UUT 20 Analysis of the safety of the nuclear power industry of Ukraine in extreme operating conditions

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1. The purpose of the project and subjects of the investigation

- Major blackout of nuclear power units became one of the main causes of nuclear (severe) and radiation accidents with catastrophic environmental consequences at the Fukushima-1 in 2011.

The main cause of the major plant blackout (MPB) accident at the Fukushima-1 in 2011 was the tsunami flooding of the NPP site and diesel generators supporting the operation of active safety systems with electric pumps. Damage to the nuclear fuel and destructive steam-gas explosions with catastrophic radiation releases into the environment were the consequences of the MPB accident.

After the great accident at the Fukushima-1, the world nuclear power industry was tasked with improving the strategies for managing MPB accidents, taking into account the Fukushima lessons.

Post-Fukushima inspections at all US nuclear power units identified insufficient technical and operational availability to effectively manage MPB accidents at nuclear power plants.

- Dozens of emergency shutdowns of power units occurred under today's extreme operating conditions of Ukrainian nuclear power plants (especially Zaporizhzhia NPP). They were caused by complete or partial external blackout due to external military influences.

- The results of calculation modelling of MPB accidents at nuclear power plants with WWER (water-cooled water-moderated energetic reactor) have found that the design passive safety systems (do not require long-term power supply) do not prevent severe accidents with damage to nuclear fuel and destructive gas-steam explosions.

- Thus, the modernization of strategies and systems for managing major blackout accidents at power units with WWER is relevant.

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2. Tasks of the project

❑Currently, there are two main directions for improving the strategies for managing MPB accidents at nuclear power plants:

Implementation of additional mobile diesel generators (MDG) to ensure the operability of active safety systems,
And development of promising passive safety systems to prevent severe accidents at nuclear power plants.

➢The first of these directions is limited by the lack of guarantees for a quick and efficient connection of the MDGs during MPB accidents and a high material costs. In particular, there were MDGs at the Fukushima nuclear power plant, but in the end, severe accidents could not be prevented.

➢The second of these directions is limited by the need to qualify new/promising passive safety systems for the conditions of MPB accidents. According to the IAEA terminology, qualification means a calculation, experimental or calculation&experimental substantiation of the reliability and operability of systems/equipment in operating, transient and emergency modes.

- An analysis of the known results of modelling accidents at NPPs with WWER reactors found that a violation of nuclear safety conditions unambiguously occurs during initial accident events with a major blackout.

- The use of an emergency feed pump with a steam drive from a steam generator (SDAFWP) is a promising approach to improve the efficiency of managing major blackout accidents at nuclear power plants.

The qualification of SDAFWP for reliability and operability during major plant blackout accidents is a necessary condition for the implementation of this approach.

- The proposed project considers qualification of a promising steam-driven emergency feed pump for managing MPB accidents at nuclear power plants with WWER.

➢The project objective:

To qualify SDAFWP for the conditions of MPB accidents at NPPs with WWER.

➢The project tasks:

1. To develop a method for qualifying SDAFWP for MPB accident conditions.
2. To analyze the found results and make practical recommendations.

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3. Waiting for project results

- The project substantiates the criteria and conditions for qualification of a steam-driven emergency feed pump in transient and operating modes to ensure the successful safety functions for removing residual heat from the reactor and to maintain the required level of feed water in the steam generator; as well as to prevent reliability-critical water hammers on the equipment of safety-related systems at nuclear plants with WWER.

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4. Road map of the project

❑Traditionally, NPP safety analysis is based on probabilistic and deterministic modelling of accidents of various types (pipeline leaks/ruptures, failures of NPP safety-related systems, power unit blackouts, etc.). The deterministic analysis of the safety of nuclear power plants with WWER is based on the results of accident modelling using thermohydraulic codes.

❑An analysis of the results of modelling with deterministic codes for accidents at NPPs with WWER has found the followings.

✓In most cases, there are negative "code user" effects, when for the same accidents the results of modelling with the same codes, but by different users, are differ significantly,

✓Code models do not take into account the possibility of thermodynamic instability of various types in safety systems that control accident processes.

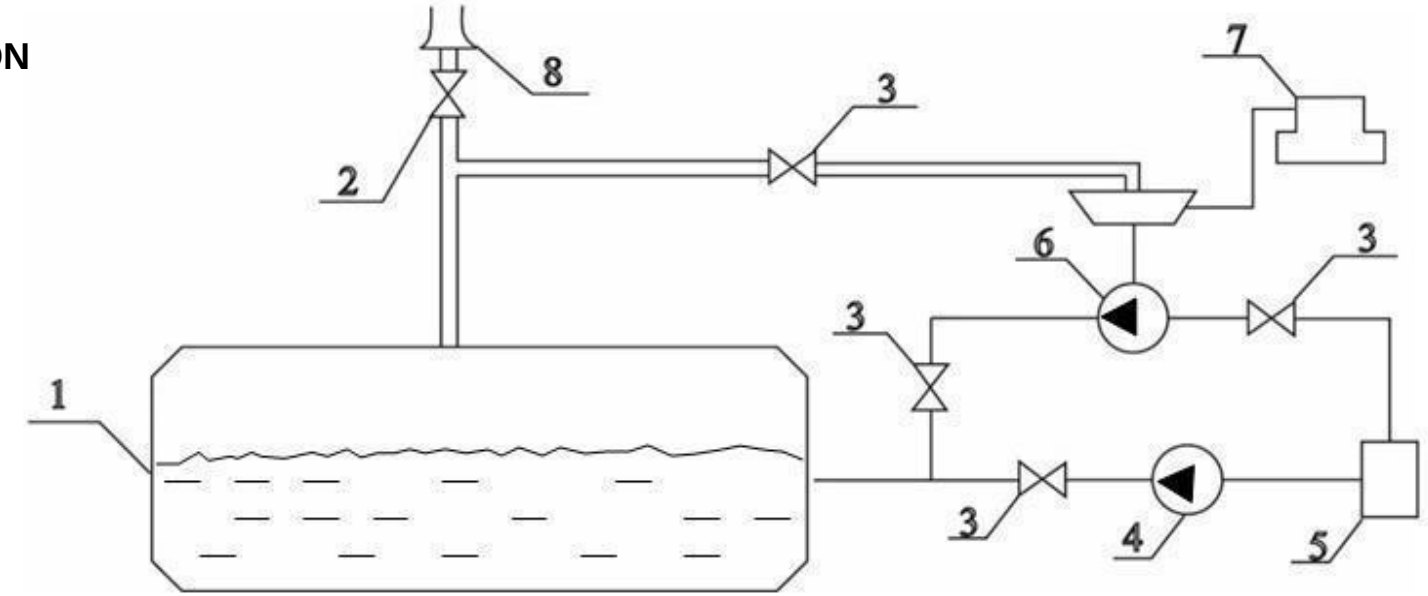
- Thus, the qualification of alternative passive safety systems that ensure the successful safety functions for the reactor residual heat removal (SF HR) and for the required feed water level in the steam generator volume (SF SG) should be based on alternative methods for thermodynamic modelling that exclude the "code user" effects and take into account the conditions for thermodynamic instability in safety systems.

- For effective MPB accident management, we propose Professor Korolyov's idea to use an auxiliary feedwater pump with a steam drive from a steam generator (SDAFWP). A SG turbine-driven feedwater pump is considered as a prototype of such a pump. For many years these pumps have been successfully operated at NPPs with WWER.

Methods for qualification of SDAFWP for MPB accident conditions

SCHEMATIC DIAGRAM OF SDAFWP CONNECTION

1 – steam generator,
2 – main steam isolation valve (MSIV),
3 – stop valves,
4 – AFWP,
5 – AFWP feed water accumulators;
6 – SDAFWP,
7 – deaerator,
8 – NPP turbine.



The SDAFWP system is connected as a redundant system for AFWP with common feed water accumulators. Steam in the SDAFWP steam drive comes from SG; and the "waste" condensate enters the deaerator or feed water accumulators of SDAFWP.

The general qualification of SDAFWP is divided into the following sub-stages.

- Qualification for the conditions for starting SDAFWP before the operating mode.
- Qualification for the successful safety functions for SF HR and SF SG in the SDAFWP operating modes.
- Qualification for the conditions of the lower steam pressure limit for SDAFWP operability.

The necessary conditions for the SDAFWP qualification are met with the design and technical characteristics of the SDAFWP system that satisfy the conditions:

$$\frac{LG_A}{t_A \Pi[\Delta P_{p0} - (P_{v0} - P_A) - \xi G_A^2/(\rho_l \Pi^2)} < 1$$

$$I_P + I_G \frac{G_A}{P_{v0}} \geq 0 \qquad \mu_v > 0{,}2$$

Where

t_A = 14222s is time of lowering the feed water level in the SG to less than 1.35m (design setting for AFWP valve opening),

ΔP_p is pressure head developed by a steam-driven pump

G_A is the nominal AFWP flow

P_v is the steam pressure

L is a total pipeline length

μ is flow coefficient in the steam drive,

Π is the flow area of the feed pipeline

P_A is pressure in the AFWP water accumulators,

ξ is total coefficient of hydraulic resistance in the SDAFWP system,

ρ_l is the density of feed water

❖The found qualification conditions are consistent with the corresponding experimental data from the SDAFWP model stand of Professor Korolyov.

❖The found conditions must be taken into account when designing the SDAFWP SG system for NPPs with WWER.

5. Obtained project results

❖The presented project for the first time performs the qualification of the SDAFWP operability and reliability to ensure the necessary safety functions during of MPB accidents.

❖The project substantiates the criteria and conditions for qualification of a steam-driven emergency feed pump in transient and operating modes to ensure the successful safety functions for removing residual heat from the reactor and to maintain the required level of feed water in the steam generator; as well as to prevent reliability-critical water hammers on the equipment of safety-related systems at nuclear plants with WWER.

❖Based on their own conservative thermohydrodynamic model “reactor – steam generator – steam-driven emergency feed pump”, the authors determined the design and technical requirements for the system of the steam-driven emergency feed pump corresponding to the established qualification criteria and conditions.

❖It was found that the effective operability of an emergency feed pump with a steam drive from a steam generator is acceptable at a steam pressure in the steam generator of more than 0.3MPa. At lower pressures, passive heat removal systems with natural circulation can be used.

❖The results obtained can be applied in the modernization of strategies and systems for managing major blackout accidents at nuclear power units.

❖For further cooperation, a new project ANALYSIS OF THE ECOLOGICAL SAFETY OF EUROPE UNDER EXTREME OPERATION CONDITIONS OF UKRAINIAN NPPs is proposed.

Acknowledgment

This project was made possible through the UK-Ukraine twinning grants scheme, funded by Research England with the support of Universities UK International and UK Research and Innovation

Thank you very much for your attention!

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Web page of the project on the website of the Odessa Polytechnic National University:

https://op.edu.ua/international/projects/uk-ukraine-twinning-initiative-20