A Wrap-up of the **Technical Sessions**

KERNTECHNIK, with its unique range of topics, covers a wide variety of aspects: Uranium enrichment, advanced reactor technologies, safety aspects of nuclear energy, service for existing fleets, long-term operation, modernization and new construction activities, decommissioning and dismantling, final disposal of radioactive waste, nuclear fusion and the role of nuclear energy in the context of the energy transition and climate protection.

In addition to keynotes and special formats, the Technical Sessions in the four categories **Competence and Safety, International Trends and Development, Decommissioning & Waste Treatment, Interim Storage & Final Storage** cover a wide range of scientific, technical and organizational issues.

This ranges from knowledge management and maintenance of expertise to thermodynamics, fluid dynamics and neutronics, reliability and safety analyses for existing NPPs and nuclear facilities, new construction projects, advanced reactor concepts including research reactors, innovative systems and components, model development and validation, fuel supply, enrichment and re-enrichment, fusion technology and its materials, decommissioning and dismantling of NPPs and research reactors, radiation protection and radiological characterization, automation, digitalization and industrialization in dismantling, conditioning of nuclear fuels and radioactive waste, waste management, nuclear transport and storage containers, integrity and behaviour of irradiated nuclear fuels.

For this edition of the KERNTECHNIK, the contributions from the **Young Scientist Workshop** were integrated into the Technical Sessions for the first time. All contributions from the **Technical Sessions** are briefly summarized in the following sections.

Competence and Safety

Dr. Thorsten Hollands
Gesellschaft für Anlagen- und Reaktorsicherheit

Dr. Walter Tromm
Karlsruher Institute for Technology

Dr. Thomas Mull
Framatome

Prof. Dr. Marco K. Koch
Ruhr-Universität Bochum

Florian Krist
Young Generation Kerntechnische Gesellschaft

The Technical Session TS1 *Competence and Safety* consisted of three parts with a total of 17 presentations.

Part 1

The first set of presentations was chaired by **Thorsten Hollands** (Gesellschaft of Anlagen- und Reaktorsicher-heit (GRS)).

The first presentation was held by **Boyu Pan** (RWTH Aachen University) and focused on the preventive improvement of reactor safety through the development of accident-tolerant fuel systems (ATF), in particular zirconium cladding tubes coated with the Cr2AlC which belongs to the MAX phase materials group. The study titled ***A hybrid experimental and numerical investigation on the Cr2AlC-coated zirconium for accident-tolerant fuel systems*** investigated the mechanical properties and failure mechanisms of the coated zirconium cladding tubes by a combination of experimental and numerical methods. The main experimental methods include uniaxial tensile tests, nanoindentation tests and in-situ three-point bending tests carried out in a scanning electron microscope under quasi-static conditions. These tests contribute to the characterization of the mechanical properties and damage development of the Cr2AlC-coated zirconium samples. The results show that cracks in the Cr2AlC coating propagate to the zirconium substrate under mechanical stress. Numerical simulations were per-formed to determine the critical stress and strain variables at the points of crack initiation and propaga-tion. In the study, the Yoon2014 model is used to account for the effect of strength gradient in zirconium and a Weibull distribution is used to predict the probability of fracture. The results show that the maximum principal stress criterion can predict the brittle fracture in the coating, while the modified Bai-Wierzbicki damage model describes the crack propagation in the substrate.

The contribution by **Julia Krieger** (Ruhr-Universität Bochum, PSS) dealt with severe accident analyses in Small Modular Reactors (SMR). In her presentation titled ***Analyses of a postulated severe accident in a generic Small Modular Reactor using AC²***. Ms. Krieger first gave an overview of integral pressurised water reactors as an SMR concept with high probability of realization and presented the specifics of the passive emergency core cooling concept. The analyses were carried out by simulations of a severe accident scenario with the system code package AC². As a result of the postulated rupture of the Chemical and Volume Control System (CVCS) line under station blackout conditions, the system pressure in the RPV drops rapidly, while the pressure in the containment rises due to pressure compensation. In parallel, the coolant level in the RPV drops and the core is exposed, causing it to gradually degrade as the decay heat can no longer be dissipated sufficiently. After approx. 152 min, core melting processes start and after approx. 180 min, molten core material is transferred to the lower reactor plenum. The analyses show that the integrity of the RPV can be maintained.

The presentation ***Simulation of COTELS experiments with AC²-COCOSYS and MELCOR*** by **Maximilian Hoffmann** (Ruhr-Universität Bochum; PSS) dealt with the evaluation of the capability of the AC²-COCOSYS software to simulate flooded molten core concrete interaction (MCCI) in light water reactors based on experiments from the COTELS project. The main objective was to evaluate and improve the AC² model base including comparative simulations with the American simulation code MELCOR. The analysis emphasises the need to adjust the effective heat transfer coefficients in AC²-COCOSYS to accurately simulate the heat transfer from the melt to the top and indicates areas where the model could be improved, particularly with regard to the heat transfer mechanisms caused by a water layer. Key findings from the COTELS C5 and C6 experiments show that AC²-COCOSYS requires parameter adjustments to accurately represent the experimental erosion results. In contrast, MELCOR exhibits larger deviations due to its less flexible parameter adjustments. The experiments show potential model improvements in the simulation of heat transfer and evaporation mechanisms in flooded scenarios and emphasise the need for further research and development.

The presentation given by **Nicole Richter** (Ruhr-Universität Bochum, PSS) focused on the ***Development of a machine learning (ML) model to predict the long-term cooling of debris beds*** that form in the reactor pressure vessel (RPV) during severe nuclear accidents. Ensuring effective cooling of these debris beds is crucial for accident mitigation. Although conventional simulation codes are accurate, they require significant computational resources. The aim of this research is to develop an ML model that reduces the computational effort by predicting the coolability of debris beds, with the dryout time being the most important outcome. Within the analysis, artificial neural networks (ANNs) are used, and various network structures are tested, including simple ANNs, polynomial approximation, Padé approximation and Fourier Neural Operators (FNO). The training data for these models are based on the Dryout experiments of the DEBRIS test facility of the Institute of Nuclear Engineering and Energy Systems (IKE) at the University of Stuttgart and are generated with the 3D detail code COCOMO which is developed by IKE. The initial results show that even simple ML models can accurately predict the dryout time, with the FNO and polynomial approximation models showing the best performance. In general, the results show that these ML models can provide good predictions for new, unseen data, indicating their potential for practical application. Ms. Richter suggests further developments to improve the prediction accuracy and to apply the models to real applications.

The next presentation with the title ***Experimental Investigation of the CHF and Post-Dryout Heat Transfer with R-134a at High Subcritical Pressure*** was held by **Nikolai Rensch** (Karlsruhe Institute of Technology, KIT). Mr. Rensch investigated the critical heat flux (CHF) and heat transfer after drying out with R-134a in a vertical round tube under high subcritical pressures. Therefore, more than 100 CHF and 10,000 post-dryout data points were obtained and analysed. The experiments were conducted at the KIT Model Fluid Facility using a vertical pipe with an inner diameter of 10 mm and a length of 3700 mm. The results show that CHF decreases significantly with increasing pressure, shifting to lower critical quality values. After drying out, two temperature profiles emerge: one with a temperature peak followed by a decrease, indicating increased heat transfer by droplet evaporation at higher mass flows, and another with slow temperature increase after sharp jump, indicating less effective heat transfer. Higher pressures led to lower CHF values and temperature peaks in the post-dryout region, which can be attributed to altered fluid properties. These findings are of particular importance for the safety and efficiency of supercritical nuclear systems, especially in scenarios where pressures fall below critical values.

The last presentation in the first set of presentations titled ***Extension of the AC² program package for the simulation of debris beds in the lower reactor plenum*** was given by **Jan Peschel** (Ruhr-Universität Bochum, PSS). Mr. Peschel outlined in this talk the development of a fast-running computer model for the simulation of debris beds in the lower reactor plenum with the system code package AC². The model is intended to simulate the conversion of molten core material into a porous debris bed due to the interaction of melt and water, considering heat transfer processes and friction-induced pressure losses in single-phase and two-phase flows. The model, which has been integrated in AC², was validated by simulations of experiments of the DEBRIS test series. Mr. Peschel showed based on the results that the developed model DEMON reproduces the thermal behaviour observed in experiments. Its capabilities were demonstrated in the simulation of the cooling phase of bottom flooding experiments with cylindrical stainless-steel particles under conditions up to 1000 K and 0.5 MPa. The model performs comparably well to established models such as those of ASTEC and COCOMO by predicting the thermal behaviour and quench front progression in debris beds. The results showed that it is capable of simulating the thermal behaviour of reflooded, superheated particle beds. Future work will focus on further validation and extension of the model to include radial nodalization and possible remelting of the debris bed.

Part 2

The second set of presentations was chaired by **Thomas Mull** (Framatome).

The first presentation titled ***A-priori assessment of sub-grid scale heat flux modelling in large-eddy simulation for varying Prandtl numbers*** was given by **Magnus Schweiger** (University of the Bundeswehr Munich). Mr. Schweiger presented the methodology of the large-eddy simulation (LES) for sub-grid scale terms for the heat transfer in metal cooled reactor concepts. To evaluate the LES the results of direct numerical simulation (DNS predictions for a horizonal flow between two plates were used. The results show that the Clark's gradient model performs better than the diffusion hypothesis model, but the general performance decreases with increased Prandtl number. Deficits for the gradient diffusion hypothesis model occurred especially in rotation-dominated flow regions. By application a two-dimensional deconvolution formulation parallel to the wall improved the results. As a consequence, the proper near-wall scaling of the sub-grid scale heat flux could be achieved.

In the second presentation **Fabian Wiltschko** (Karlsruhe Institute of Technology, KIT) gave an inside view into heat transfer of supercritical R134a by giving the talk ***Experimental Investigations of the Heat Transfer to Supercritical R134a in Circular Tubes with Rough Surface***. Firstly, he introduced the Model Fluid Facility (KIMOF) at KIT in which the experiments were performed, followed by a description of the methodology of data processing to estimate heat transfer parameters for supercritical R134a. Finally, the developed correlation for the Nusselt number was evaluated against existing correlations. The results of the experiments showed that heat transfer is enhanced for small changes in thermophysical properties, while for small mass fluxes a sharp peak occured for smooth tubes which is damped for rough tubes. For large mass fluxes these peaks are less high for rough surfaces. The assessment of the correlation showed that too many impacts lead to significantly multiple solutions, which indicated potential for further improvement.

As third speaker **Sebastian Leopoldus** (University of Stuttgart, IKE) gave the presentation with the title ***Critical Review of Okawa's Film Flow Model***. He introduced the model of Okawa for film flow and gave three possible improvements of this model to better predict the heat transfer. First, neglecting the film velocity in the interfacial shear force for the derivation of the film thickness. Second, the assumption of a linear dependence between the shear entrainment rate and the film thickness. Third, a more robust calculation using the Weber number and liquid Reynolds number instead of asserting an equilibrium between the shear entrainment rate and the deposition rate for calculating the initial entrained fraction at the onset of annular flow. Mr. Leopoldus concluded that the identified improvement potentials would lead to a more adequate prediction of the film flow. By the modifications an enhanced physical relevance could be offered as well as understanding the complex dynamics involved in annular flow. Based on that further research and validation was recommended.

In the fourth presentation ***Heat Transfer Enhancement for Nucleate Boiling with Microlayer Evaporation on Micro-pillar Arrayed Surface*** given by **Jinming Zhang** (Helmholtz-Zentrum Dresden-Rossendorf, HZDR) firstly the numerical method using the PHASTA solver was described to predict two-phase flow and heat transfer. The DNS simulations are able to predict the microlayer formation and evaporation under consideration of the bubble growth based on local temperature gradients. Mr. Zhang presented that three different microlayer morphologies could be observed: the undisturbed microlayer, the disturbed microlayer and the disrupted microlayer. In the DNS simulations different dependencies for these morphologies could be identified. These dependencies gave a detailed inside into the mechanisms of enhanced heat transfer by the structure of the surface in nucleate boiling. Finally, he proposed x-ray supported experiments to evaluate the findings of the DNS simulations.

The fifth contribution to this session titled ***Effect of Bulk Condensation on Containment Atmosphere Mixing*** was given by **Allen George** (Forschungszentrum Jülich). After introduction of the necessity of bulk condensation in the containment for safety issues like pressurization the methodology for the simulation with OpenFOAM-based 'containmentFOAM' CFD package was shown. The focus was on the modelling of phase change, fog transport and population balance. Mr. Allen also pointed out the importance of model verification and validation against suitable experiments. The results of the validation of the model improvements/implementation against THAI HM-2 show the impact of bulk condensation on e.g. the density change because of the latent heat release and the mixture composition change. In contrast to wall condensation the effect bulk condensation on water/steam balance was smaller. Finally, Mr. Allen concluded that the implementation is efficient and robust in the used CFD approach which could be used for more application-oriented cases.

Gürel Özesme (Karlsruhe Institute of Technology, KIT) gave the last presentation of the session with the title ***Impact of the boundary conditions and buoyancy on turbulent heat transfer at supercritical pressure: LES study***. Firstly, the specialties of the material properties and their changes for supercritical pressure and their impact on the heat transfer were pointed out. To investigate these changes and impact in case of a horizontal flow large-eddy simulations (LES) were carried out and compared to direct numerical simulations (DNS). The results show that LES can qualitatively and with some deviations quantitatively reproduce the results of the DNS simulations. Mr. Özesme concluded that for supercritical flows numerical experiments can support the understanding of the turbulent heat transfer. For further work the application of real geometries of components was identified.

Part 3

The third set of presentations was chaired by **Florian Krist** (Young Generation Kerntechnische Gesellschaft) and **Thomas Mull** (Framatome).

The first presentation titled ***Sustainable development of CFD software for the modelling of reactor cooling circuits*** was given by **Ronald Lehnigk** (Helmholtz-Zentrum Dresden-Rossendorf, HZDR). Mr. Lehnigk started recapitulating that computer codes, particularly CFD codes, are becoming more and more important for investigations into reactor safety research. A well-recognized CFD tool is the open-source software provided by the OpenFOAM Foundation. For such open-source codes in the context of reactor safety research, quality assurance plays a basic and pivotal role. All code extensions from different sources must be kept compatible with updates and the whole, permanently growing code system must be subject to continuous validation. To this end, in Germany Helmholtz's Federate IT Services have provided the GitLab Authority "Helmholtz Codebase". The processes on the basis of which it is working for were described. This platform offers various software installation options, which are suitable for a variety of end user systems.

The second contribution dealt with the assessment of external impact onto buried infrastructures in the context of modern concepts for nuclear facilities to be located completely or partly underground. **Lars Heibges** (RPTU University of Kaiserslautern-Landau) reported on ***Numerical and empirical approaches to quantify the protective effect of soil***. He analysed different guidelines and standards for the assessment of projectile impact into soil. Then he compared the different approaches, the results of which are scattering significantly, to current experimental test data and presented own numerical investigations. In order to properly model key nonlinear effects he developed a novel combined solution using a discrete element method (DEM) for the soil and a finite element method (FEM) for the projectile. His combined model provides realistic estimations for the penetration depths and hence leads to proper assessment for the protective effect from the soil.

Third speaker was **Lukas Helm** (RPTU University of Kaiserslautern-Landau). He presented a ***Comparative Analysis of Direct Methods for Deriving Floor Response Spectra*** from Ground Response Spectra in the context of nuclear facilities seismic safety. There are two main approaches to calculate floor response spectra, time-history analysis and direct calculation from ground response spectra. Mr. Helm's study compared different methods for the calculation of such floor response spectra with the spectra-to-spectra method, including the present European and German standards as well as an approach of Yasui et al. from 1993. The comparison was accompanied by numerical simulations and revealed significant differences. The results contribute to the understanding of the applicability of the direct calculation method in the seismic analysis of structural systems. The Yasui approach leads to results which are closest to those of numerical calculations but they overestimate maximum amplitudes in the resonance region significantly. The author recommended further investigation and analysis.

Lars Ackermann (Framatome) reported on ***Optimizing Shielding Fuel Assembly Design***. A major limiting parameter for extension of the lifetime of many NPPs is the neutron fluence of the reactor pressure vessel. Moreover, new requirements on flanges may require including them into corresponding neutron flux management considerations. Framatome's shielding fuel assemblies reduce the neutron flux in critical locations, while the reactor power can be kept at full level or even be increased. The shielding effect is generally achieved by replacing outside-oriented fuel rods (or parts of them) by rods (or rod parts) with non-fissile material. Several years of experience and a corresponding evolution of shielding fuel assembly designs allow customization and optimization of the shielding factor and correspondingly of the operation flexibility. Modifications in radial and axial design as well as different levels of enrichment are key features of this solution. Locally, factors of 5 to 7 can easily be achieved today and for both, design and licensing there is plenty of experience.

Bruno Miglierini (Framatome), last speaker in this last part of session TS1, presented the state of the art of the ***Development of VVER Fuel Engineering Services at Framatome***. In the frame of the diversification of the VVER fuel market, Western vendors are developing sovereign and independent solutions for this particular nuclear fuel design. Framatome has been developing corresponding fuel engineering services, too. The development of VVER fuel engineering services is progressing based on variousEuropean respectively in-house calculation codes and advanced methodological approaches. The deployment of these capabilities also enables their use for back-end activities such as decay heat calculation, fissile material composition assessment and the analysis of thermo-mechanical fuel rod behaviour during dry storage. Mr. Miglierini described several applications, comprising full core simulation including neutronics, thermal hydraulics and thermomechanics, fuel assembly bow predictions and others.

International Trends and Development

Dr. Kai Kosowski
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Dr. Andreas Schaffrath
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Dr. Tatiana Salnikova
Framatome

Dr. Walter Tromm
Karlsruher Institute for Technology

The session *International Trends and Developments* consisted of two parts with six presentations each. Both parts were well attended, with between 50 and 100 participants, and provided interesting topics.

The first set of presentations was chaired by **Andreas Schaffrath** (Gesellschaft für Anlagen und Reaktorsicherheit (GRS)) and **Walter Tromm** (Karlsruhe Institute of Technology, KIT) and dealt with Micro- (MMR) and Motel Salt Reactors (MSR). The second set of presentations was chaired by **Kai Kosowski** (Preussen Elektra) and **Tatiana Salnikova** (Framatome) and dealt with new, innovative nuclear technologies and trends. Below a summary of the content of all twelve contributions is given.

Part 1

Andreas Schaffrath (Gesellschaft für Anlagen und Reaktorsicherheit (GRS)) und **Jörg Starflinger** (University of Stuttgart, IKE) opened the first set of presentations with an overview lecture titled ***Development and validation of a calculation chain for the simulation of so-called Micro Modular Reactors***. Here the structure and first results of the research alliance MISHA (Modelling of Innovative Micro Modular Reactors (MMRs) with potassium filled Heat Pipes with the nuclear simulation chain of GRS) were presented. This alliance if funded by the Federal Ministry of Education and Research (BMBF) and will enable the two project partners to carry out own independent safety analyses of MMRs and to evaluate their safety concept and risks during operation and transport. The background of this project is, that MMRs are currently being developed in various countries to replace diesel generators in both, civilian and military contexts. MMR designs can be transported by trucks, ships and a irplanes and can be set up and put into operation, shut down, dismantled and transported to other locations in just a few days. Transport through German territory (e.g. airspace) or operation in the immediate vicinity of Germany is a plausible scenario in the medium term. As incidents and accidents cannot be excluded, independent national expertise is required to evaluate these designs. In the frame of this research alliance four PhD thesis (two at IKE and GRS each) shall be created in which open key issues relating these reactors are addressed and resolved. This includes inter alia neutron kinetic of the core and necessary improvements and validation of the GRS code FENNECS, the improvement of the thermohydraulic code ATHLET as part of the AC² code system, the construction, manufacturing and testing of potassium heat pipes and the ATHLET improvements of simulation of air and supercritical cooling loops. Each of these previously mentioned topics was deepened in a further presentation or poster session.

Subsequently, **Norman Dünne** (University of Stuttgart, IKE) reported on the ***Neutronic modelling of the Special Purpose Reactor MMR with SERPENT as a part of the MISHA project***. Mr. Dünne created a detailed model of the Los Alamos National Laboratory (LANL) Special Purpose Reactor (SPR) in SERPENT. Afterwards the model was tested for several con-figurations of the control drums as well as the central control rods and results were compared with com-putational results published by the Idaho National Laboratory (INL) for the same cases INL. While reactivity values for the case 'all poisons out' agree well with the INL results, whereas the cases applying the absorber objects showed comparatively larger deviations. Especially the control drums prove to be challenging to model accurately, resulting in signifi-cantly increased reactivity and reduced shut-down margins. However, the reactivity remains below the de-sired margin of 5% stated by INL. Mr. Dünne continued that the macroscopic cross-sections calculated with this model will be used in further simulations with the codes FENNECS and ATHLET as part of the MISHA project and that the results obtained from SERPENT will be used as reference data for core parameters.

Ruggero Meucci (University of Stuttgart, IKE) presented in ***Advancing Micro Modular Reactor Safety: Experimental analysis on Liquid Metal Heat Pipe Prototypes in the MISHA Project*** first results of constructing and testing full-size nuclear-grade high-temperature heat pipes and a Heat Pipe Tester (HPT). The HPT, designed with modular flexibility, facilitates testing of heat pipes of varying lengths and diameters under different conditions, enabling comprehensive performance evaluation and advancing the understanding of heat pipe efficiency in diverse applications. All materials needed for their construction have been procured and the assembly process is ongoing. The HPT design make possible to set working temperatures or working linear heat flows, while providing a suitable cooling on the condensation side and a continuous estimation of thermal losses along the tester. Once operative the HPT will enable to record the heat transport performances of multiple heat pipes at different working temperatures, at different tilting angles and with longer or shorter evaporation and condensation zones. In short, a wide range of experiments will be possible in which the limits of various heat pipes can be reached safely. Also, the realization of three heat pipe prototypes will make possible to assess the efficiency of well-known wick structures in applications that require long heat pipes.

Jakub Bronik (University of Stuttgart, IKE) provided an overview about his own ***Experimental investigation of the heat transfer at and post critical heat flux in CO_2 flow at high subcritical pressures***. Basically, supercritical fluids, such as water or CO_2, have promising properties for advanced nuclear reactor systems. For the safety assessment of thermohydraulic systems using these fluids, a deep understanding of heat transfer in the transcritical pressure range is crucial, especially during startup, shutdown, or loss-of-coolant accidents. Despite extensive research at reduced pressures below $pr = p/p_{crit} = 0.7$, data above this ratio up to the pseudocritical pressure is limited. A comprehensive experimental study was conducted by Mr. Bronik at the SCARLETT facility, focusing on critical heat flux (CHF) and post-CHF heat transfer characteristics of CO_2. Two 2-meter-long tubular test sections with 6 or 10 mm diameter and detailed instrumentation yielded results under vertical upward flow conditions, providing data for dry-out and departure from nucleate boiling mechanisms, CHF limits, and post-CHF heat transfer coefficients. The transition from bubble boiling to film boiling was observed, causing a significant rise in wall temperature. While from experiments in 6 mm pipes at different pressures revealed an approximately linear correlation between CHF and mass flux, the experiments in the 10 mm pipe showed slowed increase. In 10 mm pipes, CHF performance at $pr = 0.8$ surpassed that at $pr = 0.7$.

The next two presentations dealt with so-called Molten Salt Reactors (MSRs). First **Marco Viebach** (Technical University of Dresden, WKET) lectured on ***NAUTILUS: Experimental Methods for investi- gating innovative approaches to nuclear waste***. The project aims to contribute to the understanding of innovative approaches to nuclear waste management and reactor safety. For this purpose, the Research and Training Reactor AKR-2 at TU Dresden is used to develop experimental methods to determine nuclear data, which involve spectrum measurement, the pile oscillator and neutron transmission. Focusing on chloride base molten salt fast reactors, these methods will be used to investigate the cross sections of chlorine and the impact of an enrichment in chlorine-37. The gained data is used in downstream simulations of these reactors to elaborate on the meaningfulness and the safety of the operation of these reactors as nuclear waste burners.

Last **Wilfried Hahn** (Copenhagen Atomics) presented a concept of a ***Thorium molten salt Reactor as Breeder***. According to his explanations the goal is to be able to construct one reactor per day. Copenhagen Atomics (CA) assumed energy prices of 2 cents per kwh in serial production and small materials use. CA's business model envisages financing, building, owning, operating the reactors on the customer site and decommissioning. Blanket salt, fuel salt, heavy water and the outer cocoon of the so-called onion core can be used for 50 years or more. The materials inside the reactor core get damaged by neutrons and corrosive salt and will be replaced every 5 years. This reactor can also use waste from classical nuclear reactors and get 10 times more out of their spent nuclear fuel than what the first reactor was able to extract. The waste left behind needs to be stored above ground for 300 years vs. 100.000 years of expensive deep geological storage for the traditional waste.

Part 2

In the first contribution of second set of presentations, **Robert Altschaffel** (Otto-von-Guericke University of Magdeburg, ITI) addressed the growing threat of cyber-attacks in his presentation ***Fingerprints of the network behavior of control technology for the evaluation of safety mechanisms*** and described the difficulties in evaluating safety related systems. His approach aimed at using synthetically generated network traffic for evaluation purposes with dummy data segments that have no harmful effects. The presentation provided conceptual ideas for generating a comprehensive, plant-specific pattern of communication within a control system.

In the second contribution of the session, the topic of cyber-attacks was addressed again, but from a different perspective. In the presentation ***Machine learning in nuclear industries: anomaly detection***, **Romarick Yatagha** (Framatome) explained to what extent artificial intelligence (AI) systems can be used also in the field of nuclear technology and what potential they must have. Improving the efficiency of monitoring systems is one aspect, but trust in AI is the fundamental prerequisite for implementation in security systems of critical infrastructure, stated the young scientist. Using an example of a small test rig with several liquid tanks, pipes, valves and sensors, he described what contribution machine learning can make in terms of detecting anomalies in physical systems caused by insider threats and/or from external cyber-attacks. The study showcased a novel model for detecting anomalies in physical systems with cyclical processes, emphasizing the importance of explainable AI in ensuring comprehensibility and trustworthiness of AI systems among operators.

The next contribution dealt with cyber-attacks as well, but from the perspective of preventive measures. It examines the question of how to avoid manipulation at replaceable hardware. **Erkin Kirdan** (Framatome) presented in his talk ***Detectiv physical controls for NPPs, interim storage*** an innovative security solution that protects hardware components of instrumentation and control systems, such as plug-in cards in switch cabinets, against manipulation by using tamper-proof stickers. The risk of unauthorized physical replacement of plug-in cards is reduced and the associated possible introduction of cyber malware into the instrumentation and control systems of facilities of the critical infrastructure can be avoided preventively. General overall safety and operational reliability are improved.

In the fourth presentation of this session, we left the topic of cyber security and focused on components. In the presentation ***Additive manufacturing – innovative manufacturing process! Revolutionary component manufacturing in nuclear technology?***, **David Lauer** (KSB) illustrated new possibilities for manufacturing using 3D printing processes. Beside the challenges involved in qualifying components, he reported current applications, advantages and future prospects of additive manufacturing in the context of nuclear applications. This new type of manufacturing technology has great potential to change component manufacturing in nuclear technology.

In the fifth presentation, we left the technology behind and devoted attention to regulatory issues. In his presentation, **Christian Raetzke** (independent lawyer) examined the ***Challenge of regulating SMRs*** from a legal perspective. SMRs offer the prospect of opening areas of application that have previously been closed to nuclear energy. However, the basic approach, according to which these reactors are to be built both modularly and in a standardized manner in factories and only assembled on site, is probably the greatest challenge. Standardization of the design and an abandonment of having to conduct new licensing procedures in each country is essential for such a concept. Therefore, harmonization of national requirements and the introduction of an internationally recognized operating license are of crucial importance.

In the last contribution of this session, ***Laser-based nuclear fusion and a spin-off technology for non-destructive intermediate level nuclear waste container inspection***, **Marc Zimmer** (Focused Energy) took the audience on a journey into the nuclear fusion, specifically laser-driven inertial confinement fusion. On the path of investigation and research for solutions for a fusion power plant, technologies developed so far can be used nowadays to drive innovations apart from the original goal "fusion power generation". One of this spin-off technologies are laser-driven radiation sources. Dissociated from fusion research, this laser-driven technology enables the non-destructive testing and characterization of heavily shielded objects such as containers for low and medium-level radioactive waste.

Decommissioning & Waste Treatment

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The session *Decommissioning & Waste Treatment* was moderated by **Anke Traichel** (EWN), **Frank Apel** (KTG) and **Thomas Seipolt** (NUKEM) in alternating compositions.

Part 1

The technical sessions about *Decommissioning & Waste Treatment* within the nuclear engineering tasks were kicked off by **Hans-Georg Willschütz** (PreussenElektra) giving a presentation on ***Steps towards releasing the containment vessel in KKS***. Here, Mr Willschütz outlines the final steps taken by the Stade Nuclear Power Plant (KKS), which was shut down in 2003, on the way to being released from the German Atomgesetz. A key part of this process is the preparation of radiological clearance of the containment vessel and all other components remaining in the reactor building until conventional demolition, as well as the approval of clearance in accordance with the German Strahlenschutzverordnung. A specific procedure was developed for the particular situation in the KKS and special technical solutions were applied which made it possible to carry out inspections, cleaning and stripping work as well as measurements at great heights and in large, narrow gaps. The presentation illustrated the initial situation in KKS, the procedure and the specific technical solutions used along the way. These included, among other things: the dismantling of the entire building structures within the containment. In parallel, the so-called „standard" building decontamination and clearance (German acronym GeDuF) took place. Following this, the demolition of the two former control area buildings will be applied for. In summary, the current measurements show that these building structures are ready for clearance.

The next contribution was presented by **Bastian Weinhorst** (Safetec). Under the title ***Material clearance measurement under the influence of naturally occurring radioactive material***, a study was carried out on the application of the simulation software SIStec for large clearance monitors (LCM). A novel approach was presented to consider the contribution of naturally occurring radioactive nuclides (NORM) when analysing measurements by an LCM. The combination of functions of the software used enables an accurate estimation of the NORM contribution and thus the residual activity due to contamination or activation of the material. This is particularly important during the decommissioning of nuclear power plants, which entails a large amount of material that must be disposed of, released, or permanently stored. For