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NETWORK

TECHNICAL REPORT ON CURRENT APPROACHES AND REQUIREMENTS REGARDING SAFETY ASSESSMENT OF DESIGNS WITH MAJOR IMPLEMENTATION OF PASSIVE SYSTEMS

RESULT OF THE ANSWERS COLLECTED IN THE "QUESTIONNAIRE ON HOW TSOS ARE FACING PASSIVE SYSTEMS IMPLEMENTATION IN PRESENT AND FUTURE REACTORS

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OBJECTIVE OF THE DOCUMENT

The interest for the development of passive safety system (PSS) for nuclear power plants has always been present in the large picture of reactor development and design. Following the Fukushima Daiichi NPP accident this interest has become a subject of even greater attention thanks to the potential benefits that can be added to nuclear reactor safety. The introduction of PSS into Small Modular Reactors (SMR) and Advanced Modular Reactors (AMR) seems natural because of the design goals of these reactors (safety and economics). Additionally, the possibility of the introduction of PSS in existing nuclear power fleets is today under scrutiny by operators, TSOs and regulatory bodies.

In the recent past, many International Organizations have dealt with and have been involved in the preparation of documents related to several aspects of PSS. The main examples are the "Regulatory Aspects of Passive Systems" from WENRA (WENRA, 2018) [1], "Progress in Methodologies for the Assessment of Passive Safety System Reliability in Advanced Reactors" from IAEA (IAEA-TECDOC-1752, 2014) [2], "Status Report on Reliability of Thermal-Hydraulic Passive Systems" from OECD (OECD, 2024) [3]. In this frame, a common shared position of the members of the European Technical Safety Organisation Network (ETSON) is desired in order to promote, among them, the harmonization of the safety assessment approaches. This is even more important because not all ETSON members have participated or contributed to the above-mentioned initiatives.

Within ETSON, the Expert Group 6 (EG6) devoted to the "Safety Fluid Systems" had been established with the scope to share experiences regarding light water nuclear installations. The work performed by the group in the past produced the Technical Safety Assessment Guide (TSAG) "Safety Fluid Systems" delivered in 2015 (ETSON, 2015) [4], although it is still relevant, does not address any specific characteristic or indication related to the passively operated safety systems. The objective of the reactivated EG6 workplan until 2025 is to produce a new or updated version of the TSAG on approaches related also to the safety assessment of PSS, mainly for light-water applications, but with possible extension to other advanced fluid systems in case of interest for the ETSON members.

As a preparatory phase, the present questionnaire has been drafted to collect updated information about the interests and the best practices pursued by the ETSON members facing the PSS implementation in present and future reactors from any possible aspects (design, performance, safety assessment, reliability and probabilistic safety assessments, code validation, gaps/needs of R&D, etc.). This questionnaire was sent to participants in 2022. The quick evolution of this subject (new prototypes announcements, research projects, etc.) means that some answers may not be necessarily up to date.

This Technical report summarizes the responses collected from ETSON members.

TABLE OF CONTENTS

1 QUESTIONNAIRE DESCRIPTION 4

2 SYNTHESIS OF INTERESTS IN PASSIVE SAFETY SYSTEMS FROM A TSO PERSPECTIVE 6

3 AGGREGATION OF THE ANSWERS TO QUESTIONNAIRE 9

3.1 Topic 1 – Types of passive systems 9

3.2 Topic 2 – Design and safety rules 11

3.3 Topic 3 – Deterministic approach 14

3.4 Topic 4 – Probabilistic approach 16

3.5 Topic 5 – Codes qualification 18

3.6 Topic 6 – Operating requirements 20

4 SUMMARY AND FINAL CONSIDERATIONS 22

5 CONSIDERATIONS IN RELATION TO THE OECD QUESTIONNAIRE 24

APPENDIX 1 QUESTIONNAIRE TEMPLATE 25

1 Information 25

2 Topics of interest 25

3 TSO experience regarding passive systems 26

APPENDIX 2 QUESTIONNAIRE FROM OECD/WGAMA DISTRIBUTED IN 2016 30

APPENDIX 3 REFERENCES 32

1 QUESTIONNAIRE DESCRIPTION

The questionnaire is divided in two sections: the topics of interest and the questionnaire itself.

The "topic of interest" aims to collect at a glance the main interests from the TSO perspective related to some aspects of the PSS applications, and this is divided in six topics:

1. Design and safety rules – Performance, activation, Defence in Depth, application of single failure criteria, consideration of hazards.
2. Deterministic approach – final state, penalization of input data, aggravating single failure, research of penalizing configuration for Design Basis Condition (DBC), study of cliff-edge effects.
3. Reliability – Methodology to assess reliability, determination of functional failure, Integration in Probabilistic Safety Assessment (PSA).
4. Codes qualification – Uncertainties, experimental facilities, need of experiments to support validation of codes.
5. Operating requirements – Commissioning tests, periodic tests, maintenance, inspectability, technical operating specifications.
6. Kind of fluid used by passive system – coolant technology.

For each item, ETSON members were invited to specify their level of interest: "for information only" or characterized by an "active contribution". In case of active contribution, an example of feedback or contribution would be appreciated.

Choosing "for information only" may indicate a general interest in the topic, e.g. when there is an internal program not directly related to the subject, but whose outcomes may have implications or relevance for the own national R&D.

The second part is the "questionnaire" on the ETSON member experience regarding the PSS and this section has been divided in six topics:

1. Types of passive systems
2. Design and safety rules
3. Deterministic approach
4. Probabilistic approach
5. Codes qualification
6. Operating requirements

The first topic requires to introduce and describe one kind of passive system under investigation by the ETSON member, with some specifications about its safety function, performance, etc.

The second collects information about specific requirements and rules adopted about PSS applications, the relation between the PSS and the DiD strategy, how to guarantee operability and availability, activation issues, etc.

The third regards the deterministic approach followed by ETSON member, the assessment, the definition of safe state, how to identify the aggravating single failure, how to consider internal and external hazards, how to face unexpected activations.

The fourth would collect information about specific approach for PSA, the methods, the success criteria, the uncertainties evaluation, etc.

The fifth is dedicated to the numerical analysis, collecting information about the TSOs participation to project or benchmark activities relative to PSS in order to test and develop the numerical codes, codes gaps and needs, etc.

The last regards the operating requirements of PSS, from their test on dedicated experimental facilities up to the maintenance in the NPP.

The assessment of the reliability of a PSS is a complex and overarching challenge, closely related to many of the topics discussed above.

In the Appendix 2 have been reported the questions given by the OECD in 2016, to which this questionnaire is connected indeed. The purpose is to allow the ETSON members who already participated to the OECD action, to update and expand the information supplied, but also to give a wider overview on the main subjects related to the PSS to the ETSON members that did not participate

2 SYNTHESIS OF INTERESTS IN PASSIVE SAFETY SYSTEMS FROM A TSO PERSPECTIVE

This section presents a synthetic analysis of the interests expressed by ETSON members regarding PSS application in nuclear power plants, collecting the responses provided in the "Topics of interest" section of the questionnaire, with the aim to outline their priority areas and which active contributions they are given on the fields.

Design and Safety Rules

ETSON members show significant interest in design and safety rules, emphasizing the importance of Defence in Depth and the application of single failure criteria. While many ETSON members have expressed an active contribution on this aspect, from the practical examples emerge that up to now there are usually no specific rules for the extensive implementation of PSS versus the active ones.

Deterministic Approach

Regarding the deterministic approach, the ETSON Members are all interested in the following topic: definition of adequate final safe state, consideration of aggravating single failure, and of penalizing configurations/hypothesis for Design Basis Condition (DBC), study of cliff-edge effects and, in general, highlighting the need to evaluate and manage extreme situations. Interest is shown both for information and for active contributions. Some ETSON Members promote uniform standards for active and passive systems even if the way to apply them may differ.

Reliability

The reliability of PSS is a crucial theme, in particular the methodologies to assess reliability, the determination of functional failure and integration into Probabilistic Safety Assessment (PSA). ETSON Members aim for active contributions or at least to stay informed. Some ETSON Members support uniform reliability standards for passive and active safety systems, underlining the belief that the reliability principles should not differ based on system type. This should highlight the need for a common approach to safety and reliability standards. Active participation on past and future international projects may foster a unified understanding of PSS performance across the nuclear safety community.

Code Qualification

ETSON Members demonstrate a robust engagement in code qualification efforts. The organizations are actively involved in numerous EU and internal projects that serve as platforms regarding the needs for validating thermal-hydraulic codes against experimental datasets. For instance, activities carried out within many European projects over the last decade, reflect a collective commitment to strengthening the knowledge base needed to ensure code adequacy. Through these collaborative efforts, ETSON Members together with other involved stakeholders work towards ensuring that the thermal-hydraulic codes used to design and perform accident analysis of nuclear reactors are thoroughly tested, verified, and capable of accurately simulating the behaviour of PSS under various conditions duly identified. These projects often involve working groups (WG) where ETSON Members contribute with their expertise and collaborate on research initiatives. The answers indicate a shared need for further experimentations to support code validation carried out with adequate experimental facilities (SET, CET, IET).

Operating Requirements

Commissioning tests, periodic tests, and the maintainability of PSS represent critical aspects in the life cycle of nuclear installations. While few ETSON Members have shown interest in shaping the technical operating specifications and maintenance requirements, it's acknowledged that not all ETSON Members are currently positioned for an active role in this domain. The absence of specific reference designs means that, for many ETSON Members, the focus on operating requirements remains predominantly informative, deferring active engagement until reference design becomes more established.

Types of Fluid Used by Passive Systems

Interest in the cooling technologies used by PSS shows a variety of approaches and preferences among ETSON Members. Water-cooled systems collect unanimous interest among all ETSON Members, indicative of their established presence in the industry. BelV shows a keen interest in the application of liquid metals, along with others, reflecting a drive towards exploring solutions for future Gen-IV reactor designs. Gas (sCO2) and sodium systems, while not at the forefront of active development, maintain a steady interest for informational purposes, indicating their relevance and potential.

These varied interests underscore the ETSON Members' collective commitment to investigating a spectrum of coolant technologies to advance the safety, efficiency, and sustainability of nuclear installations.

Aggregation of the Topics of Interests

From the answers received, the topics of interest can be sorted by number of organisations involved or interested in them. The resulting list is as follows:

1. Codes qualification
2. Deterministic approach
3. Design and safety rules
4. Reliability
5. Operating requirements.

It thus appears that the topics motivating the most active actions from the participants are devoted to code qualification, deterministic approach and design & safety rules.

PSS reliability and their operating requirements are not as investigated as these previous topics, probably due to the absence of a real concept being under assessment. This hierarchy might be modified in the following years, with the arrival of several SMR concepts embedding PSS.

Conclusions

The analysis of the "Topics of Interest" section of the questionnaire has collected priorities and individual contributions of ETSON Members in several fields of PSS application. The aggregation of responses highlights a strong inclination towards active contribution and knowledge sharing in key areas of PSS.

While the treatment of passive systems is in many cases approached in the same manner pursued for active systems, some organizations are still investigating the best way to incorporate PSS into the established framework of nuclear safety.

The active participation of ETSON Members in European projects and International WGs devoted to PSS assessment, SMRs, etc. constitute a common ground to promote the harmonization of the safety demonstration with particular focus on code validation supported by new sets of experimental data from adequate test facilities.

The willingness to adopt a more integrated and collaborative approach among ETSON members represents a fundamental step towards the continuous improvement of nuclear safety through the effective use of PSS. The information gathered and synthesized in this Technical Report will be used to develop a new or updated version of the TSAG on (Passive) Safety Fluid Systems.

3 AGGREGATION OF THE ANSWERS TO QUESTIONNAIRE

3.1 Topic 1 – Types of passive systems

Q1_1 – Could you please choose one passive system (based on natural circulation) that was analysed or will be analysed in the short term by your TSO and describe it briefly?

3.1.1 BELV (BELGIUM):

Passive System: MYRRHA RVACS (Reactor Vessel Auxiliary Cooling System)

Description: MYRRHA RVACS is an abbreviation for the reactor vessel auxiliary cooling system. It serves as a decay heat removal system wherein the decay heat generated by the core is transferred from the core to the reactor vessel (RV) through in-vessel natural circulation of the coolant. Subsequently, the heat is conveyed to the ultimate heat sink, which is the air, through ex-vessel natural circulation of the air.

3.1.2 ENEA (ITALY) AND LEI (LITHUANIA):

Passive System: E-SMR Passive Decay Heat Removal System (Within the frame of ELSMOR[1] project)

Description: The passive system analysed in the ELSMOR project is a natural circulation loop that simulates a decay heat removal system. The heat source is a plate-type heat exchanger, and the heat sink is a condenser immersed in a water pool. The thermal power is around 500 kW. The system is an experimental facility; therefore, the main application is to develop experimental data for code validation.

3.1.3 GRS (GERMANY):

Passive System: NuScale SMR passive cooling and decay heat removal system

Description: The passive primary cooling system in combination and the passive decay heat removal system needs to be evaluated together. Specific descriptions are not given.

Additional info: GRS has concentrated on aspects of passive safety within several SMR designs, enhancing its analysis tools to support safety evaluations. Research has primarily been on scaled test facilities for

[1] ELSMOR (Towards European Licencing of Small Modular Reactors" funded by European Union under Grant n. 847553

decay heat removal, among others. GRS also validated its AC² code for the NUWARD[2] and NuScale designs, focusing on submerged containment cooling.

3.1.4 IRSN (FRANCE):

Passive System: Theoretical passive system

Description: The system considered is a Safety Condenser (SACO) implemented in Flamanville 3 EPR reactor in place of emergency SG feedwater system.

Additional info: Current French PWRs utilize primarily active safety systems, complemented by passive features like gravity-driven control rods, pressure-triggered safety injectors, natural circulation cooling, and hydrogen recombiners. There's no extensive use of passive systems in licensed French nuclear plants yet, but discussions on SMRs like NUWARD are exploring these aspects. IRSN is collaborating with industry stakeholders to address the safety demonstration challenges of designs incorporating significant passive systems. In this working group, a theoretical case is considered, which corresponds to the implementation of SACOs on Flamanville 3 EPR reactor in place of emergency SG feedwater system.

3.1.5 JSI (SLOVENIA):

Passive System: focused on define the licensing roadmap for sCO2-4-NPP to achieve TRL9 (full-scale production).

Description: system description not given

Additional info: although not directly involved in the design or development of passive systems, JSI has been engaged in two significant H2020 projects related to passive safety systems: PIACE[3] and sCO2-4-NPP. Within PIACE , JSI has worked on adapting the SIRIO[4] experimental facility to match PWR conditions through detailed scaling and design rules, leading to successful simulations using the RELAP5/MOD3.3 code that confirmed the facility's suitability for future experiments. In the sCO2-4-NPP[5] project, JSI has focused on identifying regulatory requirements for the design of a passive decay heat removal system and has contributed to the detailed design of its components. Moreover, JSI has conducted an independent review of the proposed system, drawing on international experiences in licensing such systems.

3.1.6 PSI (SWITZERLAND):

Passive System: Containment Wall Cooling (CWC) Passive Safety System application on PKL[6] facility

Description: The CWC consist in an open loop in natural circulation, where a heat exchanger placed in the containment environment provides the heat removal (by condensation) and an external pool open to the environment acts like heat sink.

Additional info: PSI has used the US-NRC TRACE code to study how the PKL facility's reactor coolant system interacts with the PASI[7] facility's containment heat removal system. The research focused on the Containment Wall Coondenser (CWC) system's efficiency in removing residual heat during Small Break LOCA scenarios. The

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[2] NUWARD is EDF Group's subsidiary 100% dedicated to SMR.

[3] PIACE (Passive IsolAtion CondEnser), funded by European Union under Grant n. 847715

[4] SIRIO - Sistema di rimozione della potenza di decadimento per reattori nucleari innovative (System for decay heat removal in innovative nuclear reactors). Facility at SIET, Piacenza Italy

[5] sCO2-4-NPP, funded by European Union under Grant n. 847606

[6] PKL, German acronym for Primary Coolant Loop Test Facility, FRAMATOME facility at Erlangen Germany

[7] PASI facility at LUT University, Lappeenranta, Finland

TRACE model was validated with experimental results, showing good agreement, especially regarding core exit and peak cladding temperatures. The study provided insights into the containment passive cooling system's natural circulation and its impact on reactor performance.

3.1.7 RSD (UK):

Passive System: Since details of its clients' information cannot be shared, the two passive systems considered are generic for PWR applications.

Description: the first is a system providing decay heat removal from the primary circuit in the event of loss of the duty system, operating before any breach of fuel clad or primary circuit may occur. The second is a containment cooling system following a LOCA.

3.1.8 VTT (FINLAND):

Passive System: AES-2006 Passive Heat Removal System (PRHR SG)

Description: No specific description

Additional info: VTT has been working on the AES-2006 Passive Heat Removal System (PRHR SG), also known as the PHRS SG in VVER terminology, within the past two years. The experience comes mainly from modeling and confirmatory safety analysis.

Overall, the answer to this question effectively conveys the active research and development efforts into passive safety systems across Europe, underlining a collective push towards nuclear reactors with significant passive feature implementation. The variety of systems and approaches taken by the ETSON members reflects the broader trend of seeking innovative solutions to safety challenges in the nuclear industry.

Q1_2 – For the next questions, could you please focus on this passive system (application, safety function, performance, etc.)?

The purpose of this question was to orient the ETSON members' attention towards a particular passive system operating in natural circulation, ensuring that their subsequent responses would be well-informed and specific. The above-mentioned passive systems (Q1_1) have been identified by each organization as their reference for the questions to follow.

3.2 Topic 2 – Design and safety rules

The following questions aim to gather detailed information not only on the passive systems themselves but also on the decision-making and evaluation processes that ETSON members use to incorporate such systems into their safety and design standards.

Q2_1 – Do you have specific requirements for passive systems and, if you do, which one? : already available/ work in progress / no specific requirements

In response to Q2_1, **the ETSON members have indicated that while there are no specific requirements dedicated to passive safety systems (PSS), the principles governing the application of the active systems remain appropriate.** The WENRA RHWG's 2018 report on passive systems is the main reference to highlight some specific characteristics of the PSS about redundancy, diversification, and independence of the systems (WENRA, 2018).

Some organizations have pointed out that while the safety requirements for passive systems are generally the same as for active systems, the implementation approach of PSS may differ, even if safety requirements are the same as for active ones. Nevertheless, specific attributes of passive systems may require additional justifications during licensing processes, thus suggesting ongoing discussions on this topic.

In some national contexts, regulatory frameworks (like Safety Assessment Principles (SAPs) clearly express a preference for passive over active systems, particularly those that are inherently safe within the ALARP demonstrations. Similarly, Slovenian regulations promote the utilization of passive safety functions to reduce reliance on active safety functions, monitoring and human intervention.

In another context, regulators as STUK, have introduced an alternative redundancy criterion for PSS under certain conditions. For example, allowing the (N+1) redundancy criterion for PSS, instead of the traditional (N+2).

Some ETSON members, like those involved in the ELSMOR project, anticipate future specifications of requirements for passive systems to emerge from ongoing detailed analyses.

The mission time of 72 hours for passive systems seems to be a commonly accepted standard for PSS, though this might differ based on individual TSO considerations and scenarios.

Q2_2 – How does the Defence in Depth (DiD) demonstration impacted by passive systems? For which level of DiD is designed the passive system (level 3a, 3b, 4?) or which DiD level(s) is the best place for passive systems and why?

In their collective responses to Q2_2, **ETSON members acknowledge the integration of passive systems within the key levels 3 and 4 of the Defence in Depth, where they are essential in preventing and mitigating accident progression, aiming to reduce core damage frequency and large early release frequency.**

Some approaches emphasizes that while passive systems should be acknowledged within the DiD strategy, they should not replace the comprehensive protection strategy that encompasses both active and passive safety measures.

Certain ETSON members report that the passive system for primary cooling and decay heat removal is relevant across all DiD levels. Other organizations emphasise that the use of passive systems must be aligned with DiD principles, highlighting the necessity for independence between DiD levels. Some members also point out the potential need to complement passive systems with active systems at the same level to enhance safety and to evaluate the influence of their associated functioning on the accident progression.

In some regulatory frameworks, the PSS are not explicitly mentioned, though examples exist, as a passive auxiliary subsystem which is integrated alongside active systems (ex:. turbine driven pump, in addition to 2 motor driven pumps). This reflects a common approach in which passive and active systems are treated similarly for safety demonstration purposes.

The ETSON members insights reveal a shared understanding of the value of passive systems within the comprehensive safety architecture of DiD, albeit with differing regulatory perspectives and implementation strategies. There is an emphasis on the independence of safety measures across different DiD levels and on the robust integration of PSS, especially in critical safety functions.

Q2_3 – How is activated the passive system? How long does it take from t0 (start of accident) to nominal conditions? Are specific phenomena or issues expected during the start-up phase?

Regarding the activation of passive safety systems, **among ETSON members there is a general emphasis on systems activating autonomously under predetermined conditions without dependence on off-site power. The**

time to reach nominal operating conditions is a critical factor, aiming for the shortest duration possible to prevent any early-phase critical reactor conditions. The timing is subject on the specific passive system capacity and transient boundary conditions, varying from seconds to hour.

Specific start-up issues, such as the inception of natural circulation, are considered during the design phase to ensure reliability. Some ETSON members pointed-out that oscillations of pressures/levels or water hammer effects during activation are areas to be investigated.

The activation is typically triggered by conditions like temperature or pressure thresholds, with the driving force for activation being buoyancy, counterbalanced by frictional losses.

In summary, ETSON members recognize the essential nature of passive system activation timing in the broader context of nuclear safety, with specific phenomena during start-up being acknowledged as critical to overall system performance.

Q2_4 – Do you consider internal and external hazards in the design or assessment of passive system?

The ETSON members agree on the necessity of considering both internal and external hazards in the design and evaluation of passive systems. In absence of a reference design, it is generally required to account for all hazards. Although all the members lack experience with fully licensed design incorporating major passive systems, they endorse the WENRA view that passive systems must operate successfully under hazard-induced conditions without compromising the safety functions.

Certain ETSON members identify the importance of including external hazards in safety case evaluations. Other organizations do not differentiate between active and passive systems regarding hazard protection, suggesting that the same rules are generally applied to both, as supported by some national safety regulations.

Q2_5 – What are the characteristics of passive system in order to be robust to single failure (redundancy, diversification?)

The ETSON members emphasize the importance of implementing redundancy and diversification in passive safety systems to comply with the single failure criterion, ensuring the reliability of such systems.

Some members pointed out that redundancy is more straightforward to implement, each system capable of fulfilling the safety function independently. Diversification must be considered when relevant to the reactor design and in case the implementation is viable.

Usually, the responsibility to demonstrate the effectiveness of the implemented safety systems is assigned to the licensees.

Certain ETSON members are currently considering how to effectively apply the single failure criterion in safety demonstrations based on passive systems. However, they recognize that there are aspects of the single failure criterion aligned with those for active systems, particularly concerning the components essential for initiating passive system operation.

Some organization state that the single failure criterion may appear in two different ways in the safety cases. It can be seen as a design feature that influences the redundancy level in the system architecture and as a penalizing assumption in Design Basis Accidents (DBAs), both accounted to ensure a high degree of confidence that acceptance criteria are met.

Q2_6 – What is the order of magnitude of the duration of the passive system's mission? Is it a factor in the choice of whether or not to implement a passive system in view of the *difficulties that could be associated with demonstrating its effectiveness over the long term?*

The operational period for passive safety systems may vary, but there is common consensus among the ETSON members to consider 48/72 hours as mission time for PSS. Lower timing should be subject to the external emergency plan.

In general, the PSS may assure safety functions for an extended period, often designed to operate for weeks. This duration is essential in the safety cases, with the specific time dependent on reactor design and regulatory requirements. Some members have not yet defined a precise duration due to the absence of designs with passive system integration

3.3 Topic 3 – Deterministic approach

3.1 Specific requirements for deterministic studies for design mainly based on passive systems.

Q3.1_1 – What general requirements or criteria are used for the deterministic assessment of passive safety systems?

For the deterministic assessment of passive safety systems, the ETSON members commonly apply the same requirements as for active systems. However, it is highlighted that a more detailed parametric analysis is often necessary to account for the unique characteristics and operational conditions of PSS.

Some members suggest paying specific attention to the functional failure that may occur when the boundary conditions deviate from the design values.

In some national regulatory frameworks, the effectiveness of these systems, whether active or passive, must be proven through fault sequence analysis. It is up to the duty holders to set deterministic criteria in their safety cases, which regulators will judge based on established SAPs.

3.2 Safe state

Q3.2_1 – What is considered as a safe state for designs mainly based on passive systems?

The aim for passive systems is the same as active ones: achieving cold shutdown when feasible, or at least ensuring conditions where power, pressure, and temperature can be controlled externally after passive systems have served their purpose. The success is accomplished when the system is able to maintain parameters like pressures and temperatures within safe limits, and more globally: the reactivity is under control, the reactor coolability is assured, and the confinement remains intact.

Some ETSON members have identified a potential risk that the cold safe state could not be reached easily by using only passive systems. In this case, defining a 'hot' safe state may become necessary, although this could raise additional safety considerations. Certain members suggest that thermal-hydraulic instability over the operating range leading to pressure/temperature fluctuations would be a concern to be covered in the safety cases.

Q3.2_2 – What are the associated requirements (temperature, pressure, duration, possibility of intervention, etc)?

The target conditions for a safe state in passive systems aim for low temperatures and pressures. The Regulators typically do not prescribe specific numerical values in the requirements; these are assessed on a case-by-case basis and must be approved by the authority. In certain regulatory frameworks, specific conditions for passive system performance (e.g. temperature and pressure values) are defined, in particular for advanced reactor designs. Additionally, ensure that the peak fuel temperature remains below acceptable limits is a common requirement.

Q3.2_3 – Do you need any specific complementary systems to allow to reach cold conditions, if this state is not reached by using only passive systems? Are this complementary systems safety classified?

In general, reaching the safe state depends on the specific design of the passive system.

Some ETSON members report that their passive systems are sufficient to achieve a safe state without complementary systems. Others indicate that additional systems may be necessary and must be safety-classified as well.

3.3 Identification of adequate aggravating single failure

Q3.3_1 – What is the approach retained to determine for each safety study the adequate aggravating single failure (engineering judgement, sensitivity studies, Failure Mode and Effect Analysis…) ?

The determination of an "aggravating single failure" in passive safety systems involves several methods. Engineering judgment, backed by sensitivity studies and Failure Mode and Effect Analysis (FMEA), plays a crucial role in defining failure criteria and reliability requirements.

Some ETSON members prefer event trees and FMEA over engineering judgment, emphasizing the benefit of numerical codes to define the safety limits during passive system operations. In certain national contexts, the single failure is covered by redundancy, while the aggravating single failure, used as an assumption in the deterministic safety studies, is typically addressed through engineering judgment, sensitivity analyses, and/or FMEA. Some members rely on engineering judgment in the absence of extensive data, highlighting the diverse approaches to ensuring the utmost safety in passive system design and evaluation.

Q3.3_2 – Is this safety approach adapted or modified for a design mainly based on passive safety systems?

The consensus among ETSON members is that no significant change is currently applied whether a design relies on active or passive systems. However, some changes of paradigm are anticipated with the introduction of Small Modular Reactors, which will likely depend more on passive systems. The ELSMOR project explored this area further, and considerations such as non-activation, performance deterioration, and false actuation of PSSs are recognized as critical factors in safety demonstrations. Several members have not provided specific answers, indicating that this is an area of ongoing development and research.

Q3.3_3 – Is functional failure taken into account in order to identify the adequate aggravating single failure?

The responses highlight varying levels of consideration for "functional failure" in passive safety systems. For some ETSON members the definition of functional failure is not even recognized, while other organizations emphasize its relevance. The low-intensity phenomena that passive systems rely on could be prone to functional failure due to design sensitivity or operational discrepancies, potentially leading to system non-actuation or unexpected behavior. Some members consider that the determination of the most penalizing aggravating failure for each safety study of the safety analysis report should consider functional failure. The acknowledgment of functional failure importance may depend on the practices of the local nuclear authority in different countries.

3.4 Internal and external hazards

Q3.4_1 – What kind of hazards are considered for the design of passive systems and in the safety demonstration (extreme cold or hot external temperature, fire, explosion, storm, etc)? How are they addressed?

Most ETSON members consider environmental conditions, like extreme temperatures, fire, or storms, as potential aggravators in safety analyses. While a proper design should ensure passive systems can withstand these hazards, there is no universally applied specific approach for their assessment.

Some members mention international guidelines, such as those from WENRA or IAEA, highlighting that measures for design basis accidents should remain effective during natural events, and stressing that the safety-grade systems should endure environmental conditions from hazards. It is crucial to evaluate the sensitivities of passive systems to environmental changes. For example, if a system uses the atmosphere as a heat sink, changes in air temperature or moisture could impact its performance. Similarly, structural deformations from seismic events may affect systems relying on natural fluid circulation.

The demonstration of sufficient margins for 'cliff-edge effects' might be more challenging for passive systems due to their potential narrow range of operating conditions. **Thus, specific attention should be given to boundary conditions resulting from hazards to ensure that the conditions for a successful operation of the passive safety system are still met.**

3.5 Unexpected activation

Q3.5_1 – How is considered unexpected activation of passive system in the safety demonstration? In this case, how is stopped the passive system? What are the requirements applicable to the means used to stop the passive system in these conditions?

While spurious activation of passive safety systems is not desirable, they should be designed to move the reactor into a safer state if it happens. Some organizations report that the spurious activation is included in their PSA. Certain innovative designs have incorporated modifications in their Protection and Safety Monitoring System to address spurious initiations, leading to the reactor trip. In some cases, the PSS are designed to provide a 30-minute automated or passive response window upon detection of an event. For other organizations, the importance of this issue is recognized, but further investigation or design-specific considerations may be required.

3.4 Topic 4 – Probabilistic approach

Q4_1 – What general requirements or criteria are used for the probabilistic assessment of passive safety system.

The responses reflect a diverse range of experiences and methodologies regarding the probabilistic safety assessment (PSA) of passive safety systems. Some ETSON members acknowledge the need for specific approaches or have participated in significant research projects facing the REPAS (Reliability Evaluation of Passive Systems) or RMPS (Reliability Methods for Passive Systems) methodologies to understand and quantify the reliability of passive systems, with respect with their failure probability due to thermal-hydraulic mechanisms used by these systems. The need for uncertainty analysis and modeling tailored to passive system thermal-hydraulics is highlighted. However, the practical implementation of PSA for passive systems appears limited, with some members citing a lack of specific examples or experience, particularly in countries where passive systems have not been implemented or licensed. It's noted that the probability of PSS failure should be minimized, and the PSA approach should not differ fundamentally from that applied to active systems, although the uncertainty may be more challenging to quantify due to the wider range of performance variation in passive systems. Overall, while methodologies and experiences vary, the aim is to ensure that PSS failure probabilities are as low as reasonably achievable.

Q4_2 – What is the approach used to assess the reliability of the system (FMEA, RMPS, other)? Do you presently develop or work on a specific reliability method?

Some ETSON members have contributed significantly on the development of methodologies, such as REPAS, and are actively working to validate their applicability for passive and active systems with the same safety function.

Other organizations adopt alternative approaches, such as the APSRA methodology as a standard in their reliability analysis, until they are ready to perform advanced thermalhydraulic analyses for specific components.

Certain members reported ongoing efforts to apply RMPS to assess functional reliability and to integrate this into a PSA for specific transient events.

It is also noted that conducting thorough analysis and testing across all potential accident scenarios is crucial, with emphasis on defining and justifying modeling assumptions, such as whether to include or exclude certain components or pathways.

In some cases, organizations rely on the FMEA methodology to support reliability assessment.

The responses reflect the current state of development and application of reliability assessment methods for passive systems across different organizations. From these various approaches, **the integration of robust reliability assessment methods for passive systems into comprehensive safety analyses remains an evolving field.**

Q4_3 – What is the success criterion for the performance of passive system?

The responses reveal that the importance of defining success criteria for passive systems is acknowledged. In some cases, no significant distinction is made between passive and active systems, in other cases, it is introduced a timeframe wherein passive systems should demonstrate their heat removal capability, typically 72 hours.

Other organizations are in the process of establishing specific success criteria for passive systems, particularly in relation to functional reliability assessments for certain advanced reactor designs.

In some cases, the success criterion is linked to the target mission of the system, implying a specific, context-dependent criterion.

Q4_4 – What is the approach retained to assess the uncertainties on each parameter? Is this approach specific to passive systems?

There is an acknowledgment of the challenges involved in assessing uncertainties for passive systems, with a mix of methods like expert judgment and tailored approaches that emphasize testing, experimental data, and T/H numerical simulations to find the performance bounds and reliability of PSS.

Some ETSON members detail their involvement in developing the REPAS methodology, which requires the calculation of uncertainties by T/H simulations and even expert judgment, potentially expanding the unreliability region of the system. They note that this approach is not exclusive to passive systems but, in this case, can be more demanding due to the extensive number of calculations required to investigate the parameters uncertainty range.

Other members also use the expert judgment to assess uncertainties, suggesting that this is a standard approach both for active and passive systems, others highlighted the crucial role of experimental data, both from SET and IET facilities, which help in setting out the operational domain and associated uncertainties of a particular PSS.

Q4_5 – Is functional failure considered? If so, what is the method used to assess functional failure (RMPS/Reliability Methods for Passive Systems, others)? What is your experience regarding this approach (advantages, drawbacks, difficulties)?

The responses highlight that while methodologies like REPAS and APSRA are in place for the reliability assessment of passive systems, there is a notable gap in addressing functional failures specifically. In some cases, the functional failure is not treated differently from other types of failure, indicating a potential area for development within PSA of passive systems. This gap suggests a need for dedicated approaches to assess the impact of functional failure in PSS, given their reliance on low intensity physical phenomena, e.g. natural convection, which may be prone to performance instability.

Q4_6 – How are common cause failures on redundant passive systems taken into account?

In many cases, the ETSON members either do not specify a defined position on CCFs, or they apply the same considerations to both passive and active systems.

Some members have reported examples of CCFs involving active valves to isolate the SGs and valves to open the decay heat removal system flow path in the reactor pool.

Other members highlight the specific behaviour of PSS, noting that their performance may vary significantly in case of CCFs, ranging from complete failure to partial operation depending on system condition

3.5 Topic 5 – Codes qualification

Q5_1 – Do you participate to international projects related to passive systems? If yes, which ones and provide a description of the objectives and content of your participation in these projects?

While some ETSON members have not reported participation in European projects due to their focus on significant development projects within their respective countries, the majority have shown a strong participation in past or ongoing international projects, mainly European, aimed at benchmarking, developing, and validating system T/H, CFD and severe accident codes against experimental data for both active and passive safety systems.

These projects, such as PASTELS, ELSMOR, and TANDEM, focus on a broad spectrum of activities including the development of methods for light water SMRs safety assessment, integration of SMRs into hybrid energy systems, and safety analysis of new reactor designs. There's a collective effort towards enhancing experimental research infrastructure, improving and qualify safety analysis codes, and establishing procedures for safety evaluation. Key among these efforts is addressing the safety of passive systems through experimental data, simulation tools, and methods that ensure the applicability and transferability of large LWR reactor knowledge to the new reactor concepts.

Here is a non-exhaustive list of projects and working groups with ETSON members participation:

EU: PASTELS[8] , ELSMOR, TANDEM[9] , PIACE, sCO2-4-NPP, SASPAM-SA[10]

OECD: ETHARINUS[11] , ATLAS[12] -

Other: OECD/NEA/CSNI WGAMA, SNETP, ETP, EU SMR partnership, NUGENIA.

Additionally, a new EC project called EASI-SMR (Ensuring Assessment of Safety Innovations for SMR) have started in fall 2024. This project addresses the safety issues related to the LW-SMR to provide advances that should support implementation of such technologies as soon as possible. The safety issues of passive safety systems are covered in this project.

Q5_2 – What are the codes used for the safety analyses using passive systems? Are the codes ready/qualified to perform calculations with passive systems? What are the improvements required to perform these calculations? If possible, please provide the range of conditions covering operation of passive systems and give examples of ranges of conditions out of codes domain of validation and that required specific experimental tests to validate code?

The responses suggest an active engagement in many projects to benchmark and qualify thermal-hydraulic system codes for passive systems, as well as CFD and severe accident codes.

The broad spectrum of codes used by the ETSON members are somewhat listed below:

- T/H system: TRACE, RELAP5, CATHARE, ATHLET (AC2)
- CFD: ANSYS CFX, OpenFoam
- Severe accident: MELCOR, ASTEC, COCOSYS, GOTHIC

Based on the collective feedback regarding the qualification of codes for PSS analysis, it's evident that existing codes, for a certain extent, can address PSS scenarios. However, **there is a clear call for further validation against experimental tests tailored to specific challenges associated with passive systems.** This includes accurate 3D phenomena simulation within large pools and the mixing processes inside reactor pressure vessels, which are critical for predicting the behavior of passive safety features under varied conditions.

Moreover, there is a need to validate codes against experimental data for condensation processes with different orientations and geometries of tubes, such as vertical, inclined, horizontal, and helical, where the dynamics of phase change and heat transfer are complex and significantly affected by the presence of non-condensable gases. The codes must accurately account for these gases, which can alter the heat removal efficiency and overall system performance, particularly considering that their presence is almost never avoidable in accident scenario.

To summarize, further efforts are needed to qualify the systems codes at all the development levels:

1. Need of SET, IET test experimental data,
2. Development of new features and correlations for the codes themselves, in

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[8]PASTELS (PAssive Systems: Simulating the Thermal-hydraulics with ExperimentaL Studies)" funded by European Union under Grant n. 945275

[9] TANDEM (Small Modular ReacTor for a European sAfe aNd Decarbonized Energy Mix)" funded by European Union under Grant n. 101059479

[10] SASPAM-SA (Safety Analysis of SMR with PAssive Mitigation strategies - Severe Accident)" funded by European Union under Grant n. 101059853

[11] ETHARINUS (Experimental Thermal Hydraulics for Analysis, Research and Innovations in NUclear Safety), OECD/NEA Project.

[12] ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation), OECD/NEA project

collaboration between users and developers,
3. Benchmark of the codes and establishment of best practices for the users,
4. Development of uncertainty and sensitivity methods and analysis.

Here below are listed some of the main physical phenomena that should be object of further investigation or improvement for system codes:

- thermal stratification/mixing in large pools.
- mixing in RPV,
- condensation processes inside/outside horizontal, inclined, vertical, helical tubes,
- heat exchange at low Re number,
- two-phase flow in helical coil heat exchangers,
- presence of non-condensable gasses,
- flow instabilities,
- flow hydraulic resistance (pressure drops).

On the other hand, the CFD codes are fully qualified for single-flow simulations, but the computational effort remains too high for two-phase flow simulation, presenting a significant challenge in current applications on PSS.

The ongoing development and refinement of models, along with benchmarking against dedicated experiments, aims to enhance the reliability of code predictions for PSS. The collaborations in international projects allow to create a comprehensive validation framework for code development to be used for the safety analysis of both existing and new generation designs

3.6 Topic 6 – Operating requirements

Q6_1 – Are full scale tests in experimental facilities or on-site commissioning tests performed in your country?

The responses indicate that **full-scale testing of passive safety systems is quite rare.** Some ETSON members reported past experience with full-scale tests, such as those conducted for integral test facilities and PSS demonstrations for specific reactor designs. In other cases, the test facilities for PSS are typically scaled down.

Some countries have not yet performed full-scale tests, while others rely on on-site commissioning for heat removal systems evaluation. Certain nuclear plants conduct periodic tests on passive accumulators and turbine-driven auxiliary feedwater pumps, with commissioning tests for any new systems.

Large-scale testing capabilities are available in some experimental facilities for containment system behaviors and phenomena, particularly for ALWR designs and large-scale separate effects tests.

Currently, planned experiments are focused on PSS studies for SMR applications. In some countries, operational experiences with these systems are typically managed by the license holder and overseen by the regulator and TSO.

Q6_2 – How do you ensure the availability of passive systems? How are performed periodic tests to check the adequate overall passive systems operation? How is checked each unitary function (opening of valves, etc.)?

While many ETSON members have given no answer on this specific item, for the others the maintenance and inspection protocols for PSS do not fundamentally differ from those for active systems and should be based on the system classification.

Some nuclear plants that mainly use active systems, conduct periodic tests on passive sub-systems, following specific procedures.

These include full flow tests for accumulators with check for leakages, and operational tests for feedwater system valves.

Q6_3 – To guarantee the qualification over the whole plant lifetime, what parameters (necessary to justify the operability) are followed during day to day operation? Which kind of instrumentation is installed or shall be taken into account to ensure the monitoring of the operational conditions?

Also, in this case many ETSON members have given no answer. However, some organizations highlighted that fundamental requirements for maintaining passive systems are essentially the same as for active ones. Some members pointed out the daily verifications of borated water volumes and nitrogen pressures.

Other members affirm that the most important parameters to be monitored to fully rely on PSS lifetime availability include water levels, pressures, temperatures, and valve positions. Adequate instrumentation should be installed to monitor all these critical parameters.

Q6_4 – How start of passive system is guaranteed even in extreme cold conditions, especially when final ultimate heat sink is located outside (by tests, controls, conditioning/continuous operation, electric tracing by heating cable, others)? What are the extreme cold conditions considered? How is performed conditioning of passive system (continuous operation, other…)?

Only few ETSON members has given an answer to this question.

Some responses says that nuclear power plants located on the coast area may possibly undergo frazil ice formation of the sea and this event is considered as design basis hazard. In such cases, design measures ensure an adequate water supply of the required quality even during such conditions. In other context, extreme cold conditions for PSS are not expected since they are inside the containment.

Some members noted that managing extreme cold conditions for PSS depends also on the reactor location. The mitigation strategies include continuous operation at lower efficiency, heating, temperature control, and ensure the reliability of the instrumentation.

Q6_5 – Maintenance, inspection: what are the main characteristics and constraints specific to passive systems?

There is a consensus that the fundamental requirements for maintaining and inspecting passive systems are similar in principle to those for active systems.

In some cases, specific maintenance and inspection protocols are recommended in environment exposed to extreme hot/cold conditions.

For some ETSON members, the PSS subsystems undergo routine testing and inspections as mandated by technical specifications and industry standards like the ASME Code, typically during an outage. It was also highlighted that the modularity of PSS may potentially allow more straightforward testing and component replacement processes during plant outages, like refuellings.

4 SUMMARY AND FINAL CONSIDERATIONS

Trying to summarize all the information provided, it seems that the current experience of ETSON members in the treatment of passive safety systems (PSS) is both varied and evolving.

In the following, some potential conclusions are drawn from the information gathered:

- There is a clear indication that ETSON members are extremely interested in the development and application of PSS. This is driven by the well-identified benefits of PSS in enhancing safety, particularly following lessons learned from accidents like the Fukushima Daiichi NPP.
- The ETSON members are actively contributing to and collaborating on international projects and working groups. These projects aim to benchmark, develop, and validate system thermal-hydraulic, CFD and severe accident codes against experimental data dedicated to passive safety systems, indicating a collective commitment to improve the safety standards.
- Although, in many cases, there are no specific safety requirements for PSS distinct from active systems, the integration of passive systems should be established within the framework of nuclear safety. For instance, the Defence in Depth (DiD) strategy should be applied to PSS, where they play a crucial role in preventing and mitigating accident progression. Additionally, many ETSON members acknowledge that PSS may have unique characteristics that justify a more careful consideration to fully harness their potential in enhancing nuclear safety.
- The reliability of PSS is a focus area, with methodologies like REPAS and RMPS being applied to assess their reliability. ETSON members are extremely involved in the ongoing development and refinement of simulation codes to better predict the behavior of passive systems and related physical phenomena.
- Many ETSON members agree on the fact that the maintenance, testing, and inspection of PSS would not differ fundamentally from active systems, with strategies like continuous monitoring and testing/maintenance during the outage periods. Nevertheless, for the maintenance/testing/inspection actions requiring a change of system state (for example start-up of the system or part of the system), feasibility will have to be investigated. Indeed, some passive systems' start-up may be triggered by the destruction of some of their parts. Thus, such PSSs could be started up only once.
- The ETSON members recognize the need to ensure that passive systems can operate effectively in extreme environmental conditions (hazards).
- Despite the advancements in recent years, there is an expressed need for additional experimental data to support code validation and to further investigate the operational parameters of PSS.

- The engagement of ETSON members in sharing their experiences and knowledge through participation in working groups and research initiatives is vital for harmonizing safety assessment approaches across Europe.

Furthermore, up to now no safety case embedding implementation of innovative passive safety systems has been proposed in Europe. As a result, many members did not bring precise answers to some more “practical” safety questions of this questionnaire. This paradigm is evolving rapidly since many SMR designs are being developed nowadays.

Whatsoever, from all these observations, it is evident that while significant progresses have been made in the understanding and application of PSS, ongoing research, collaboration, and knowledge sharing among ETSON members are essential for continued advancements. The members collective efforts in participating in European projects and international working groups stress the importance to converge towards a unified approach to safety and reliability standards, with possible specificities to account for the regulatory and national policies of each country. The information collected in the present questionnaires provide a robust frame for future discussions, research, and implementations of passive safety systems.

5 CONSIDERATIONS IN RELATION TO THE OECD QUESTIONNAIRE

A similar questionnaire was proposed in the OECD "SOAR on reliability of thermal-hydraulic passive systems" (OECD, 2024), which offers insights that align closely with the findings from the ETSON questionnaire, revealing several shared conclusions and distinctions:

- Both questionnaires highlight the lack of a unified, internationally accepted definition of passive systems. The OECD report emphasizes the diversity across countries, where some countries rely on general interpretations, while others adopt internationally recognized definitions, such as those from the IAEA, or develop their own based on specific regulatory requirements. This underscores a need for standardization to enhance consistency across nuclear safety practices.
- Both questionnaires highlight a broad consensus regarding the key role that passive safety systems may play in incidental or accidental transients in NPPs. The findings reinforce that PSS could be particularly beneficial in the framework of Defence in Depth (DiD) strategies, especially in preventing and mitigating accident progression. Both surveys reflect the critical position that PSS hold within the safety design philosophy of advanced reactors.
- The answers from OECD questionnaire show that there are different ways to treat PSS with respect to the single failure criterion. In some countries, PSS may be excluded from this criterion if their reliability is demonstrably high. Other countries do not make difference between active and passive safety systems, or distinguish between short-term or long-term accident mitigation. This indicates diverse regulatory perspectives on PSS reliability standards that may benefit from harmonization.
- While there are no reactors in the EU that embed PSS in their design, it is not the case for all OECD countries: for instance, passive safety systems are used in Japan's BWRs. In both questionnaires, TSOs consider that operation of experimental facilities devoted to studying PSS are at least not common.
- Both participants agree on the fact that a PSA for PSS requires a complex approach and dedicated methodologies, and that further effort is needed to achieve consensus in this area.

APPENDIX 1

QUESTIONNAIRE TEMPLATE

1 Information

Please provide your name, country of residence, e-mail address and the organization you represent.

Contact person:

Country:

Company / Organization:

E-mail:

2 Topics of interest

Topics	For information only	Active contribution	Practical examples already available? Yes/No and which ones?
1. Design and safety rules (Defence in Depth, application of single failure criteria, consideration of hazards, activation, performance…)			
2. Deterministic approach (final state, penalization of input data, aggravating single failure, research of penalizing configuration for Design Basis Condition (DBC), study of cliff-edge effects…)			
3. Reliability (Methodology to assess reliability, determination of functional failure, Integration in Probabilistic Safety Assessment (PSA)…)			
4. Codes qualification			

(uncertainties, experimental facilities, need of experiments to support validation of codes…)			
5. Operating requirements (Commissioning tests, periodic tests, maintenance, inspectability, technical operating specifications…)			
6. Kind of fluid used by passive system			
Water			
Gas			
Liquid metal			
Others			

3 TSO experience regarding passive systems

Topics	Questions
1 Types of passive systems	Q1_1 : Could you please choose one passive system (based on natural circulation) that was analysed or will be analysed in the short term by your TSO and describe it briefly? *[question related to OECD Q.5 in Appendix]* Q1_2 : For the next questions, could you please focus on this passive system (application, safety function, performance, etc.)?
2 Design and safety rules (Defence in Depth, application of single failure criteria, consideration of hazards, activation, performance…)	Q2_1 : Do you have specific requirements for passive systems and, if you do, which one? already available/ work in progress / no specific requirements *[question related to OECD Q.2 in Appendix]* Q2_2 : How does the Defence in Depth (DiD) demonstration impacted by passive systems? For which level of DiD is designed the passive system (level 3a, 3b, 4?) or which DiD level(s) is the best place for passive systems and why? *[question related to OECD Q.3 in Appendix 2]* Q2_3 : How is activated the passive system? How long does it take from t0 (start of accident) to nominal conditions? Are specific phenomena or issues expected during the start-up phase? Q2_4 : Do you consider internal and external hazards in the design or assessment of passive system? Q2_5 : What are the characteristics of passive system in order to be robust to single failure (redundancy, diversification?) Q2_6 : What is the order of magnitude of the duration of the passive system's mission? Is it a factor in the choice of whether or not to implement a passive system in view of the difficulties that could be associated with demonstrating its effectiveness over the long term?
3 Deterministic approach (final state, penalization of input data, aggravating single failure, research of penalizing configuration for DBC, study of cliff-edge effect…)	3.1 Specific requirements for deterministic studies for design mainly based on passive systems Q3.1_1 : What general requirements or criteria are used for the deterministic assessment of passive safety systems? *3.*2 Safe state

	Q3.2_1 : What is considered as a safe state for designs mainly based on passive systems? Q3.2_2 : What are the associated requirements (temperature, pressure, duration, possibility of intervention, etc)? Q3.2_3: Do you need any specific complementary systems to allow to reach cold conditions, if this state is not reached by using only passive systems? Are these complementary systems safety classified? 3.3-Identification of adequate aggravating single failure *For example, in France, the single failure is considered at several steps of the safety approach:* - *Design of the system: redundancy to enable the system to ensure its function even in case of single failure on its components or* - *Deterministic safety studies: an additional single failure is applied as a penalizing assumption of deterministic safety studies to check the safety criteria (called "aggravating single failure"). The choice of the adequate aggravating single failure (the most penalizing regarding safety criteria) can be made by engineering judgement, sensitivity studies, Failure Mode and Effect Analysis.* Q3.3_1: What is the approach retained to determine for each safety study the adequate aggravating single failure (engineering judgement, sensitivity studies, Failure Mode and Effect Analysis….)? *[question related to OECD Q.9 in Appendix 2]* Q3.3_2 : Is this safety approach adapted or modified for a design mainly based on passive safety systems? *[question related to OECD Q.11 in Appendix 2]* *Apart from mechanical and electrical failures, another type of failure, called "functional failure" may lead a passive safety system to fail. Indeed, a passive safety system may rely on low-intensity phenomena (e.g. natural convection) which, under certain conditions, may be insufficient to perform its function. Such failure may occur when the phenomena at play are sensitive to system geometry (e.g. head loss sensitivity), ambient parameters and mismatches between design expectations and actual conditions. This type of failure, referred to as a "functional failure", may lead to non-actuation or shutdown of a passive safety system, or unexpected operating conditions.* Q3.3_3: Is functional failure taken into account in order to identify the adequate aggravating single failure? 3.4 Internal and external hazards *Some passive systems may be very sensitive to environmental changes induced by hazards, for example :* - *Environmental conditions that change air temperature, moisture and particles concentration in the air for a system that uses the atmosphere as heat sink,*

	- *Fire that could modify the necessary temperature distribution in a system that uses buoyancy for fluid circulation,* - *Pipe deformation in the case of seismic event or load drop for a system that uses natural fluid circulation.* Q3.4_1 : What kind of hazards are considered for the design of passive systems and in the safety demonstration (extreme cold or hot external temperature, fire, explosion, storm, etc)? How are they addressed? 3.5 Unexpected activation Q3.5_1: How is considered unexpected activation of passive system in the safety demonstration? In this case, how is stopped the passive system? What are the requirements applicable to the means used to stop the passive system in these conditions?
4 Probabilistic approach (potential specific approach for PSA, methodology to quantify reliability, determination of functional failure, success criterion...)	Q4_1 : What general requirements or criteria are used for the probabilistic assessment of passive safety systems? Q4_2 : What is the approach used to assess the reliability of the system (FMEA, RMPS, other)? Do you presently develop or work on a specific reliability method? *[question related to OECD Q.10 in Appendix 2]* *When assessing the reliability of a passive system, a success criterion shall be chosen to determine if the system operates properly or fails. For instance, for passive systems such as Safety Condenser (SACO), the success criteria could be :* - *reach of safe shutdown state before 24 hours,* - *removal of 100 % of residual power at any time* Q4_3 : What is the success criterion for the performance of passive system? Q4_4 : What is the approach retained to assess the uncertainties on each parameters? Is this approach specific to passive systems? Q4_5 : Is functional failure considered? If so, what is the method used to assess the functional failure (RMPS/Reliability Methods for Passive Systems, others)? What is your experience regarding this approach (advantages, drawbacks, difficulties)? Q4_6 : How are common cause failures on redundant passive systems taken into account?
5 Codes qualification (uncertainties, experimental facilities, need of experiments to support validation of codes...)	Q5_1 : Do you participate to international projects related to passive systems ? If yes, which ones and provide a description of the objectives and content of your participation in these projects? *[question related to OECD Q.7 in Appendix 2]* Q5_2 : What are the codes used for the safety analyses using passive systems? Are the codes ready/qualified to perform calculations with passive systems? What are the improvements required to perform these calculations? If possible, please provide the range of conditions covering operation of passive systems and give examples of ranges of conditions out of codes domain of validation and that required specific experimental tests to validate code?
6 Operating requirements (Commissioning tests, periodic tests, maintenance, inspection, technical operating specifications...)	Q6_1 : Are full scale tests in experimental facilities or on-site commissioning tests performed in your country? *[question related to OECD Q.6 in Appendix 2]*

	Q6_2 : How do you ensure the availability of passive systems? How are performed periodic tests to check the adequate overall passive systems operation? How is checked each unitary function (opening of valves, etc.)? Q6_3 : To guarantee the qualification over the whole plant life time, what parameters (necessary to justify the operability) are followed during day to day operation? Which kind of instrumentation is installed or shall be taken into account to ensure the monitoring of the operational conditions? Q6_4 : How start of passive system is guaranteed even in extreme cold conditions, especially when final ultimate heat sink is located outside (by tests, controls, conditioning/continuous operation, electric tracing by heating cable, others)? What are the extreme cold conditions considered? How is performed conditioning of passive system (continuous operation, other...)? Q6_5 : Maintenance, inspection: what are the main characteristics and constraints specific to passive systems?

APPENDIX 2

QUESTIONNAIRE FROM OECD/WGAMA DISTRIBUTED IN 2016

- Q.1. Do you have any definition in your organization on passive systems (e.g. as stated in your national nuclear regulations)? If yes, please provide the definition. If no, please provide a definition on passive systems that could be appropriate in your view.
- Q.2. Do you consider that specific requirements are needed for passive systems? Do you know of any regulatory requirements or guidelines for the design and/or operation of passive systems (e.g. in relation to expected level of reliability)? If such a requirement or guideline is available, please provide a description and/or reference documents.
- Q.3. Do the assumptions considered in thermal-hydraulic analysis for different plant conditions (i.e. DBC 1-4, DEC 1-2) differ for passive and active systems with respect to single-failure criterion as well as maintenance activities? If yes, please specify the differences.
- Q.4. Are passive systems dedicated to accident mitigation (or control) currently used/planned to be used in nuclear power plant(s) in your country? If yes, please provide a concise system description and/or available reference documents if available to share.
- Q.5. Is design or development of passive systems in the scope of your current activities? If yes, please provide a summary description and/or available reference documents.
- Q.6. Does your organization operate any demonstration and/or experimental facilities related to thermal-hydraulic passive systems? If yes, please provide a description and/or available reference documents.
- Q.7. Do you have any experience or ongoing activities in the field of passive system safety assessment (including thermal-hydraulic and/or probabilistic analyses) to share? If yes, please provide a list of tools, methods, computational code(s) used and a short description of your experience. Please describe whether these elements were specifically developed for applications to passive systems and how they have been qualified for such applications.
- Q.8. What do you consider as the most significant advantages, drawbacks and challenges with respect to design, operation and safety analyses of passive systems, if available to share?
- Q.9. Do you use a specific taxonomy for describing the failures of passive system components, i.e. what types of components can fail and how? If yes, then please provide a

brief description of that taxonomy (component types and associated failure modes) and/or some reference documents if possible.

- Q.10. Do you use any reliability data for passive systems (e.g. failure to start and/or failure to run or any other applicable failure modes) in any of your safety assessments? If yes, please provide a description and/or reference document if possible.
- Q.11. Does the emergency operating procedures (EOPs) used in your domestic nuclear facilities contain any instruction to catalyze the performance of the passive system in case of a system start-up failure and/or to prevent the aggravating effects due to a passive system malfunction?
- Q.12. If you have any further remark regarding thermal-hydraulic passive systems, please elaborate it here.

APPENDIX 3

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