Institute for Nuclear and Energy Technologies

Structure and Laboratories of the Institute for Nuclear and Energy Technologies

Thomas Schulenberg

The Institute for Nuclear and Energy Technologies (IKET) at KIT addresses selected problems of energy conversion from thermal power to electric power for future power plants, which shall not emit CO_2. Traditionally, these were nuclear power plants, for which IKET concentrates primarily on their safety features and on methods to mitigate severe accidents. Motivated by the nuclear accident in Fukushima, a focus of the research topics within recent years was on the retention of core melt inside the reactor vessel and inside the containment to prevent other power plants from running into similar catastrophes. In its working group on Severe Accident Research, IKET is operating a test facility LIVE for core melt retention inside the vessel, using molten salts to simulate a corium pool in the lower plenum. Fig. 1 shows a view into the open test facility with an inner diameter of 1 m, representing the lower plenum of a reactor. Hot, molten salt can be poured into this vessel, and concentric electric heaters simulate the residual heat of the core melt. The facility can be cooled from outside, such that the melt solidifies to a protecting crust at the vessel walls.

Fig. 1: View into the open test facility LIVE for in-vessel melt retention experiments.

The MOCKA facility, shown Fig. 2, is simulating the interaction of molten corium with concrete inside the containment, using molten zirconium and thermite at realistic temperature and viscosity. The working group on Severe Accident Research is performing these spectacular tests outside, avoiding the risk of hydrogen detonations arising from the decomposition of concrete. Here, the residual heat is added as chemical heat by dropping additional thermite into the test crucible, using the supply system as indicated in Fig. 2. Tests have been performed with different kinds of concrete, with and without rebar, giving the design of future core catchers a solid technical basis.

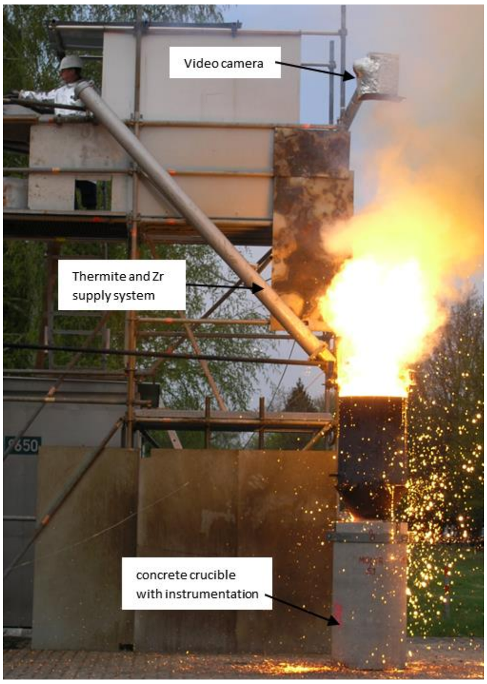

Fig. 2: MOCKA test of molten corium interaction with concrete

For off-site emergency management, the working group on Accident Management Systems is developing and deploying the decision support system JRODOS, which became the most accepted information system for off-site nuclear emergency management today. Fig. 3 shows a screen shot of the information, which may be given to civil protection organizations in case of a release of radioactive material from a nuclear facility. Colors indicate regions, where an increased gamma dose rate will have to be expected within the next hours, such that evacuation plans or other risk mitigation action can be decided. JRODOS is installed today in 20 European countries and in Asia, expanding its applications every year.

The methodology has been applied meanwhile also to other hazards with severe potential consequences on public health or on the resilience of critical infrastructures in case of a breakdown of power supply.

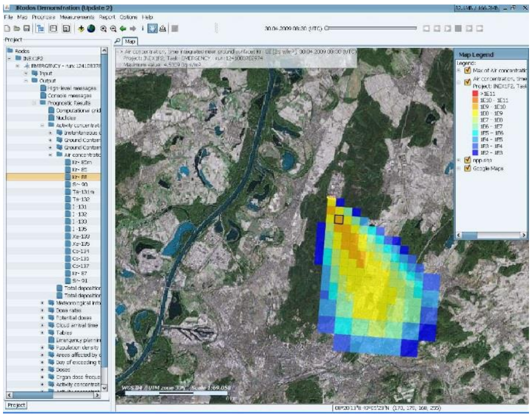

Fig. 3: Total effective gamma dose rate, predicted after a fictive nuclear accident (JRODOS screen shot)

Besides water-cooled reactors, IKET has been looking as well at innovative nuclear energy systems, either designed for a closed nuclear fuel cycle or for transmutation of spent fuel, both indicating potential alternatives to direct nuclear waste disposal. In this context, generic tests of reactor components for the lead-bismuth cooled research facility MYRRHA, to be built in Belgium, are performed in the THEADES test facility of the Liquid Metal Laboratory KALLA at IKET, shown in Fig. 4. Up to 40 tons of liquid PbBi can be operated there in a large loop at temperatures up to 400°C to test realistically the mock-up of future nuclear reactor components. The PbBi loop CORRIDA, situated next to the THEADES loop, is operated at elevated temperatures up to 550°C, testing material samples for the Institute for Applied Materials at KIT. In addition, a loop with liquid sodium and one with liquid lead are ready for operation in the same laboratory, providing a comprehensive research infrastructure for all kinds of liquid metal experiments.

Fig. 4: Look into the Liquid Metal Laboratory KALLA with its THEADES test loop.

In its Transmutation group, IKET is studying several severe accident scenarios of liquid metal cooled reactors, which are simulated numerically with the SIMMER code in international collaboration. The Institute could thus keep a wider range of nuclear expertise, including advanced neutron physics and reactor kinetics, which is still well recognized in Europe and Japan. For illustration, Fig. 5 shows a predicted fuel particle distribution after a postulated fuel pin failure in the MYRRHA test facility. As the coolant PbBi has a similar density as UO_2, fuel particle may float in the coolant and may be taken away from the reactor core to coolers and pumps. Such predictions are needed during the design phase to protect the facility from severe secondary damage.

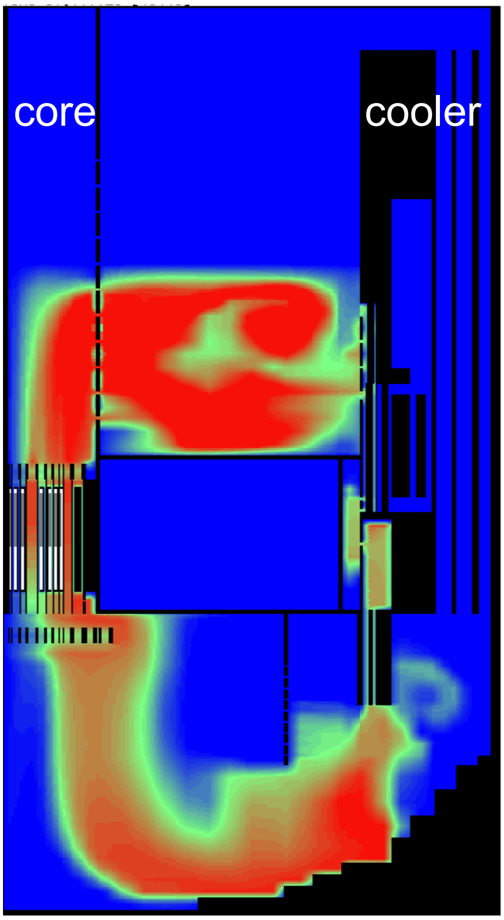

Fig. 5: Fuel particle distribution 90s after a fuel pin failure in MYRRHA

Driven by the German government decision to phase out of nuclear power by 2022, the Institute is working today also on questions of nuclear fusion and on conversion of renewable energies. Its long term experience with liquid metals and with magneto-hydrodynamics enabled studies of flow of PbLi in breeding blankets, which will be exposed to strong magnetic fields in a fusion reactor. The working group on Magneto-Hydrodynamics is operating for this purpose the unique test facility MEKKA with liquid NaK, simulating liquid PbLi, but at room temperature, including its interaction with magnetic fields. Fig. 5 shows a look into the MEKKA laboratory, where a test section connected with the NaK loop is just being inserted into a magnet with up to 3.6 Tesla for magneto-hydrodynamic measurements.

Fig. 6: Insertion of a NaK test loop into the magnet of the MEKKA laboratory.

Liquid PbBi, on the other hand, became a promising coolant for concentrated solar power plants. With its test facility SOMMER, shown in Fig. 7, the Liquid Metal Laboratory is studying the highly effective heat transfer from the focus of a parabolic solar mirror to an energy conversion system using liquid metals as an energy carrier. A heliostat of 30 m^2, visible in the foreground of Fig. 7, is following the sun to illuminate a parabolic mirror of 4m x4 m, visible in the background, which in turn focusses the solar power to a liquid metal receiver inside the building. The focal point could easily melt a steel plate with its peak heat flux of 2.5 MW/m^2, if uncooled, but the PbBi cooled tubes of the receiver are keeping the surface sufficiently cold.

Fig. 7: Test facility SOMMER for concentrated solar power in the Liquid Metal Laboratory.

A high potential for renewable energies, even though economically still rather questionable in Germany, is the use of geothermal energies. For a reasonable energy conversion to electric power, these must be at a temperature of at least 130°C, which is available in Germany only at a depth of several thousand meters. The working group on Energy and Process Engineering at IKET is studying, therefore, such concepts also in international collaboration, e.g. with Indonesia, where even hotter water is found at a significantly lower depth. For effective energy conversion of low temperature energy sources, IKET has developed and built the test facility MONIKA, using propane as a working fluid of a supercritical Rankine cycle. Instead of a geothermal borehole, a thermal power of 1 MW is produced there simply with a boiler to test the facility.

Another interesting application of this process is the conversion of low temperature waste heat to electric power, e.g. from cogeneration power plants in summer times or from chemical facilities. Like with geothermal energies, the challenge is here again to develop a low cost, competitive system. The group is studying also the water chemistry and the physical properties of the geothermal brine with its high concentrations of salt. They predict the occurrence of scale and of released gases in heat exchangers and they developed an in-situ measurement system for continuous monitoring of physical properties.

Fig. 8: Test facility MONIKA with a Rankine cycle of supercritical propane.

A promising carbon free energy carrier for future energy systems is hydrogen. IKET has gained long-term experience with safety aspects of this fuel already since the 1990ies. At these times, hydrogen was rather considered as a safety issue of nuclear power plants during severe accidents, demonstrated impressively by the Fukushima power plant, which exploded due to the production and ignition of hydrogen. Today, hydrogen is often considered and tested as an innovative fuel for automobiles, busses or trains, and the experience of the Hydrogen working group with potential hazards of hydrogen and their mitigation became the basis for safety research for hydrogen driven vehicles. The Hydrogen team has thus supported the installation and operation of a hydrogen fueled shuttle bus at KIT, Fig. 9, and performed tests of innovative hydrogen tanks in its hydrogen test center HYKA. Their code systems GASFLOW and COMB3D are used today worldwide to predict concentrations of released hydrogen in closed buildings like reactor containments, tunnels or garages, and to estimate the mechanical loads on the building structure in case of a detonation.

Another interesting task of this group is the prediction of dust explosions, with and without the additional effects of exploding gases.

Fig. 9: Hydrogen gas station and shuttle bus, supervised by IKET and ProScience.

Can hydrogen be produced from natural gas without CO_2-emissions? The KALLA team has developed and demonstrated indeed an innovative gas reformation process, which decomposes methane into hydrogen and elementary carbon at high temperatures. The chemical reaction is performed in liquid tin, which serves as a catalyst for methane reduction, and solid carbon could be produced at the tin surface, Fig. 10.

Fig. 10: Carbon produced from pyrolysis of methane in the KALLA laboratory.

Prediction and measurement of two-phase flow of steam and liquid has traditionally been a focus of IKET, applicable to all kinds of power plant concepts using the Rankine cycle for energy conversion. In collaboration with a consortium of research and industry partners in the NUBEKS project, the working group on Multiphase Flows has recently performed critical heat flux tests in its COSMOS-L facility at pressures up to 3 bar. The detailed data were taken by the other partners then to validate innovative prediction methods for the occurrence of a boiling crisis. Other numerical modelling activities of IKET are including stratified two-phase flows, steam injectors with direct contact condensation, and heat transfer phenomena close to the critical pressure, which were studied in doctoral theses.

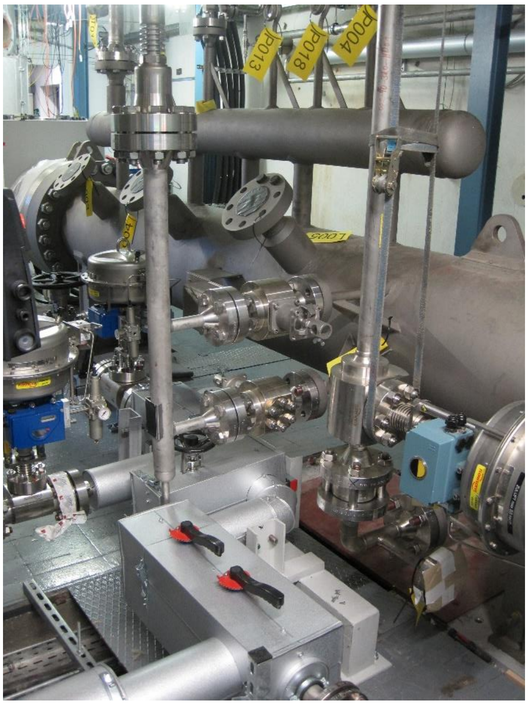

Fig. 11: Evaporator of COSMOS-H, designed for critical heat flux experiments at high pressure.

A large two-phase flow loop COSMOS-H with pressures up to 170 bar has been installed next to the low pressure facility, Fig. 11, being commissioned in near future. The facility has a total heating power of 1.2 MW and can produce a steam/water mass flow up to 1.4 kg/s. An optical access to the test section shall enable laser-optical measurements at high pressure, which might give a completely new insight into the physics of nucleate boiling.

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.

An overview of the structure of IKET is given by the organization chart, Fig. 12. Each working group is acting independently in its research field, but they are all supported by a joint infrastructure, comprising a metal workshop, manufacturing urgent test components, a welding shop, and an electromechanical workshop. A view into the metal workshop, Fig. 13, shows that the Institute is well equipped with machines and tools to support the test laboratories most effectively. Indeed, the high number of large test facilities could hardly be operated without this joint collaboration.

Other tasks of the infrastructure include the IT-administration, business administration and public websites. The Infrastructure team is active as well in education and training activities. Every year, at least six 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.

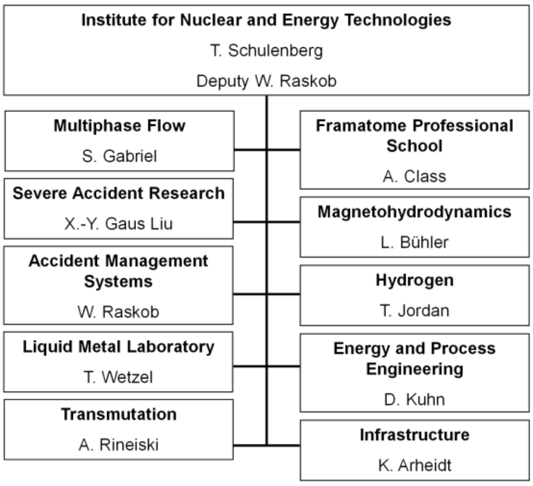

Fig. 12: Organization chart of the Institute for Nuclear and Energy Technologies

Fig. 13: View into the metal workshop of IKET.

By the end of 2018, around 90 scientists, engineers and technicians have been working at IKET on this wide range of CO_2-free technologies for energy conversion. They contribute to the HGF-programs on Nuclear Safety

(NUSAFE), Nuclear Fusion (FUSION), Renewable Energies (EE) as well as Storage and Cross-linked Infrastructures (SCI), with a focus on NUSAFE. Fig. 14 illustrates that more than 2/3 of the IKET employees were still needed in 2018 for tasks in NUSAFE, despite the German phase-out plans of nuclear power.

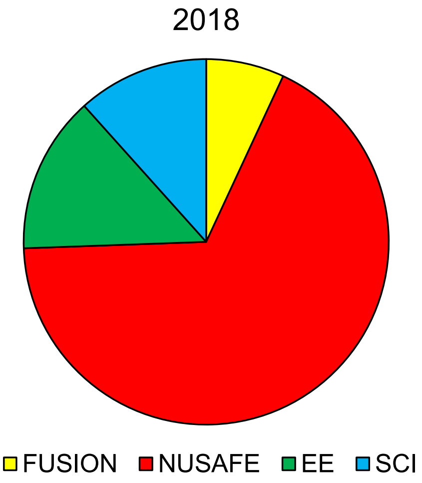

Fig. 14: Assignment of IKET personnel to HGF programs.

Results of the scientific program of IKET have been documented in more than 100 publications per year. Some highlights of recent achievements will be outlined in the following paragraphs. A list of all relevant publications of the Institute can be found in the attachment.