Passive safety systems for plant life-time extension and nuclear new build

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ABSTRACT

After recent events, where reactor core cooling could no longer be guaranteed, or risked to be no longer guaranteed due to loss of electric power supply, attention is paid to passive safety systems not only for future reactor design but also for existing power plants. Development of such passive safety systems to nuclear power plants, which are already being in successful operation, is to be pursued as a step forward towards ultimate safety and therefore to (re)gain further acceptance of nuclear power in public, especially when it comes to plant lifetime extension and nuclear new build.

In order to guarantee safety in case of loss of electricity supply, attention is paid to passive safety systems. Presently, nuclear industry has gained experience in the design and development of passive safety systems in their advanced Gen III reactor designs for new build. Also many operating European rectors are already equipped with passive safety systems, however, mostly not conceived for a full passive operation for a duration of 72 hours and without passive control of the safety system [1][2][3].

Historically a peak nuclear capacity had been under construction around the year 1980 [4]. Provided that those plants will require fundamental modernization and upgrade after 40 years of lifetime (i.e. the lifetime most of them were initially designed for), a peak of modernization and upgrade agitation can be anticipated for the year 2020. It may be assumed that at least some of the operating license renewals will be accompanied by a retrofit of a (passive) safety system. Therefore, it is worth to anticipate potential upgrading directions and requirements of the authorities. A comprehensive source on potential orientation of requirements may be the ENSREG European Stress Tests that have been carried out in Europe in 2011 [5].

From the ENSREG analyses and in particular the appearance of Topic 2 (loss of safety system) it can be seen that peak scoring of safety improvement need is identified at issues as alternate cooling and heat sink, AC and DC power supply, spent fuel pools and, and mobile devices, i.e. all of these issues that may be directly addressed by passive safety systems [5].

In order to identify the technological options to cope with residual heat removal in Station Black Out and Loss of Ultimate Heat Sink conditions, several workshops assessed the technological options with respect to their capability to reply to the assessment criteria retrofittability, proven technology, technical efficiency, and practicability/costs.

Depending on if the prevention or the mitigation of the accident are to be pursued as global goal, several general options are feasible in each case. Whereas the control of the accident leads basically to issues of melt-retention, for the case of accident prevention the options seem to be more numerous: From durable materials, over technologies to supply water to the secondary (or primary) side of the reactor, technologies to generate electric power (to be used to drive safety systems or at least I&C functions) from the residual heat of the core, and technologies from non-nuclear industries up to now not known/not used in the nuclear field.

However, when it comes to the question of reliability, i.e. proven technology, only fewer options can be retained. Among those, steam driven turbines coupled to electricity generator or coupled to a feed water pump, thermoelectric systems, feed water accumulators, and additional heat exchangers/cooling circuits with air as ultimate heat sink can be identified. Also well proven technologies from other industries, e.g. aerospace, microelectronics, or oil and gas industry show promising potential. Among those technologies heat pipes were identified as suitably efficient, passive heat transport device and also supercritical CO_2 cycles that are employed in oil and gas industry (waste heat to power conversion). However, it seems evident that everything connected or related to the primary circuit is rather demanding to install (in-containment) and rather demanding to license. Also the pure use of gravity as passive driving force requires water reservoirs located at high elevation which also is a priori costly, technically and from the licensing point of view regarding protection against air plane crash and earthquake.

Therefore, finally rather few technological options show real promising technical an economic potential to be efficiently retrofitted to existing plants: Among those are the steam driven electricity generator (for safety system and I&C electric supply), the steam driven and/or jet pump feed water supply, heat pipes, supercritical fluids, feed water accumulators, and heat exchangers with air as ultimate heat sink. Two main constraints may apply to any retrofitted system: The space available in operating plants to accommodate the additional system and its impact on the existing safety concept (licensing basis) of the plant.

Presently, AREVA has gained experience in the implementation of a passive cooling system in the wet fuel storage facility in Gösgen, Switzerland and the design and development of passive safety systems in its advanced BWR design KERENA. Those 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. Those systems have extensively been tested and technically matured at the dedicated INKA test facility located on the AREVA site in Karlstein, Germany.

Complementary similar experiments can be performed for PWR designs. AREVAs PKL large scale test facility (primary circuit test facility) is used to conduct experiments on the thermal-hydraulic behaviour of PWRs during operational transients and accidents. In particular it is planned to qualify at PKL the so called Passive Pressure Pulse Transmitter (PPPT) initially developed in the context of KERENA, as passive controller device for passive safety systems. Moreover, these large scale tests shed light on the possible interference of newly developed passive and existing active safety systems.

These issues will be addressed within the European platform NUGENIA that has been set up to be the starting point of a more ambitious and united community to advance the safe, reliable and efficient operation of nuclear power plants. Within NUGENIA, partners from European countries team together and define the dedicated joint project proposal APASS (Assessment of Passive Safety Systems) for the EURATOM working programs [6][7] of the European Commission. The 22 institutions who expressed their interest in this project are situated in 13 European member states and in Switzerland and Ukraine. The envisaged reactor designs cover Western European PWR, Eastern European VVER and the transferability to Northern European BWR. The joint project is thus also considered as an important contribution to harmonization of approaches for nuclear safety in Europe. The project will include partners from industry, from research centres, TSOs, SMEs, and from universities. Selected utilities are supporting the APASS project with their experience as rector operator in its Advisory Board. It is anticipated that by developing passive safety systems public support of nuclear power is improved.

More comprehensive digest on the subject is provided in reference [8].

[1] IAEA-TECDOC-1624 - Passive Safety Systems and Natural Circulation in Water Cooled Nuclear Power Plants

[2] IAEA-TECDOC-920 - Technical feasibility and reliability of passive safety systems for nuclear power plants

[3] IAEA-TECDOC-1752 - Progress in Methodologies for the Assessment of Passive Safety System Reliability in Advanced Reactors

[4] IAEA - Power Reactor Information System (PRIS)

[5] European Nuclear safety regulators Group (ENSREG). Compilation of recommendations and suggestions: Peer review of stress tests performed on European nuclear power plants

[6] European Commission C(2014)5009 of 22 July 2014: EURATOM WORK PROGRAMME 2014 –2015 - Revised

[7] European Commission C(2015)6744 of 13 October 2015: EURATOM WORK PROGRAMME 2016 – 2017

[8] M. Pöhlmann, S. Nießen, Considering passive retrofits in Europe. Nuclear Engineering International, March 2016