Regulatory Guidance on the Reliability and Performance of Nuclear Passive Safety Systems

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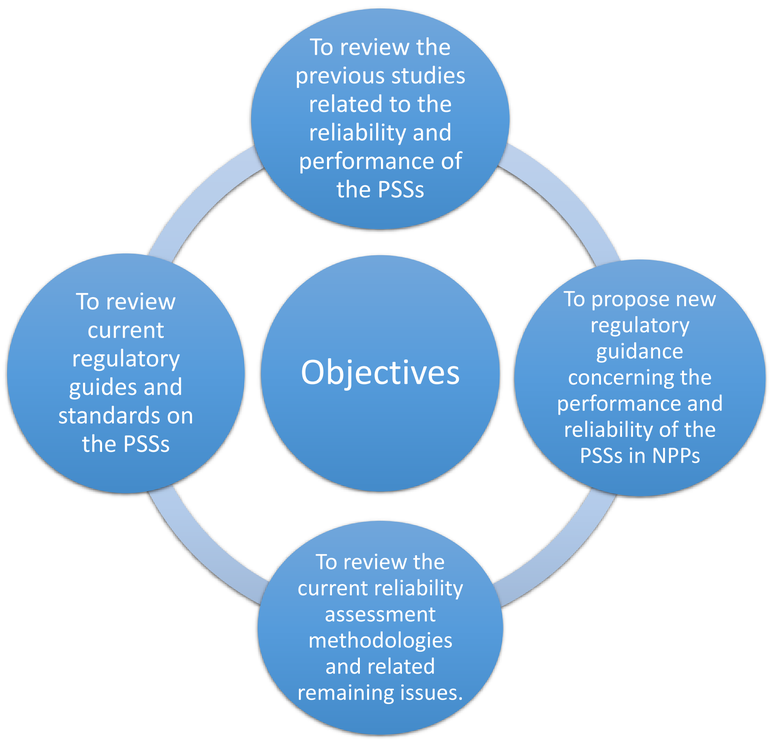
Introduction

In recent years, advanced technologies of NPP are making more extensive use of Passive Safety Systems (PSSs) because of their high reliability and low cost. However, the weak driving forces of many of such PSSs based for instance on natural circulation pose significant challenges to the design and safety demonstration of PSSs.

In addition, nuclear regulatory bodies worldwide are facing also important challenges in the licensing of the PSSs and innovative reactor designs.

The number of studies related to the reliability and performance of PSSs is limited and has not provide clear guidance due to their complexity.



Safety Assessment for Performance and Reliability of PSSs

Performance Assessment	Reliability Assessment
❑ In order to evaluate the performance of a PSS, it is necessary to have a very good understanding of the physical phenomena used to actuate and operate the system,. ❑ A PSS's performance characteristics shall be demonstrated for the entire duration of the functions performed, and for the entire service life of the facility.	❑ A PSS may rely on low-intensity phenomena (e.g. natural convection) which, under certain conditions, may be insufficient to perform its function. ❑ Specific methodologies appeared to be necessary in order to properly evaluate the reliability of PSSs, with particular emphasis on assessing the failure probabilities of thermal-hydraulic mechanisms used by these systems.

Regulatory Review to the Reliability and Performance of PSSs

In 2015, Nuclear Energy Agency (NEA) agreed to initiate a survey on regulatory practices to assess PSSs used in new nuclear power plants design. The survey was distributed among 19 institutes from 12 countries. Main findings of this dedicated survey are summarized hereby.

1. No unified internationally accepted and applied definition exists regarding PSSs
2. The current regulations have not yet been fully prepared for the implementation of these systems in most of the countries.
3. Most countries do not have specific requirements for PSSs reliability analyses.
4. PSSs may be exempt from single failure criterion in some countries. In other countries the regulations do not differentiate between active and passive systems from this aspect.
5. The main drawback of PSSs is that passive mechanisms typically rely on small driving forces
6. The main challenges regarding PSSs are related to the safety evaluation (including both T-H and PSA) of these systems.
7. There is no internationally accepted guideline on how to identify contributors that may induce the failure of the system including failure modes and mechanisms.
8. There is no operating procedure on how to catalyze the performance or to prevent the aggravating effects of PSSs.

Reliability Analysis Methods for PSSs

This Table shows a comparison between three different methodologies of reliability assessment

#	Method	Functions	Strengths	Weaknesses
1	REPAS (Reliability Evaluation of Passive Systems)	▫ characterize in an analytical way the performance of a PSSs	▫ provide numerical values that can be used in more complex safety assessment study ▫ used to optimize a PSS	▫ a large number of calculations with best estimate codes are needed. ▫ It was found to be too expensive
2	RMPS (Reliability Methods for Passive Safety)	▫ identification of the sources of uncertainties. ▫ propagation of the uncertainties through thermal-hydraulic models. ▫ introduction of PSS unreliability in accident sequence analyses.	▫ provides realistic assessment of the PSS reliability, which adapts to T-H model complexity ▫ integration of PSS reliability into a PSA study	▫ does not account for the interaction between the hardware failure and, functional failure of PSS. good only for one accident scenario.
3	APSRA (Assessment of Passive System Reliability)	▫ determine the deviation which influence the system performance ▫ evaluating the effect of these deviations on PSS performance using qualified T-H codes	▫ deviation causes are obtained from experimental data values and plant operational experience data. ▫ the failure probability of PSS is evaluated using classical PSA techniques like fault tree analysis	▫ limited experience in the operation of PSSs and lack of suitable experimental databases

Regulatory Guidance to the Reliability and Performance of PSSs

Performance Assessment

To ensure that the PSS using low driving forces can provide a safety function with a high level of reliability should recognize and the following:

- **Environmental Conditions**
- Safety Margins
- Human Actions
- Internal and External Hazards
- **Dynamic Behavior**
- **Failure Mode Analysis**
- Validation for the Computer Modelling Codes

Reliability Assessment

❑ When evaluating the reliability of PSSs, it is important to consider the difficulty in producing conclusive probabilistic safety assessments (PSAs).

❑ The event sequence in real accidental and transient situations can be very dynamic.

❑ Even though PSSs do not need any human intervention for their operation, still the effect of subjective decisions of operator for other active systems working in combination with PSSs can have an adverse effect on PSS performance and reliability.

❑ Areas to improve methodologies and to resolve related open issues:

1. The uncertainty in these predictions could be only reduced by verifying the codes for different PSSs and relying more on experimental data.
2. In order to capture this dynamism, event trees must be replaced with discrete DETs.
3. To resolve the uncertainties in the reliability assessment, one has to build the models of such parameters from the data that has been continuously monitored around the applications of PSSs.

Conclusion

There is a strong need for the development and demonstration of consistent methodologies and approaches for evaluating their reliability and performance, particularly concerning the following:

- Performance assessment: assessing the performance of PSSs requires a very good understanding of the physical phenomena underlying their operation, as well as the necessary simulation capabilities for such phenomena.
- Reliability assessment: specific development approaches appear to be necessary in order to properly evaluate the reliability of PSSs with particular emphasis on assessing the failure probabilities of thermal-hydraulic mechanisms used by these systems.

Future research addressing this specific topic relevant to advanced reactors should be steered towards all these points in order to foster and add credit to any proposed approach Also, an in-depth investigation and quantification of inherent passive systems issues related to its functional failure and dynamic reliability should be initiated.