Institute for Nuclear and Energy Technologies

Structure and Laboratories of the Institute of Nuclear and Energy Technologies

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The Institute for Nuclear and Energy Technologies (IKET) is situated with its offices and research laboratories in Campus North of Karlsruhe Institute of Technology (KIT).

The research of IKET focuses on conversion from thermal power to electric power for future power plants without CO2 emission, on hydrogen technologies for energy storage and on safety. Traditionally, nuclear power plants, for which IKET concentrates on their safety features and on methods to mitigate severe accidents, were in the focus of investigation. IKET uses its competence, gained from a profound experience in numerical simulation and in design and operation of large-scale experimental facilities to apply this knowledge more and more in the area of renewable energies.

The combination of science and technology with education and training is a systematic approach at KIT, and IKET is contributing accordingly to courses in mechanical engineering, supervises several bachelor and master theses each year and coordinates master programs in energy technologies. Compact courses on energy technologies are given also in executive master programs and in the Framatome Professional School, which is funded by industry and managed by IKET.

Resources

The employees of IKET contribute in the research field energy of the Helmholtz Association (HGF) to the research-programs Nuclear Waste Management, Safety and Radiation Research (NUSAFE), Fusion (FUSION), Renewable Energies (EE) as well as Storage and Cross-linked Infrastructures (SCI), with a focus on NUSAFE. By the end of 2019, around 75 scientists, engineers and technicians have been working at IKET on this wide range of CO_2-free technologies for energy conversion. Fig. 1 illustrates that more than half of the IKET employees were still working for the NUSAFE program, despite the German phase-out decision, but in accordance with the German energy politics and the 7th Energy Research Program of the German Federal Government. Around two third of the employees were funded in 2019 by the Helmholtz Association (HGF), the others by third party funds of the European Commission, by industry, by German ministries or by other research funds. Doctoral students as well as students of the Baden-Wuerttemberg Cooperative State University (DHBW) were filling around 20% of these positions at IKET. In addition, students perform their bachelor or master theses or spend an internship in the research laboratories of IKET.

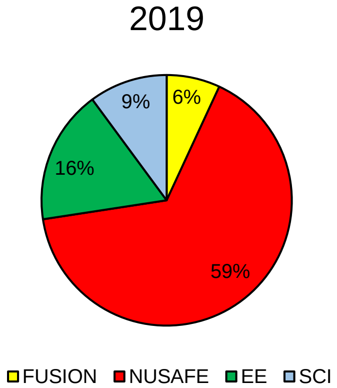

Figure 1: Assignment of IKET personnel to HGF programs.

An overview of the structure of IKET is given by the organization chart, Fig. 2. Each working group is acting in close collaboration with the other groups, particularly in its own research program.

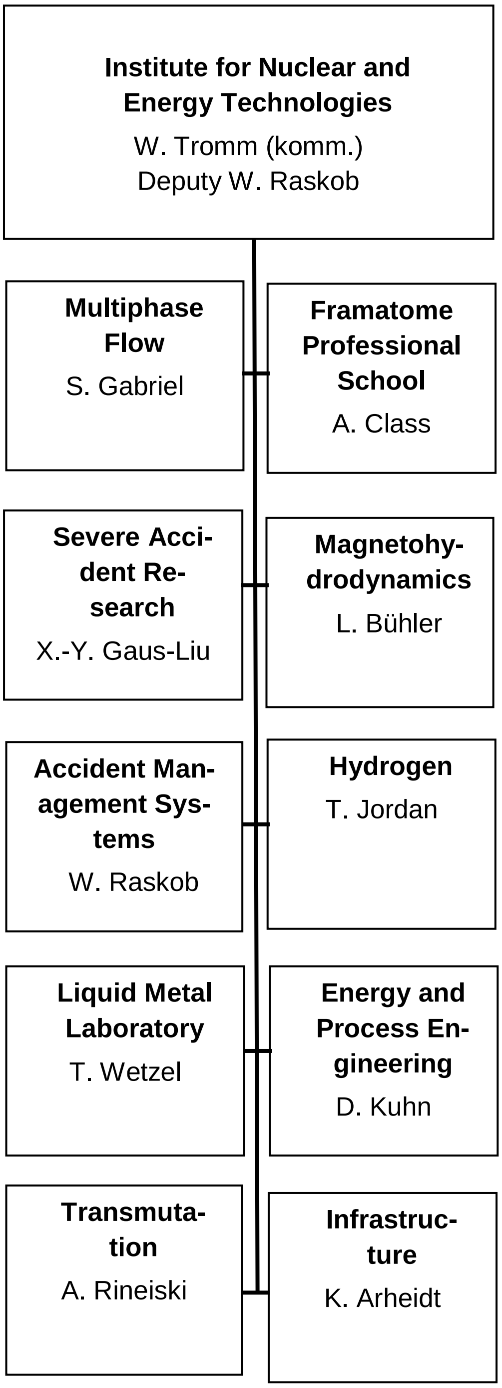

Figure 2: Organization chart of the Institute for Nuclear and Energy Technologies

Working groups on Severe Accident Research, and on Transmutation as well as the Framatome Professional School have been concentrating in 2019 primarily on nuclear applications, whereas the Karlsruhe Liquid Metal Laboratory (KALLA) and the Hydrogen group were addressing nuclear as well as renewable energy technologies. The working group on Magneto-Hydrodynamics is primarily working on nuclear fusion applications, whereas the working group on Energy and Process Engineering is rather concentrating on geothermal energies. The working group Multiphase Flows is mainly experimentally investigating technically relevant, complex flow phenomena. The field of activity currently comprises mainly the complex structure of the COSMOS-H high-pressure loop. The working group on Accident Management Systems continued to extend the application of its simulation models to several critical infrastructures. Thus, the institute covers a wide field of different energy technologies, and the share of its personnel resources on the different research topics reflects the requirements of the Helmholtz Association's energy research field.

They are all supported by a joint infrastructure, comprising a metal workshop, manufacturing urgent test components, a welding shop, and an electromechanical workshop. Other tasks of the infrastructure include the IT-administration, business administration and public website of the IKET. The Infrastructure team is active as well in education and training activities.

Every year, at least four students of the Baden-Württemberg Cooperative State University are employed by IKET, managed by the Infrastructure group, to work with the research teams as part of their educational program.

Working in a research area with industrial application IKET practices a Quality Management System appropriate to EN ISO 9001.

International Research Projects

Most studies performed at IKET are embedded in international research projects. A few extraordinary highlights for 2019 are given below:

Highlight: Hydrogen group: HyTunnel-CS

The Hydrogen group is strongly involved in the HyTunnel-CS project. The aim of the HyTunnel-CS project is to perform pre-normative research for safety of hydrogen driven vehicles and transport through tunnels and similar confined spaces. The main ambition is to facilitate hydrogen vehicles entering underground traffic systems at risk below or the same as for fossil fuel transport. The specific objectives are: critical analysis of effectiveness of conventional safety measures for hydrogen incidents; generation of unique experimental data using the best European hydrogen safety research facilities and three real tunnels; understanding of relevant physics to underpin the advancement of hydrogen safety engineering; innovative explosion and fire prevention and mitigation strategies; new validated CFD and FE models for consequences analysis; new engineering correlations for novel quantitative risk assessment methodology tailored for tunnels and underground parking; harmonised recommendations for intervention strategies and tactics for first responders; recommendations for inherently safer use of hydrogen vehicles in underground transportation systems; recommendations for RCS.

The objectives will be achieved by conducting inter-disciplinary and inter-sectoral research by a carefully built consortium of academia, emergency services, research and standard development organisations, who have extensive experience from work on hydrogen safety and safety in tunnels and other confined spaces. The complementarities and synergies of theoretical, numerical and experimental research will be used to close knowledge gaps and resolve technological bottlenecks in safe use of hydrogen in confined spaces. The project outcomes will be reflected in appropriate recommendations, models and correlations. HyTunnel-CS will reduce over-conservatism, increase efficiency of installed safety equipment and systems to save costs of underground traffic systems.

The 1st progress meeting was hosted in Karlsruhe by the Hydrogen working group on the 11th-13th September 2019.

Figure 3: HyTunnel-CS consortium and SAB members at the 1st progress meeting in Karlsruhe, 13th September 2019.

Highlight UNF: CONFIDENCE

First of January 2017, the CONFIDENCE (COping with uNcertainties For Improved modelling and DEcision making in Nuclear emergenCiEs) project started as Task 9.1 of the H2020 project CONCERT. The project focuses on identifying and reducing uncertainties in the release and post-release phases of an emergency. The latter includes the transition between the short-term post-release and recovery phases (e.g. the first year(s)). The group emergency management (UNF) coordinated CONFIDENCE. The scientific challenges were addressed though six interlinked work packages (WP), with an additional E&T WP. UNF also contributed to several work packages and coordinated WP6.

Besides the improved Multi Criteria Decision Analysis tool described in this report, UNF was heavily engaged in enhancing the decision support system JRODOS for nuclear and radiological emergencies to deal with uncertain input of weather and source term. In this respect, JRODOS was extended by an ensemble generator and an ensemble visualisation engine (ensemble approach means realisation of a state by many simulations with slightly different initial conditions). A typical application case consists of an ensemble of 20 weather files and 3 source terms (realistic, worst and optimistic case) with their probabilities of occurrence. The resulting 60 scenarios are processed in one project and stored individually. In a second step and evaluation module allows visualising probability functions of interesting results such as areas of early countermeasures. The percentiles represent probability that a grid point is affected by a particular countermeasure. The 50% percentile means that in our example with 60 cases, 30 result in a countermeasure at that location. Visualisation is still an issue that needs further discussion with decision makers. Colour tables of the visualisation can be adapted by the user

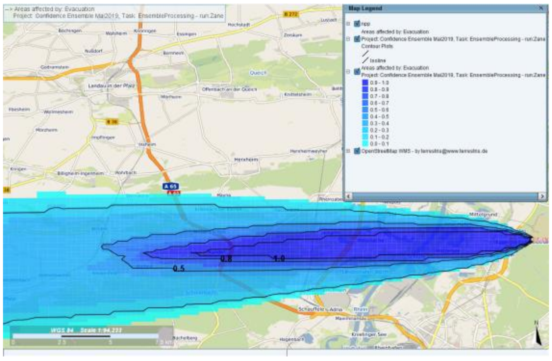

Figure 4: Map from the JRODOS ensemble processor for ensemble runs with blue colour table and added contour plots separating areas with fraction borders of 1, 0.8, 0.5 and 0.2

Future research will concentrate on the testing of the ensemble approach in particular related to operational applications, communicating to decision makers and lay people as well as comparing different weather providers with each other. There is one important question not resolved: Do the numerical weather prediction ensemble really represent the uncertainty of the weather?

Highlight KALLA working group:

Liquid metals are tested as heat transfer fluids in concentrating solar power systems in the SOMMER test facility (Fig. 1) at Karlsruhe Liquid Metal Laboratory KALLA. The excellent heat transfer properties of liquid metals allow building more compact and efficient receivers. The thermal receiver tubes in the focal point, which are heated by the concentrated solar power, can be cooled more efficiently than with the currently used molten salt mixture. In the SOMMER loop, the liquid lead-bismuth eutectic (LBE) is pumped through the spiral thermal receiver and is afterwards cooled down in an air cooler to enter the pump again. In 2019, experiments under sunlight conditions with heat flux densities of up to 4 MW/m² have been successfully performed in the SOMMER test facility. It was demonstrated that liquid metal can be handled under varying conditions and can efficiently cool the receiver pipes at extremely high heat flux densities.

Figure 5: SOMMER test facility; left: parabolic mirror; right: liquid metal loop with thermal receiver in the focal point (Foto: F. Fellmoser)

Hydrogen from Natural gas without CO2 Emissions

Figure 6: Methane pyrolysis by means of a bubble column reactor allows for the climate-friendly use of fossil natural gas.

In the current energy debate, hydrogen is increasingly considered a key to the success of the energy transition. Hydrogen is a clean source of energy and can be used for the production of electricity and heat and in the mobility sector or in industrial processes, such as for the production of steel. Experts of the International Energy Agency IEA calculated that admixture of 20% of hydrogen in the European gas grid could reduce CO2 emissions by 60 million tons per year. This corresponds to about the amount emitted by Denmark in a whole year.

Direct thermal cracking of methane and other hydrocarbons can be a way to produce hydrogen from natural gas without direct CO2 emissions. For this purpose, the KALLA team, in cooperation with the Institute for Advanced Sustainability Studies e.V. in Potsdam, started developing a process for the continuous decomposition of methane in a bubble column reactor filled with liquid metal to produce hydrogen and solid carbon some years ago. They continued research on the technology over the last years and have entered into a joint project with the industry partner WintershallDea in 2019, to further advance this technology towards use in industry.

Highlight SAR-group: JIMEC experiments for the EU-Project ESFR-SMART

To increase public acceptance of nuclear power in Europe and secure its future role, the significantly higher safety of new reactors compared to traditional reactors has to be demonstrated. The 4-year ESFR-SMART project (European Sodium Fast Reactor Safety Measures Assessment and Research Tools), launched in September 2017 aims to enhance the safety of Generation-IV Sodium Fast Reactors (SFR), in particular the commercial-size European Sodium Fast Reactor (ESFR).

In course of a less probable accident that a corium pool builds up in the core region, dedicated corium relocation measures with Corium Transfer Tubes will minimise the core melt mass in the core region to avoid recriticality.

A great safety concern in this case is the impingement of a high-temperature and high-momentum corium jet on the metallic core catcher material. Although both oxide corium and metallic corium can be relocated, metallic corium is considered to be more crucial on the core catcher ablation process due to its low solidifying temperature and therefore the less potential to build up a protecting crust layer.

The JIMEC (Jet Impingment on Metallic Core-catcher) tests performed by the Severe Accident Group (SAR) of IKET provided prototypical experimental data to quantify the risk. JIMEC tests are designed firstly to create a metallic jet with stainless steel composition and with designed superheat and fall height; and secondly to record the ablation process of a 40 cm thick substrate of the same material composition as the jet. The mass of the metallic melt is 1000 kg, and the jet velocity at the substrate surface is about 5 m/s.

The prototypical test data provided insights to a wide application range within and also beyond the nuclear safety research.

The main conclusion of the experiments is that the ablation process slows down after the melt jet mass was firstly retained in the molten pool inside the ablated pit. The ablation velocity before and after this event was constant with an ablation velocity of less than 2 cm/s before and slowed down afterwards to less than 1 cm/s. This effect could be called “pool effect”, which means that the deep melt pool prevents the direct energetic contact of the melt at the pit bottom.

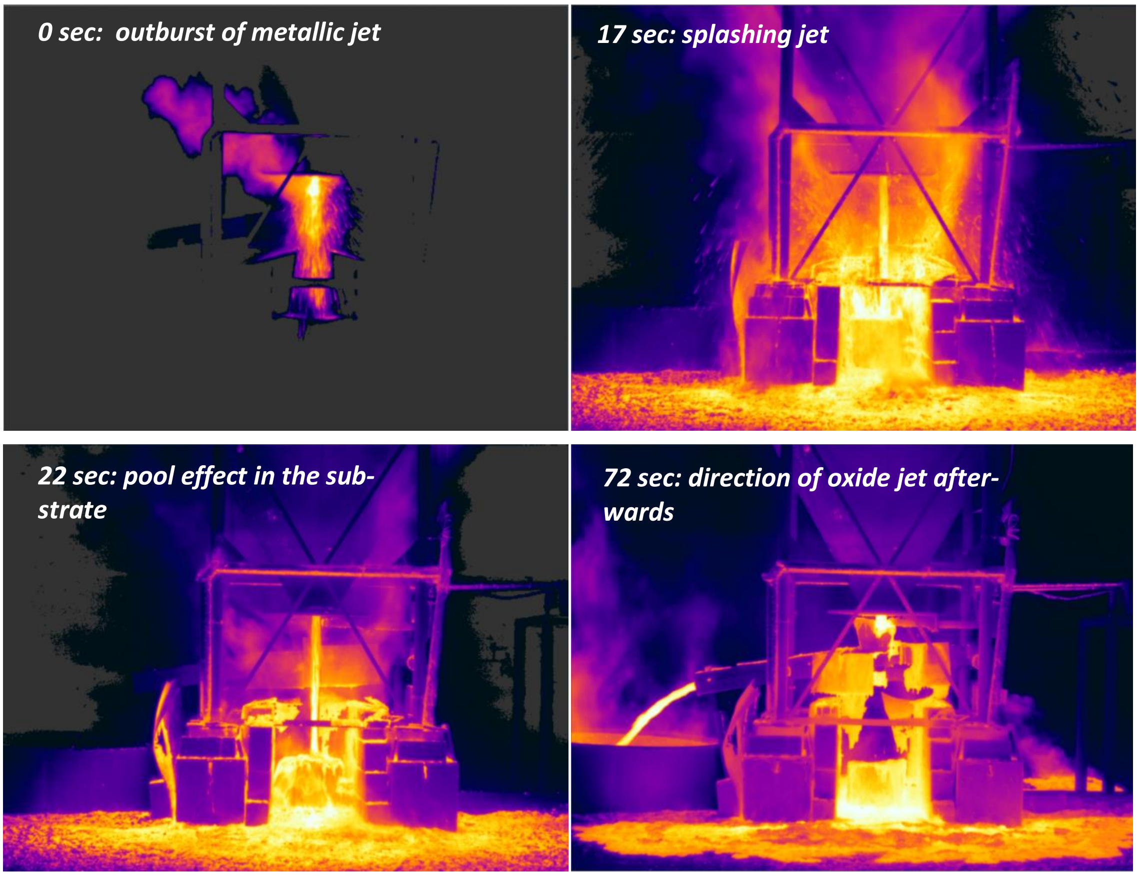

Figure 7: shows the impingement of a 40 mm diameter steel jet on a steel substrate: on the top, the jet has direct contact with the substrate during the initial period, while at the bottom, the jet falls into a molten pool and reduces its ablation effect after a certain depth reached in the ablated pit

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