Considering passive retrofits in Europe

Nuclear providers have gained broad experience in the design and development of active safety systems which provide a high level of safety to the running fleet. But less attention has been paid to the retrofitting of passive safety systems to reactors already in operation. By Markus Poehlmann and Stefan Niessen

Passive cooling of the spent fuel pool is already in use at the Goesgen nuclear plant in Switzerland

Active safety systems are state-of-the-art technology in all running nuclear power plants and guarantee safe operation. As the cornerstone of nuclear safety they are not questioned. The current trend to extend the lifetime of many reactors worldwide creates a need for retrofitting, including the renewal or addition of safety systems. In such cases, passive systems may offer an alternative or a complement to active systems. In particular, implementation of autonomous systems can avoid or limit modifications to existing systems such as power distribution, HVAC systems, and others.

Passive safety systems that have been retrofitted are already operating. In the early 2000s the Goesgen plant in Switzerland ordered from Areva a passive cooling system for its wet storage facility instead of active ones for two reasons: safety (it was robust in case of loss of power supply) and operational benefits (lower maintenance costs and power consumption). Passive autocatalyst recombiners (PARs) that prevent hydrogen accumulation in the containment have also been installed in many plants during post-Fukushima processes.

But are there other more opportunities for passive systems? A systematic approach is necessary to get an overview of opportunities that are worth to be developed further.

Market potential

In 1980, half of today's operating reactors were under construction. Assuming that those plants will require fundamental modernisation and upgrade after 40 years of operation (i.e. their initial design life), modernisation and upgrade work is likely to peak in 2020.

Analysing this on a plant-by-plant basis, across the world's operating nuclear reactor fleet, gives the result shown in Figure 1. It can be seen that in the forthcoming decade (2016-2025) at least 14 units must renew their operating licences each year, 150-200 units in total. This is almost half of the world's nuclear power reactor fleet.

It is unlikely that all the operating licence renewals will include retrofitting a safety system. However, it is worth looking at some contemporary sources of information to get an idea of what issues could be discussed when it comes to operating licence renewal. One such source may be the European Nuclear Safety Regulators Group (ENSREG) European

Figure 1. Expected schedule for nuclear plant lifetime renewals around the world (Based on data from IAEA/PRIS)

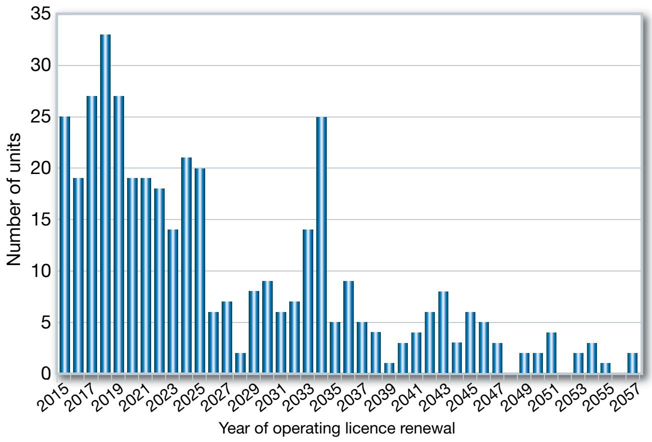
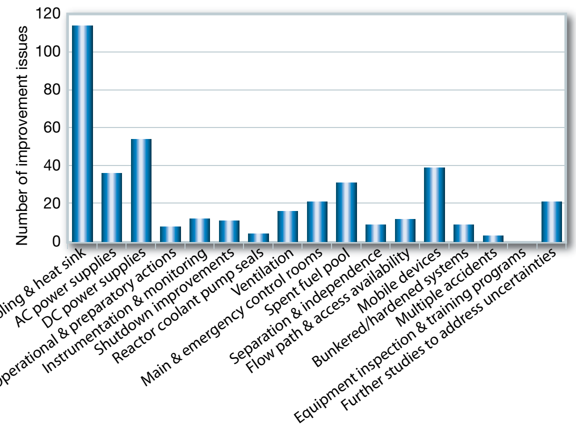


Figure 2. Loss of safety systems improvements to be considered the European nuclear power reactor fleet



Stress Tests carried out in Europe in response to the Fukushima Daiichi accident in 2011.

Figure 2 provides statistics on the appearance of ENSREG Topic 2 (loss of safety system) issues throughout the European nuclear fleet. Peak scoring are issues such as:

- Alternative cooling and heat sink;
- AC and DC power supply;
- Spent fuel pools;
- Mobile devices.

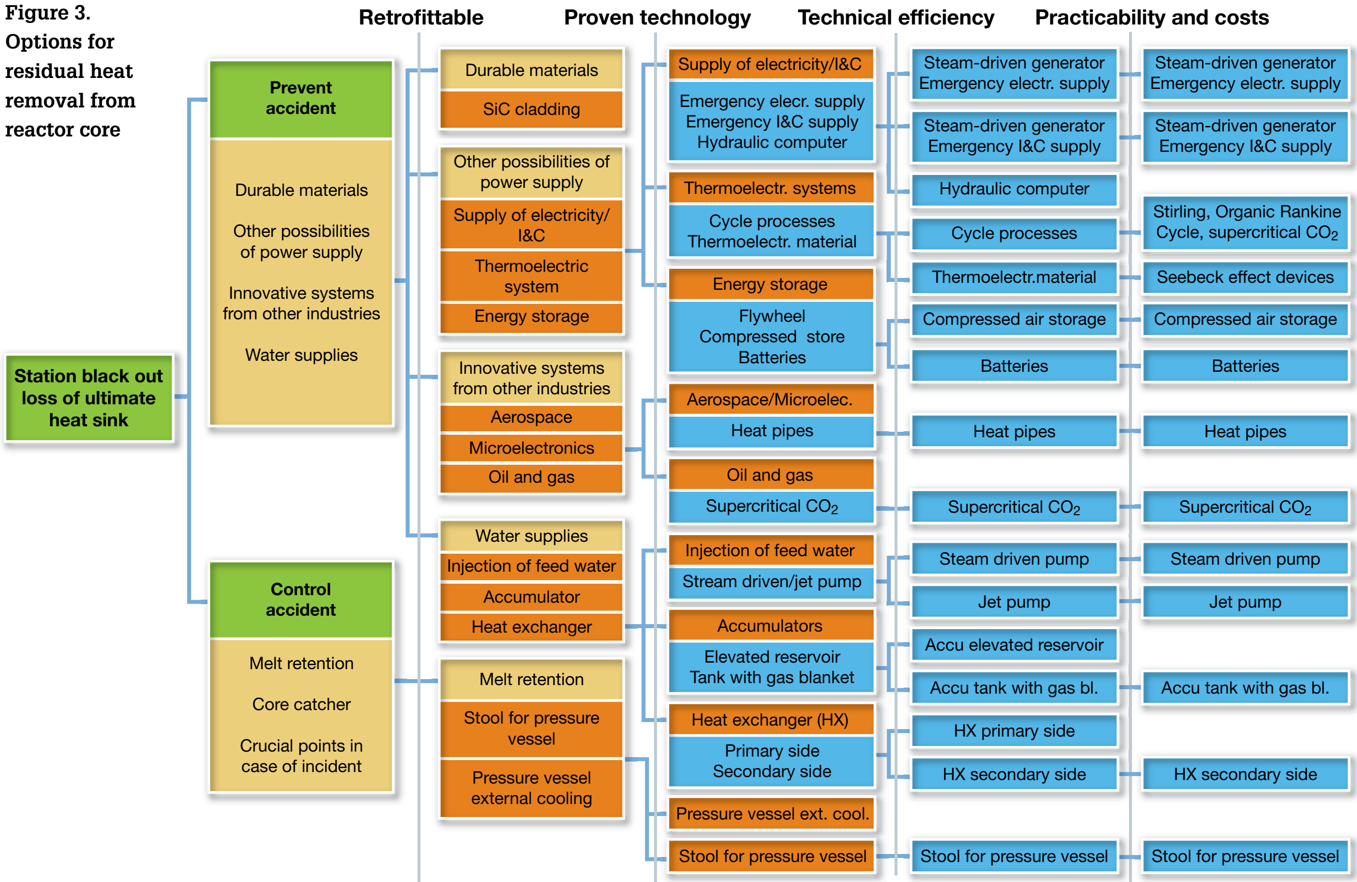
Each of these four issues may be directly addressed by passive safety devices. Alternative cooling and heat sink might be provided by retrofitted passive cooling systems, for example using air as an alternative heat sink. Another idea worth pursuing is AC and DC power supply by steam driven generators, directly converting the plant's residual power to electricity. Thermoelectric devices may also be used.

Beyond the licensing renewal of operating nuclear plants, it may be worth considering the potential for passive safety technology in dismantling and decommissioning (D&D). For any optimised D&D schedule, self-sufficient operation of nuclear systems is crucial while other parts of the plant are being demolished. This could be fulfilled by passive systems, which can be independent from other plant installations.

Passive solutions for SBO

Residual heat removal is key during station blackout and loss of ultimate heat sink conditions. There are several options to safeguard this goal, most of them active systems. Additional passive technological options have the potential to be further developed.

Figure 3. Options for residual heat removal from reactor core



Areva's commitment

Areva has gained experience in the implementation of a passive cooling system in the wet fuel storage facility in Goesgen, Switzerland and the design and development of passive safety systems in its advanced BWR design.

Those BWR safety systems comprise passive reactor pressure vessel water injection, passive emergency core cooling and passive containment heat removal systems, and a passive actuation of safety features without the need of I&C. The systems have extensively been tested and technically matured at the dedicated INKA test facility located in Karlstein, Germany.

Similar experiments can be performed for PWR designs. Areva's PKL primary circuit test facility conducts experiments on the thermal-hydraulic behaviour of PWRs during operational transients and accidents including:

- Overall system responses and system interactions;
- Demonstration of safety margins and evaluation of PWR operating procedures for design and beyond-design-basis events.

The scaling concept of the PKL test facility aims to simulate the thermal hydraulic system behaviour of a 1300MW PWR plant:

- Heights 1:1;
- Volumes and power scaling 1:145;
- Primary/secondary pressure 45/60 bar;
- Core simulator with 314 electrically heated rods, core power up to 10%, original rod diameter and pitch;
- Four steam generators, each featuring 28 tubes of original geometry.

Any kind of suitable passive safety system as those proposed in Figure 3 can be attached and tested in the PKL test facility, in particular at integral tests regarding interactions with active systems.

The criteria for the assessment of these technological options are:

- Retrofittability;
- Proven technology;
- Technical efficiency;
- Practicability and cost.

The results of the assessment are shown in Figure 3. Depending whether prevention or mitigation of the accident is the goal, several general options are feasible in each case.

In accident prevention there are more options: durable materials, technologies to supply water to the secondary (or primary) side of the reactor, technologies to generate electric power from the residual heat of the core (to be used to drive safety or I&C functions), and technologies from non-nuclear industries not previously used in nuclear. But when it comes to reliability and proven technology, there are fewer options. They are steam driven turbines coupled to an electricity generator or feedwater pump, thermoelectric systems or electrical storage devices, including batteries, feedwater accumulators and additional heat exchangers or cooling circuits with air as the ultimate heat sink.

Well-proven technologies from other industries show potential. Among those technologies, heat pipes were identified as suitably efficient passive heat transport device along with supercritical CO_2 cycles used in the oil and gas industry.

The last decisive criterion in Figure 3 is the economic effort. Any measure related to the primary circuit is highly demanding to license and install. Also, using gravity requires water reservoirs at high elevation which is also costly, and challenging to protect against airplane crash and earthquake.

Finally, as seen in the utmost right column in Figure 3, few options could potentially be efficiently retrofitted.

Those that can, are the steam driven electricity generator, the feedwater supply (steam driven or jet pump), energy storage, heat pipes, supercritical fluids, feedwater accumulators and heat exchangers. The major issues in retrofitting passive safety technology are technical efficiency and practicability at reasonable cost. Two main constraints apply here: the space available and its impact on the existing licensing basis of the plant.

The matter of space is highly design specific and needs to be investigated individually for each plant. The potential impact on the licensing basis is easy to find: passive safety systems should have no or little connection to the instrumentation and control in order to minimise interaction with the existing safety concept. It is clear that specific issues need to be considered with care.

However, only few of the above listed passive safety systems are already developed to maturity and R&D is necessary in order to understand in particular failure modes of passive safety systems and their potential interaction with active (safety) systems.

European project initiatives

As a product demonstrating the success of the three networks SNETP TWG Gen II&III, NULIFE and SARNET, the European platform NUGENIA is the starting point of a more ambitious and united community to advance the safe, reliable and efficient operation of nuclear plants. In NUGENIA, partners from European countries have defined a joint project proposal for the European Commission's Euratom work programmes. Utilities are invited to accompany the activities as operator advisory partners.

In order to operate efficiently in the event of a loss of ultimate heat sink or station blackout, the scope of this joint project will be to assess if passive safety systems can be a possible solution for residual heat removal from the reactor coolant system.

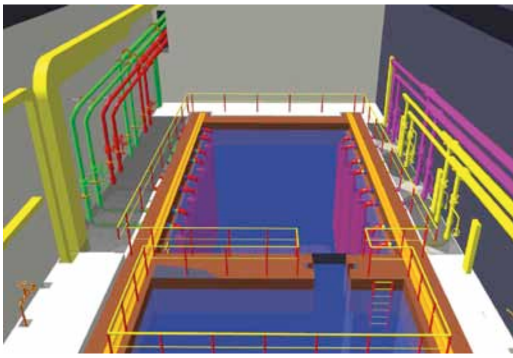


Figure 4: Illustration of pool coolers and system piping

Several potential options for passive safety systems, as specified in Figure 3, will be assessed against the technical feasibility of integration in Gen II, Gen III and Gen III+ designs, the licensing required and the potential economic benefit. The cost will be assessed by comparing the whole product life-cycle cost of the passive safety systems (investment, manufacturing, installation, operating and power consumption cost) versus active systems.

The project will allow exchange between passive systems research design organisations and regulatory institutions. Recommendations will be developed on how to use the existing capabilities of passive systems. It is important to develop a common understanding of the safety benefits of passive systems as well as their weaknesses related to their qualification, efficiency, and potential failure modes in usage conditions.

It will be important to develop a common understanding of how passive systems can be used, deterministic and probabilistic, where they are more or less reliable and failure probabilities. Surveillance testing must be reviewed to understand the usability and acceptance of passive functions.

The scope of the project suits the outline of Euratom's 2015-2016 and 2016-2017 work programme. A consortium of 13 partners from eight European countries jointly submitted a project titled APASS (Asssessment of Passive Safety Systems) to successive project calls.

The results of this programme will be made public and thus contribute to progress in the safety revamping of nuclear plants. ■

About the authors

Dr. Markus Poehlmann and Dr. Stefan Niessen, AREVA GmbH, Corporate Research & Development, Innovation- and Patent Management, Paul-Gossen-Strasse 100, 91052 Erlangen, Germany