parts as well as special ventilation equipment to provide adequate visibility, filtration and dehumidification. The construction and all surfaces of the system are designed to minimise accumulation of any particles. The water used for the high-pressure cleaning process is collected and transported through a water recovery station where radioactive particles are removed by special filters.

Very recently a test system was delivered for the fully-automatic, remote-controlled decontamination of steam generator pipes using high-pressure water up to 3,000 bar. First tests with this system have shown promising results.

Fully-automated cleaning systems are state of the art for industrial applications and are used whenever a large amount of identical parts need to be cleaned in a short period of time. Most of the parts that need to be decontaminated during decommissioning of NPPs are unique in shape and structure so that fully-automated industrial solutions cannot be adopted directly. The focus of current research activities at RST GmbH is to provide fully-automated decontamination solutions by a robot in case of higher radiation levels, e.g. working with medium-level waste.

SESSION 4: Waste Management, Conditioning and Final Disposal

Waste Management of Structures of Buildings and Containment

Professor Dr. Peter Jehle

What was undoubtedly one of the most serious accidents in the history of the civilian use of nuclear power, the triple accidents at the Fukushima Dai-ichi NPP on 11 March 2011, led to the decision of the German government to end the use of nuclear energy in a structured manner. In 2012, a total of 16 nuclear power plant units were already shut down and in the process of decommissioning. Of the remaining 18 power plant units, 9 are still in operation at 8 locations. All units have to be shut down in the next few years. The federal government therefore set the dates for the final shutdown of each of these units and listed these in the Atomic Energy Act. The last facility is scheduled for shutdown in 2022.

This presentation gave an initial overview of post-operation phases, the decommissioning process and the decommissioning strategies. An interesting fact here is that in Germany, a standardised set of rules for a mandatory procedure in the decommissioning phase does not exist currently. The legislative framework of national or international laws, especially §7 of the German Atomic Energy Act, is summed up in the form of a manual and determines the steps of safe enclosure or dismantling of the reactor and nuclear facilities. The differentiation and classification of radioactive waste is an additional point to be considered.

In the past years, a great deal of experience in decommissioning and demolition of nuclear power plants has been acquired. In future years we can develop and improve the technical capabilities. An important element will be public acceptance of all these activities.

Research for the Safe Management of Nuclear Waste

Professor Dr. Dirk Bosbach

The safe management of radioactive waste arising from electricity generation including its ultimate disposal in a deep geological disposal facility is one of the great challenges of our times. Roughly 300 nuclear power plants worldwide will reach the end of their envisaged lifetime by 2030 and need to be decommissioned. Technologies for the decommissioning of nuclear facilities and for the safe management of the associated waste have been developed in recent decades. Current R&D activities are focussing on optimisation of aspects such as exposure of personnel to radiation, economics, and others.

However, it seems that some special waste streams arising from the decommissioning of nuclear installations have not been in the focus of R&D activities in the past. This special waste, some of it referred to as 'problematic radioactive waste' by the IAEA, contain radioactively contaminated toxic metals such as beryllium, cadmium or mercury, spent ion-exchange resins, radioactively contaminated NAPL and decontamination fluids, wastes containing asbestos, PCB, and so on, plus mixed waste with elevated concentrations of chemotoxic/hazardous constituents.
Although the volumes of a number of these special waste streams are expected to be comparatively small, there are specific challenges associated with their safe management, arising from their associated chemotoxicity, the potential release of radionuclides (during temporary storage and/or under disposal conditions), their incompatibility with established conventional treatment and conditioning techniques, analytical challenges regarding the adequate determination of radioactive and chemotoxic inventories, etc.
The presentation provided an overview of current R&D activities at Forschungszentrum Jülich in relation to the treatment of some types of special waste and its transformation into new shapes and forms for safer and more compact storage.

R&D on Treatment and Disposal of Radioactive Waste resulting from Accident at Fukushima Dai-ichi NPS

Yasuaki Miyamoto

The properties of the waste generated by the accident at the Fukushima Dai-ichi Nuclear Power Station differ from those of the radioactive waste (waste from operation) generated in a conventional Nuclear Power Station in the following respects (but not exclusively): the waste includes radionuclides originating from the core fuel, it may include a sea water component resulting from the reactor core cooldown immediately after the tsunami and the accidents, and it includes the zeolite and sludge with high radiation emission rates for which the results of processing and disposal are not evident at present. Additionally, the generated amount is also large with various levels of contamination. In order to improve our prospects of being able to safely process and dispose of this radioactive waste, we implement R&D after understanding different points in relation to conventional radioactive waste.
The Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF) performs the role of a Centre of Excellence (COE) in the decommissioning of

the Fukushima Dai-ichi Nuclear Power Station and the implementation of measures for the treatment of contaminated water, by offering strategy planning, R&D planning and progress management support in relation to important problems.

According to the government and NDF strategy, the purpose of TEPCO's Fukushima Dai-ichi Decontamination and Decommissioning (D&D) Engineering Company is to implement the decommissioning comprising aspects such as safety control, and the International Research Institute for Nuclear Decommissioning (IRID) serves as the organisation responsible for the development of critical decommissioning technologies on a mid- and long-term basis

An overview of the processing and disposal of the radioactive waste generated at the Fukushima Dai-ichi Nuclear Power Station is shown in the "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Dai-ichi Nuclear Power Station Units 1-4". It must be demonstrated that the mentioned milestones "Making Basic Policy for Processing & Disposing of Solid Waste" and "Confirmation of Prospect on Safety for Processing & Disposing of Solid Waste" can be reached by 2017 and 2021 respectively.

Apart from the waste from the reactor cores, such as fuel debris, the waste generated at the Fukushima Dai-ichi Nuclear Power Station can be classified roughly into rubble and fallen trees or secondary waste produced from contaminated water treatment.

The rubble and fallen trees stemming from construction-related activities in the wake of the accident and subsequent decommissioning, etc., are stored in an area prepared within the site of the Fukushima Dai-ichi Nuclear Power Station. Heaps with an air dose of less than 0.1 mSv/h are accumulated outside, whereas heaps with an air dose of 0.1-1 mSv/h are kept under curing sheet and heaps with an air dose of 1-30 mSv/h are stored in soil-covered interim storage facilities, temporary storage equipment and vessels. The high-level radioactive waste is stored in solid waste storage facilities. Fallen trees, branches and leaves are chipped and stored in temporary storage tanks as a measure for reducing radioactivity levels in the air and the risk of fire. Trunks with low doses are accumulated outside.

The contaminated water generated by the cooling of the reactor cores is purified by contaminated water treatment facilities consisting of a caesium removal system, a desalination system and the Advanced Liquid Processing System.

The caesium removal system essentially consists of a caesium adsorption device and a secondary caesium absorption vessel, with zeolite, the adsorption material, generated as waste.

Although the decontamination device, which is another caesium removal system in which the caesium flocculates and settles using nickel ferrocyanide, is no longer in operation, 597 cubic metres of sludge, which would be waste, have been stored. This will not increase in future.

Radionuclides other than caesium, such as strontium, are removed in the Advanced Liquid Processing System. At the moment, several Advanced Liquid Processing Systems are working and an increasing amount of waste generated from the facilities, which is composed of slurry and adsorption material, has been stored in the HIC.

Regarding the processing and disposal of radioactive waste, R&D is conducted from four viewpoints: Identifying Properties; Study on Long-Term Storage Method; Study on Processing of Waste; and Study on Disposal of Waste.

Especially in the case of "Identifying Properties", "Study on Processing of Waste" and "Study on Disposal of Waste", sharing the R&D results for mutual benefit is important to provide feedback for each development project for the purpose of optimisation. At the core of this research is a 'Waste Stream', which refers to the waste management process, from generating and storing to processing and disposal of the waste.

Contaminated radionuclides, such as rubble sampled at the Fukushima Dai-ichi Nuclear Power Station, were analysed as Identifying Properties. As we evaluate the correlation between Cs-137, which is a main contaminated radionuclide, and other radionuclides, Co-60 and Sr-90, we expect to find a correlation with Cs-137. As for the actinoids nuclides, although a level of 10-3 Bq/g was detected in the rubble samples collected on the first floor of the reactor buildings at Unit 1 and Unit 3, it is not possible to make any judgements on a correlation with Cs-137 at this time.

Moreover, actinoids nuclides with 10 Bq/cm^2 level were detected in a sample of the floor surface coat taken from the fifth operating floor of the reactor building of Unit 2. This suggests the contamination situation inside the reactor building is possibly different in each unit, and even in the same unit, it might be different on each floor.

At this stage, apart from Identifying Properties, we are focussing on the following items and research on them continues: Sorting of Information Regarding the Inventory and Coexistence Substance in Waste, Processing of Waste Generated from Treatment of Contaminated Water and Long-term Storage Measures for the Waste and Prospect of the Disposal Classification of Each Waste and Establishment of Selection Criteria.

List of References

[1] IAEA; Nuclear Power Reactors in the World; IAEA-RDS-2/34; Vienna (Austria) 2014.

[2] Stahl, T.; Strub, E.: Gesellschaft für Anlagen- und Reaktorsicherheit (GRS): Stilllegung kerntechnischer Anlagen; Köln (Germany) 2012.

[3] VGB PowerTech e.V., Arbeitskreis Abfallmanagement: Entsorgung von Kernkraftwerken; Essen (Germany) 2011.

[4] Paul, M. et al.: Decommissioning including financial precaution; IAEA joint convention of the safety of spent fuel management and on the safety of radioactive waste managment 2006; Wien (Austria) 2006.

[5] Noyes, R.: Nuclear waste cleanup technologies and opportunities; 1st edition; New York (USA) 1995.

[6] E.ON Kernkraft GmbH (Hrsg.): Kernkraftwerk Würgassen – 12 Jahre erfolgreicher Rückbau; Hannover (Germany) 2009.

[7] E.ON Kernkraft GmbH (Hrsg.): Vom Kernkraftwerk zur "Grünen Wiese – Stilllegung und Rückbau des Kernkraftwerks Würgassen; Hannover (Germany) 2008.

[8] Anthofer, A.; Lippmann, W.; Hurtado, A.: Development and testing of a laser-based decontamination system.
In: Journal of Optics & Laser Technology 48 (2013); pp. 589-598.

[9] Anthofer, A.; Lippmann, W.; Hurtado, A.: Laser decontamination of epoxy painted concrete surfaces in nuclear plants. In: Journal of Optics & Laser Technology 57 (2014); pp. 119-128.

[10] http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Japan/; 25.04.2015.

[11] http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Germany/; 11.05.2015.

[12] Brandauer, M.; Gentes, S.; Starflinger, J.: Entwicklung eines Separationsverfahrens zur Behandlung des Sekundärabfalls der Wasser-Abrasiv-Suspensions-Schneidtechnik; KONTEC15; Dresden (Germany) 2015.

[13] Hess, U.; Grove, T.; Denkena, B.: Definierter Abtrag hochbewehrter Stahlbetonstrukturen; KONTEC15; Dresden (Germany) 2015.

[14] Sell, H.; Finkenberg, H.: Decontamination of steam generator pipe bundles by means of high-pressure water-jets; KONTEC15; Dresden (Germany) 2015.

[15] Kern, P.; Gentes, S.: MANOLA – Vorstellung des Manipulator- und Transportwagensystems; Jahrestagung Kerntechnik 2012; Berlin (Germany) 2012.

[16] Mende, M. et al.: Environment modeling and path planning for a semi-autonomous manipulator system for decontamination and release measurement; World Automation Congress (WAC) 2014; Waikoloa Village (USA) 2014.

[17] Metzger, W.; Held, C.: Liedke, T.: Virtueller Teststand zur Unterstützung des fernhantierten Rückbaus der Verglasungseinrichtung Karlsruhe (VEK); KONTEC15; Dresden (Germany) 2015.

[18] http://www.iabg.de/en/business-fields/mobility-energy-environment/remotely-operated-handling-systems-for-nuclear-applications/; 13.05.2015.

[19] Brandt, F.; Schäfer, T.; Claret, F.; Bosbach, D.: Heterogeneous formation of ferric oxide nanoparticles on chlorite surfaces studied by x-ray absorption spectromicroscopy (STXM); In: Chemical Geology 329/3 (2012); pp. 42-52.

[20] Becker, U.; Risthaus, P.; Brandt, F.; Bosbach, D.: Thermodynamic properties and crystal growth behavior of the hashemite (BaSO4–BaCrO4) solid solution; In: Chemical Geology 225 (2006); pp. 244-255.

[21] Kern P., Gentes S., Notheis S., Mende M., Hein B., Wörn H., MAFRO: Ein semi-autonomes Manipulatorsystem für die Dekontamination und das Freimessen von Oberflächen; KONTEC 2015: 590-597; 25.-27.03.2015; Dresden, Germany

[22] Hentschel S., Börsch F., Gentes S., Feil H., Entwicklung einer automatisierten Wandfräse zum Dekontaminieren von Betonoberflächen beim Rückbau kerntechnischer Anlagen; KONTEC 2015: 617-622; 25.-27.03.2015; Dresden, Germany

[23] Brandauer M., Starflinger J., Gentes S., Physical Separation and Disposal of WAS Secondary Waste from the Decommissioning of Nuclear Facilities; FILTECH 2015; L14-03 – P085; Köln, Germany

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German Research and Innovation Forum Tokyo

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Technische Universität Dresden

The Technische Universität Dresden (TUD) is one of eleven German universities that were identified as an "excellence university". TUD has about 37,000 students, 4,400 publicly funded staff members – among them over 500 professors – and approximately 3,500 externally funded staff members, and is therefore the largest university in Saxony today. The Chair of Hydrogen and Nuclear Energy is part of the Institute of Power Engineering at the Faculty of Mechanical Science and Engineering. The research and teaching content is based on an understanding that there is a national and international demand for preserving and enhancing competence in nuclear technology to guarantee the safety of nuclear reactors today and in the future.

tu-dresden.de/en

University of Fukui

Since its foundation in 1949, the University of Fukui has served as a centre of academic and cultural activities which promotes education and research in science and technology in order to improve the wellbeing of the people. U Fukui has played a role of regional centre of nuclear technology, since there are 14 nuclear power plants in the prefecture where the university is located. It is also contributing to education and technology development on nuclear decommissioning issues from an academic standpoint.

www.u-fukui.ac.jp/eng

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