7 Department of decommissioning of nuclear facilities

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Overview

The integration of the decommissioning department into the program-oriented funding research of the Helmholtz Association in 2015 allows a focused addressing of this important issue between research on the reactor safety and the disposal of nuclear waste.

The shut-down of eight active German nuclear power plants in 2011 and the subsequential shut-down of the remaining facilities up to 2022 will lead to a big challenge of parallel decommissioning of a large quantity of large scale facilities in a very short time frame. The starting point will be in 2017, where most of the facilities of 2011 will finally acquire the license for finally proceeding with the decommissioning of their facility.

Considering this development, activities within the established decommissioning center of the KIT in 2015 have been further extended to an international level by establishing the "Decommissioning Cluster" in February 2016. This endeavor has gathered five big entities in the region to a joint venture with regard to harmonizing and strengthening E&T, R&D as well as maintaining competences in the field of decommissioning. The partners of this new group are the Duale Hochschule Baden-Württemberg (DHBW), the Paul Scherrer Institut (PSI), the University of Stuttgart, the Joint Research Center (JRC) of the European Commission, and the KIT (see Fig. 1).

The set-up, coordination and continuous strengthening of this cooperation is being supported by the Ministry of Science, Research and the Arts (MWK) of the State of Baden-Wuerttemberg since December of 2016.

The great need of focusing on the decommissioning of nuclear facilities is, however, not limited to the German nuclear phase-out. The European Commission assumes that by 2025 approx. one third of the 145 nuclear facilities currently in use will be put out of service [2], apart from estimates of almost 300 nuclear power plants going into decommissioning by 2030. For this reason, the European Commission has created the ELINDER initiative (European Learning Initiatives for Nuclear Decommissioning and Environmental Remediation). On 2nd of December 2016, fifteen partners have signed a memorandum of understanding to establish a European decommissioning training and education program, allowing a standardization and improvement of the education system in this field on a European level.

Fig. 1: *Partners of the "Decommissioning Cluster" [1].*

Other activities of the program comprise the further intensification of international partner relations, such as with the Fukui University in Japan. As a coordinated effort, an international symposium was organized in Osaka in October 2016, followed by a two-day student workshop about the decommissioning of Fukushima at the University of Fukui, moderated and taught by Dr. Larry Boing from the Argonne National Laboratory and Mr. Martin Brandauer from KIT.

In December 2016, Dr.-Ing. Patrick Kern defended his doctoral thesis. His work contributes significantly to the development of automatized robotic systems for the characterization and decontamination of concrete surfaces. Dr. Kern has extensively studied the behavior of vacuum suction plates and provided a first-of-a-kind model for the prediction of force transfer of these units both in normal as well as tangential direction [3]. His findings will provide a substantial contribution to future systems in this field, since suction plates allow a flexible and reliable fixation of systems and components without significant changes to the surface to be treated (like e.g. bolting).

Further major topics will be addressed in more detail below.

Knowledge database for the decommissioning of nuclear facilities

In order to successfully handle decommissioning projects, comprehensive data and information is vital; e.g. to establish state-of-the-art decommissioning processes, define future R&D in the field, develop improvements on technical and management issues, both on a national and international level. For this reason, a comprehensive decommissioning database based on a team collaboration platform by Atlassian Inc. has been set up in 2016 and implemented in 2017. The software selected gathers information of different types e.g. papers, articles, other databases, books, news, etc. (Fig. 2).

Hence, the purposes of the database are:

- Fast and easy information access with links to detailed content

- Data and document storage
- Illustration of the current decommissioning status of nuclear facilities, decommissioning knowledge and technologies
- Information compilation
- Identification of relevant characteristic values for nuclear decommissioning projects and procedures and further development of decommissioning technologies
- Creation of a basis for future research, standardization and optimization procedures

The key advantages of the Atlassian system software *Confluence* are the user friendly, intuitive interface which is based on a Wikipedia format (Fig. 3), the data entry and upload possibilities, the openness of the system for further processing, and evaluation tools. The integration of tables, documents, and links makes it a powerful tool for combining management aspects with technical procedures and therefore providing an overall overview of and interconnection with information needed for the planned R&D in decommissioning of nuclear facilities.

For this information compilation, a top-down structure has been set up as can be seen in Fig. 4. This structure shows an overview of the topics analyzed in depth in the database.

By 2018, it is planned to further collect, handle, and process different relevant information within the database, to create tools for the analysis and processing of recent, ongoing and completed decommissioning procedures. The tools will further allow the identification of relevant characteristic values for nuclear decommissioning procedures and development of decommissioning technologies.

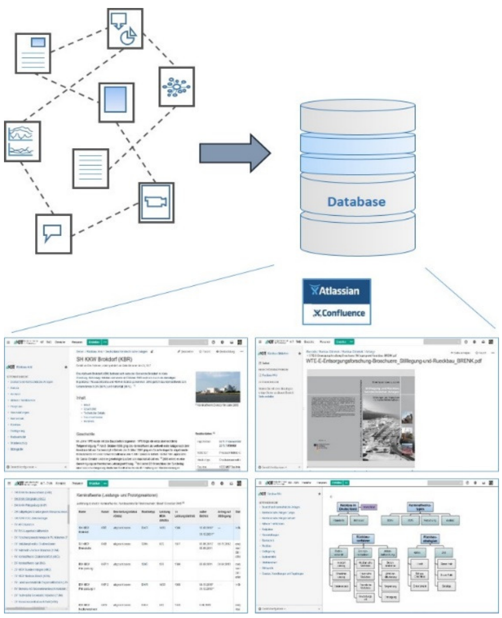

Fig. 2: *Illustration of information gathering and processing with the Atlassian database system.*

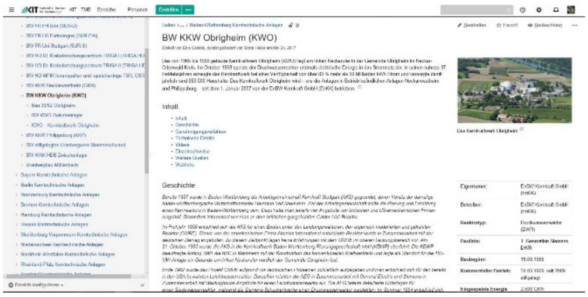

Fig 3: *Example page of the database.*

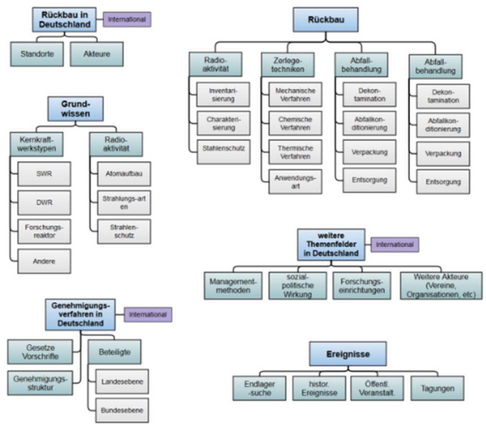

Fig. 4: *Structure of topics pursued in the database.*

Development of a system for the surface decontamination of reinforced concrete structures

One of the decontamination challenges of concrete structures is the deep decontamination of cracks, fractures, and the removal of steel fixtures (e.g. anchor plates, dowels, etc.). This procedure requires the application of a tool, which can not only remove a deep layer of concrete but also deal with the reinforcement within the structure while generating a smooth enough surface to allow the subsequent measurement of contamination. The different properties of the materials (i.e. concrete and steel) make it very challenging to design a tool that can deal with a ductile and a brittle material at the same time. State-of-the-art decontamination tools for this application are usually relying on the usage of two different set of tools for each of the components.

In a joint effort, a novel patented tool is being developed by the Karlsruhe Institute of Technology (including this working group and the chair of mobile machinery), the Institute of Production Engineering and Machine Tools (IFW) at Leibniz University Hannover, Kraftanlagen Heidelberg GmbH, and Herrenknecht AG. The system allows the removal of highly reinforced concrete, the removal and transportation of debris, as well as suitable storage and packaging of the debris for the nuclear repository. These efforts are being sponsored by the Federal Ministry of Education and Research through the project

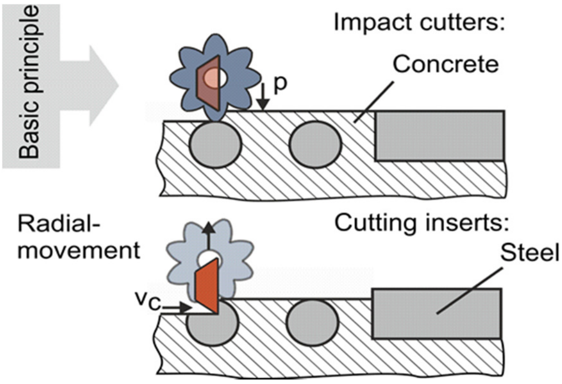

***Fig. 5:** Operating principle of the tool [4].*

02S9093C „Definierter Abtrag hocharmierter Stahlbetonstrukturen (DefAhS) “.

Prior to the system development, a survey of the requirements has been carried out with the following results: a surface removal up to a depth of 5 mm (90% of the cases), and a depth removal up to 300 mm (10%). The system will have a modular design with a machining system and a corresponding carrier device, both designed to fit through a standard door opening of 1x2 m. It will allow the machining of walls, ceilings, wall projections and wall openings with slide adjustments, achieving similar efficiency (0.1 m³/h) and life time of the cutters and inserts (up to 3h) of established technologies. A detection and control system has been integrated into the tool to identify the required machining parameters per material properties (concrete or steel) [4].

To fulfil the requirements for machining concrete and steel, the system uses a hybrid-removal procedure. The concrete is crushed by impact cutters with floating bearing to uncover steel installations and reinforcement rods. Due to the ductile properties of the uncovered steel inlays, the impact cutters are bounced back. Cutting inserts have been placed 6 mm radially inwards to allow milling of these ductile materials, reducing the cutting speed of the tool accordingly. The approach design of the tool can be seen in Fig. 5.

These two kinds of tools are installed on modules, which are attached to a drum (see Fig. 6). Each module is equipped with a shaft mounting and the impact cutters. On top of this part of the module, seven cut-

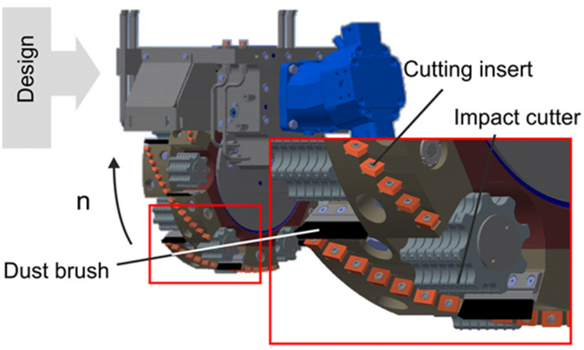

***Fig. 6:** Design principle of the tool [4].*

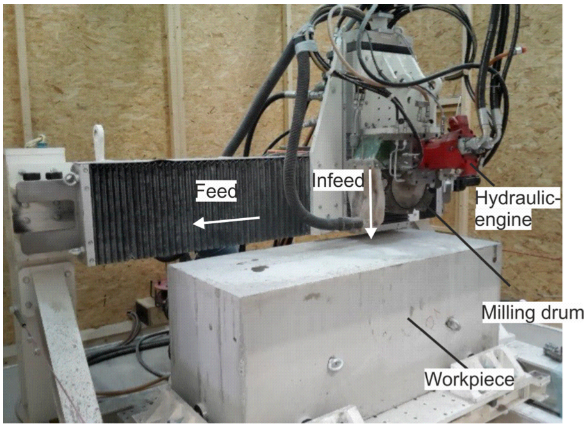

***Fig. 7:** Test rig for experimental analysis [4].*

ting inserts are fixed with a certain offset.

The hydraulic engine with an offset gearbox and centrally placed bearings allows the drum to rotate freely up to the specified depth of 30 mm (see Fig. 6).

To remove the debris produced during machining, brushes are placed on each side of the modules behind the impact cutter. With these, the debris is removed from the machining area and conveyed to the suction system behind the drum. The suction system also holds the detection sensors for the speed control of the unit.

For the experimental evaluation of the newly developed tool, the set-up has been carried out in the workshop of the Institute for Technology and Management in Construction (TMB) at the KIT (see Fig. 7).

Here, the preliminary technical feasibility of the novel tool will be tested. Following this, experimental tests to determine the necessary process forces for the milling tool and the wear behavior of different carbide cutting materials for various parameters will be tested. Based on these results, the optimum cutting material will be selected and the operating points for the milling tool will be determined.

Treatment of secondary waste from the water abrasive cutting technique

For the treatment and disposal of the secondary waste caused by the application of the water abrasive suspension cutting, two research approaches have been followed in previous years. On the one hand, research has been undertaken to treat the secondary waste by a novel physical separation method of the radioactive particles contained in the mixture. The second approach analyzed the possibility of admixing the secondary waste into the concrete which is used to fill-up KONRAD containers.

The first approach involves the significant reduction of the radiological inventory and hence improves the safety in the handling, conditioning and disposal of the material. With the possibility of systematically disposing of this fraction, the usage of the remaining material for the concrete mixture is enabled while avoiding unforeseen agglomeration of highly activated particles. The combination of both approaches

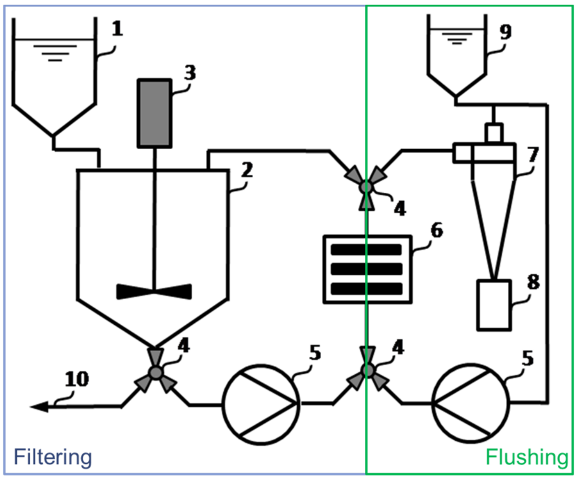

Fig. 8: *Applied process chain of the preliminary test rig [5].*

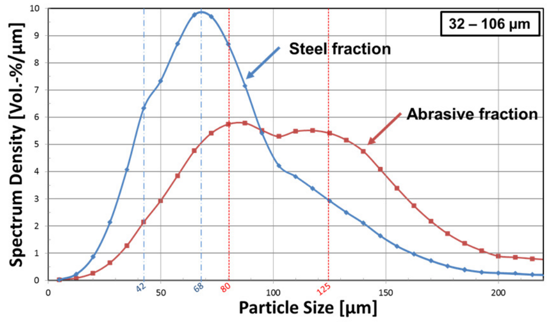

Fig. 10: *Different size distribution of the fractions in the mixture in the size of 32 – 106 µm [5].*

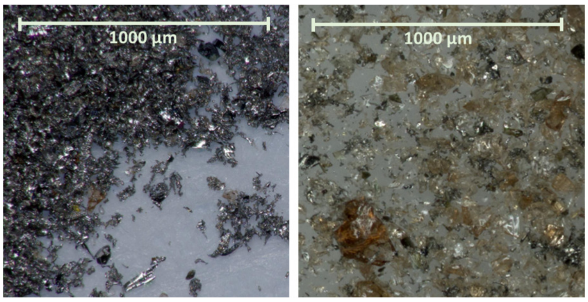

Fig. 11: *Different consistency of separated fraction dependent on operation parameters of the system [5].*

allows the treatment of this radioactive waste, which, up to date, had to be disposed of in a final repository.

The process chain of the separation system can be seen in Fig. 8.

In order to develop a prototype separation system with components that might be applicable for the usage with activated waste, a big effort has been made to develop a test rig, which is as insusceptible towards malfunction as possible. Furthermore, to reduce costs, only commercially available components have been used while taking considering a possible decontamination of the components in the later application.

In order to profit from the water's shielding effect and to also track possible leakage in the system, the abrasive and steel mixture from the water suspension cutting is suspended using a slurry feed tank (**2**). With membrane pumps (**5**) the suspension is pumped through a magnetic filter (**6**) in a closed loop for the magnetic separation of the steel fraction. A magnet filter has been chosen for this application and can be seen in the following Fig. 9. The magnet rods used in the system do not require additional power supply and provide easily accessible surfaces for later decontamination. The four permanent magnet rods (**1**) of the filter are inserted through the front of the unit into casing tubes (**2**) which seal the chamber of the filter off. Therefore, the suspension can be filtered in a leakage-free environment. By inserting or withdrawing the magnet rods, the magnetic filtering can be turned on and off.

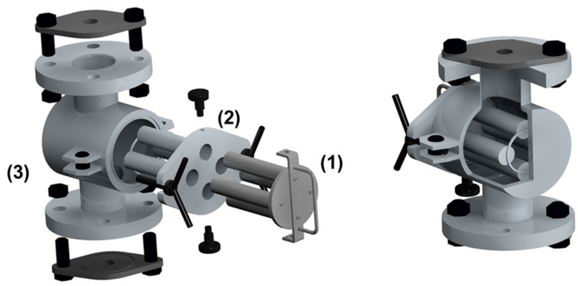

Fig. 9: *Magnet rod filter used in the separation system [5].*

The magnetic filtering loop of the separation system is operated with this filter for a predefined time. After this filtering loop, the magnet rods of the filter are removed and a second loop is used to flush the filter using fresh water. The separated steel particles (activated fraction) are drained out of the system by a hydro cyclone (**7**) and collected into a depository container (**8**). The remaining equipment for the separation system is a prior feed tank (**1**), the drivetrain and corresponding agitator (**3**) of the slurry feed tank, a fresh water supply (**9**) and 2/3-way valves (**10**) to operate both closed loops sequentially.

The experimental investigation of this system has shown very different results in the properties of the flushed fraction depending on the operation parameters of the system (flow rate, particle loading or filtering time). In Fig. 10 two exemplary fractions of very different consistency are shown. Depending on the set of parameters, the separated fraction is either mostly composed of steel particles (left of Fig. 10) or a mixture of steel particles with a large quantity of abrasive particles (right of the same figure).

To allow the characterization of these obtained fractions, a detailed characterization of the original mixture after the cutting has been carried out [5]. For this reason, the mixture has been classified by size and in addition sorted by magnetic susceptibility. These fractions have been analyzed as to their particle size distribution. This has been carried out by a system set up at the Institute for Technology and Management in Construction (TMB) using an absorbance measurement technique. These analyses have shown that the steel fraction within the mixture has a far smaller

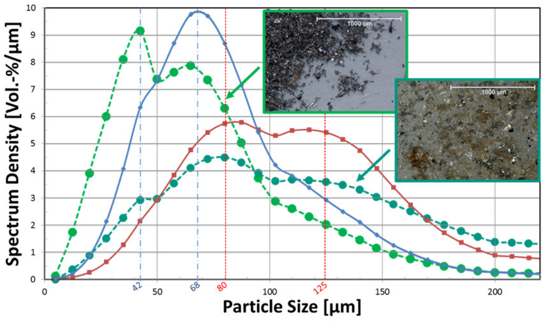

Fig. 12: Different size distribution of the fractions compared to fraction of the experimental analysis [5].

particle size compared to the abrasive particles. There is a clear difference in particle size distribution of the finest fractions of steel particles and abrasive particles, as can be seen in Fig. 11.

With these findings (for details please refer to [5]) a clear assignment of the separated fraction can be achieved by the particle size distribution of the analyzed sample. This association becomes clearer when combining the results of the particle size distribution of the two samples of Fig. 10 with those shown in Fig. 11. This can be seen in Fig. 12.

In the comparison of Fig. 12 the difference between the particle size distribution of the different samples is explicit. These findings allow a new and simple characterization of the separated fractions of the developed separation system, i.e. a qualitative evaluation of the achieved results. Therefore, this analysis permits a quick estimation of the fractions gained during the separation without having to rely on extensive and time consuming chemical analysis. With further efforts, this evaluation process can be included in the separation system, making the online evaluation possible.

With this method, the separation process will be further analyzed using variations of the system parameters flow rate and particle loading and filtering time to achieve a good estimation of the best operating parameter for the magnetic separation of particle mixtures using a magnet rod filter. This is the basis of ongoing research for the treatment of secondary waste of the water abrasive suspension cutting in the nuclear decommissioning field.

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