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Vulnerability, safety and response of nuclear power plants to the hydroclimatic hazards

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The Great Tohoku Earthquake and Tsunami, and the severe accident at Fukushima Dai-ichi nuclear power plant 2011 alerted the nuclear industry to danger of extreme rare natural hazards. The subsequent "stress tests" performed by the nuclear industry in Europe and all over the world identifies the nuclear power plant (NPP) vulnerabilities and define the measures for increasing the plant safety.
According to the international practice of nuclear safety regulations, the cumulative core damage frequency for NPPs has to be 10-5/a, and the cumulative frequency of early large release has to be 10-6/a. In case of operating plants these annual probabilities can be little higher, but the licensees are obliged to implement all reasonable practicable measures for increasing the plant safety. For achieving the required level of safety, design basis of NPPs for natural hazards has to be defined at the 10-4/a [U+23AF] 10-5/a levels of annual exceedance probability. Tornado hazard is some kind of exception, e.g., the design basis annual probability for tornado in the US is equal to 10-7/a. Design of the NPPs shall provide for an adequate margin to protect items ultimately necessary to prevent large or early radioactive releases in the event of levels of natural hazards exceeding those to be considered for design. The plant safety has to be reviewed for accounting the changes of the environmental conditions and natural hazards in case of necessity, but as minimum every ten years in the frame of periodic safety reviews. Long-term forecast of environmental conditions and hazards has to be accounted for in the design basis of the new plants.
Changes in hydroclimatic variables, e.g., storms, tornadoes, river floods, flash floods, extreme temperatures, droughts affect the operability and efficiency as well as the safety the NPPs. Low flow rates and high water temperature in the rivers may force to operate at reduced power level or shutdown the plant (Cernavoda NPP, Romania, August 2009). The practice demonstrated that the NPPs could safely withstand the meteorological extremes (Katrina hurricane, 2005). However the floods at some sites cause significant safety issues.
Design of NPPs and their response to extreme hydroclimatic events depends on the features of particular hazards, e.g., predictability, possibility and time available for the protective actions, potential for causing cliff-edge effects and the possible combinations of events. The uncertainty of the prediction of extreme values for the design and safety assessment is a fundamental issue.
In the paper the consequences of hydroclimatic extremes are analysed for nuclear power plants. The possibility of operational response to extremes is presented. The safety margins are assessed with respect to the effects caused by hydroclimatic extremes. The direct actions (e.g. wind) and the indirect consequences (e.g. changing of ground water level) are also considered. Methods for accounting the uncertainties of the characterisation of low probability hazards are also considered. The preparedness to severe hydroclimatic conditions / events and actions for mitigation and management are presented and discussed. The considerations in the paper are illustrated by the case of the Paks Nuclear Power Plant, Hungary.