European Nuclear Safety Regulators Group

ENSREG

2nd Topical Peer Review Summary Report

"Fire Protection"

(May 2025)

EXECUTIVE SUMMARY AND MAIN RECOMMENDATIONS

Background

In 2014, the Council of the European Union (EU) adopted Directive 2014/87/EURATOM[1] amending Directive 2009/71/EURATOM (Nuclear Safety Directive) in order to incorporate lessons learned from the accident at the Fukushima Daiichi nuclear power plant in 2011, and to take account of the subsequent EU stress-tests findings. Recognising that cooperation between Member States can give added value in terms of nuclear safety, transparency, and openness towards stakeholders, as well as delivering continuous improvements, the revised Nuclear Safety Directive introduced a European system of 'Topical Peer Reviews' (TPR) that commenced in 2017 and take place at least every six years thereafter.

The purpose of Topical Peer Reviews is to provide a mechanism for EU Member States to jointly examine topics of importance to nuclear safety, to exchange experience and to identify opportunities to strengthen nuclear safety. The process also provides for participation, on a voluntary basis, of non-EU countries hosting nuclear installations.

In November 2020, at its 41st plenary meeting, ENSREG decided, based on a proposal of WENRA, that the topic of the second Topical Peer Review (TPR II) would be "Fire Protection" at nuclear installations, and nominated the Chair and vice-Chair of the TPR II Board that would oversee the peer review activities. Subsequently, nominations were sought for national experts, rapporteurs and team leaders to perform the peer review.

Following a public consultation, the Terms of Reference (ToR)[2] and the Technical Specification (TS)[3] of the Topical Peer Review prepared by WENRA, as well as a Stakeholder Engagement Plan[4], were approved by ENSREG in June 2022 and published on the ENSREG website thereafter.

All nuclear installations covered by the Nuclear Safety Directive are considered in TPR II. Given the large number of nuclear installations that come within the scope of the TPR, and in order to keep the peer review exercise manageable, WENRA proposed a methodology to select the candidate installations to be reported on in the national assessments, with the perspective that insights from the peer review conducted on the selected installations will be transferable to the other national installations ("represented" installations).

This methodology was applied by the national competent authorities of each participating country. Based on ENSREG's request, the list of installations selected at national level together with the rationale for the selection was reviewed by the team leaders in the TPR Board, and the outcomes were reported to ENSREG at its 52nd plenary meeting in April 2023, prior to the completion of the national assessments.

Scope, Objectives and Organisation of the Topical Peer Review

This topical peer review on fire protection was intended to:

- Enable participating countries to review their provisions for fire protection to identify strengths and weaknesses;
- Undertake a European peer review to share operating experience and identify findings: common issues or challenges at EU-level, good practices, areas of good performance and areas for improvement;
- Provide an open and transparent framework for participating countries to develop appropriate follow-up measures to address areas for improvement.

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2014.219.01.0042.01.ENG
[2] https://www.ensreg.eu/sites/default/files/attachments/terms_of_reference.pdf
[3] https://www.ensreg.eu/sites/default/files/attachments/technical_specification.pdf
[4] https://www.ensreg.eu/sites/default/files/attachments/stakeholder_engagement_plan.pdf

The review process consisted of three phases:

- In the first phase, national self-assessments were conducted against the WENRA Technical Specification. Results of the self-assessments carried out by the 22 participating countries were documented in the **National Assessment Reports (NARs)** and published in November 2023.[5]
- The second phase, involving the experts' review, started just after the NARs had been published and made available for questions and comments from all stakeholders. As an indication of the interest and commitment to the TPR II and the importance of the selected topic, this phase resulted in more than 2600 questions and comments combined from the nominated peer review experts, participating Member States and all stakeholders. Subsequently, two workshops were organised to discuss the results of the self-assessments, the questions and comments on the NARs, the replies to the questions, as well as the findings from the experts with a view to identifying and discussing both generic and country-specific findings on fire protection. Draft reports (Topical Peer Review Summary Report and Country Review Reports) were issued prior to the relevant workshops as an input for the workshop discussions.
- In the third and final phase of the Topical Peer Review, this Topical Peer Review Summary Report has been compiled addressing the generic findings of the review process. The country review reports document country-specific findings that provide an input for National Action Plans (NAcPs).

Eighteen European Union Member States with nuclear installations together with Switzerland, Türkiye, Ukraine, and the United Kingdom participated in the peer review. The regulators of the participating States nominated a total of 48[6] experts and rapporteurs to carry out the review on the different thematic areas of the NARs as part of the 'TPR team' of reviewers. The entire Peer Review process and activities were overseen by the Topical Peer Review Board, which comprised seven senior regulators from EU Member States, a senior manager from the European Commission (EC) and a Technical Secretariat provided by the EC.

In the workshops, there were up to 175 participants[7], including observers from South Africa as well as representatives from the International Atomic Energy Agency (IAEA), the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD), and from the nuclear insurance company Nuclear Electric Insurance Limited (NEIL).

Main Outcomes of the Topical Peer Review

ENSREG selected "fire protection" as the topic for this Topical Peer Review, recognising fire as a significant risk to many nuclear installations.

As a key component of the TPR process, the NARs provide informative insights into national practices and regulatory approaches. Comprehensive fire protection strategies - encompassing prevention, as well as active and passive measures - are widely implemented. Fire safety analyses and regular inspections play a key role in identifying and addressing potential gaps. The exchange of operational feedback and best practices further strengthens fire risk management.

The TPR review has highlighted a diverse range of approaches and solutions adopted across participating countries. While variations exist in fire protection implementation, no critical deficiencies were identified in the fire protection strategies of the installations within the TPR scope. The TPR review has noted the importance of applying all levels of defence-in-depth to ensure robust fire protection, supported by thorough fire safety analyses. Effective fire load management remains a priority, with leadership, accountability, and a strong safety culture playing a crucial role in minimizing fire risks.

[5] Ukraine's NAR was made available in March 2024. All national assessment reports are available on the ENSREG website: https://www.ensreg.eu/country-specific-reports-tpr-ii

[6] This figure is the total number and includes substitutions of a few experts and rapporteurs during the period of the review

[7] The thematic workshop hosted 128 in-person attendees (51 licensees, 54 regulators, 23 others, including the TPR team) plus about 44 online participants. In the country review workshop, there were 135 in-person attendees (51 licensees, 62 regulators, 22 others including the TPR team) and around 40 online participants

As part of this TPR, site visits to selected research reactors were introduced, offering peer reviewers valuable opportunities to observe the practical and operational implementation of fire protection measures.

The peer review identified both good practices and challenges at the EU level, which are detailed in this report, along with national areas of good performance and areas for improvement outlined in the Country Review Reports.

Recommendations to the participating countries and to the European Nuclear Safety Regulators Group (ENSREG)

National and ENSREG action plans should be developed to address the identified areas for improvement and challenges.

The National Action Plan (NAcP) should address the results of the self-assessment and respond to the country specific findings outlined in the country review report. Furthermore, the Board recommends that participating countries consider how the insights from the TPR, in particular their country specific findings, are transferable to their "represented installations" when developing their NAcP. Additionally, the Board encourages participating countries to examine all findings from this peer review - regardless of their categorisation (good practice, area of good performance, area for improvement) - and assess their applicability to enhance fire protection.

The peer review identified challenges where European-level action could enhance fire protection and support consistency of approaches. The Board recommends that ENSREG develop an action plan to address these challenges.

Transparency

One of the objectives of the TPR was to promote transparency and provide opportunities for stakeholder participation. In line with the 'ENSREG Stakeholder Engagement Plan', the TPR II activities included the following elements:

- Making information available about the TPR process and contents through the ENSREG website (availability of fact sheets on the TPR, publication of the NARs, access to the workshop presentations and final peer review reports);
- Organisation of a public stakeholder meeting at the beginning of the process to inform about the background and objectives of EU peer reviews and collect views;
- Opportunities for further public participation through submission of the draft technical specification, draft terms of reference and a draft stakeholder engagement plan to a public consultation via the ENSREG website; provision of a public platform for stakeholders to submit questions and comments on the NARs contents; publication of written responses to the consultation of the TPR process documents and replies to stakeholder questions on the NARs;
- Organisation of a further stakeholder meeting at the end of the process to discuss the results of the review.

Despite a strong external participation in the initial public stakeholder event in 2021 which informed about the choice of the topic and the public participation opportunities, less stakeholder interest was observed in the subsequent stages of the process despite expectations that the choice of topic (fire-protection) would encourage public attention.

In Conclusion

The peer review successfully met the generic goals and objectives set out in the Nuclear Safety Directive and in the Terms of Reference established by ENSREG. It provided a valuable opportunity for participating countries to assess their fire protection provisions, share information and experience, and provided an open and transparent framework for countries to develop appropriate follow-up measures.

Contents

0. INTRODUCTION

0.1 The Nuclear Safety Directive

Nuclear safety is of utmost importance to the EU citizens. On 25 June 2009, the Council of the European Union adopted Directive 2009/71/Euratom establishing for the first time a Community framework for the nuclear safety of nuclear installations, which provides binding legal force to the main international nuclear safety principles. The Directive aims to maintain and promote the continuous improvement of nuclear safety.

The Council amended the Nuclear Safety Directive in 2014 (Council Directive 2014/87/Euratom) *“in view of the technical progress achieved through the provisions of the IAEA and by the Western European Nuclear Regulators Association (‘WENRA’) and responding to the lessons learnt from the stress tests, carried out in 2011 and 2012, and the Fukushima nuclear accident investigations,”* (Directive recital 15).

The amended Directive requires EU Member States to give the highest priority to nuclear safety at all stages of the lifecycle of nuclear installations. This includes carrying out safety assessments regularly and identifying and implementing reasonably practicable safety improvements in a timely manner.

0.2 General overview of Article 8e – Peer Reviews

Recognising the importance of Peer Reviews in delivering continuous improvement to nuclear safety, the revised Nuclear Safety Directive introduced a European system of topical peer reviews commencing in 2017 and occurring at least every six years thereafter. It notes, *“…peer-reviews have proved to be a good means of building confidence, with the aim of developing and exchanging experience and ensuring the common application of high nuclear safety standards.”* (Recital 22).

The amended Directive requires (Recital 23, 2nd paragraph) that "*Member States, through their competent regulatory authorities making relevant use of ENSREG, and building on the expertise of the WENRA, should every six years define a methodology, Terms of Reference and a time frame for Peer Reviews on a common specific technical topic related to the nuclear safety of their nuclear installations. The common specific technical topic to be considered should be identified among the WENRA safety reference levels or on the basis of operating experience feed-back, incidents and accidents and technological and scientific developments. Member States should perform a national self-assessment and make arrangements for common peer reviews by other Member States' competent regulatory authorities of their national self-assessment.*"

The legal provisions regarding the Topical Peer Review mechanism are specified in the Article 8e "Peer Reviews" of the amended Nuclear Safety Directive where it is stated:

> *"1. ….*
>
> *2. Member States shall ensure that, on a coordinated basis:*
>
> *(a) a national assessment is performed, based on a specific topic related to nuclear safety of the relevant nuclear installations on their territory;*
>
> *(b) all other Member States, and the Commission as observer, are invited to peer review the national assessment referred to in point (a);*
>
> *(c) appropriate follow-up measures are taken of relevant findings resulting from the peer review process;*
>
> *(d) relevant reports are published on the above-mentioned process and its main outcome when results are available.*
>
> *3. Member States shall ensure that arrangements are in place to allow for the first topical peer review to start in 2017, and for subsequent topical peer reviews to take place at least every six years thereafter.*

According to the Directive (Recital 23, 3rd paragraph) "*Reports on the findings of those peer reviews should be produced. Member States should establish national action plans for addressing any relevant findings and their own national assessment, taking into account the results of those peer review reports. The peer review reports should also form the basis of any summary report of the outcome of the Union-wide topical peer review exercise prepared collectively by the competent regulatory authorities of the Member States. The summary report should not aim to rank the safety of nuclear installations but rather focus on the process and technical findings of the topical peer review so that the knowledge gained from the exercise can be shared*."

0.3 Objectives of the Topical Peer Review (TPR)

On the basis of proposals made by WENRA, at its 41st meeting[8] in November 2020, ENSREG identified **"Fire Protection"** as the topic for this TPR due to the safety significance of the topic for nuclear installations.

The generic objectives for the Topical Peer Reviews are defined in the Directive (see above). In addition, the TPR terms of reference sets the following objectives:

- Enable participating countries to review their provisions for fire protection to identify strengths and weaknesses;
- Undertake a European peer review to share operating experience and identify findings: common issues or challenges at EU-level, good practices, areas of good performance and areas for improvement;
- Provide an open and transparent framework for participating countries to develop appropriate follow-up measures to address areas for improvement.

0.4 Purpose of the Summary Report

The purpose of this report is to present the outcomes of the peer review process, with a particular focus on generic topics of interest identified by the TPR II Team and discussed during the thematic sessions of the workshop. Additionally, the report outlines the good practices and challenges that were agreed upon during the workshop.

The country-specific findings from the peer review process are documented in the Country Review Reports, which can be accessed on the ENSREG website.

[8] https://www.ensreg.eu/sites/default/files/attachments/minutes_of_the_41st_meeting_of_ensreg.pdf

1. DESCRIPTION OF THE PEER REVIEW PROCESS

1.0 Topic and scope of the TPR

Based on a proposal from WENRA, ENSREG identified "fire protection" at nuclear installations as the topic for this TPR since fire is among the significant risks for many nuclear installations. Fires can occur at many locations in an installation and may be capable of challenging multiple structures, systems and components (SSCs) relevant to safety simultaneously, being a possible cause of common cause failures. A fire could also involve nuclear and/or radioactive materials and lead to the release and dispersion of these. In addition to being an independent event itself, fire can be induced by other external or internal hazards or events. It can also itself induce other internal hazards (e.g. flooding, explosion).

None of the previous evaluations and benchmarks initiated after Fukushima at the European level covered fire protection, thus it is a subject that can lead to new insights. It is also a topic that is relevant for all nuclear installations, subject to a graded approach. Aspects other than nuclear safety are not in the scope of the TPR.

The TS identifies three specific thematic areas as subject of the peer review, namely ‘Fire safety analyses’, ‘Fire prevention and passive fire protection’, and ‘Active fire protection'.

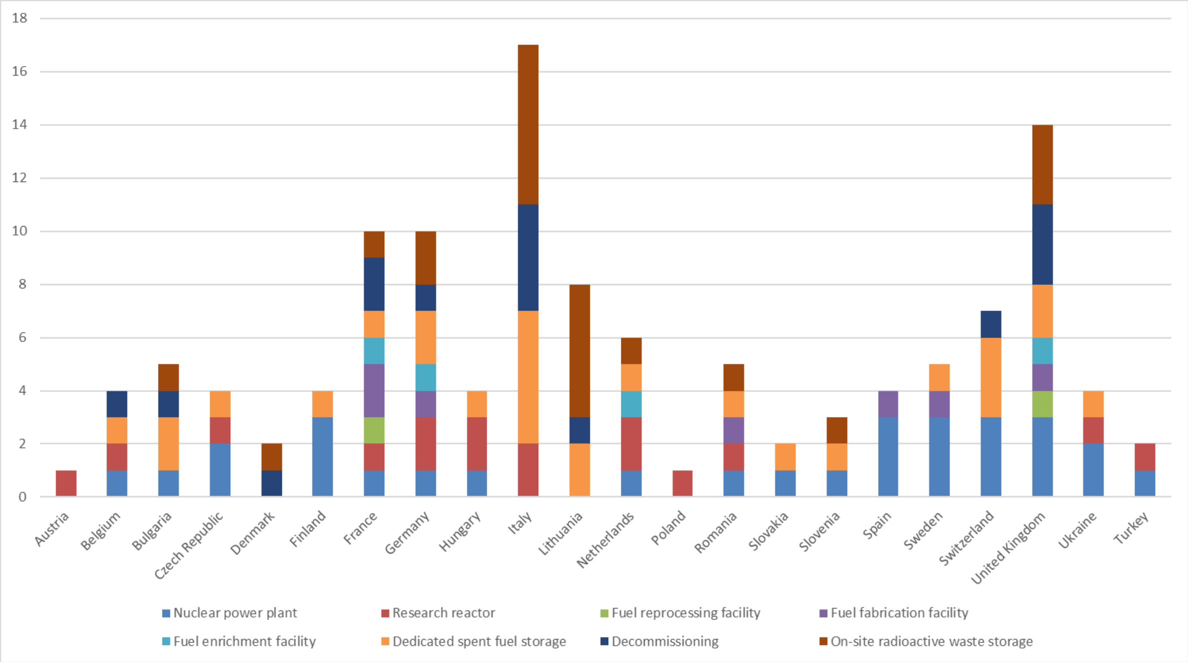
All nuclear installations within the scope of the Nuclear Safety Directive were considered within the TPR II. Given the large number of nuclear installations that come within the scope of the TPR and to keep the Peer Review exercise manageable, the national competent authorities of each participating country performed a selection, based on the methodology proposed by WENRA, of the installations to be reported on in the national assessments (candidate installations). In addition, insights from the peer review conducted on the candidate installations will be transferable to the other national installations represented by the candidate ones.

At the 47th ENSREG plenary meeting, ENSREG *“agreed to a review process of the national proposals of the nuclear installations to be reported on involving the team-leaders (TL) in the TPR-II Board; however, the final selection of installations would be a national decision”.*

Based on this decision, the list of installations selected at national level together with the rationale for the selection was reviewed by the team leaders appointed in the Board and reported to ENSREG (52nd ENSREG plenary meeting, April 2023) prior to the start of the national assessments. In its report[9], the Board gives the conclusions of the review, in particular with recommendations for providing further justification or inclusion of some complementary installations. ENSREG underlined that the final selection of installations would be made by the national competent regulatory authorities, and that the outcome of the Board’s review should be considered as recommendations for the authorities to follow.

[9] https://www.ensreg.eu/sites/default/files/attachments/tpr_ii_boards_review_of_national_selections.pdf

The distribution of the final choice of 122 candidate nuclear installations is shown below:



1.1 Project Organisation

1.1.1 Topical Peer Review Board

The TPR Board was established at the 41st meeting of ENSREG in November 2020, to provide leadership and to supervise the peer review process. For this TPR, the TPR Board also coordinated the preparatory activities for the TPR process. The Board comprised the Chair, a Vice Chair, a senior manager from the European Commission (EC), three thematic Team Leaders and two Country Group Team Leaders, and an EC Technical Secretariat:

Position	**Name**	**Organisation**
Chair	Sylvie Cadet-Mercier	ASN (FR)
Vice- Chair	Lamberto Matteocci	ISIN (IT)
European Commission Representative	Michael Hübel	DG ENER
Thematic Team Leaders		
Fire safety analyses	Miguel Ángel Jiménez Garcia	CSN (ES)
Fire prevention and passive fire protection	Robert Jansen	ANVS (NL)
Active fire protection	Gisela Stoppa	BMUV (DE)
Country Group Team Leaders		
Group 1	François Henry	BEL V (BE)
Group 2	Dainius Brandišauskas	VATESI (LT)
Technical Secretariat	Bharat Patel	DG ENER

1.1.2 The TPR Team

In December 2020, the TPR Board on behalf of ENSREG asked ENSREG members and observer countries to nominate suitable experts that could perform an in-depth technical (peer) review of the participating countries' NARs according to the following:

- each EU Member State and other participating country[10] had the right to nominate one or more experts for each of the different thematics;
- based on required competencies described by the Board[11], experts were nominated by their countries based on their qualifications and experience; information on the experts´ background was provided to facilitate the composition of balanced teams;
- in nominating their experts, countries also indicated whether they could serve as Team Leaders or Rapporteurs;
- the appointment of Team Leaders and Rapporteurs was agreed jointly by ENSREG and the TPR Board.

The final list of rapporteurs was as follows. The list of experts is detailed in Annex I:

	Name	Organisation
Thematic Rapporteur		
Fire safety analyses	Eunate Armañanzas Albaizar	CSN (ES)
Fire prevention and passive fire protection	Stefan Borghoff	BMUV (DE)
Active fire protection	Laima Kuriene	ANVS (NL)
Country Group Rapporteur		
Group 1	Evaldas Kimtys	VATESI (LT)
Group 2	Luca Cretara	ISIN (IT)

Based on the nominations, three teams of experts were created according to the identified thematic areas:
- Fire safety analyses
- Fire prevention and passive fire protection
- Active fire protection.

The experts reviewed the NARs under the guidance of their respective Thematic Team Leaders. The nominated experts, rapporteurs and Board Members represented altogether a 'TPR Team' of 57 persons (42 experts, 6 rapporteurs, and 9 Board members)[12] coming from 22 different countries (EU and non-EU) as well as the European Commission.

1.1.3 European Commission support

According to Directive 2014/87/Euratom, the European Commission has the role of observer in the Topical Peer Reviews. It also has the role of facilitator in providing a secretariat support for all phases of the process. In this TPR, the European Commission was represented in the TPR Board and Commission experts from the JRC and DG ENER participated in the team of experts.

1.2 Project Implementation

1.2.1 Technical Specification, Terms of Reference and Stakeholder Engagement Plan

The Technical Specification, which defines the content and the template of the National Assessment Report, was drafted by WENRA; the Terms of Reference (ToR) and the Stakeholder Engagement Plan were prepared by ENSREG working groups. The TPR Board finalised the ToR before submission to ENSREG.

[10] TPR II terms of reference allow for participation on a voluntary basis of non-EU countries hosting nuclear installations
[11] Also described in the Terms of Reference
[12] These are the originally nominated team members, and figures include substitutions during the period of the review

After making draft versions of these documents available for consultation by stakeholders including the public between 13 April and 27 May 2022[13], final versions of the documents were approved by ENSREG and published on its website in June 2022[14], thereby launching the TPR II process.

1.2.2 Preparation of National Assessment Reports (NARs)

The Peer Review exercise is a requirement under Article 8e of the Nuclear Safety Directive for EU Member States, but several non-EU countries also participated in the TPR II on a voluntary basis. The 22 participating countries comprised:

- EU Member States: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Lithuania, Netherlands, Poland, Romania, Slovakia, Slovenia, Spain, Sweden;
- Non-EU countries: Switzerland, Türkiye, Ukraine, United Kingdom.

The NARs were prepared by the national nuclear safety regulators based upon the assessments made by the installations' operators, and following the WENRA Technical Specification. The reports were published on the ENSREG website in November 2023[15] [16].

1.2.3 Desktop Review

The review by the TPR II experts was organised by thematic areas.

The TPR Board provided guidance to the experts throughout the review stages, and to ensure consistency of the Peer Review. Each expert was responsible for the review of several installations for a given thematic area. Based on their initial review of the NARs, the experts sought clarifications and further details on the NARs' descriptions of the fire protection thematic areas during a written Q&A phase which ran from February - April 2024 (see also Annex II – Statistics about the Q&A).

Based on their review, the experts identified:

- specific 'topics of interest' for further in-depth discussion in the thematic sessions of the workshop (described in Sections 03 to 08 of this report);
- country-specific findings to be addressed in the country review workshop (detailed in the Country Review Reports).

As an additional element to complement the desktop review, it was decided that inclusion of a limited number of site visits would be beneficial to the TPR II process as an additional means for sharing experience and national practices on specific fire protection issues and directly involving licensees as well as regulators. These site visits were focused on research reactors, since fire protection is not covered to the same extent by the international review missions to which they are subject. The visits were conducted by teams composed of members of the Board and experts of the TPR Team.

1.2.4 Peer Review Workshops

The thematic workshop took place in Luxembourg from 9 to 12 September 2024 with around 128 in-person representatives from the participating and observer countries[17], including licensees. Participants also attended from the European Commission, IAEA, OECD/NEA, WENRA, as well as a representative from the nuclear insurance field. All the sessions were web-streamed on a secure network and about 44 online participants from regulatory authorities, licensee companies, TSOs and other subject experts joined to follow the discussions.

Discussions at the thematic workshop were structured around a number of 'topics of interest' identified by the peer review experts based on commonalities and differences in the fire protection approach in the participating countries, principally with a view to sharing experience, but as well to

[13] https://www.ensreg.eu/tpr-ii-public-engagement
[14] https://www.ensreg.eu/tpr-ii-process-documents
[15] https://www.ensreg.eu/country-specific-reports/EU-Member-States-tpr2
[16] https://www.ensreg.eu/country-specific-reports/other-countries-tpr2
[17] Observers from non-participating countries in the EU (Luxembourg) and outside the EU (South Africa) were present as well as online.

highlight any good practices and challenges (see Annex III for the TPR findings definitions). To facilitate an informed exchange of views amongst the workshop participants, a draft version of this summary report was distributed ahead of the workshop, containing a description of the topics of interest, the aspects proposed to be discussed and the expected outcomes from the discussion.

The conclusions of the thematic workshop are documented in this report, as described in the ToR.

Furthermore, the country review workshop took place in Luxembourg from 30 September to 3 October 2024 gathering around 135 in-person participants and around 40 online attendees. The workshop focused on national experience with regard to fire protection, to enable thorough discussions on issues raised in the question-and-answer phase, and to conclude on the findings categorised as areas of good performance or areas for improvement (see Annex III for the TPR findings definitions). The Country Group Team Leaders were responsible for steering the discussions of the different experts involved in the three thematic areas to arrive at a consensus on proposed country-specific findings. The conclusions of this workshop are documented in the country review reports, as per the ToR.

1.3 Public information and interaction

In accordance with the ToR and the ENSREG 'Guidance for National Regulatory Organisations — Principles for Openness and Transparency'[18], a TPR II Stakeholder Engagement Plan was developed by ENSREG, to strengthen engagement with all stakeholders including the public, industry, regulatory authorities, government bodies and other interested parties, such as NGOs, identifying activities to ensure the peer review process and outcomes are visible to stakeholders and the public.

1.3.1 Information on the ENSREG website

Dedicated webpages were created on the ENSREG website for public information about the TPR II. These were updated throughout the peer review process.

The NARs were published by the national regulators on their websites and were also made available through the ENSREG website from November 2023[19]. In addition, the questions and answers on the NARs were published on the ENSREG website[20]. The 'Powerpoint' presentations of the TPR team as well as those of the national delegations at each of the workshops were also made available publicly[21].

The TPR Summary Report [this report], after endorsement by ENSREG Members, was published on the ENSREG website, together with the 22 country review reports with the country-specific findings[22].

Participating countries will prepare National Action Plans, whilst ENSREG will prepare its own action plan addressing 'EU-wide challenges'. These plans will also be published on the ENSREG website.

1.3.2 Public Events

As a prelude to the TPR II activities, on 22 June 2021, a first stakeholder event took place online to inform interested parties about the different European peer reviews and specifically about the TPR II process and timeline, and the technical basis for the choice of the topic of fire protection. Opportunities for public participation during the process - such as the possibility for posting questions on the NARs - were also highlighted. The event was web-streamed, and more than 140 stakeholders coming from industry, regulatory authorities, NGOs and TSOs participated. The agenda and presentations are available on the ENSREG website [23].

A further public information meeting will be organised once the peer review reports have been published to complement the public engagement and transparency activities associated with TPR II.

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[18] http://www.ensreg.eu/document/guidance-nro-principles-openness-and-transparency
[19] https://www.ensreg.eu/country-specific-reports-tpr-ii
[20] Available by following the country reports section on https://www.ensreg.eu/country-specific-reports-tpr-ii
[21] https://www.ensreg.eu/tpr-ii-thematic-workshop; https://www.ensreg.eu/tpr-ii-country-review-workshop
[22] Available by following country peer review reports at https://www.ensreg.eu/country-specific-reports/EU-Member-States-tpr2 and https://www.ensreg.eu/country-specific-reports/other-countries-tpr2
[23] https://www.ensreg.eu/tpr-ii-public-engagement

2. REGULATORY FRAMEWORK

The TPR II Technical Specification for the NARs specifically asks in regard to the regulatory framework:

- *to include a brief overview of the regulatory system relevant to fire safety to allow understanding of requirements and guidance and their implementation related to the development and implementation of the overall fire safety regime.*
- *to identify key regulatory documents and guidance as well as technical standards used domestically.*
- to *describe how international standards are used in developing the overall fire safety programme including:*
  - *relevant WENRA Safety Reference Levels (SRLs),*
  - *IAEA Safety Standards and other guidance, including the proven practices*.

The NARs present the national regulatory framework related to fire protection: they show large differences between countries and types of installation in the way to regulate nuclear fire protection in the nuclear installations.

The differences concern in particular:

- **the applicable requirements**
  - In most countries, there are specific nuclear safety requirements related to fire protection that complement the conventional fire safety requirements (e.g. Belgium, Bulgaria, Finland, France, Germany, Hungary, Italy, Lithuania, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye, Ukraine, the United Kingdom). Nuclear safety requirements are primarily aimed at protecting structures, systems and components relevant for nuclear safety and radiation protection from fire and ensuring safety functions, whereas conventional fire safety requirements are more focused on the protection of people and property;
    It can be noticed that the nuclear fire safety requirements are applicable in most countries specifically to NPPs, and not to other types of nuclear installations (e.g. Romania, Spain, Sweden, Ukraine). In such cases, the non-NPP nuclear installations are regulated by conventional fire requirements. One country is in the process of revising their nuclear fire protection regulations so that they apply to all nuclear installations (Romania);
    Most of these countries mention that the WENRA SRLs for NPPs are included either in their regulations or in guidance;
  - In some countries, the requirements for fire protection in nuclear installations are the conventional fire safety requirements, applicable to any industry or industrial building (Austria, Denmark, the Netherlands, Poland). In the Netherlands, the nuclear fire safety requirements are included in the licence conditions.

- **the Authorities in charge of fire protection in nuclear installations**

  In most countries, fire protection in nuclear installations is regulated by both the nuclear safety authority and the national authority responsible for conventional fire safety. Depending on the country, this may be entities such as the fire authority, fire rescue service, labour inspectorate or building authority. In some countries, fire events are to be reported to both authorities.

3. REPORTING, SHARING AND USE OF EXPERIENCE FEEDBACK

Types of installations mainly concerned

This topic is applicable to all types of installations.

Background and justification

Operating experience feedback from nuclear installations and activities and, where relevant, from elsewhere, is a key means of enhancing nuclear safety. The lessons learned from operating experience (internal and external) may be used in subsequent periodic safety reviews, self-assessments or peer reviews. They can be drawn from the analysis and exchange of information on fire safety related events (fire events[24] and events with deterioration or failure/malfunction of fire protection features). Lessons learned from such events can reveal weaknesses that can often be resolved with adequate (technical or organisational) provisions.

There are several WENRA SRLs for NPPs addressing operating experience feedback, in particular:

> (WENRA SRL B2.5) "*The licensee shall ensure that relevant operating experience, international development of safety standards and new knowledge gained through R&D-projects are analysed in a systematic way and continuously used to improve the plant and the licensee's activities.*",
> (WENRA SRL C3.5) "*Provisions shall be made in the management system to collect, process and document operating experience. Internal and external experience shall be used to improve safety.*"

Similar requirements are provided in the WENRA SRLs for research reactors. Most of the requirements are in principle also applicable to all nuclear installations.

The TS for the NARs specifically asks for the following in regard to experience feedback:

- *"how fire safety has developed and improved in the installations based on lessons learned from internal and external events and other sources such as Periodic Safety Reviews, Safety Review Missions, inspections, testing and maintenance, fire safety research and regulatory scrutiny,*
- *how operational feedback of experience is shared amongst all relevant stakeholders."*

During the desktop review, the TPR Team noted that the participating countries provided varying levels of information relating to operating experience feedback (categorisation, reporting, use etc). For this reason, the topic of interest "use of experience feedback" was chosen for thorough discussions at the thematic workshop, focusing on the following subtopics:

1. Fire safety related events and their reporting
2. Information sharing on feedback from fire safety related events
3. Developments in fire protection and improvements of fire safety resulting from operating experience feedback.

The objective of this transversal topic of interest - relevant for fire safety analysis, but even more so for improving the fire protection programmes in the installations, including fire prevention, active and passive fire protection - was to compare practices between countries and for different types of nuclear installations and to get an overview of the above subtopics.

1. Fire safety related events and their reporting

It is essential for enhancing nuclear (including radiation) safety to analyse and consider nuclear installations' internal and external (national and international) operating experience regarding fire safety related events, such as:

- fire events (including smouldering fires),

[24] According to the NFPA Standard Glossary of Terms and cited in the OECD/NEA FIRE Database, a fire event is defined as:

- Process of combustion characterized by the emission of heat accompanied by (open) flame or smoke or both
- Rapid combustion spreading in an uncontrolled manner in time and space

- events resulting from spurious actuations of fire protection features with potential associated harmful effects,
- events with a deterioration or failure/malfunction of active and/or passive fire protection features.

Therefore, recording these events is relevant to understanding lessons learned and to introduce improvements. Categorisation of fire events is important to help analyse the causal factors, severity, and consequences in order to identify potential improvements in fire prevention, active and passive fire protection measures.

Many countries mention that all fires or fire events, whatever their categorisation, are recorded by the licensee. During inspections, the regulatory body can review the records, the analyses and the actions put in place.

The mandatory reporting to the regulatory authority is based on a safety related categorisation of the events with given criteria as part of the nuclear regulations. Nevertheless, this categorisation is different across participating countries. There are differences in the approaches and criteria applied for analysing and reporting the events, in particular for reporting fire and/or fire events without significance to nuclear safety:

- In each participating country, fire events with significance to nuclear safety are reported to the regulatory authorities. In many countries (e.g. Belgium, France, Germany, Lithuania, Spain, Ukraine), there are dedicated criteria, reporting and investigation deadlines, etc;
- In some countries, any fire or fire event, whatever its safety significance, is to be reported to the regulators (e.g. Denmark, Finland, Italy);
- For most of the countries, criteria for reporting apply to both fire events and events related to the fire protection features;
- In many countries, the activation of the public fire brigade leads to an immediate notification to the regulatory authority (e.g. Belgium, France);
- In Slovenia, the licensee also reports on each fire event and each real or false fire alarm on an annual basis.

Moreover, in some countries, in addition to the reporting to the competent nuclear authority, reporting to the conventional fire safety authorities is also required.

Furthermore, all safety significant fire events meeting international reporting criteria (e.g. INES or IRS from the IAEA) are reported to these databases. Additionally, ten participating countries are members of OECD NEA FIRE (Fire Incidents Records Exchange) project and submit fire events from nuclear power plants to the OECD NEA FIRE Database based on their national reporting criteria.

In conclusion, the participating countries clearly demonstrated that the operators of nuclear installations record all fire events and report fire events with significance to nuclear safety to the regulators in charge. However, there are differences in the approaches and criteria applied for analysing and reporting the events.

2. Information sharing on feedback from fire safety related events

The TPR Team identified the interest to discuss the sources of operating experience available to operators and regulators and the procedures to make such information available and usable, notably for countries with a small number of certain types of nuclear installations, in order to extend the knowledge base regarding fire events.

There is a wide exchange of information on fire events between the licensees of the same type of installation on a national level and, for NPPs and RRs, on an international level (e.g. via WANO or between experts from reactor owners groups (BWROG, PWROG, RROWG, etc.)), and also in several countries between licensees of different types of nuclear installations (e.g. Belgium, France, UK).

It is clear that the regulators also exchange information on fire events with a potential significance for installations of the same or similar type: it may be within regulators´ experts groups, such as the KWU

Regulators Group, the VVER Regulators Forum, or between experts of neighbouring countries in bilateral meetings or commissions, etc.

At national level, there are dedicated groups for the exchange of fire operating experience in nuclear installations. Fire protection working groups in Spain, in which representatives of some NPPs participated, and the Nuclear Industry Fire Safety Coordinating Committee in the UK were mentioned as examples. In Germany, Information Notices are issued for sharing information on the operating experience between operators, regulators and other stakeholders (e.g. manufacturers).

Many countries mentioned as well information sharing between on-site and off-site fire brigades.

In summary, various mechanisms are used for the exchange of information from the nuclear installations´ fire safety related operating experience at national or international level: IAEA databases (such as INES, IRS, etc), OECD/NEA FIRE Database, WANO, or some reactor specific groups. The use of international means for sharing and accessing operating experience and using insights for fire safety related improvements in the nuclear installations is valuable, particularly if the own national experience is limited.

However, the information on fire safety related events is spread over various different databases at international level, which contain different level of details, and sometimes, the data is not directly usable. The participating countries recognised the need for a unique repository for sharing fire events of any nuclear installation with sufficient information for its direct use by other countries. They highlighted the ongoing **challenge** of accessing useful information in international organisations' databases and recommended improvements, especially in terms of event-related data, to enhance its usability for operators worldwide. Additionally, in this context a guidance is needed in order to define common reporting criteria and the type of information required, ensuring this information is useful to operators of various nuclear installations.

The following has been identified as a TPR II Challenge:

> **Challenge:** ***A need for a unique repository for sharing information on fire safety-related events for all types of nuclear installation, based on defined criteria for categorisation and reporting***
>
> Further information on the identified challenge is available in Annex V.

Furthermore, as fire is a risk for any industrial activity, exchanging information with conventional non-nuclear industry and drawing lessons from fire events in conventional industries are also a means to learn from such events and to identify existing weaknesses or areas for improvement. Licensees do consider experiences from non-nuclear installations with fires (e.g. battery fires) or the performance, particularly of active fire protection features and/or fire barrier elements with active function, as far as applicable to their installations. The main contributions from non-nuclear industry come from oil and chemical industries. Lessons learned from fire events from national non-nuclear areas are widely considered in various participating countries.

This is more often done on an expert level and not in a very formalised manner in the most countries. However, in some countries, it is more formalised:

- in Finland, accident events are discussed annually with other industrial plants as part of the activities of the Finnish Fire Officers' Association, and the national OTKES (Safety Investigation Authority) investigates all significant accident events in the country;
- In Finland and Sweden, the ‘Norderf’ forum for example provides the Nordic nuclear power plants with external experience from the nuclear industry worldwide;
- in France, the ARIA database (Analysis, Research and Information on Accidents) managed by the BARPI (Bureau d'Analyse des Risques et Pollutions Industrielles) provides industrial fire operating experience: it lists incidents, accidents or near misses, including fires that have caused or could have harmed the public or the environment.

Furthermore, some countries mentioned about their actions following a significant fire event in a non-nuclear context, e.g.:

- The United Kingdom mentioned the implementation of learning from experience feedback following the Grenfell tower fire. The Office for Nuclear Regulation (ONR) wrote to all licensees requiring that the use of combustible cladding and linings be reviewed. ONR subsequently assessed the adequacy of the responses and actions taken by licensees to reduce the risks to life and nuclear safety;
- France mentioned as well that lessons learned from a significant fire event in a chemical plant resulted in new requirements from the regulatory body and new provisions in fire safety of nuclear installations.

These actions have been identified as a TPR II Good Practice:

Good Practice: ***Implementing learning from experience feedback from fire events in non-nuclear settings.***

Further information on the identified Good Practice is available in Annex IV.

3. Improvement of fire safety analyses and fire protection provisions resulting from operating experience

The feedback from the operating experience from the nuclear installations themselves and, where relevant, from other nuclear installations (similar or not) is a key means for enhancing safety.

All participating countries report that their licensees learn from their own experience and implement improved fire protection provisions in their installations as required by the WENRA SRLs.

Use of experience feedback for fire safety analyses

The workshop discussions showed that operating experience feedback does not really impact deterministic fire hazard analyses as a conservative approach is applied in most countries.

However, and at least for NPPs, the operating experience from fire events and from functional failures of fire protection features is addressed at the probabilistic safety analyses (PSA) level for estimating fire occurrence frequencies (as a starting point of fire event trees) and reliability data for fire protection provisions (needed for the end states of the fire event tree branches).

The discussions and answers to questions showed that in some countries (e.g., Belgium, France, Germany, Lithuania, the Netherlands, Spain) the experience feedback from fire events as well as from events with deterioration or failure/malfunction of fire protection provisions has been commonly considered in the fire safety analyses for all types of installations and resulted in several improvements of the fire protection over time.

Use of experience feedback for fire protection provisions

Many countries reported on modifications of fire protection means based on installation specific or national experience feedback (failure, malfunction etc):

- Germany, the Netherlands, and Switzerland reported replacements or changes in the design of fire dampers and fire doors resulting from the national and/or international experience feedback according to reporting of deterioration and/or failure of such components;
- Lithuania reported a modification of the procedure to perform technical maintenance of fire protection means after some events with malfunctioning of fire protection features;
- Italy reported a change in the gas fire extinguishing agent in the fixed fire suppression system of a waste storage facility as result of an overpressure event due to a spurious actuation of the CO2 gas extinguishing system;
- France reported, concerning its NPPs, the automatisation of transformer fire extinguishing systems activated upon fire detection and changes to safety instructions for roofing worksites after bitumen fires on roofs.

Some countries (e.g. Belgium, Bulgaria, the Netherlands, Spain) point out that various upgrades arose from recommendations issued by their insurers.

Finally, it was highlighted that human factor related improvements (e.g. organisational, safety culture, etc) are a significant part of the installation or site specific fire related operating experience but that those improvements are rarely shared with other nuclear installations, particularly those abroad.

Conclusion

Recording and analysing fire safety events in nuclear installations is essential for improving safety. In many countries, fire events are recorded by licensees and reviewed by regulatory bodies during inspections. While all countries report significant fire events to regulators, the categorisation and reporting criteria differ across countries, especially for less significant events. In addition to nuclear authorities, conventional fire safety authorities may also be notified.

Information sharing on fire safety lessons occurs both nationally and internationally through databases, forums, and expert groups. International databases like the IAEA's INES and IRS and the OECD NEA FIRE Database record fire safety related events, ensuring cross-border sharing of lessons learned. However, **a challenge** was raised concerning the need for a unique, centralised repository for fire events from all types of nuclear installations, including sufficient information on these events to enhance its usefulness. Additionally, lessons from non-nuclear industries, such as oil and chemical sectors, are also used to improve nuclear fire safety. A **good practice** that was shared concerns the application of experience feedback from fire events in non-nuclear settings.

Many countries use operational experience feedback to replace or upgrade fire protection provisions, such as fire dampers or doors, fire suppression systems, and maintenance procedures. It was highlighted that improvements related to human factors and safety culture are less frequently shared internationally. Feedback from the operating experience is as well used in PSA to estimate fire occurrence frequencies and fire protection provisions’ reliability.

4. FIRE SAFETY ANALYSES

4.0 General methodologies for deterministic fire safety analyses

Types of installations mainly concerned

In general, this topic is applicable to all types of installations.

Background and justification

As mentioned in the TS[25], the requirements *WENRA SV 6.1, SV 6.2* for nuclear power plants, S3.1, S3.2, S3.3 for research reactors, S-30 for spent fuel storage facilities and waste storage facilities apply for fire safety analyses:

(WENRA SV 6.1) A fire hazard analysis shall be developed on a deterministic basis, covering at least:

- *all plant operational states of normal operating and shutdown, a single fire and consequential spread;*
- *any plant location where fixed or transient combustible material is present;*
- *credible combinations (see RL E6.1) of fire and other events (including external hazards).*

The deterministic analysis shall be complemented by PSA in order to evaluate the fire protection arrangements and to identify risks caused by fires.

(WENRA SV 6.2) The extent of reliance on on-site or off-site fire brigades shall be shown to be adequate in the fire hazard analysis.

(WENRA S 3.1) A fire hazard analysis shall be carried out and kept updated to demonstrate that the fire safety objectives are met, that the fire design principles are satisfied, that the fire protection measures are appropriately designed and that any necessary administrative provisions are properly identified.

(WENRA S 3.2) The fire hazard analysis shall be developed on a deterministic basis, covering at least:

- *for all normal operating and shutdown states, a single fire and consequential spread, anywhere that there is fixed or transient combustible material;*
- *consideration of credible combination of fire and other PIEs likely to occur independently of a fire;*
- *fire hazards due to experiments.*

(WENRA S 3.3) The fire hazard analysis shall demonstrate how the possible consequential effects of fire and extinguishing systems operation have been taken into account.

(WENRA S-30) The licensee shall make design arrangements for fire safety on the basis of a fire safety analysis and implementation of defence in depth (prevention, detection, control and mitigation of a fire).

The TS also mentions that these SRLs are applicable to all other types of installations, applying a graded approach.

The TS specifically asks in regard to fire safety analyses:

- For reactors:
  - *the fire safety objectives,*
  - *the scope of the analysis,*
  - *the event combinations (e.g. seismic events), if considered in the analysis, including the rules and/or criteria applied to consider such event combinations,*
  - *the assumptions and methodologies applied to perform the analysis,*
  - *the fire phenomena and their analysis.*

[25] The TS clarifies that the term ‘fire safety analysis’ covers both deterministic fire safety analyses, such as a Fire Hazard Analysis (FHA), as well as probabilistic fire risk analysis (called Fire PSA).

- For fuel cycle facilities:
  - *the fire safety objectives,*
  - *the scope of the fire safety analyses, e.g. a deterministic fire hazard analysis (FHA), or others,*
  - *the types of scenarios and phenomena considered, how it is justified that they are the most relevant (bounding scenarios),*
  - *the combinations of events considered in fire safety analysis and the rules/criteria applied to consider such event combinations.*
- For spent fuel storage, waste and installations under decommissioning:
  - *the fire safety objectives,*
  - *the requirements on the scope, assumptions and methodologies applied to perform the fire hazard analysis,*
  - *the event combinations considered in the fire safety analysis.*

During the desktop review, the TPR team noticed differences in objectives, scope and approaches, including e.g., assumptions and screening. For this reason, the topic of interest (TOI) “General methodologies for deterministic fire safety analyses” was chosen for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. Objectives and Scope of fire safety analyses
2. Approaches reported in NARs: Types of analyses and approaches
3. Standards and guidelines
4. Assumptions
5. Fire Phenomena.

The objective of this topic of interest in the workshop was to get an overview of the objectives and scope of the deterministic fire safety analyses, deterministic fire safety analyses types, methodologies applied, standards, guidelines and assumptions, and to understand the state-of-the-art of fire induced phenomena modelling.

1. Objectives and scope of fire safety analyses

All countries specifically reported that the high-level objectives of the fire safety analyses are to support nuclear and radiation safety. In this regard, the NARs outline some specific objectives, including:

- Demonstrating compliance with the nuclear fire protection goals. For example, for NPPs in operation, demonstrating that the plant can be safely shutdown and maintained in this safe state in case of fire;
- Using the results from fire safety analyses as input to the qualification of SSCs important to safety;
- Demonstrating compliance with the conventional non-nuclear fire protection goals.

Several countries mentioned also the protection of workers and asset safety.

The discussion at the thematic workshop confirmed that the objectives listed above are generally the same for all types of nuclear installations. However, some installations (e.g. “small” research reactors and nuclear power plants under decommissioning, waste facilities) focus less on safety issues and more on worker safety and conventional asset safety.

Regarding the scope of the fire safety analyses, it can be concluded that all sources of radioactivity in the nuclear installations, all operational states and all types of fire events (internal, external and combinations of fires with other events) are considered using a graded approach. In particular, it was reported in the NARs that external fires and explosions with potential consequential fires are among the postulated initiating events.

Some criteria establishing the scope of the analyses mentioned in the NARs are:

- Hazard potential,
- Specific physical locations: fire risk assessments are prepared for buildings which are important from the point of view of nuclear safety and to the extent provided for by applicable regulations.

In conclusion, all participating countries have developed deterministic fire safety assessments with similar objectives, although for NPPs the focus is mainly on nuclear safety, while other facilities focus more on safety of workers and asset safety. All countries also reported similar scopes of the analyses, including the requirement to justify the screening criteria followed when applied.

2. Approaches reported in NARs: types of analyses and approaches

As reported during the workshop, the family of deterministic fire safety analyses may encompass the Deterministic Fire Safety Analysis (DFSA) and the Fire Hazard Analysis (FHA). Both terms are often used interchangeably to assess the effects of a single fire in a single compartment, the fire load involved and thereby the potential to damage plant SSCs important to safe shutdown or to safety in a given room, as well as the identification of the fire protection systems therein.

Some countries (like Spain) mentioned that for NPPs they have also carried out “Safe Shutdown Fire Analysis (SSFA)”, which can be complementary to the analyses mentioned above. This SSFA identifies the success paths for achieving the safe shutdown of the plant in case of any single fire and therefore helps to identify the SSCs to be fire-protected at every given location.

The results from various fire safety analyses are used to justify that fire protection SSCs meet the needed functional requirements, e.g. pump capacity of fire pumps, and that SSCs in general have the environmental qualification to survive fire direct and secondary effects. An example of the use of fire safety analyses to justify the performance-based fire safety design of the enlargement of an interim spent fuel facility in Slovakia was put forward.

There are two general approaches described in the NARs to perform the deterministic FSA:

- Fire Containment Approach (FCA) – conservative
- Fire Influence Approach (FIA)[26] – less conservative, used mainly in case of larger spaces

The overall DFSA/FHA steps that can be identified in the NARs are:

- Identification of items (SSCs) important to safety and determination of the location of individual components in fire compartments;
- Fire data collection (fire initiators, amounts of combustible materials, fire prevention, detection and suppression/extinguishing systems and procedures etc) and modelling;
- Analysis of fire propagation and possible consequences on items important to safety;
- Determination of the required fire resistance rating of fire barriers and their elements;
- Determination of passive and active fire protection means;
- Identification of cases where additional separation/segregation and/or additional protection is required;
- Assessment of secondary fire effects.

Based on the discussions during the workshop sessions, it can be concluded that countries follow similar approaches and steps when carrying out their fire safety analyses.

[26] Fire influence approach: in this approach, it is credited the fact that it may take some time for the fire to damage a given element in the cell or room so it may be not damaged at all in a short time lapse. This requires a fire propagation analysis in which elements like energy of the fire source/s, the development of the fire, their location respective to other fire loads or the fire targets and their sensitivity to the fire (damage criteria in terms of temperature, distance to the flame, etc.) have to be considered and analysed in different scenarios

3. Standards and guidelines

The IAEA Safety Report Series (SRS) No. 8, "*Preparation of Fire Hazard Analyses for Nuclear Power Plants*" is the most commonly referred standard regarding the use of the fire containment and the fire influence approaches.

Some of the other generic references that are commonly mentioned in the NARs are:

- WENRA issue E Design Basis, e.g., specifically for NPPs regarding consideration of internal hazards and combinations of events and SV internal hazards, e.g., the SRLs for any general internal hazard and the additional SRLs for internal fire
- 10CFR50, Appendix R, Section III.G on fire safe shutdown analysis
- NUREG-1805 Fire Dynamics Tools (FDTs) – Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program
- SSG-3 Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants (Rev 1, 2024)
- SSG-4 Development and Application of Level 2 Probabilistic Safety Assessment for Nuclear Power Plants (2010)
- SSG-64 Protection against Internal Hazards in the Design of Nuclear Power Plants (2021)
- SSG-77 Protection Against Internal and External Hazards in the Operation of Nuclear Power Plants (2024).

The latter two IAEA safety guides were mentioned at the thematic workshop as being applicable also to facilities other than NPPs in a graded manner.

In conclusion, all the countries participating in the workshop acknowledged the various requirements applicable to fire safety analyses. However, differences in the standards applied were highlighted: some countries explicitly follow US standards, e.g. NFPA-805, while others apply their own specific standards and guidelines.

Some participants in the thematic workshop noted that existing standards and guidelines often present high-level objectives and suggested that having a guide to translate these objectives into detailed requirements for safety analyses would be beneficial, particularly for certain types of installations. Additionally, some participants identified gaps in the guidelines for conducting fire safety analyses under some operating conditions, such as when a nuclear power plant is not operating at full power. The proposed guide could help address these gaps by providing a clearer direction for such scenarios.

The following has been identified as a TPR II Challenge:

> **Challenge:** ***Development of guidelines to convert high-level objectives mentioned in the standards into detailed requirements for carrying out safety analyses, especially for some type of installations or conditions of operation.***
>
> Further information is available in Annex V.

4. Assumptions

Some of the most common assumptions applied in deterministic fire safety analyses, as identified in the NARs, include:

- Fire occurrence assumption: A fire is postulated to occur whatever the nature, quantity, type and configuration of the combustible masses present are;
- Single-fire assumption: Only one fire can occur at a given time in the facility. The possibility of simultaneous and independently-caused fires affecting different rooms in the same plant unit, or across different plant units, is not postulated;
- Component failure assumption: All components inside a fire compartment are assumed to fail by the effect of the fire;
- Fire suppression assumption: No credit is given to fixed (mainly automatic) fire-extinguishing systems and equipment or to manual firefighting;

- Conservative assumptions: They are generally applied. Amongst the ones referred to during the workshop were those included in the Swiss Guideline ENSI-A01[27] for deterministic safety analyses. These include the following:
    - independent single failure: the failure of automatic fire detection and fire-fighting measures as well as components of fire compartments shall be included in single failure considerations,
    - one redundant train in (scheduled) maintenance,
    - total loss of offsite power,
    - credit for safety systems only within the first 10 hours of the event,
    - no credit given to operator actions during the first 30 minutes of the event.

The reviews of the NARs and of the answers to the questions show that the different countries in general apply a set of conservative requirements or assumptions to their deterministic fire safety analyses. Nevertheless, more flexible and realistic assumptions for some specific cases might be accepted if they are adequately justified: for example, Sweden mentioned that some more realistic assumptions could be credited, e.g. use of repair actions after a reasonable time and use of portable equipment currently available.

In conclusion, most countries include the same type of assumptions in their analyses, although some are more focused on conservative assumptions while other allow the use of more realistic assumptions in some specific detailed analyses.

5. Fire Phenomena

Fire safety protection requires an in-depth knowledge about fire phenomena. This is important for fire prevention, as well as for the overall plant design of fire detection and suppression features and in order to address potential impacts derived from direct and secondary effects of fire.

The main fire-induced phenomena identified through the NARs and the discussions held during the workshops were:

- Pressure effects from the fire that might impair fire-barriers,
- Effects of smoke and soot on sensitive (e.g. electrical or electronic) equipment,
- Spurious actuation/signals of electric or electronic components - single and multiple spurious operations (MSO),
- Secondary effect from fires such as flooding by fire extinguishing agents (water), etc. including potential criticality concerns in specific facilities.

Besides, the effects of high energy arcing faults (HEAF) with ensuing fires and smouldering fires are considered as fire events in some countries.

Experimental tests are essential to understand the fire-induced phenomena and to increase knowledge of the behaviour and performance of components and fire protection features under fire conditions. It enables as well to improve the analytical capacity of the tools used in the fire safety analyses. This knowledge has to be regularly reviewed and updated to ensure the continued applicability of the predictive tools.

France for example has established an experimental approach, from small to large scale, and as well as developed in-house codes or numerical tools. The main objective is to assess fire phenomena (effects of pressure on fires, production and impact of soot on equipment, physics of confined fires etc) to support the assumptions credited in the fire safety analyses. This has been identified as a TPR II Good Practice:

[27] This guideline regulates the scope, methodology and the boundary conditions for the deterministic technical safety analysis for existing nuclear installations

Good Practice: *Extensive series of tests carried out to assess the effects of fire on elements (electrical equipment, fire doors, cables, seals, etc.) credited in the fire safety analyses to confirm their assumed resistance to the fire-induced phenomena.*

Further information on the identified Good Practice is available in Annex IV.

Most countries apply a fire compartment approach that implicitly accounts for the most important direct and indirect effects and consequences of fires as it assumes conservatively the complete loss of SSCs in the compartment, whatever the reason may be (heat, smoke, light or others). However, France mentioned it carries out as well specific analyses considering the phenomena to verify the robustness of the fire barriers (for example, that the fire doors ensure their function, even with the pressure effects).

Conclusion

All countries participating in the workshop recognised that the primary objective of fire safety analyses is to support nuclear and radiation safety. These analyses aim to demonstrate compliance with nuclear fire protection goals, qualify safety-critical SSCs, and ensure worker and asset safety. While nuclear power plants focus mainly on nuclear safety, other facilities such as research reactors and waste facilities place greater emphasis on worker and asset protection.

Countries use various deterministic approaches, such as Fire Hazard Analysis (FHA) and Fire Safe Shutdown Analysis (FSSA), to assess fire impacts on SSCs important to safety. While the IAEA guidelines are widely referenced, countries may follow different standards and assumptions, with some adopting more conservative or realistic assumptions.

Countries participating in the workshop acknowledged the ongoing **challenge** that existing standards often present only high-level objectives and recommended the development of a guide to translate these into detailed safety analysis requirements, particularly for specific types of installations.
Fire safety protection relies on a deep understanding of fire phenomena, including both direct and secondary fire effects. Experimental tests are essential for enhancing knowledge of fire behaviour and improving fire safety tools. A **good practice** concerns the conduct of an extensive series of tests to assess the effects of fire on elements (electrical equipment, fire doors, cables, seals, etc.) credited in the fire safety analyses to confirm their assumed resistance to the fire-induced phenomena.

4.1 Analysis of radiological consequences

Type of installations mainly concerned

This topic is applicable to fuel fabrication and other fuel cycle facilities, waste storage facilities and installations in decommissioning.

Background and justification

As mentioned in the TS, the fire protection means aim at mitigating secondary fire effects and maintaining safety functions, including mitigation of the radiological consequences of the fire. Indeed, in the presence of radioactive materials, a fire can disperse the materials and thereby lead to radioactive releases to the environment.

The TS for the NARs specifically asks to provide information about:

- *assessment of radiological impact following a fire event, as postulated in the safety analysis of the installation, in relation to the safety and radiological objectives;*
- *specifically for fuel cycle facilities: confinement provisions used in case of fire (static or/and dynamic confinement) and the strategy regarding the maintenance of dynamic confinement considering the risk of fire propagation through ventilation systems. Which and how fire detection systems (and/or other systems such as filter clogging detection and alarms, etc.) initiate operations on the confinement function in case of fire to limit radioactive releases.*

During the desktop review, the TPR Team noted that countries have followed different methodologies and assumptions to carry out the analysis of radiological consequences of a postulated fire. Facilities in which radioactive materials are handled (waste management and storage, facilities, spent fuel storage facilities, installations under decommissioning) as well as fuel fabrication facilities seem to be most sensitive to radioactive release in case of a fire.

Since the purpose, processes and risks are very different amongst these types of facilities, the fire safety analyses may have to consider different sets of phenomena, assumptions and scenarios as well as measures to be taken to limit the radiological consequences in case of a fire, like the combined use of static and dynamic confinement, ventilation management, etc.

For this reason, the topic of interest “Analysis of radiological consequences” was chosen for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. Specific provisions to limit radiological releases in the event of fire and associated qualifications
2. State of knowledge on the different phenomena to consider.

The objective of discussing this topic of interest in the workshop was to compare practices between different operators of different types of nuclear installations to get an overview of analysis practices (combination between static and dynamic containment, ventilation management during the fire) and sharing data/needs for R&D (proportion of radioactive materials involved in the fire, airborne release factors of the radioactive material(s) involved, effectiveness of the ventilation systems despite the fire, filters clogging by soot, examples of fire scenarios to study).

1. Specific provisions to limit radiological releases in the event of fire and associated qualifications

There are specific provisions to limit radiological releases in the event of fire (static containment, ventilation management, filtration systems, etc). Indeed, the confinement of radioactive materials released to the air outside the installation in case of fire is based on a combination of static and dynamic containment measures. For combustible radioactive waste its treatment and conditioning in proper packages represent the main preventive measure against releases in case of fire.

The fire could damage corresponding static containment measures (walls, including elements such as doors or dampers, glove boxes, etc) if they are not fire resistant. Secondly, especially when the ventilation is turned off, a fire in a well-confined room can lead to rising temperatures and pressure inside the room. These effects are rarely considered in the analysis. They induce an increase of leaks outside the premises which may require dedicated containment provisions, including containment systems “surrounding” these premises.

Concerning dynamic containment, several possible ventilation management objectives or procedures in the installations have been presented in the NARs and during the thematic workshop:

- modification of the ventilation air flow in the event of fire,
- stopping the air supply and maintaining the air exhaust in the rooms where the fire breaks out,
- maintaining ventilation of the rooms peripheral to those rooms where the fire breaks out.

France reported having dedicated ventilation management procedures for the installations concerned by fast fire growth (e.g. for dedicated storage room for flammable liquid) to avoid overpressure in the room in case of fire. Moreover, some dedicated equipment has been presented to limit the consequences of a fire that can lead to a release of radioactive material into the air, in particular reinforced ventilation systems (ventilation ducts, including filters, dampers etc) resisting to temperature. France and UK reported the use of special filters that can operate at “high” temperatures (100, 200 or 500 °C). France also uses fire dampers that can be closed or opened at high temperatures to protect the filtration system (CTHEN[28] standards). These features need adequate qualification to prove their effectiveness in case of fire.

[28] French acronym for Technical Center for Nuclear Equipment Approval (Centre Technique de l'Equipement Nucléaire).

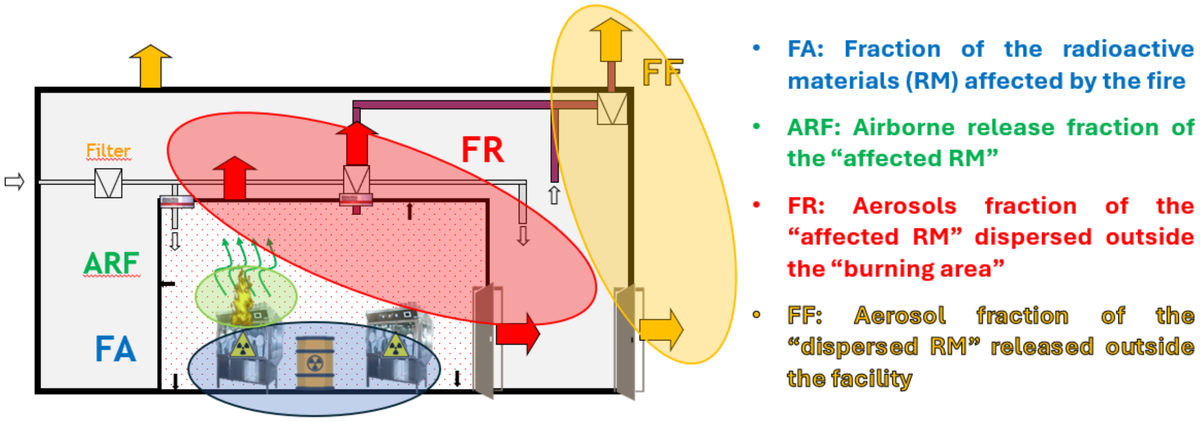
In addition, extinguishing provisions may also be provided to prevent the combustion of contaminated materials. For example, in Belgium, there are sprinkler systems to protect filters from a fire in order to limit the dispersion of contamination that could be contained inside the filter.

2. State of knowledge on the different phenomena to consider

As the purpose, processes and risks are very different amongst these types of facilities, the fire safety analyses may have to consider different sets of phenomena, assumptions and scenarios, for example, regarding the failure mechanisms of waste packages due to fire, the airborne release fractions and respirable fractions, the deposition/redeposition in structures, the filtration efficiency, or the filter clogging by soot.

This topic of interest is focused on the state of knowledge of different phenomena concerning the analysis of potential radiological releases in case of fire in a nuclear installation. As shown in the figure below, the corresponding parameters important to estimate the amount of the potential release of radioactivity to the environment (source term) are the following:

- Amount of radioactive material affected by the fire (FA);
- Airborne release fraction (ARF) of radioactive material affected by the fire[29];
- Aerosols fraction of radioactive material dispersed into the facility (FR) and finally released to the environment (FF).



First of all, during the dedicated workshop, a small number of countries (France, Germany, Italy, Sweden, Switzerland, UK) have mentioned using specific methodologies and assumptions regarding these parameters for the analysis of potential radiological consequences in case of fire in a nuclear installation. While some of these documents are public (from TPR countries or the USA), others are not publicly available.

Concerning the amount of radioactive material that could be affected in case of fire, this usually depends on the fire scenarios considered for the installation. This must be assessed on a case-by-case basis. For example, in Romania, it is assumed that the maximum amount of nuclear material is involved in the fire (fuel fabrication facility). Conversely, a cask could protect radioactive material from a fire (e.g. Switzerland, Lithuania).

When a fire could potentially lead to the release of radioactive material into the air, the NARs typically provide insufficient details on the physical parameters (such as ARF) used in the analysis. When such details are provided, it seems the corresponding values were determined several decades ago. However, some countries, including France, Germany, and Romania, have conducted or are currently conducting research on these parameters. One of the key challenges in this research is the difficulty of

[29] Coefficient representing the amount of a radioactive material suspended in air and made available for airborne transport under a specific set of induced physical stresses.

identifying a representative surrogate for plutonium or uranium materials, given that their direct use is not possible.

The aerosols fraction of radioactive material dispersed into the facility and finally released to the environment depends on the containment efficiency as described above.

Conclusion

Some countries consider conservative analysis with regard to the amount of radioactive material affected by the fire. Other countries rely on dedicated equipment (e.g. cask) to limit this amount.

In order to limit the consequences of a fire that could lead to a release of radioactive material into the air, specific fire designed containment equipment has been implemented, in particular dedicated ventilation management, multiple containment barriers, reinforced ventilation equipment resisting to temperature. These features need adequate qualification to prove their effectiveness in case of fire.

It is currently difficult to have a comprehensive overview of the practices, in particular:

- the physical parameters governing the aerosols fraction of radioactive materials released into the air;
- the justification of the performance of the containment of radioactive materials during a fire (efficiency of the ventilation/filtration system and airtightness of the premises/buildings).

According to the value of these parameters, the estimated radiological consequences of releases could show a wide variation. The relevance of the calculated radiological consequences therefore deserves further consideration.

As a result, further research and knowledge-sharing on the phenomena and key parameters for estimating radiological consequences in the event of a fire could be beneficial.

4.2 Approach to updating the FSA (methodologies and data)

Types of installations mainly concerned

This topic is applicable to all types of nuclear installations.

Background and justification

General requirements regarding FSA methodologies mentioned in the TPR II Technical Specification (TS) are listed in chapter 4.0.

As mentioned in the TS, the requirement WENRA SV 3.3 for NPPs, S 3.1 for research reactors regarding the fire safety analyses update apply to other nuclear installations according to the graded approach:

> *(WENRA SV 3.3) The hazard assessment, applied methods and input data as well as the utilization of the results, including implementation of actions, shall be justified, documented and kept up to date;*
>
> *(WENRA S 3.1) A fire hazard analysis shall be carried out and kept updated to demonstrate that the fire safety objectives are met, that the fire design principles are satisfied, that the fire protection measures are appropriately designed and that any necessary administrative provisions are properly identified.*

The TS for the NARs specifically asks for the following with regard to the fire safety analysis update:

- for nuclear power plants:
  - *the management of changes to and updates of the fire safety analyses in the context of Periodic Safety Reviews (PSRs) including their consideration at the plant;*
  - *the approach how the fire safety analyses are updated to reflect relevant modifications to the NPP;*

- for research reactors:
  - *the management of changes to the fire safety analyses in the context of Periodic Safety Reviews (PSRs);*
  - *the approach how the fire safety analyses are updated to reflect relevant modifications to the research reactor;*
- for the fuel cycle facilities, *the most risk significant plant modifications (implemented and planned) based on fire safety analyses*.

During the desktop review, the TPR Team noted that the information related to updates of the FSA varies between the participating countries and the different types of nuclear installations. For this reason, the topic of interest "Approach to updating the FSA (methodologies and data)" was chosen for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. Sources to derive the need for fire safety analyses updates
2. Fire safety analyses (deterministic and probabilistic) and their updates.

The objective of this topic of interest was to compare practices between different operators of different types of nuclear installations and to get an overview of the approach to updating the FSA.

1. Sources to derive the need for fire safety analyses updates

Updates of the fire safety analysis may be required or needed due to e.g., a changing regulatory framework, changes in the operating status of the plant, plant modifications, operational feedback, safety reviews, feedback from regulatory oversight, developments in the modelling tools or simply due to the evolving state of science and technology.

The non-nuclear regulatory framework for fire safety, involving different stakeholders (e.g. insurance companies) and authorities in fire protection, may also lead to the need for fire safety analyses updates.

The principles and practices for updating safety analyses, considering new data and assumptions related to changes in either the physical configuration of the installation, its operating conditions, the methodology or the codes applied, etc, are likely to have many common aspects between countries. However, the review has also identified areas where differences exist. These may be related to the differences in regulation and also to national practices.

Almost all countries mentioned in the NAR that they carry out PSRs including deterministic fire safety analyses (mainly FHA and as far as applicable Fire PSA) at least every 10 years. In addition, all participating countries outlined in the discussion that they consider intermediate updates when necessary: triggers for updating the FHA may be new/updated regulations, plant modifications that affect fire safety, environmental changes, changes of the surroundings of a facility, modifications of operational procedures, significant fire events and R&D.

In some countries, a periodic update of FHA is required in addition to the one performed in the PSR. For example, in Slovenia, this should take place at least every two years and the revision of the FHA includes all changes (modifications and other changes on SSCs or mode of operation, which can be performed through work order or Corrective Action Programme) performed in previous period.

2. Fire safety analyses (deterministic and probabilistic) and their updates

FHA/Fire PSA are making use of different analytical tools and fire simulation codes (simple zone models such as CFAST, or more complex CFD codes such as FDS, etc.), depending on the given fire safety related issue and complexity.

Some licensees reported that sophisticated calculations are performed by external contractors, others perform those calculations on their own, in some cases supported by their own research activities. Calculations by the regulators or experts authorized by them are also performed in some countries.

As mentioned above, updates in the fire safety analyses may result from new knowledge or development of new models in codes and tools used for fire modelling:

- Information sharing of new knowledge is performed by cooperation with academia and research institutions or by participating in– mainly international – collaborative research projects such as the 'International Collaborative Fire Modelling Project' (ICFMP) for nuclear power plant applications analytical project or the OECD/NEA or experimental projects PRISME and FAIR;
- Code updates are released quite often by the developers. However, some licensees mention that they do not use the last updates and, for practical reasons, prefer to rely during several years on the use of a given version that has been validated.

Conclusion

Fire safety analysis updates may be required due to regulations, plant modifications, operational feedback, safety reviews, new knowledge or the development of updated models and tools for fire modelling. Non-nuclear fire safety frameworks, involving stakeholders like insurance companies and authorities, can also trigger updates.

All countries conduct Periodic Safety Reviews (PSRs) at least every 10 years, which involve assessing the relevance of fire safety analyses and, if necessary, developing a plan to update them. As FHA/Fire PSA are carried out using various analytical tools and fire simulation codes, updates to models and tools may be required. However, licensees often prefer to continue using validated versions of codes for practical reasons, as adopting the latest updates would require significant resources for validation.

4.3 Fire PSA in NPPs: Scope, criteria, and level of conservatism

Type of installations mainly concerned

This topic is applicable to installations for which Fire PSA is conducted (NPPs, some RRs).

Background and justification

According to international standards, PSA for internal hazards, in particular Fire PSA, is required as part of the PSA that is mandatory for NPPs in most countries as a complement of deterministic FHA. Fire risk assessment aims at analysing fires as one of the most risk-significant internal hazards.

Moreover, Fire PSA plays an important role in identifying spatial dependencies and the need for separation/segregation of redundant trains.

PSAs are an important tool to identify strengths and weaknesses and to assess the overall safety and risk profile of a nuclear installation, indicating the need of realism for their use in practical applications.

As mentioned in the TS, the requirements *WENRA SV 6.1, E 6.1 for NPPs and E 6.1 for research reactors* applies for fire safety analyses:

> *(WENRA SV 6.1) A fire hazard analysis shall be developed on a deterministic basis, covering at least:*
>
> - *all plant operational states of normal operating and shutdown, a single fire and consequential spread;*
> - *any plant location where fixed or transient combustible material is present;*
> - *credible combinations (see RL E6.1) of fire and other events (including external hazards).*
>
> *The deterministic analysis shall be complemented by PSA in order to evaluate the fire protection arrangements and to identify risks caused by fires.*
>
> *(WENRA E6.1): Credible combinations of individual events, including internal and external hazards, that could lead to anticipated operational occurrences or design basis accidents, shall be considered in the design. Deterministic and probabilistic assessment as well as engineering judgement can be used for the selection of the event combinations.*

As mentioned in the TS, "*There are no formal requirements for a Fire PSA for research reactors, but for some research reactors with a higher risk profile a Fire PSA is however applied*."

The TS for the NARs specifically asks with regard to the probabilistic safety analyses for nuclear power plants *"the scope of the Fire PSA performed for the installation:*

- *PSA levels of the study,*
- *plant operational states included in the analysis,*
- *analysis on reactor and/or spent fuel storages (spent fuel pools, etc.),*
- *the main results of the Fire PSA:*
  - *the most important accident sequences,*
  - *the contribution of the fire events to the overall PSA results."*

During the desktop review, the TPR Team noted the scope of Fire PSA is different from one country to another and that there is a large variation in the contribution of fires to core damage frequency (CDF). For this reason, the topic of interest "Fire PSA: Scope, criteria, and level of conservatism" was chosen for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. Scope of the Fire PSA in the different countries,
2. Screening criteria for event combinations and fire scenarios,
3. Level of conservatism in a Fire PSA,
4. Sensitivity/uncertainty analyses,
5. Contribution of fire events to the overall PSA results.

The objective of this topic of interest was to compare practices amongst the different operators and to get an overview of various approaches regarding the scope and results of Fire PSA, the conduct of uncertainty and sensitivity analysis and strategies to address conservatism in PSAs.

1. Scope of the Fire PSA in the different countries

The scope of Fire PSA varies across countries, with most of them performing Level 1 PSA for full power operations, some extending to all plant operational states, and Level 2 for all reactor states.

In particular, some countries (Bulgaria, France, the Netherlands, Spain, Slovakia) mention their PSAs are full scope (all plant operational states, all plant internal events, internal and external hazards) up to Level 2.

Regarding Level 3 PSA,

- the Netherlands performs Level 3 PSA as required by the regulatory body,
- in United Kingdom for Hinkley Point C, the Level 3 PSA is ongoing,
- Spain and Sweden mention they do not intend to perform Level 3.

2. Screening criteria applied for event combinations and fire scenarios

Additionally, the application of screening criteria – in terms of threshold values for the fire-induced core damage frequency - may extend or reduce the set of scenarios and events to be considered in the analyses, thereby affecting the interpretation of the scenarios with a very low probability.

During the workshop, considering event combinations in PSA:

- Some countries (Belgium, the Netherlands, Slovenia, Sweden, Switzerland, Ukraine) mention using quantitative screening criteria (from 10^{-9} to 10^{-7}) for any scenario;
- Switzerland considers combinations of fires (different fires occurring simultaneously) as single fires cannot lead to core damage above the threshold frequency in their analyses;
- Spain emphasizes that data sources for event combinations frequency are necessary to assume event combinations in Fire PSAs;
- Finland and France mention the combination of internal event with fire.

3. Level of conservatism in a Fire PSA

Understanding the different approaches and assumptions in Fire PSA, ranging from highly conservative to more realistic, is essential for developing effective strategies that balance safety and operational efficiency.
In this regard, the use of conservative assumptions (instantaneous failure of equipment, conservative time of failure of fire protection features, etc) versus more realistic ones can significantly impact Fire PSAs results, thereby influencing decisions related to corrective actions and the prioritisation of modifications.

Most countries acknowledge the use of some conservative assumptions in PSA:

- Sweden acknowledges a mix of conservative and non-conservative assumptions, such as assuming failure of all equipment in a fire area and assuming that fire doors are closed. Such assumptions must be justified;
- France uses a multi-step approach, initially conducting a conservative analysis where all equipment in a room is assumed to fail, followed by a more detailed analysis with realistic assumptions if needed;
- Belgium applies conservative assumptions regarding cable failure due to the lack of a 3D representation of cables;
- The Netherlands conducts a qualitative screening based on conservative assumptions for their high flux research reactor;
- Spain applies a conservative approach while performing a qualitative and quantitative screening. For those areas not screened out using conservative analysis, a detailed analysis is performed. There is an additional acceptance criterion that the regulator has imposed to those plants following the risk-informed licensing basis: for those plants some design modifications were performed to improve those areas with a conditioned probability of core damage equal to 1 in case of fire.

4. Sensitivity/uncertainty analyses

Utilising robust analytical tools such as fire simulation codes and performing sensitivity and uncertainty analyses enhance the accuracy and reliability of Fire PSA. Moreover, the use of plant specific data as far as possible increases the level of confidence in the results of the assessment and supports the identification of the most appropriate modifications. This approach increases the level of confidence of the Fire PSA as a means to analyse the fire-related risks in a traceable and reliable manner.

Some countries (Belgium, France and Spain) mention that they carry out sensitivity analyses:

- Spain performs sensitivity analyses considering variations in fire frequencies, in the probability of failure of fire brigade and in the probability of short-circuits;
- Belgium performs sensitivity analyses on the truncations values, non-suppression probability curves, Fire Dynamic Simulation models and other key parameters;
- France uses the 'MAGIC' fire simulation code and the Risk Spectrum PSA code with sensitivity analyses.

5. Contribution of fire events to the overall PSA results

There is a large variation in the contribution of fires to the overall damage estimates (core and, in some countries, also fuel damage frequencies in line with IAEA SSG-3, Rev. 1) and to the radioactive release frequencies (large and/or large early release frequencies, in line with IAEA SSG-4, Rev. 1) within PSA:

- The contribution of fires to core damage results varies significantly, ranging from 1 % to 60 %.
- In Level 2 PSA, the contribution of fires is lower compared to Level 1 PSA.

Nevertheless, the availability of detailed Fire PSA may allow to identify specific scenarios or locations in the plants that are particularly sensitive to fire risk. Therefore, some countries have reported about plant modifications as result of conservative approaches in their analyses or aiming at reducing the impact in some specific fire scenarios. The following examples were provided:

- Finland mentioned one example involving a ventilation hole between the turbine hall and pump house, which was closed without conducting a specific analysis;
- Spain mentioned that the analyses with conditioned probability of core damage equal to 1 led to the rerouting of cables at the Almaraz plant;
- Sweden indicated that, as part of a project to replace switchgear, the analysis of the modification and cable routing changes revealed a small increase in the CDF. To mitigate this, they decided to permanently block one door to minimise the impact on CDF.

Conclusion

The scope of Fire PSA varies across countries, with most of them performing Level 1 PSA for full power operations, some extending to all plant operational states and Level 2 for all reactor states. The contribution of fire events to the overall CDF varies significantly, with fires accounting for a substantial percentage of the total CDF in some cases. The information in the NARs did not allow to further analyse the reasons behind these differences, which exist even for similar reactor technologies.

Screening criteria, such as fire-induced CDF thresholds, affect the range of scenarios considered, influencing low-probability scenario interpretations frequency.

The use of both conservative and realistic assumptions can impact Fire PSA results, thereby influencing decisions on corrective actions and the prioritisation of modifications. Sensitivity and uncertainty analyses enhance the reliability and accuracy of Fire PSAs.

Some countries have reported plant modifications derived from Fire PSAs aiming at reducing the fire risk in specific scenarios or locations.

4.4 Use and application of FSA results

Type of installations mainly concerned

In general, this topic of interest is applicable to all types of installations.

Background and justification

As mentioned in the TS, the requirement WENRA SV 6.1 for NPPs, S3.1 for research reactors and S-30 for spent fuel storage facilities and waste storage facilities apply to the fire safety analyses:

> (WENRA SV 6.1) *A fire hazard analysis shall be developed on a deterministic basis. The deterministic analysis shall be complemented by PSA to evaluate the fire protection arrangements and to identify risks caused by fires;*
>
> *(WENRA S 3.1) A fire hazard analysis shall be carried out and kept updated to demonstrate that the fire safety objectives are met, that the fire design principles are satisfied, that the fire protection measures are appropriately designed and that any necessary administrative provisions are properly identified;*
>
> *(WENRA S-30) The licensee shall make design arrangements for fire safety on the basis of a fire safety analysis and implementation of defence in depth (prevention, detection, control and mitigation of a fire).*

The TS also mentions that these SRLs are applicable to all other types of installations, applying a graded approach.

The TS for the NARs specifically asks with regard to this topic of interest to report:

- *how fire safety has developed and improved in the installations based on lessons learned from internal and external events and other sources such as Periodic Safety Reviews, Safety Review Missions, maintenance, fire safety research and regulatory supervision;*

- *the most risk significant plant modifications (implemented and planned) based on fire safety analyses;*
- *the prevention and protection measures to be adopted as result of the fire hazard analysis.*

Fire safety analyses can help identify the need for plant modifications (in design and/or operation) and can support to prioritise improvements. However, during the desktop review, the TPR Team noted that little information was provided regarding the use of fire safety analyses for the definition of modifications to enhance safety.

For this reason, the topic of interest "Use and application of FSA results" was chosen for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. Use of FHA and Fire PSA to identify plant modifications to increase fire safety,
2. Approaches used to identify and prioritise plant modifications for enhancing fire safety,
3. Monitoring of the FHA and Fire PSA input elements to identify potential deviations.

The objective of this topic of interest was to compare practices amongst the different operators of different types of nuclear installations and to get an overview of the improvements in design, procedures, etc., originated by the safety analyses carried out in fire protection.

1. Use of FHA and Fire PSA to identify plant modifications to increase fire safety

Fire PSA complements deterministic fire safety analyses by providing a more comprehensive assessment, allowing analysts and decision-makers to identify and evaluate the strengths and weaknesses of a design or operation. This helps ensure that no single fire or facility feature disproportionately impacts the overall fire risk, leading to a more balanced and effective fire safety strategy. In addition, PSA provides an input for the identification of plant modifications to increase fire safety under the ALARP principle of reducing risks.

During the workshop, some countries highlighted specific examples of important modifications resulting from the FHA:

- France explained that they carried out amongst others the following modifications: a new alarm system that reports to the control room was implemented on specific plant doors; additionally, some doors were replaced by ones with higher fire resistance ratings, cable protection was improved in specific cases to avoid cable inflammation, and additional automatic suppression systems were installed;
- Spain mentioned that the Multiple Spurious Operation (MSO) analysis led to physical modifications such as fire wraps upgrade and the installation of new wraps and additional automatic suppression systems. They also referred to new procedures for operator manual actions that had been validated and reviewed by the regulator. Additionally, they stated that the regulation IS-30 issued in 2011, establishing additional deterministic requirements, led to the installation of a seismically resistant system to supply fire water to locations housing SSCs necessary to achieve safe shutdown in case of safe shutdown earthquake (SSE); improvements on or construction of new alternative shutdown panel, etc. Furthermore, they mentioned that after the Fukushima accident, some additional scenarios were analysed resulting in the development of new FLEX strategies, applicable in case of fire;
- Belgium stated that, in order to gain additional time from the beginning of the fire until losing the safety functions, they focused their modifications on slowing down the progression of the fire by installing new coatings, new automatic suppression systems and additional passive protections on specific equipment. They also emphasized that plant personnel are trained and regularly drilled to ensure they can perform the necessary actions within the required timeframes during such scenarios;
- Slovenia detailed that, as a result of the Krško FHA, they carried out many modifications to support the separation of redundant trains: fire doors, fire barriers, wire wrappings, rerouting cables, etc., prioritising the implementation through the use of the Fire PSA impact. They also

informed that after Fukushima, as a result of a specific PSA sensitivity analysis, they installed an alternative control room;

- The UK reported that in Hinkley Point C, most of the design changes as a result of FHA were wrapping cables, installation of heat screens, relocation or removal of fire sources, increased coverage of sprinklers and controls on transient fires.

The discussion highlighted how safety improvements may vary depending on the level of risk. There is no standard reference for risk reduction from a modification, as the degree of conservatism in the PSA and the contribution of the Fire PSA to the overall risk are dependent on the design and PSA assumptions.

It was also highlighted that sharing information on design modifications to improve fire safety is valuable across different types of installations. Analyses stemming from the exchange of operating experience should take into account the risk impact, economic considerations, and regulations specific to each installation type. In this context, Germany noted the potential benefits for research reactors (RRs) from the lessons learned at nuclear power plants (NPPs).

As a conclusion, no significant differences have arisen amongst the countries´ approaches for the use of FHA to define modification to enhance fire safety. The benefit in implementing modifications is usually dependant on the design. However, communication on improvements across different installations could be further strengthened.

2. Approaches used to identify and prioritise plant modifications for enhancing fire safety

PSA also allows to identify and analyse complex interactions in more detail than through a deterministic assessment, aiding risk-informed decision-making and therefore serving as an input for the assessment of plant modifications and prioritisation of improvements.

The discussions on prioritising modifications revealed differing approaches across the participating countries. It was generally emphasized that, for operational purposes, it is essential to consider not only priorities but also the timeframes for implementation. Major (higher priority) modifications may be time-consuming while lower impact modifications may be easier and quicker to implement. In addition, factors such as costs, long-term operation consideration or radiation protection for workers were also mentioned as key drivers in the decision-making process.

3. Monitoring of the FHA and Fire PSA input elements to identify potential deviations

Fire Safety Analysis (both deterministic and probabilistic) are based on assumptions about plant layout, fire barriers, fire loads and their distribution, availability of fire detection and suppression systems and equipment, human actions (e.g. plant operators' actions, fire brigade) etc. All the above aspects need to be suitably implemented and monitored to ensure the continuous validity of the FSAs and their results and conclusions.

Deviations in these inputs may affect the assumptions and consequently the results of the FSAs. Therefore, it is crucial to identify and analyse these deviations to determine whether compensatory measures (temporary or permanent) are needed to ensure that the validity of the fire safety assessments is not impacted, and the objectives of the fire protection are still met. For that purpose, procedures and responsibilities must be established to specify, analyse and implement compensatory measures and/or corrective actions and to monitor their usefulness, effectivity and reliability. These measures include a programme for an adequate maintenance, control, and in-service inspections of fire protection features.

Countries generally have systematic approaches in place in their administrative procedures and tools. As specific contributions from the different countries:

- UK mentioned that they have for example hypothesis on the transient fire loads that have to be met and, as a result, they have implemented a tool to control the transient loads in the different compartments. Should there be an increase in those loads, a specific administrative action would be carried out to reduce them;

- Sweden mentioned the specific case of their fire protection systems that as required by the plant technical specifications undergo specific tests. Should a specific system fail those tests, compensatory measures would be put in place. The process carried out to choose these measures would be supported by the fire experts;
- Belgium indicated that if they found an impairment on a FP equipment, they would analyse the consequences on the Fire PSA and the FHA, although this is not done systematically;
- France stated that, in the specific case of compartmentation monitoring, in NPPs they have a person in charge of this issue and if there were a deviation, they would have to classify it depending on its importance. They mentioned additionally that they have a limit on the number of deviations and a limited time to resolve them depending on the importance of the deviations. They finally added that during the time of non-compliance they would have to implement compensatory measures.

Regarding deviations, the operating experience feedback session highlighted that most inspection findings in the facilities were related to the divergence from strict compliance with well-established procedures. The issue of deviations and its management in a facility can reveal underlying issues related to safety culture, emphasizing the importance of fostering a strong safety culture to ensure adherence to procedures.

Conclusion

The workshop emphasized the importance of Fire Hazard Analysis (FHA) and Fire Probabilistic Safety Assessment (Fire PSA) in identifying and implementing plant modifications to improve fire safety. PSA enables a more detailed analysis of complex interactions than deterministic assessments, supporting informed risk-informed decision-making. It serves as a crucial input for evaluating plant modifications and prioritising improvements, ensuring a more comprehensive approach to enhancing fire safety.

The workshop discussions highlighted varying approaches to prioritising modifications, stressing the importance of considering both priorities and implementation timeframes for operational efficiency. Decision-making factors, such as cost, long-term operation, and radiation protection, were also identified as key drivers.

Deviations in assumptions related to plant layout, fire barriers, and detection systems can impact FSA results, making continuous monitoring essential. Countries implement systematic approaches to track deviations and define appropriate compensatory measures to ensure fire safety.

5. FIRE PREVENTION

5.0 Management of fire loads

Type of installations mainly concerned

This topic of interest is applicable to all types of installations.

Background and justification

As mentioned in the TS, the requirement WENRA SV 6.11 for NPPs, S 5.1 for research reactors, and S-26 and S-27 for waste storage facilities and spent fuel storage facilities applies to this fire prevention topic:

> *(WENRA SV 6.11): In order to prevent fires, procedures shall be established to control and minimize the amount of combustibles and the potential ignition sources. […];*
>
> *(WENRA S 5.1): In order to prevent fires, procedures shall be established to control and minimize the amount of combustible materials and minimize the potential ignition sources that may affect items important to safety. […];*
>
> *(WENRA S-26): The licensee shall establish operational limits and conditions (OLCs) in order to maintain the storage facility and waste and spent fuel packages or unpackaged spent fuel elements in a safe state during facility operation;*
>
> *(WENRA S-27): The defined OLCs (see S-26) shall consider, in particular, and as appropriate: […] potential aspects of gas generation from waste or spent fuel, in particular the hazards of fire ignition, explosion, waste and spent fuel package or unpackaged spent fuel element deformations and radiation protection aspects; […].*

The management of fire loads in nuclear installations is a means to minimise the likelihood of fires and their consequences. The management of fire loads is related to the admissible fire loads. It is considered in the fire safety analysis and in the design of fire protection provisions to be implemented. Their control in nuclear installations is key to ensuring safety.

The TS for the NARs specifically asks for the following in regard to the management of fire loads:

- *the process in the installation´s design for minimizing the likelihood of fire, with due regard to the characteristics of radioactive waste in storages;*
- *the fire prevention means including specific needs due to the installation´s operation and processes (flammable liquids, pyrophoric materials, optimized layout of buffer zones for temporary waste storage, etc.);*
- *in accordance with the fire analysis considerations, the procedures for management and control of fire loads and ignition sources (e.g., minimisation and segregation of fixed and transient combustibles to the extent practical*) […].

During the desktop review, the TPR Team noted that varying information relating to the management of fire loads had been provided. Specifically, the TPR team noted differences in practices for the same installation types ranging from qualitative approaches to fully quantitative approaches.

The management of transient combustible materials (temporary fire loads) was explained by some countries however others did not describe them in detail. There was also variability in the frequency of inspections and accountabilities for management of fire loads across the operating organisation. Similarly, some participant countries consider all combustible materials e.g. including fire protected cables whereas some exclude some loads from analysis.

For the above reasons, the topic of interest management of fire loads was chosen for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. Fire load inventory documentation and management (transient and permanent)
2. Roles, responsibilities and frequency of inspections

3. Fire load input for the design and safety analysis of fire protection systems

The objective of this topic of interest was to compare practices between different operators of different types of nuclear installations and to get an overview of how the management of fire loads is considered to ensure adequate minimisation and control during the lifetime of the installations.

1. Fire load inventory documentation and management (transient and permanent)

Minimisation of fire loads and consideration of the (admissible) limits for permanent and transient fire loads is an important part of fire management. However, across installation types, there are different approaches to the management of fire loads (permanent and transient). Some are more qualitative (concepts), others are more quantitative (tools such as fire load indexes, fire load spreadsheets, etc). However, the approaches are defined by parameters which were not generally provided or described, in particular regarding the limits for permanent and transient (temporary) fire loads, the consideration of new types of fire sources (e.g. lithium-ion batteries) or the items that may be excluded.

Workshop discussions confirmed that most countries state an expectation of fire load minimisation and exclusion of fire loads wherever possible. Approaches to quantify fire loads generally include surveys/quantification from the design phase throughout the operating lifetime of the installations (by means of regular walkdowns). A wide range of accountancy tools (databases and spreadsheets), varying in levels of sophistication, have been implemented across the participant countries.

The identification of admissible fire loads per room is applied in some countries and installations. In this context, countries also referred to the re-evaluation of fire loads as part of change control or modification processes so that fire load limits are not exceeded. France shared that, for example in NPPs, predetermined, occasional and worksite temporary storage areas are subject to written justification of their duration and need. They are subject to risk analysis and are limited in duration to three months maximum per user and per zone.

Countries such as Belgium, Finland, France, Spain, and the UK, referred to regular or continuous evaluation of the fire loads, and consideration of nuclear safety significance of rooms and SSCs in decisions as to the allowable fire load, including temporary storage. In Belgium, fire loads are identified by bar-codes that are regularly checked/scanned to assess whether the load is placed in the allowable location. This has been identified as a TPR II Good Practice.

> **Good Practice:** ***A dynamic system to manage storage area for transient fire loads and other non-combustible materials***
> Further information is available in Annex IV.

Key improvements and learning shared by the participant countries included:

- fire load minimisation through reduction of packaging materials (Finland);
- a hierarchical approach to the use of scaffolding boards at sites (UK), optimisation of storage locations (Belgium, UK);
- introduction of local flammable storage cabinets to limit the size of large, centralised storage and unprotected flammables during use (Finland, Spain);
- reflections on the hazards and risks of new technologies and widespread introduction of lithium-ion batteries which is leading to the introduction of storage and charging battery cabinets fitted with technology to detect anomalies (the United Kingdom);
- keeping combustible waste properly sealed in storage facilities (Germany).

Vehicles and newer technologies such as lithium-ion batteries were considered as areas of focus. Fire load exclusion, minimisation, and appropriate controls during storage and use, including activities such as battery charging, have led to the introduction of additional monitoring and fire protection means.

Overall, rigorous management of fire loads, both fixed and transient, require effective elimination, and minimisation through hierarchical and quantitative approaches that replace or reduce combustible inventories, taking into account the nuclear safety significance of SSCs in the areas and the presence of waste or radioactive contamination.

2. Roles, responsibilities and frequency of inspections

It is important to regularly verify by inspection the actual permanent and transient fire loads and the adequacy of their management. The roles and responsibilities of personnel in defining, controlling and verifying fire loads or detailed procedures were generally not available in the NARs. Expectations in this area can nevertheless be found e.g. in IAEA SSG-77, paras. 10.7, I.10 and I.16c.

Examples of licensee inspection practices were shared during the workshop. It is noted an increasing use of consolidated databases accessible by all users. Spent Fuel, Waste Storage and Fuel Cycle Facilities in the UK referred to multilayer oversight of fire loads through use of dashboards and independent reviews. There were reflections from several participants that despite processes and tools, unjustified fire loads are still being discovered at times (France). Countries agreed that this is an on-going consideration and concern. The participants emphasised the crucial role that visible leadership and accountability for fire safety from the top has in establishing and maintaining the right safety culture for adherence to arrangements by all, including contractors.

There are scheduled and unscheduled fire rounds daily, weekly, monthly depending on the fire load class of the areas particularly in NPPs (Spain, UK). Switzerland reported that shift personnel carry out weekly and monthly inspection rounds according to checklists.

Overall, having in place clear roles and responsibilities in the inspection of fire loads is shared by most countries and so is the need for regular inspections depending on the inventories and nuclear safety risks. While temporary fire loads are subject to controls and inspections, areas of difficulty persist, for example, in the need for continuous reinforcement through leadership and the need for vigilance of combustible waste materials when a waste route is not clear or yet established.

3. Fire load input for the design and safety analysis of fire protection systems

The expected linkage between fire analysis, management of the fire load and design of passive fire protection measures was often not detailed by the participant countries. It was therefore important to get a global view, particularly on the following issues:

- whether the fire resistance ratings of the compartments are considered when allowing temporary and/or fixed storage of combustible materials;
- whether there are claims on the presence of non-combustible materials (e.g. fire-retardant cables) and if they are accounted for in the fire safety analysis and the design of fire protection provisions including fire barriers / fire compartment boundaries;
- practices used in the determination of the fire resistance rating of fire compartments including their penetrations as well as other safety measures and design features e.g. ventilation ducts, in accordance with the combustible inventories and fire load density [MJ/m^2] of the compartment.

Valuable reference in this respect is provided in IAEA SSG-64, paragraphs 4.6 to 4.12: recommendations on fire load minimisation and use of fire-resistant materials.

When discussing the link between fire load management and provision of fire protection measures, some countries such as Italy, the UK and Lithuania stated that fire load criteria have been implemented via standards or legal requirements and the use of ISO fire curves, and limits such as 900 MJ/m^2 for 60 min were cited.

Combustible materials including fire resistant or protected cabling are expected to be included in the calculations in some countries, but this practice is not shared across all countries. It is important that the full fire load is included to ensure appropriate resilience against the worst-case fire. Specifically, countries such as Finland and the UK informed that all combustible materials including fire resistant or protected cabling are expected to be included in the calculations, whereas others do not include them. However, for example, Czech Republic stated that cable routes in which only cables complying with the test according to IEC 332.3 Cat. A are used are not considered as fire loads if assessed that no other fire loads in the compartment could endanger these cable routes in the event of a fire.

In some countries, provisions allowed for the exclusion of fire loads from consideration when contained in fire-resistant containers. There was also discussion on the rationale for Slovenia to introduce combustibles (radiation shielding by polyethylene) in the structures of a spent fuel storage facility when most countries considered that concrete build is preferrable. The participating countries indicated that practicable compensatory measures should be introduced.

Limits and minimum distances for the placement of such temporary loads were cited. For the control of transient combustibles, Spain, for example, shared a method for limiting the accumulation of transient flammable and combustible materials in and around buildings containing safety important SSCs. The procedure specifies several prohibited storage locations inside buildings containing safety important SSCs, as well as around buildings and safety-related tanks in outdoor areas up to a distance of 8 m, defined in accordance with the NFPA-30 "*Flammable and combustible liquids code*" (2024).

Most countries confirmed that additional measures such as portable fire extinguishers are provided when allowing temporary fire loads, and these are generally patrolled by the fire safety teams or fire brigade/ authority at the site.

Conclusion

The management of both permanent and temporary fire loads is a critical element of fire protection strategies, as demonstrated by the participating countries. Fire load minimisation is widely recognised and implemented. The participants highlighted the vital importance of visible leadership and top-level accountability for fire safety. Continuous vigilance is required to maintain effective control of combustible loads throughout the lifecycle of installations. While some countries expect all combustible materials, including fire-protected items, to be accounted for in fire safety analyses, this practice is not yet universally adopted. Several countries reported using accountancy tools, such as databases and spreadsheets, with varying levels of sophistication, to support effective monitoring and control of fire loads. A **good practice** shared by Belgium involved the use of mobile scanning devices for visual identification and inspection of fire loads. Additionally, most countries ensure the provision of supplementary fire safety measures, such as portable fire extinguishers, when temporary fire loads are allowed, with regular patrols to monitor their compliance.

5.1 Management of ignition sources

Type of installations mainly concerned

This topic of interest is applicable to all types of installations.

Background and justification

As mentioned in the TS, the requirement WENRA SV 6.11 for NPPs, S 5.1 for research reactors and S-26 and S-27 for waste storage facilities and spent fuels storage facilities applies to this fire prevention topic:

> *(WENRA SV 6.11): In order to prevent fires, procedures shall be established to control and minimize the amount of combustibles and the potential ignition sources. […]*
>
> *(WENRA S 5.1): In order to prevent fires, procedures shall be established to control and minimize the amount of combustible materials and minimize the potential ignition sources that may affect items important to safety. […]*
>
> *(WENRA S-26): The licensee shall establish operational limits and conditions (OLCs) in order to maintain the storage facility and waste and spent fuel packages or unpackaged spent fuel elements in a safe state during facility operation.*
>
> *(WENRA S-27): The defined OLCs (see S-26) shall consider, in particular, and as appropriate: […] potential aspects of gas generation from waste or spent fuel, in particular the hazards of fire ignition, explosion, waste and spent fuel package or unpackaged spent fuel element deformations and radiation protection aspects; […].*

The TS for the NARs specifically asks in regard to the management of ignition sources:

- *in accordance with the fire analysis considerations, the procedures for management and control of*
  - *ignition sources (e.g., minimisation and segregation of fixed and transient combustibles to the extent practical), and*
  - *"hot work" to handle maintenance or other work (e.g., experiments in research reactors, decommissioning operations, daily start and stoppage of dismantling works in installations under decommissioning) where there are risks of fire ignition.*

The management of ignition sources in nuclear installations is a measure to minimise the likelihood of fires and their consequences. Furthermore, the management of ignition sources is related to the design of passive fire protection measures and fire safety analysis. Their control in nuclear installations is key to ensuring safety. The objective of this topic of interest was to compare practices between different operators of different types of nuclear installations in the scope of the TPR II with comparable activities, to get an overview of ignition source controls including of hot work activities, and to identify potential good practices and potential challenges.

It was expected that the NARs would describe the process in the installation's design and the administrative process in place for minimising the likelihood of fire. This was to cover, in accordance with fire safety analysis considerations, management and control of ignition sources (including "hot work") to handle maintenance or other operations (e.g., experiments in research reactors, daily start and stoppage of dismantling works in installations under decommissioning). These aspects have been covered in the NARs very differently. Some NARs included detailed arrangements and approaches for the control of ignition sources, with clear roles and responsibilities, while others did not.

An important learning from the OECD/NEA FIRE Database is that hot work is one of the major causes of fire events for nearly all types of operating power reactors. The role of hot work as a cause of fires in other installation types is described in the NARs only by some participating countries. In this respect the identification of ignition sources from hot work, inspection and verification policy, and temporary measures during hot work are key issues.

For the above reasons, the topic of interest "management of ignition sources" was chosen for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. Approaches for systematic identification and management of ignition sources
2. Roles and responsibilities for the management of hot work
3. Temporary or compensatory fire prevention, protection and suppression measures during hot work.

The objective of this topic of interest was to compare practices between different operators of different types of nuclear installations and to get an overview of how the management of ignition sources is considered to ensure adequate minimisation and control during the lifetime of the installations.

1. Approaches for systematic identification and management of ignition sources

For a systematic identification of ignition sources from hot work, chemical reactions, high energy arcing faults (HEAFs), hot spots, hot gas, overheating or failure of electrical or mechanical SSC, human actions/factors and ATEX during operation, maintenance and modifications, it is helpful to refer to IAEA SSG-77, paras. 9.7, 10.7 and Appendix I, paras I.23–I.41- and specifically to hot work.

There is recognition that there is a wide range of potential ignition sources and types of activities that introduce them, in particular, hot work. Countries generally reflected that there is not a universally agreed definition of what constitutes hot work. However, most participating countries have methodologies and permit systems in place for control of ignition sources and higher risk activities such as hot work.

Some installations, in Belgium for example, apply limits to hot work certificates to specified durations e.g. 1 day. Shorter durations e.g. 12 hrs were cited in some UK installations, with notifications to responsible persons/ control room. Both countries showed hierarchical approaches e.g. hot works undertaken only if there are no viable alternatives.

Indeed, most countries stated the need for minimisation of hot work activities through alternative approaches, e.g. cold cutting: however, they recognise these can still lead to ignition, and equally, there is no universally agreed definition of what constitutes cold-cutting methods.

2. Roles and responsibilities for the management of hot work

There are varying levels of coverage on the roles and responsibilities for the management of hot work at the installations. Only a few countries identified the permit duration, the inspection activities and roles associated with assessment and approvals of hot work permits. Expectations in this area are described for example, in IAEA SSG-77, paras I.34, I.37 and I.38.

While most NARs referred to permit systems being used, some licensees and countries have classification of hot work activities into major or minor which then dictates the level of inspection and controls including maximum allowable duration of permits (UK).

Finland showed that hot work sites are inspected before work starts and require post-work inspections. In France, information showed that work permits in NPPs must be transmitted to the site fire-fighting service 48 hours before the start of the hot work. Patrol rounds are carried out and recorded in daily tracking sheets, and there are hold points at end of works to check for hot spots with thermal cameras.

In UK NPPs, the roles of individuals such as ‘Hot Work Selected Person’ who assesses the activities, the ‘Hot Work Controller’ who assesses and approves when satisfied that all controls are in place, has been further reinforced with a further Independent Verification step (a qualified individual separate from the activity).

The importance of training and oversight of contractors in order to ensure a proper conduct of hot work was highlighted by Germany and Finland.

Overall, clear definition of roles and responsibilities, permit systems and approvals, pre- and post-work checks including independent verification are some key descriptors of effective management of hot work activities across countries.

3. Temporary or compensatory fire prevention, protection and suppression measures during hot work

Some countries generally refer to the introduction of temporary or compensatory fire prevention and protection measures during hot works. However, the process to identify the appropriate mitigation measures is not generally provided. IAEA SSG-77, paras. 10.7(a), I.36, I.38 and I40-41 are a helpful reminder of some of the provisions that could be expected.

During the workshop, countries shared approaches applied, and typical compensatory measures taken which showed some differences. Most participants referred to the removal of fire loads, the provision of additional fire extinguishers, supervision by onsite fire brigades or fire safety teams. Germany stated that in some installations, after hot works the automatic fire detection is re-established and there is repeated inspection of the work area after hot works with 30-min periodicity up to 90-min. Additionally, oxygen monitoring is used in confined spaces. Thermal imaging has been increasingly used in those installations that use them to check for hot spots post-work.

France queried the use of spark filters and arresters, and the UK shared experience in the introduction of spark mitigation in ducting following learning from an ignition during hot work. There was also reference to water-cooled cutting (Spain) and ‘point of work’ plan checks before work is allowed to commence (France).

Some licensees limit the level of fire detection system and alarm disablement while others do not. For example, a fuel cycle facility in the UK limits disablement to single detector or group of detectors only. A similar approach is reported by the Netherlands (only local temporary disablement, with permission and/or supervision of the fire brigade). Some countries (Finland, UK) reported that use of thermal imaging is now in place, and this followed learning from fires including operating experience from Finland on a roof fire initiated by hot works.

Operating experience and lessons learned from shortfalls in the control of ignition sources was shared by multiple countries, which then reflected the main improvements introduced. Key considerations included:

- ventilation management adjustments to prevent smoke ingress,
- vigilance when working on decommissioning or ageing facilities due to the possibility of combustibles being present but hidden within the fabric of buildings, or the poor instruction of contractors, and the importance of point of work layout and control of work at height.

The use of technology including cameras has been increasingly reported and this has been identified as a good practice in TPR II:

> **Good Practice: *Thermographic cameras installed on worksites, or in case of the failure of a detector, with different detection zones and alarms***
>
> Further information on the identified Good Practice is available in Annex IV.

Finally, the increasing introduction of new technologies such as lithium-ion batteries has been identified as a TPR II challenge requiring further research and collaboration in the development of fire safety guidelines for their appropriate use, charging and storage.

> **Challenge**: ***A need to consider new types of ignition sources (e.g. lithium-ion batteries)***
>
> Further information on the identified challenge is available in Annex V.

Conclusion

The systematic identification and management of ignition sources, such as hot work, chemical reactions, and mechanical failures, is critical for fire safety. Countries emphasise the importance of controlling hot work activities, but there is no universally agreed definition of what constitutes hot work. Permit systems and risk assessments are commonly used to manage hot work, with defined roles and responsibilities for approvals and inspections, often including pre- and post-work checks. Temporary fire prevention measures, such as fire extinguishers and thermal imaging, are implemented during hot work, with varying approaches across countries. Lessons learned highlight the importance of vigilance in decommissioning, as well as the need for better training and oversight of contractors. A **good practice** shared by France involves the use of thermal cameras that has proven effective in managing ignition sources. Additionally, the introduction of emerging technologies like lithium-ion batteries at nuclear installations has been recognised as an ongoing **challenge** requiring further research and fire safety guidelines development.

6. PASSIVE FIRE PROTECTION

6.0 Ageing management of passive and active fire protection SSCs

Type of installations mainly concerned

This topic of interest is applicable to all types of installations.

Background and justification

The requirements WENRA I 1.1, I 1.2, I 1.3, I 2.2 and SV 6.11 for NPPs on ageing management of passive and active fire protection SSC are applicable also to other nuclear installations.

> *(WENRA I 1.1): The licensee shall establish suitable organizational and functional arrangements to manage physical ageing and technological obsolescence of in-scope SSCs with foresight and anticipation through the entire lifetime of the plant, including design, construction, commissioning, operation and decommissioning phases. The licensee shall mitigate ageing degradation effects and prevent them, were reasonably practicable.*
>
> *(WENRA I 1.2): In order to accomplish the safety functions through the entire lifetime of the nuclear power plant, the licensee shall, within the integrated management system: implement an effective overall Ageing Management Programme and address technological obsolescence.*
>
> *(WENRA I 1.3): The following SSCs shall be included in the scope of ageing management: SSCs important to safety, other SSCs whose failure may prevent SSCs important to safety from fulfilling their intended functions.*
>
> *(WENRA I 2.2): The licensee shall provide monitoring, testing, sampling and inspection activities to assess ageing effects and to detect, in a timely manner, unexpected behaviour of the in-scope SSCs or degradation symptoms. Where necessary, corrective actions shall be taken in a timely manner, taking into account prioritization by safety significance. Acceptance criteria against which the need of corrective actions is evaluated shall be defined.*
>
> *(WENRA SV 6.11): […] In order to ensure the operability of the fire protection measures, procedures shall be established and implemented. They shall include examination, inspection, maintenance and testing of fire barriers, fire detection, alarm features and extinguishing systems.*

The TS for the NARs specifically asks regarding ageing management of passive and active fire protection SSC:

- *administrative measures to ensure the operability of the fire protection measures over the lifetime of the installation including inspection, maintenance and periodic testing procedures;*
- *performance assurance through lifetime;*
- *lessons learned from events, review fire safety missions, inspection and assessment on the fire prevention.*

Ageing management is implemented to ensure that the effects of ageing will not prevent SSCs from fulfilling their intended safety functions reliably throughout the lifetime of the installation (including its decommissioning) and considers changes that occur with time and use. This requires addressing both the effects of physical ageing of SSCs, resulting in degradation of their performance characteristics, and the non-physical ageing (technological obsolescence) of SSCs. This is reflected in the WENRA Safety Reference Levels WENRA I 1.1, I 1.2, I 1.3, I 2.2 and SV 6.11.

During the desktop review, generic questions were raised to address ageing management of fire protection SSCs as information on this topic was limited. This topic of interest on "Ageing management of passive and active fire protection SSCs" was therefore chosen for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. Inspection, test procedures and method used for ageing management of fire protection SSCs,
2. Lessons learned from the inspections and events.

The objective of this topic of interest was to get an overview on inspection and test procedures (methods used, frequencies) as well as, significant deficiencies and improvements for ageing management of penetrations seals, fire doors and fire hydrant network.

1. Inspection, test procedures and method used for ageing management of fire protection SSCs

The passive and active fire protection provisions cover a wide range of fire protection systems and equipment (e.g., fire detections systems, fire extinguishing systems and equipment including fire water main ring and fire pumps, hydrants, etc., fire barrier with their active elements such as fire doors, fire dampers, etc). The scope of this topic of interest was limited to fire doors, penetration seals and fire hydrant network.

The workshop discussions were beneficial to share the preventive actions (inspection, test procedures (methods used, frequency, etc) implemented for the ageing management of some fire protection features, in particular the penetrations seals, fire doors, as for barrier elements and the fire extinguishing water distribution networks. From the information presented the following can be derived:

- In all countries, **fire penetration seals** are inspected visually. Visual inspections of not less than 10 % of each type of seals is performed once per year or per outage (12 - 18 months). Depending on the finding, the sample may be enlarged.
  - Belgium: In the NPPs, there are visual inspection of 10 % of the seals typically every year or every 18 months. The seals product are tested and validated in external laboratories. There are a lot of factors that might contribute to ageing, e.g. humidity, radiation, etc. Some tests on penetration seals (with an age of 40 years) will be performed for LTO;
  - France: In the NPPs, every penetration seal is visually inspected with a five-year frequency. If there are any findings during external checks, there will be more inspections. Each type of penetration seal was tested prior to its installation in the plants. The equipment of an older plant will be tested with the original testing constraint to assess any effect of ageing;
  - United Kingdom: In the NPPs, 20 % of fire penetration seals are visually inspected annually. Some concrete penetration seals have special replacement programs due to ageing effects causing cracks. Conventional fire seals are tested at 10 % per year. Some flexible penetration seals were investigated in external laboratories. As a result, replacements were needed;
  - Finland: Some penetrations are checked every year. Usually there are checks by the fire brigade twice or three times a year. There is no percentage set concerning the number of penetrations to be inspected annually. There is a programme ongoing to perform tests on artificially aged penetration seals:
  - Spain: In NPPS, visual inspections on seals are performed at every outage (18 months) with a rate of 10 %;
  - Slovenia: Visual inspections on seals are performed every outage (18 months) with a rate of 10 %. A seal must be integral, without holes or cracks, the gap between the seal and wall must not exceed 6 millimetres and sealant material must not be hardened. If apparent changes in appearance or abnormal degradations are found, a visual inspection of an additional 10 % of each type of sealed penetration is made. This inspection process shall continue until a 10 % sample with no apparent changes in appearance or abnormal degradation is found. Samples are selected such that each penetration will be inspected every 15 years.

The absence of cracks and the gap dimensions between the seal and the wall are verified. Most countries acknowledge that originally certified penetration seals and their fire resistance ratings may degrade over time due to various factors, such as ageing effects (e.g. corrosion, cracking, elastomer degradation, material loss, hardening), inadequate maintenance procedures, and poorly implemented modifications.

- Regarding **fire doors**, in all countries fire doors are inspected visually:
  - Belgium: The testing - scope and frequency - of the fire doors includes the verification of the absence of obstructions for normally open or open fire doors equipped with an automatic closing mechanism. Visual inspection of fire doors includes checking the closing mechanism;
  - Finland: Fire doors are inspected twice a year according to preventive maintenance program and using a specific instruction. Inspection includes checks for general condition of the door and possible accessories, thermal insulation of entrance doors, condition of the seals against air or water pressure, and closing and latching;
  - Slovenia: The operability of each fire door is tested once every 6 months. Integrity, tightness, gaps, cracks and any potential damage are checked and locking and closing mechanisms tested;
  - United Kingdom: the thermal insulation of the fire door is tested.

Regarding **the fire hydrant networks**, in all countries, fire hydrant networks are inspected visually. Other inspection methods are endoscopy, ultrasonic, eddy current, etc. Full flow testing is performed, e.g. in Belgium, Germany, Slovenia. Thickness measurements can be performed on accessible parts of the systems. 100 % cannot be reached (e.g., buried parts of the piping). Pressure drops can be used to indicate hydrants pipe leak. Most finding so far have been with underground pipes.

2. Lessons learned from the inspections and events

During the workshop, some important lessons learned were presented, resulting mainly in replacements.

The most important reasons for improvements, modifications, and replacements of passive and active fire protection features in nuclear installations are ageing degradation (e.g., corrosion, cracking, radiation, wear, damage, humidity, hardening, etc) and obsolescence. In most of the countries a lot of modifications, improvements and replacements of passive and active fire protection features have been performed.

The Spanish regulator presented the operating experience regarding several penetration seals which showed defects in one NPP. A test revealed that their fire resistance rating would not be the required 3 hours but only 2 hours. About 200 penetration seals were replaced with a modified, newly designed one.

In most countries, fire doors have been partly replaced. There are different criteria for replacing a fire door: fire risk significance (PSA), critical rooms, failures, damage, degradation etc.

- Belgium: There are different criteria for replacing a fire door: wear or damage, water on the floors that impacts the seals inside the door. Doors with damaged seals by water are replaced. The most important doors, with regard to significance to nuclear/radiation safety were as well replaced as they nearly reached criteria;
- Finland: After an update of the safety requirements, the fire doors were checked by the operators. There is a campaign to replace fire doors. Replacements were started with the most important doors according to PSA results;
- United Kingdom: Certified companies checked the fire doors. Replacements are performed in case of defects. The original requirement for the doors are kept;
- Germany, the Netherlands and Switzerland reported replacements of fire doors resulting from the national and international experience feedback according to reporting of deteriorations and/or failures of such components (see chapter 3).

In all countries, fire hydrant networks and fire hydrants have been at least partly replaced due to ageing degradation (e.g., corrosion, cracking, damage).

Conclusion

Countries have implemented various inspection and test procedures for managing the ageing of fire protection components such as penetration seals, fire doors, and hydrant networks. Visual inspections of seals and doors are common, with regular checks (10 – 20 % annually) and specific tests are carried out for degradation, cracks, and functionality. Fire hydrant networks undergo visual checks and advanced methods like endoscopy and ultrasonic testing.

The primary cause for modifications and replacements is ageing degradation (e.g. corrosion, cracking, and material wear). Several countries have replaced fire doors and seals based on safety significance, with specific criteria guiding replacements. Lessons learned emphasize the importance of continuous monitoring and the need for upgrades to address obsolescence and ensure fire protection reliability.

6.1 Inspection and functionality testing of fire dampers

Type of installations mainly concerned

This topic of interest is applicable to all types of installations.

Background and justification

As mentioned in the TS, the requirements WENRA SRLs SV 6.11 for nuclear power plants and S 5.1 for research reactors are applicable to fire dampers and can be applied to other installations.

> *(WENRA SV 6.11/ WENRA S 5.1): […] In order to ensure the operability of the fire protection measures, procedures shall be established and implemented. They shall include examination, inspection, maintenance and testing of fire barriers, fire detection, alarm features and extinguishing systems.*

During the desktop review, the TPR Team noted that the methods and frequencies for inspections and functionality testing of fire dampers vary between the participating countries and the different types of nuclear installations. For this reason, the topic of interest "Inspection and functionality testing of fire dampers" was chosen for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. Approaches and methods used for inspection and functionality testing
2. Frequencies and associated justification for fire dampers' inspections and testing
3. Findings from fire dampers' inspections and testing
4. Consideration of these findings for replacement or design modifications.

The objective of this topic of interest was to provide an overview of the practices related to the inspections and testing of fire dampers, with a particular focus on non-accessible dampers, as well as the implications of inspection and testing results for modifications or replacements.

1. Approaches and methods used for inspections and testing

Dampers are actuated based on different means (passive systems (melting of fuse), pushbutton, fire detection or smoke control system). Therefore, the testing procedures are different. Inspections rely mainly on visual means.

Correct, effective and reliable functioning of the required closure of fire dampers in case of fire is essential to prevent the spreading of fire between fire compartments. To ensure this, inspections and tests (as part of the maintenance programme of the installation) are carried out to verify the state of the fire dampers and their functionality, including their actuation and closing mechanisms.

To facilitate this process, the fire dampers should be installed in a way that allows for easy testing and verification. However, some fire dampers and their actuation mechanisms are, due to constraints, positioned in very high dose or unreachable areas. As a result, inspection hatches are often placed at a considerable distance from the fire dampers, their closing mechanisms, and the detectors or systems designed to activate them. This may make it difficult to carry out inspections in general and specifically visual verifications, and therefore ITV[30] is typically used. Experience feedback of similar dampers can be credited regarding their expected performance (actuation and closing mechanisms).

[30] French acronym: Inspection télévisuelle

- In Spain, some non-accessible dampers can be remotely operated from the fire control panel, whose correct operation is checked; when not accessible, the performance of similar dampers is assumed based on those that can be inspected;
- In Slovenia, some of the dampers, which are difficult to access, are only visually inspected (e.g. mirror, camera borescope);
- In some countries (Bulgaria, Germany, Romania) there are currently no inaccessible dampers.

In most of the installations, tests of the correct actuation of fire dampers can be performed by manual activation by pulse or by simulation with a particular device on the optical fire detector, by electrical signal, by the ventilation signal or by a signal of a smoke detector.

Romania reported that the fire dampers located on the ventilation ducting have a preventive maintenance programme carried out every year that includes the following activities:

- visual checks inside of the fire damper (cleanliness, integrity, no blockages),
- fuse status check,
- actuate the damper in the closed or open position to confirm its operation.

Spain reported that for the passive fire dampers, only the mechanical part is tested to verify the closing.

Belgium reported that functionality tests are performed to verify whether the signal from the detection system successfully reaches the damper.

Germany reported that the actuation of the dampers sometimes failed during inspections due to the fact that the verification of the spring tension is difficult to perform manually in a standardised manner. A tool in a German installation was recently developed to ensure the same testing conditions are applied each time, minimising this issue.

2. Frequencies and associated justification for fire dampers' inspections and tests

The types and frequencies of inspection and testing are generally based on the technical requirements of the installation, or the vendors' recommendations.

In a few countries, the national nuclear standards provide prescribed inspection and testing frequencies for fire protection features including fire dampers (also covering the participation of the regulator). In Germany, according to conventional (non-nuclear) requirements fire dampers are inspected and tested every 6 months and if two consecutive tests of a damper do not show any findings, the test interval can be extended to 1 year.

The frequencies of inspection and functional testing of the fire dampers depend on the installation, and the type of dampers. Often only one or some of the possible actuation mechanisms are tested with a higher frequency, while damper actuation involving mechanical or electrical temperature fuses are tested at a much lower frequency as the fuses have to be replaced after testing:

- At the Spanish NPPs, the frequency depends on the type of the fire damper. A functional test is required every 24 months for types 1 (pneumatic damper) and 2 (electric damper), and every 10 years for type 3 (fuse damper) performing annually 10 % of them;
- Slovenia reported that visual inspections are performed every eighteen month and functional testing (cleaned, activated, reset) once per 72 months;
- Finland reported that for EPR OL3 NPP, physical inspection is carried once a year. The dampers have self-diagnostics to inform of any faults;
- Italy reported that fire dampers in the TRIGA Mark II research reactor undergo a functional test at least once per year, typically in conjunction with the manual activation test of the emergency ventilation system;
- Sweden reported as well that addition to inspections, fire dampers are tested automatically at an interval determined by the supplier.

3. Findings from inspection or testing of fire dampers

Inspection or testing of fire dampers may have led to maintenance, repair, equipment modifications or replacement.

The participants agreed that fire dampers occasionally may show a problem of ageing, in particular due to a legacy lack of maintenance, or simply wear down. A typical finding is a loss of tension of the springs needed for an effective closure of the fire dampers. Excessive closing times were found during tests at several NPPs: in one Swiss NPP, such effects were discovered after the installation of a new fire alarm system that registered the closing times. As a result, replacement of all fire dampers was performed. In most other cases, renewal of the tension springs has been sufficient.

Switzerland's experience from maintenance and inspection has shown that the position indicator of the fire damper must not only be interpreted visually, but that the position of the damper within the ventilation duct must also be effectively checked. To do this, the visual inspection must be carried out inside the ventilation duct or via the maintenance opening.

France mentioned that after a number of years, mechanical parts were not as smooth running as when NPPs were constructed. There is no systematic problem with the ageing, accessibility or functionality of fire dampers.

In the United Kingdom, some fire dampers at the Sellafield installation were found to be non-functional: *"An investigation into fire damper issues reported at the Encapsulation Plants in 2022 identified that a significant number of fire dampers had not been maintained in accordance with relevant good practice (such as BS 9999 [71]) and were found to be non-functional upon testing."* Work to address challenges around maintainability of fire dampers is being tackled as part of a major overhaul of the fire protection at the site.

Belgium reported the degradation of intumescent material caused by humidity or carbon dioxide.

In Germany, in the past several reportable events related to fire dampers occurred which led to several Information Notices prepared by GRS (cf. Annex A2 of the German NAR). The Information Notices resulted e.g. in improvements in the test procedures, particularly regarding the thermal actuation.

The Netherlands mentioned events concerning fire dampers (see chapter 3) as well.

4. Consideration of inspection and testing findings for replacement or design modifications

During operation, testing and inspection, inadequate functionality or failure may have been observed and recorded. Faulty components are often replaced by spare parts with the same safety specifications during maintenance. Replacements may also be performed, e.g. if original parts are obsolete or ageing. In Belgium, there is a programme for the replacement of intumescent material within fire dampers which degenerated due to age. In some cases, instead of simply replacing the failing parts, a more effective solution may involve redesigning certain components of the system or replacing them with more suitable or upgraded parts (e.g. a new damper). The process for modification of fire dampers is the same as for any other safety related equipment.

If the damper is not easily accessible or cannot be accessed (e.g. due to high radiation in the area or spatial constraints), modifications of the location of the damper or its surroundings may also be performed to allow adequate inspection and testing. For example, in Germany, inaccessible fire dampers were made accessible e.g. by adding large inspection openings in the connecting ventilation ducts.

The United Kingdom highlighted the importance of maintaining records from design to operation and reported that the operating experience feedback on the management of older fire dampers is taken into consideration for new builds which results in improving accessibility of fire dampers.

If additional fire dampers are implemented, this is usually performed in the framework of larger projects. For example, in Sweden, a recently finished project led to the replacement of every fire damper in the facility and measures to simplify the ability to inspect fire dampers with the addition of accessible inspection hatches.

Finland reported on an ongoing project to replace all the electromagnetic fire dampers with modern electrical fire dampers in reactor building cable shafts. The modification was initially started due to operating experience feedback issues from other facilities.

Lithuania reported improvements by modification on the procedure to perform technical maintenance of fire protections means after some events with malfunction of fire protection features.

Conclusion

The correct, effective, and reliable operation of fire dampers is crucial to prevent the spread of fire between compartments. To ensure this, inspections and tests are conducted as part of the installation's maintenance programme.

Fire damper inspections and tests rely primarily on visual checks, with different methods based on the actuation mechanisms. Regular inspections ensure that fire dampers function correctly, focusing on closure and actuation, but access limitations sometimes require alternative methods like mirrors, cameras, or remote operation. The frequencies of inspections and tests vary by installation and type of damper, with some dampers tested annually and others on longer cycles (e.g. every 10 years). They are generally based on the technical requirements of the installation, or the vendors' recommendations or in a few countries, from national standards.

Common issues include loss of spring tension, slow closing times, and degradation of materials, often requiring replacement or modification. Some countries have specific programmes for replacing or redesigning components to improve accessibility and functionality. Findings from inspections often lead to improvements in procedures and equipment, with operational experience influencing future designs and upgrades.

6.2 Ventilation management in case of fire

Type of installations mainly concerned

This topic of interest is applicable to all types of installations.

Background and justification

As mentioned in the TS, the requirement WENRA SV 6.6 for NPPs, S 4.4 for research reactors applies to the ventilation systems:

> *(WENRA SV 6.6): Ventilation systems shall be arranged such that each fire compartment fulfils its segregation purpose in case of fire and designed such that the ventilation of other fire compartments which contain other trains of the safety system is maintained as far as required to fulfil their safety functions;*
>
> *(WENRA S 4.4): Ventilation systems shall be arranged such that each fire compartment fully fulfils its segregation purpose in case of fire.*

The TS for the NARs specifically asks for the following in regard to the ventilation systems:

- *how the ventilation systems are designed in order to not compromise building compartmentation and to maintain access routes for firefighting;*
- *the possibilities to isolate the fire compartment penetrations by suitably rated fire dampers (automatically where appropriate).*

During the desktop review, the TPR Team noticed that there are different approaches for the ventilation management, for example some installations are equipped with fire dampers. The closure of the fire dampers can be automatically or manually actuated and this leads to stop partially or totally the ventilation system. For this reason, the topic of interest "ventilation management in case of fire" was raised for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. Issue of ventilation systems and fire dampers automatization
2. Operators' action on ventilation systems in case of fire

The objective of this topic of interest in the workshop is to compare practices between different operators of different types of nuclear installations and to get an overview of the ventilation management in case of fire.

1. Issue of ventilation systems and fire dampers automatization

Ventilation systems are equipped with dampers to avoid the spreading of the fire, and the risks associated with pyrolytic gases, smoke and other unburned material, and to facilitate intervention and control of fire consequences in the areas concerned, especially in terms of confinement of radioactive material.

The need to stop ventilation to prevent fire spreading should be carefully analysed to ensure it does not conflict with other critical safety requirements, such as maintaining depressurisation, preserving atmosphere circulation patterns, or ensuring radiological confinement (e.g. through filters). These considerations are also crucial for access and escape routes for personnel and rescue teams as well as for assessing the habitability of work areas. The management of ventilation systems in case of fire therefore requires careful consideration.

Most countries use a certain (different) level of ventilation systems automatization, particularly fire dampers closure, in case of fire.

The triggers for fire dampers closure are usually fire detectors (such as smoke detectors, temperature sensors, multi-criteria detectors) in compartments or thermal fuses directly at the dampers. Belgium reported using fire dampers that close automatically in case of filter damage by fire effects. France reported that for rooms in the fuel cycle facility with no dispersion risk, fire dampers can be automatically closed. However, for the rooms with a risk of dispersion, automatic closure is not feasible without compromising the integrity of the glove boxes. In such cases, the fire dampers closure would be managed by the operators.

In case of fire damper closure, the corresponding ventilation systems operation has to be considered to avoid the damage of active parts (like pumps, ventilators):

- In many countries, they are shut down (some automatically) to avoid damage (Lithuania, Sweden, the United Kingdom);
- many countries maintain some part of these ventilation system in operation to guarantee the overpressure for access and escape (evacuation) routes and staircases and for control points (rooms). Many countries also consider smoke removal ventilation operability for e.g. staircases (the Netherlands), control points (rooms) and the turbine hall roof (the Netherlands);
- However, some countries mentioned that they consider the smoke removal only for conventional areas, not for controlled areas (taking into account radiological safety).

However, in most countries, to avoid the conflict between fire safety and nuclear safety, the fire detection system cannot stop automatically ventilation system components with a safety function. Belgium, France and Slovenia reported that in case of fire in NPPs, a validation is needed before shutting down a safety system. Therefore, fire detection does not automatically shut down the ventilation system that performs a safety function. This is performed after confirmation by the control room. However, some ventilation systems are never shut off (e.g. diesel in Belgium).

2. Operators' actions on certain ventilation systems in case of fire

In case of fire, the ventilation management may rely on operator actions and not be triggered automatically by the fire detection system.

On fire detection, in some countries or for some installations, the ventilation system operations are managed by manual actions, considering nuclear or radiological safety issues (like the preservation of the integrity of glove boxes), habitability of access and escape routes, control points (rooms), and safety related equipment operability.

A validation by the operator in the control room is required before the ventilation can be switched off. Manual actions and related criteria are described in emergency procedures (France, Slovenia, Sweden). Some countries consider the damage or bypass of filtering elements as a trigger for some actions, for example based on the monitoring of delta-p measurements of filters.

In particular cases, manual actions can be performed by the operators in cooperation with the fire brigades (Germany, Slovenia, Sweden) or other rescue services.

Conclusion

The management of ventilation systems during a fire varies across different types of installations. Ventilation systems are equipped with fire dampers to prevent fire spread and manage risks related to pyrolytic gases, smoke and radiation. The need to stop ventilation during a fire must be carefully assessed to avoid conflicts with safety requirements, such as depressurisation, air circulation, and radiological safety.

In many countries, fire damper closure is automated through the use of fire detectors. To prevent damage to critical components, ventilation systems are typically shut down during a fire. However, certain systems, such as those for access and escape routes, are kept operational to ensure access and safe evacuation.

Most countries also maintain some part of the ventilation systems in operation considering nuclear or radiological safety issues. Manual actions by the operators to manage ventilation systems along with the associated criteria are detailed in emergency procedures.

7. ACTIVE FIRE PROTECTION

7.0 Fire detection

7.0.1 Adequate strategies for the installation of fire detectors and failure tolerance of fire detection

Type of installations mainly concerned

In general, applicable to all types of installations

Background and justification

As mentioned in the TS, the requirement SV 6.8 on Fire Detection and Alarm Systems (FDAS) in the WENRA SRLs for NPPs and S 4.1 for research reactors state as following:

> *(WENRA SV 6.8) Fire detection and alarm features, with detailed annunciation of the location of a fire to the control room personnel, shall be installed at the plant and their adequacy shall be supported by results of the fire hazard assessment. These features shall be provided with non-interruptible emergency power supplies and failures of the cable connections shall be announced to the main control room;*

> *(WENRA S 4.1) Each fire compartment or fire cell shall be equipped with fire detection and alarm features, with detailed annunciation for the control room staff of the location of a fire. These features shall be provided with non-interruptible emergency power supplies and appropriate fire resistant supply cables.*

The TS also state that the above requirements can be applied for other installations according to a graded approach.

The TS specifically asks with regard to FDAS:

- *the fire detection and alarm provisions (including subordinate systems to the extent applicable) to identify and notify occupants and fire emergency responders of any fire as needed according to the fire safety analysis (for reactor installations also including information to the control room, including systems' key features / technology and locations covered, and their emergency power and cable failure arrangements). For fuel cycle facilities, this should include a description of the balance between automated and manual detection and alarm provisions at the installation;*
- *the approaches to assure that the systems are capable to withstand the relevant ambient/ hazard conditions.*

During the desktop review, the TPR Team noted that there are different approaches for the location, type and number of fire detectors in rooms, their tolerance to failure, which may depend on the presence of SSCs or radioactive material (e.g. waste) to be protected against fire, the presence of fire loads and ignition sources, type of the room, etc.

For this reason, the topic of interest "Adequate strategies for the installation of fire detectors and failure tolerance of fire detection" was raised for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. Strategies for the installation of fire detectors
2. Adequate measures for FDAS with no addressable detectors
3. Failure tolerance of FDAS regarding a single failure.

The objective of this topic of interest in the workshop is to compare practices between different operators of different types of nuclear installations and to get an overview regarding the strategy for fire detectors installation and failure tolerance consideration.

1. Strategies for the installation of fire detectors

For the various types of nuclear installations, the strategy for the installation of fire detectors is different from one country to another:

- some countries aim for a full protection strategy, with detectors installed in all rooms, whilst allowing certain areas to be left out, like lavatories etc., according to national requirements;
- most countries have a full coverage in the radiation-controlled areas and rooms with safety relevant equipment, whilst remaining areas are covered on the basis of the results of the fire hazard analysis.

The desktop review and workshop discussions show that:

- a full protection is more often lacked in older NPP and other installation types. In some cases, systems were renewed twice over the lifetime of the NPP/installation and new systems allowed for deployment of additional detectors;
- rooms/areas that were for some installations intentionally not covered by fire detection were rooms without fire loads/ignition sources and rooms with high radioactivity which would not allow the deployment of fire detectors. However, operational experience and new developments brought solutions for fire detection in high-radiated areas. In particular, smoke aspiration detectors, camera systems, and temperature detectors which are less vulnerable to radiation were mentioned;
- during or after safe enclosure of a nuclear installation as long as fire loads and radioactivity are present, the need to maintain fire detection systems remains.

Detection is regarded as a key factor in fire protection. Most participating countries consider having detectors in all rooms as an advantage for an early detection of a fire. In several cases, the replacement of the old design FDAS have led to quantitative and qualitative improvements by using a larger amount and more sophisticated detectors.

2. Adequate measures for FDAS with no addressable detectors

The ability to announce the location of the fire on the detector level is given by addressable detectors. They allow the fire to be localised quickly.

Addressable fire detectors are installed more and more in nuclear installations, especially in the new ones, or by the implementation of an upgrade of the FDAS. Older systems locate a fire at a less detailed level and may be supported by additional measures. Different compensatory solutions have been reported:

- fire location based on a zone or room level by using distinct lines,
- fire detection line actuation is followed by detailed location by staff, e.g. fire fighters,
- use of existing cameras to confirm fires,
- installation of dedicated cameras,
- smoke and temperature sensors.

3. Failure tolerance of FDAS regarding a single failure

The failure tolerance of the FDAS (single failure of a component of the FDAS, e.g. a subsidiary fire-alarm board) should not lead to a failure of fire detection in more than one redundant safety train. There are different means to achieve failure tolerance of FDAS: for example, a high failure tolerance may be achieved by providing that the transmission of a fire detection signal runs over redundant independent components.

Operational experience of events involving a complete failure of the FDAS in all redundant trains of a certain system due to a single failure have been reported, so showing that the best solution would be to have independent FDAS. It was confirmed that a similar case might also happen in other installations but, since the majority of failures of the FDAS is self-reporting, such a situation would be probably recognized quickly.

Conclusion

Strategies for installing fire detectors in nuclear installations vary by country, with some aiming for full protection in all rooms and others focusing on high-risk areas based on fire hazard analysis. Older plants often lack complete coverage, though upgrades allow for the addition of more detectors. Some rooms were initially excluded from fire detection due to high radioactivity, but new technologies now offer solutions for these areas.

Addressable fire detectors, which precisely locate fires, are increasingly used in newer plants or upgraded systems. Older systems may lack detailed location information but are supported by compensatory measures ensuring timely fire detection in the absence of addressable detectors.

FDAS design should prevent a single failure from affecting multiple redundant safety trains. High failure tolerance may be achieved through redundant, independent components. Robustness against single failure is implemented in only a few nuclear reactors. Otherwise, the majority of FDAS failures are self-reported, allowing such situations to be quickly detected and addressed.

7.1 Fire suppression

7.1.1 Issues for the installation of fire extinguishing systems

Type of installations mainly concerned

In general, this topic of interest is applicable to all types of installations.

Background and justification

As mentioned in the TS, the requirements from WENRA SV 6.9 and SV 6.10 for NPPs, S 4.2 and S 4.3 for research reactors apply to this fire suppression topic:

> (*WENRA SV 6.9*): *Suitable fire extinguishing features shall be in place according to the fire hazard assessment. They shall be designed and located such that their rupture, spurious or inadvertent operation does not inadmissibly impair the SSCs important to safety*;
>
> (*WENRA SV 6.10*): *The fire water distribution network for fire hydrants outside buildings and the internal standpipes shall provide adequate coverage of all plant areas. The coverage shall be justified by the fire hazard assessment;*
>
> (*WENRA S 4.2*): *Fixed or mobile, automated or manual extinguishing systems shall be installed. They shall be designed and located so that their rupture, spurious or inadvertent operation does not significantly impair the capability of SSCs important to safety to carry out their safety functions*;
>
> (*WENRA S 4.3*): *The distribution loop for fire hydrants outside building and the internal standpipes shall provide adequate coverage of areas of the research reactor relevant to safety. The coverage shall be justified by the fire hazard analysis.*

These SRLs are considered applicable also to other nuclear installations according to a graded approach.

The TS for the NARs specifically asks for the following in regard to the fire extinguishing systems:

- *the approaches applied in the selection, design and location of fire extinguishing systems, according to the relevant fire hazard challenges to the SSCs important to safety and any related potential releases.*

The implementation of automatically actuated fixed fire extinguishing systems with agents such as water, foam, gas or dry chemical-based systems, should be handled carefully to ensure they respond properly and effectively in the event of fire. It should also be taken into account that the actuation of fire extinguishing systems can lead to negative effects of the extinguishing agent on humans and on items important to safety (see section 7.1.2).

During the desktop review, the TPR Team noticed that the choice of an automatically actuated fixed fire extinguishing system in specific rooms or plant areas leads to a number of issues that require clear criteria for their implementation such as selection of the type of extinguishing agent (their comparative assessment) as well as taking into account the potential damage caused by fire extinguishing agents on the protected equipment and a potential negative impact on service personnel.

For the above reasons, the topic of interest on "Issues for the installation of fire extinguishing system" was raised for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. Strategy and criteria for selecting plant areas/rooms for installing fire extinguishing systems (gas, foam, water, etc)
2. Introduction of gas fire extinguishing systems for specific rooms or plant areas and equipment;
3. Automatically actuated fixed fire extinguishing systems for plant areas with diesel generators

The objective of this topic of interest in the workshop was to compare practices between different operators of different types of nuclear installations and to get an overview of approaches regarding the strategy for fire extinguishing systems (gas, foam, water, etc).

1. Strategy and criteria for selecting rooms and plant areas for installation of fire extinguishing systems (gas, foam, water, etc)

Workshop discussions confirmed that the decision to implement fixed fire extinguishing systems depends mainly on the fire load and fire risk as resulting from the Fire Safety Analysis.

Complementary criteria are also applied considering in particular the potential impact of fire extinguishing systems according to the extinguishing agent used:

- extinguishing systems based on water are often avoided in rooms with electrical/electronic equipment in order not to damage it;
- the installation of gas extinguishers includes special provisions such as alarm (to let personnel enough time to leave the area), manual deactivation with regard to personal safety, etc.

It was mentioned by Finland that in the new plants the need for installing fixed fire extinguishing systems in cables rooms has been eliminated due to the use of new types of cables (flame retardant non-combustible cables).

2. Introduction of gas/foam fire extinguishing systems for specific rooms or plant areas and equipment

In many countries, the implementation of the gas/foam fire extinguishing systems is considered in some specific areas, especially in rooms with electrical and electronic equipment. Personnel safety is however an issue to be considered.

Different approaches exist between countries and nuclear installations, especially regarding to fixed fire gas/foam fire extinguishing systems (automatic or manual) or mobile ones:

- France has mentioned that for NPPs they use only mobile extinguishers with CO_2 due to the risk to personnel associated with automatically actuation of fixed systems;
- Belgium mentioned that due to personnel risk, only few rooms are equipped with gas extinguishing systems. These rooms are checked (to verify the presence of personnel) prior to the system manual activation. Specific rules and guidelines are available to access the rooms;
- Hungary mentioned the use of gas in several rooms with critical systems to protect the equipment. Those systems are automatically actuated; personnel have 30 seconds to leave the room but can deactivate the system from the inside;
- Finland mentioned that some cable rooms are protected with gas, as the equipment is critical for nuclear safety and water is not desirable;

- Italy mentioned that they use gas extinguishing systems in a plutonium plant (automatic) and storage repository (manual). It also reported an accident during maintenance due to unexpected discharge that resulted in overpressure and door blown away. This may be a problem, in particular for small and very tight areas. CO_2 was replaced by another gas requiring a lower concentration to perform the extinguishing function;
- Germany mentioned the trend to replace automatic gas extinguishing systems by fire detection systems combined with manually operated extinguishing systems.

3. Automatically actuated fixed fire extinguishing systems for plant areas with diesel generators

In the premises where diesel power systems are installed, diesel fuel poses the greatest fire hazard. In order to protect the installation against fires and explosions and to prevent threats to human health and life, the premises of the diesel power systems are equipped with automatically actuated fixed fire extinguishing systems.

Foam is generally used to extinguish oil fires. The use of water mist systems for extinguishing diesel generator fires was also mentioned by Hungary as a quite effective means instead or to complement foam.

Conclusion

The installation of fire extinguishing systems in nuclear facilities is based on fire risk and load, with specific considerations for the type of extinguishing agent used. Water-based systems are avoided in rooms with electrical equipment. Gas extinguishers are commonly used in these areas. They require precautions for personnel safety which vary by country: mobile extinguishers, manual activation or automatic gas systems with time delays for personnel evacuation. Diesel generator rooms often have foam systems, sometimes complemented by water mist systems.

7.1.2 Harmful effects of fire extinguishing water

Type of installations mainly concerned

In general, this topic of interest is applicable to all types of installations.

Background and justification

As mentioned in the TS, the requirement WENRA SV 6.9 for NPPs WENRA SRLs on fire extinguishing systems can be applied for other installations.

> *(WENRA SV 6.8) WENRA SV 6.9: Suitable fire extinguishing features shall be in place according to the fire hazard assessment. They shall be designed and located such that their rupture, spurious or inadvertent operation does not inadmissibly impair the SSCs important to safety.*

The TS for the NARs specifically asks in regard to fire extinguishing systems:

- *"how harmful effects of inadvertent operation are taken into account and system reliability is assured;*
- *how secondary hazards from actuation or rupture of fire extinguishing systems (flooding, challenges to radiological containment, criticality, stored waste etc.) have been considered in the safety demonstration and operational arrangements"*.

During the desktop review, the TPR Team noticed that the NARs provide either some information relating to the potential harm to structures, systems and components from the accumulation of firefighting water or discuss the arrangements to prevent spread of firefighting water (with the related potential for spread of contamination).

For this reason, the topic of interest "Harmful effects of fire extinguishing water" was raised for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. Approaches for systematic identification of harmful water effects on SSC as a result of pipe breaks (or inadvertent operation) and spray and their consideration

2. Consideration of consequences of water effects and measures taken to protect or mitigate the risks
3. Measures taken to deal with the fire water run-off and to ensure its treatment to prevent the spread of radiological contamination.

The objective of this topic of interest in the workshop was to compare practices between different operators of different types of nuclear installations and to get an overview of how harmful effects of fire extinguishing systems are considered and mitigated.

1. Approaches for systematic identification of harmful water effects on SSC as a result of pipe breaks (or inadvertent operation) and spray and their consideration

Harmful water effects on SSCs resulting from pipe breaks (or inadvertent operation) and spray should be identified to ensure that SSCs important to safety are still able to perform their required safety functions.

Some countries reported on the following harmful effects:

- flooding leading to potential failure of SSCs,
- spraying leading to potential failure of SSCs,
- short/ground-circuiting of electrical connections) leading to potential failure of SSCs,
- risk of criticality, especially in fuel cycle facilities,
- risk of dissemination and pollution.

The risk of flooding is generally taken into account in the internal flooding analyses. It was also stated that the volume of water used for fire extinguishing is very low, significantly lower than the volume resulting from a fire extinguisher piping break.

Some exclusions of the consideration of harmful effects were also identified for some installations due to either redundancy of the trains, the amount of water in extinguishing system or the distances between SSCs and the extinguishing system, the fact that fire pipes are buried or that the extinguishing system is not charged (dry columns).

2. Consideration of consequences of water effects and measures taken to protect or mitigate the risks

Since pipes carrying fire extinguishing water are very often large bore pipes with the potential to quickly inundate an installation or parts of it, water discharge from these pipes can result in significant damage to the SSCs and potentially result in radiological consequences.

IAEA Safety Guide SSG-64 identifies requirements and guidance for the types of pipe failures which should be considered, such that good practice would consider both high and low energy pipes, including an assessment of the consequences, assuming a full pipe break to demonstrate the robustness of the design. This analysis should consider instantaneous local and global effects of pipe breaks such as pipe whip, jet impingement and flooding to inform the design for the supports, protection and to identify the affected SSC important to safety. All these possible effects should be analysed and considered in the installation design, in particular for protective and mitigating measures.

It can be noticed in particular that for new build installations (mainly NPPs), internal flooding is assessed on a room-by-room basis for the consequences associated to direct flooding on SSCs, and the failure of the fire extinguish piping is considered to be a source of flooding.

Information from Spain was provided on the analysis of water levels resulting from pipe failures considered in the scope of the internal flooding analysis and the measures taken to mitigate the risk (redundant equipment in separate rooms that are not simultaneously affected by the same flooding, equipment above the flood level, protective barriers).

Romania indicated that the "*effects of discharging fire extinguishing agents, particularly water getting into electrical equipment, shall be assessed as part of the fire safety analyses*" [Cernavoda NPP]. The

United Kingdom mentioned one scenario in the fuel building in which two systems important to ensuring a safe shutdown state could be affected by backflow from the sumps. This has led to a design change which consists of a one-way flow valve to prevent flooding from damaging both systems.

The Netherlands indicated that "*To prevent the system from starting unintentionally, a second detector of the fire alarm system (flame detector) must also signal fire." [Spent fuel and radioactive waste storage facilities – COVRA].*

Germany performed some backfitting in relation to valves to deal with water. Spain has located the SSC on an elevated level and installed physical protection for pipes. Some past events were identified by the countries resulting in a release of water. If these affected safety systems, or other items important to safety, backfitting measures have been carried out after the event.

It was discussed how failures of the fire extinguishing water bearing system are considered. The United Kingdom discussed a very large flood source which had been identified on a site where it had the potential (if it failed) to affect a nearby nuclear installation. The flood source was due to ageing and degradation of the water storage system which was still required to be available by the site so operational measures were deployed such as bungs for site drains to prevent flood water reaching the local environmental water systems, monitoring of the water levels and additional inspections carried out whilst modifications were made to the physical structure of the water storage system.

The nuclear insurer NEIL stressed the importance of drains as a protective measure, e.g. turbine hall fire protection, particularly explaining the importance of routine inspections (including the use of cameras to identify potential blockages) and testing routine inspection procedures have been incorporated into the latest NEIL standards.

Concerning the operator role to mitigate the risks, operational intervention depends on the situation (what is the magnitude of potential consequences, how much time is available, what action is required, etc.) Local actions (e.g. manual closure of valves) might be necessary and exist in operating rules. Manual actions by the operator (push button) in the main control room may as well be considered.

3. Measures taken to deal with the fire water run-off and to ensure its treatment to prevent the spread of radiological contamination

The possible consequences of fire extinguishing water run-off from water-based fire extinguishing systems should also be considered in the design. The measures adopted to control fire extinguishing water run-off (such as the use of drains and collection structures) should ensure that contaminated water is not released into the environment or to areas in which it may pose a hazard to humans or the installation.

Most of the countries have provisions to collect water and perform treatment:

- *following the extinguishing of a fire, from the places that may be radiologically contaminated, the control of quality water before and after the treatment station, by taking samples from the wastewater collection tanks, was foreseen" [Triga Research reactor, Romania];*
- "*Extinguishing water from the controlled area is only discharged in a controlled manner and after activity balancing and appropriate treatment, if necessary" [NPPs, Germany];*
- *"The hall is equipped with water outlets to a system of contaminated liquid waste collection tanks" [LVR-15 – Research Reactor, Czechia].*

Information from France was provided on the renovation of the means of NPP retention of fire-extinguishing effluents. The preferred strategy is as well containment at source inside the facilities, particularly when radioactive substances are involved.

Italy described engineered measures provided for new waste facilities whereby fire water is collected in dedicated storage tanks, activity levels are measured and then either released or sent to a radwaste system for treatment prior to release.

Engineered water collection measures may be provided within the design of an installation but ad-hoc, non-engineered measures may also be required, particularly in locations where a release could occur outside a building environment.

Conclusion

The consideration of harmful water effects from pipe breaks or inadvertent operation of fire extinguishing systems is essential to ensure the safety and prevent contamination. Potential risks include flooding, electrical short-circuiting, and criticality, especially in fuel cycle facilities.

Most installations consider the consequences of water discharge and have mitigation measures, such as redundancy in equipment, protective barriers, and elevated SSC placement. Additionally, operational measures, such as valve closures and inspections, are in place to address potential flooding risks from fire water systems.

Fire extinguishing water run-off is also carefully managed to prevent contamination, with many countries implementing collection and treatment systems.

7.2 Administrative and organisational fire protection issues

7.2.1 Firefighting - different responsibilities - distribution of tasks across licensee, on-site and off-site fire brigades

Type of installations mainly concerned

In general, this topic of interest is applicable to all types of installations.

Background and justification

As mentioned in the TS, the requirement WENRA SV 5.10 and SV 6.13 for NPPs WENRA SRLs on administrative and organisational fire protection issues are relevant for other installations.

> *(WENRA SV 5.10): Adequate organisational arrangements, including minimum staffing levels, equipment, fitness for duty, skills and training, and procedures shall be in place to ensure safety, as identified by the hazard assessment;*
>
> *(WENRA SV 6.13): If plant internal firefighting capability is supported by offsite resources, there shall be proper coordination between the plant personnel and the offsite response group, in order to ensure that the latter is familiar with the hazards of the plant. Emergency training, drills and exercises shall be performed.*

The TS for the NARs specifically asks in regard to firefighting:

- *firefighting capability, responsibilities and organisation (such as onsite plant internal fire brigade, organisation between onsite and offsite firefighters, etc.)*[31]*, including*
  - *criteria for deploying onsite and offsite firefighting resources,*
  - *how coordination is achieved between the plant personnel and the offsite resources, if the plant internal firefighting capability is supported by offsite resources.*

When a fire breaks out in a facility, a rapid and coordinated response must be provided to control its spread and to extinguish it. Upon actuation of the fire detection systems in the nuclear installation, there are provisions for the alert of fire teams starting from the internal fire brigade and escalating to the external fire units.

Establishing the strategy regarding on-site and off-site fire safety units is the responsibility of the licensee. It includes agreement about responsibilities. Depending on the safety issues, the licensee has an organisation and emergency resources. There may be more or less equipped internal teams,

[31] This includes prioritisation of the different responsibilities of onsite firefighting resources if these resources are expected to also carry out other work

internal teams specialised in fighting fire outbreaks or external resources such as teams shared between operators or public emergency services.

Firefighting operations can be divided into several tasks from the moment the fire is detected. It may be detected by humans (operator or witness) and/or detected by an automatic fire detection system. These tasks can be allocated to different levels associated with increasing timescale as follows:

- Detection (automatic or by witnesses): Presence of automatic extinguishing means or use of a manual extinguisher by local workers;
- Action of the first intervention team with light equipment: Generally, specialised operators who are working in the vicinity of the fire location without specific gear or equipment;
- Action by the second intervention team (e.g. dedicated on-site fire brigade) with heavy equipment such as specific protective clothing, water jets or vehicles;
- Action by external intervention team from the neighbourhood, e.g. private firefighters from neighbouring installations (mutualised "on-site" fire-brigade);
- Action by public firefighters [off-site fire-brigade].

Depending on the issues identified, the licensee implements all or part of these different levels or means, depending on their organisation, local arrangements and the assessment of the issues. The objective to be achieved is of course the rapid extinction of the fire before it becomes uncontrollable or fully developed. If this sequence fails, the third level of defence in depth, compartmentation, must make it possible to contain the fire and its effects.

For this reason, the topic of interest "Firefighting" was raised for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. The different levels of firefighting operations the operators rely on, and their related means and responsibilities
2. The coordination of on-site and off-site fire brigades, including the definition of criteria for calling or not calling an off-site fire brigade/intervention team.

The objective of this topic of interest in the workshop was to get an overview of the operational organisation between actors from the detection of the fire until its extinction, and better insights from national approaches to share experience. The collection of information in this regard aims to provide a comprehensive overview of the different levels of firefighting intervention, including personnel, equipment, procedures and additional responsibilities.

1. Different levels of firefighting operations the operators rely on, and their related means and responsibilities

In most installations, personnel are trained to perform immediate actions in case of fire. This may be on immediate action to respond to any fire (e.g. to use portable fire extinguishers, securing specific areas, confirming the fire), on how to raise the alarm, on how to react in case of fire. Fire simulators are also used for training.

The role of the **first intervention team** after detection of a fire and its notification (first minutes) depends on the installation. This team is not necessary for fighting the fire. Its action rather includes checking for potential victims, informing / calling the right people, self-care, technical actions related to the process (e.g. to ensure if the fire compartment boundaries are intact and efficient, ventilation control, or monitoring or securing the process) while waiting for the response of the second intervention team or external emergency services.

First intervention is typically performed by teams of 2 up to 5 persons.

In some installations, immediate response to the firefighting is done: e.g. instructions can exist for the local workers to use specific portable fire extinguishers or specific means in case of specific situations. This could be the case for glovebox fires or fires in specifically closed blinded cells.

The **second intervention team** is more specialised and trained to fight a fire. For example, in a fuel cycle facility, only the on-site fire brigade generally responds to the fire due to the location of the fire or the risk of contamination.

This team can be composed by personnel from the licensee, can be mutualized between several licensees or installations. Most licensees reported to have dedicated on-site fire brigades 24/7 including relevant firefighting equipment. In some countries, it is reported that the second intervention teams are composed of public firefighters dedicated to the installation. A large variety of organisations are in place. Most differences can be noted concerning the size of these teams for similar installations: the second intervention team is typically composed of 6 to 18 firefighters per shift.

Training is performed and on-site fire brigades use fire intervention plans. The intervention time is generally around 10 minutes depending on the location of the fire in the installation.

Most NPPs and large nuclear sites with several installations have on-site fire brigades and equipment (e.g. fire trucks), which could be supported by additional agreements with off-site fire brigades.

2. Coordination of on-site and off-site fire brigades, including the definition of criteria for calling or not calling an off-site fire brigade/intervention team

Licensees have a range of agreements with off-site fire brigades. Off-site fire brigades can be activated by an alarm or by the shift manager, usually after confirmation of a fire event. Some installations arrange for training of the external forces as part of their agreement.

Off-site fire brigades have specific intervention plans for the nuclear installations. In some cases, the public firefighters are involved in the control of the nuclear installations.

Off-site fire brigades may also assist in case of severe external situations such as heavy storm, flooding, multiple fires or transport accidents, in particular events impacting potentially access routes to the nuclear installations.

In case of extreme events or disasters, the civil protection service has its own planning at regional or national level to cope with these types of events.

Conclusion

In most countries, firefighting operations in installations are organised at multiple levels to efficiently manage fire risks. However, the fire intervention teams are organised differently between countries and types of installations. There are some common practices and as well specificities due to the process or the types of risk of the installations. Most licensees rely on a quick response from the second intervention team to successfully limit the propagation of fire and to extinguish it successfully.

Coordination between on-site and off-site brigades is essential: some facilities have agreements for joint training and intervention plans with off-site fire brigades.

8. TRANSVERSAL TOPICS

8.0 Compartmentation

Type of installations mainly concerned

In general, this transversal topic of interest is applicable to all installation types.

Background and justification

As mentioned in the TS for the prevention of fire spreading, the requirements *WENRA SV 6.5 for NPPs, S 2.3 and S2.2 for research reactors state:*

> *[WENRA SV 6.5]: Use of a fire compartment approach is preferred. The fire resistance rating of the fire barriers of the fire compartment shall be sufficiently high so that the total combustion of the fire load in the compartment can occur without breaching the barriers taking into account the fire hazard analysis. If a fire compartment approach is not practicable, fire cells shall be used and duly justified by the fire hazard analysis. For fire barrier resistance assessment, oxygen availability within and oxygen supply to the fire compartment shall be conservatively considered and justified;*
>
> *(WENRA S 2.2): Buildings that contain SSCs important to safety shall be suitably* fire resistant.*
>
> **In accordance with the results of the fire hazard analysis;*
>
> *(WENRA S 2.3): Buildings that contain equipment that is important to safety shall be subdivided into compartments that segregate such items from fire loads and segregate redundant or diverse trains of a safety system from each other. When a fire compartment approach is not practicable, fire cells shall be used, providing a balance between passive and active means, as justified by fire hazard analysis.*

A fire compartment approach is an approach that gives priority to structural measures (fire resistance of structures) as part of the defence in depth measures. Fire compartments are therefore surrounded by fire barriers on all sides, including the ceiling and the floor with a requirement on their fire resistance rating (e.g. 1 hour).

A fire cell approach is an approach that compensates the absence of a full compartmentation, for example by fire resistance barriers, by spatial separation or other organizational means (e.g. avoiding excessive combustible material) to minimise the risk of fire propagation and to prevent common mode failures.

The TS for the NARs specifically asks in regard to compartmentation:

- *how the fire barriers forming fire compartment or fire cell boundaries are determined including the improvements made over the lifetime of the installation (e.g. to retain structural / mechanical integrity, to ensure delivery of the confinement function);*
- *how it is ensured that the expected fire resistance and stability ratings are fulfilled;*
- *the fire compartments and/or cells formed and a description of fire barriers and other means to prevent or delay the spreading of fire, use of self-fire extinguishing and/or fire-resistant components (connecting doors) and materials.*

During the desktop review, the TPR Team noted that the current approaches to compartmentation vary amongst the countries depending on the country specific regulations (conventional or nuclear safety specific) and types of installations. For this reason, the topic of interest "Compartmentation" was raised for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. Approaches for compartmentation and fire barriers resistance
2. Scenarios for which the application of a 'state-of-the art' compartmentation is not fully possible and compensatory measures are needed
3. Effects of fire-related compartmentation on the level of conservatism/realism of Fire PSA (comparison).

The objective of this topic of interest was to compare practices between different operators of different types of nuclear installations in order to get an overview of the fire related compartmentation, as well as the application for installations designed with older standards and/or regulations.

1. Approaches for compartmentation and fire barriers resistance

The approaches to compartmentation and physical separation for prevention of fire propagation and spreading between fire compartments or fire cells are crucial for the understanding of the proposed solutions and the adequacy of measures taken.

In line with the WENRA SRLs and IAEA requirements, e.g. in IAEA SSG-64, the fire compartment approach is generally preferred to a fire cell approach. In some cases, a fire compartment approach is not possible, and the fire cell approach is used. The fire cell approach is typically used for large buildings (e.g. the reactor building) and needs to be justified by the fire hazard analysis.

In several countries, as mentioned in chapter 2, conventional non-nuclear building requirements are used, focusing on the avoidance of fire spread and damage to property. For nuclear installations, most countries use now a specific fire regulation focusing on the protection of SSCs necessary for ensuring safety functions.

The older installations were mainly designed according to conventional non-nuclear building requirements existing at the time of their design. For newer installations, the compartmentation by suitable and reliable fire barriers is usually required by nuclear and fire specific regulations, considered in the design, and implemented during the construction. Finland reported that for older plants conventional regulations were primarily applied. In contrast, for new builds, a combination of conventional and nuclear specific regulations is used. This approach begins with the conventional requirements and then incorporates additional demands related to nuclear safety.

Furthermore, the current approaches to compartmentation vary depending on the countries as well as types and ages of installations:

- Most countries with NPPs or large RRs clearly tie their compartmentation approaches to nuclear and radiation safety. It is indicated that meeting the nuclear safety goals (including radiological safety goals) by ensuring the fulfilment of the required safety functions in case of a fire has the highest priority. It is also mentioned that nuclear regulations have more strict requirements compared to conventional fire safety requirements, for example:
    - physical separation of redundant safety SSCs (nuclear safety),
    - prescribed use of fire resistant SSCs (independent from FHA results, to ensure the safety functions); such as 3 hours fire resistance standard applied in Spain.
- Many countries regulating only installations with lower nuclear/radiological risk (such as small research reactor, spent fuel storage facilities, waste storage facilities, installations in the late stage of decommissioning) often apply conventional non-nuclear fire safety requirements as basis for compartmentation. Germany reported that a conventional approach, based on state regulations on building requirements and fire compartmentation is applied for waste storage facilities, given the fact that the radwaste itself is properly protected against fire effects by withstanding a fire according to a performance curve with 800°C for 60 min (PTB-curve);
- Mixed approaches are widely used among the participating countries depending on regulatory requirements, standards, installation type and age, or results of the risk analysis. Belgium reported that compartmentation is primarily designed in accordance with conventional standards, tailored to the specific safety function of each area. The United Kingdom reported that compartmentation has improved significantly over the past few decades, with older installations historically relying more on active suppression systems. Italy mentioned that during decommissioning, dismantling operations are conducted while maintaining the existing compartmentation. For waste storage facilities a fire cell approach is adopted.

A graded approach is widely considered depending on the type of nuclear installation, quantities of nuclear or radioactive materials, and particular technical and organizational solutions implemented.

If there are deviations from conventional regulations, the whole fire protection system has to be investigated with respect to fire and nuclear/radiological risk. Regarding the fire barriers resistance, the WENRA SRL SV 6.5 for NPPs states "*The fire resistance rating of the fire barriers representing the boundaries of the fire compartment shall be sufficiently high so that the total combustion of the fire load in the compartment can occur without breaching the barriers taking into account the results from the fire hazard analysis*".

The methods on fire barriers resistance strongly vary between countries and types of installations, depending on national approaches, experience and methodologies applied. Prescribed fire resistance ratings are used as well as ratings typically determined based on fire loads, fire load density threshold values, ignition sources and ventilation conditions.

Some countries stated that fire load criteria have been implemented via standards (for non-combustible or fire-resistant cables) or legal requirements and the use of ISO fire curves, and limits such as 900 MJ/m^2 for 60 min were cited. Some countries justify the prescribed fire barriers resistance rates by calculations of actual fire durations based on fire loads and apply an additional (conservative) margin or other measures/means for a more robust fire safety.

Usually, recommendations from insurers on fire resistance are additionally considered by the operators.

Re-assessments of compartments and fire barriers resistance are triggered by changes or modifications in the design, such as new SSCs, change of safety class, operation of the installations and systems. In these cases, the fire safety issues have to be reassessed in line with the national regulatory procedures. Evolutions in the combustible material and/or ignition source inventory also need reassessing fire safety, especially in case of installations under decommissioning. Additionally, most countries have set up time intervals for fire safety reassessment or linked the reassessment to PSR applications.

2. Scenarios for which the application of a 'state-of-the art' compartmentation is not fully possible and compensatory measures are needed

Where a subdivision of a building into fire compartments is not reasonably practicable, most of the participating countries adopt an alternate fire protection concept including additional compensatory measures, properly justified by a fire safety analysis.

It is the case in particular for installations designed to earlier standards and regulations: compartmentation with fire resistance ratings according to the state-of-the art and practice - not only from nuclear industry but also from non-nuclear building codes applied widely over Europe - is not always possible (for example due to designs with lower wall/floor/ceiling qualifications or limited space) and improvements of fire barrier resistance are also often not possible.

In this case, in order to ensure adequate fire protection, in most countries credit is typically given to additional compensatory means. Although these protection features do not represent a qualified fire barrier, together with additional protection means they can provide an effective upgrade to the original design. The range of measures outlined by different countries includes:

- administrative procedures,
- removal and minimisation of combustibles and potential ignition sources,
- encapsulations (e.g. by non-combustible containers, etc.),
- shielding of combustibles using non-combustible or very low combustible materials,
- sealing of combustibles (e.g. by non-combustible wraps),
- coatings of cables or structural elements (such as steel beams),
- sub-compartmentation of fire compartments,
- installation of oxygen reduction systems within special areas,

- implementation of additional and/or improved (according to the state-of-the-art) fire detection and alarm features,
- implementation of additional state-of-the-art fire suppressions means with suitable extinguishing agents.

The participating countries have acknowledged the specific challenges related to large compartments and fire barriers (particularly including their penetrations and active barrier elements) designed to earlier standards representing no longer the state-of-the-art. In addition, in certain areas, such as the main control room, where e.g. cables from all redundant trains converge and cannot be fully separated, or large turbine halls, where a compartmentation is not reasonably practicable, the compartment approach cannot be fully implemented. In such cases, compensatory measures based on the fire hazard analysis have to be defined and implemented.

In conclusion, where a full compartmentation is not reasonably practicable, an adequate protection level can be reached by appropriate compensatory means.

3. Effects of fire-related compartmentation on the level of conservatism/realism of Fire PSA (comparison)

The results of the FHA provide an important input for the Fire PSA, particularly with respect to the fire compartmentation as a basis for addressing fire propagation within the fire event trees in Fire PSA. Even if an adequate fire compartmentation with appropriate fire compartment boundaries by suitably qualified reliable fire barriers is present (as part of a typically conservative design approach), a Fire PSA might still assume a worst-case scenario where the entire fire compartment fails.

For a more realistic Fire PSA, the fire compartments can be further subdivided in virtual units. This subdivision allows for the more realistic assumption that a fire cannot spread to all zones in the whole compartment over a pre-defined time period. As a result, a failure of all systems and components in the compartment does not have to be assumed. This may significantly affect the Fire PSA results of some scenarios.

The issue of PSA conservatism is addressed in section 4.3.

Conclusion

Compartmentation and physical separation are essential for preventing fire propagation. While the fire compartment approach is preferred, fire cells are used for large buildings, supported by fire hazard analyses. Regulations differ by country and installation type: countries with NPPs/RRs often apply nuclear fire safety requirements focusing on the fulfilment of the safety functions. Other countries, regulating only installations with lower nuclear/radiological risks often apply conventional fire safety requirements focusing on the avoidance of fire spread and damage to property, as a basis for compartmentation.

A variety of compensatory means (technical features as well as organisational and/or administrative measures, or combinations of both as applicable), based on the fire hazard analysis, is applied in cases in which a full compartment is not reasonably practicable. The methods on fire barriers resistance strongly vary between countries and types of installations, depending on national approaches, experience and methodologies applied. Prescribed fire resistance ratings are used along with ratings based on factors such as fire loads, ignition sources, ventilation conditions and other boundary conditions. Some countries justify the prescribed fire barriers resistance rates by calculations of actual fire durations.

8.1 Decommissioning

Type of installations mainly concerned

This transversal topic of interest is applicable to all nuclear installations under decommissioning.

Background and justification

As mentioned in the TS, the requirement WENRA S-30 developed for waste storage facilities applies also to installations under decommissioning.

> WENRA S-30: *The licensee shall make design arrangements for fire safety on the basis of a fire safety analysis and implementation of defence in depth (prevention, detection, control and mitigation of a fire).*

The TS for the NARs specifically asks in regard to fire safety during decommissioning to describe:

- *the prevention and protection measures to be adopted to the different decommissioning activities according to the results of the fire hazard analysis.*

During the desktop review, the TPR Team has noted that varying information relating to development and modifications on fire prevention and passive fire safety strategies during the decommissioning phase had been provided. For this reason, the topic of interest “Decommissioning” was chosen for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. Criteria and the process carried out to identify and implement modifications on fire protection features, administrative controls, organisation and training
2. The process to update the fire hazard analysis and fire protection programme in order to reflect the changing situation of the installation.

The objective of this topic of interest is to compare practices between different operators of different types of nuclear installations and to get an overview of fire safety during decommissioning.

1. Criteria and process to identify and implement modifications of fire protection features, administrative controls, organisation and training

During decommissioning, there is a constant evolution of several factors:

- Changes in the radiological environment, including the presence (or not) of fresh/spent fuel in the installation and changes in the radiological inventories, particularly related to the presence of generated radioactive waste that could be affected in case of fire in any given location;
- Changes in fire loads with the removal of major components (turbines, generators, transformers or emergency power generators) bearing high fire loads and of potential ignition sources (e.g. pumps, motors) but as well introduction of new combustible materials and/or ignition sources (associated to an increased frequency of hot work for dismantling);
- Conduct of dismantling operations such as disassembly of equipment, systems and components as well as the demolition and decontamination of structures.

These factors could lead to:

- Adaptation or refurbishment, if needed, of existing fire protection features (e.g. fire detection and suppression systems and equipment, fire barriers, etc.);
- Regular adaptation of administrative controls and procedures commensurate with the risks present at different stages of decommissioning;
- Changes in the number of members in fire brigades and updating of their training.

Reducing fire hazards is a priority during decommissioning.

Most countries (France, Germany, Italy, Lithuania and the United Kingdom) stated that fire protection systems and equipment remain essential and continue to operate as long as there is a radiological risk associated with a fire. Germany indicates that once the installation is defueled, conventional fire protection requirements are applied.

If changes or modifications are necessary during decommissioning operations (for example due to ageing of fire protection systems/components or interferences with decommissioning operations) they are typically approved by the regulatory authorities. This approval is based on an assessment of the specific risks involved and the current condition of the installation. Typical changes during decommissioning phases include:

- Use of dedicated mobile equipment for specific operations;
- Implementation of dedicated fire watch procedures when detection systems must be temporarily disconnected;
- Installation of additional detection as needed;
- Use of fire-retardant packaging for extended storage on site;
- Storage of combustible materials separately from ignition sources;
- Placement of dismantled material into non-combustible packaging.

To minimise risks, cold cutting methods are preferred over flame cutting whenever possible. If alternative cutting technologies cannot be used, dedicated buildings/structure with their own fire protection means are used. Contaminated materials are also promptly removed and stored temporarily in designated areas.

Approaches regarding internal fire brigade services differ between the participating countries. Some countries such as Germany and Switzerland reduce the on-site fire brigade presence as decommissioning progresses. In contrast, Italy maintains the same internal fire brigade that was in place during the operational phase even at the current stage of decommissioning activities (dismantling to be conducted and also waste present on the sites). This may be reconsidered in the future as decommissioning activities progress and radiological risks due to fire decrease.

2. The process to update the fire hazard analysis and fire protection programme in order to reflect the changing situation of the installation

Regarding the update of the fire protection programme and the fire hazard analysis respectively, the countries indicated that they continue to follow the same process as during the operational phase of the installation operation, but they are commensurate with risks present at each stage of the decommissioning.

Most countries (for example, France, Germany, Italy, Lithuania and the United Kingdom) indicated that a specific fire hazard analysis is conducted for given “safety relevant” decommissioning operations according to their particular characteristics. These specific fire hazard analyses can also be used as basis for decision making on the removal of fire protection features if deemed unnecessary for the subsequent decommissioning steps. One country (Denmark) reported the fire hazard analysis at the Hot Cell Facility is not updated during decommissioning.

It was confirmed that the widespread approach for fire safety analyses during decommissioning relies on deterministic methods. Only one country (Switzerland) reported adapting its fire probabilistic safety assessment (PSA) while nuclear fuel remains on-site. Once the facilities are defueled, Switzerland does not update its fire hazard analysis.

Conclusion

During decommissioning, fire protection management requires a dynamic approach to address changes in the radiological environment, fire loads, and dismantling operations. This includes updates to detection systems, protective measures, administrative procedures, and fire brigade. Modifications in relation to decommissioning operations are generally approved by the regulator authorities based on the specific risks assessment and the current condition of the installation.

In many countries, fire protection systems remain operational until radiological fire risks are eliminated, with varying approaches to fire brigade management. Cold cutting methods are preferred to minimise risks. Contaminated materials are promptly removed and put into non-combustible packaging. Fire hazard analyses are updated according to dismantling operations and specific risks, typically using a deterministic approach.

8.2 Combinations of fires with other hazards

Types of installations mainly concerned

This transversal topic of interest is applicable to all types of nuclear installations.

Background and justification

As mentioned in the TS the requirement SV 6.1 for NPPs and E 6.1 for research reactors applies for combinations of fires and other hazards:

> *(WENRA SV 6.1/ EE 6.1): Credible combinations of individual events, including internal and external hazards, that could lead to anticipated operational occurrences or design basis accidents, shall be considered in the design. Deterministic and probabilistic assessment as well as engineering judgement can be used for the selection of the event combinations.*

For the other types of installations (fuel cycle, waste storage, spent fuel storage facilities and installations under decommissioning), the technical specification states that WENRA SRL E 6.1 is also applicable to them, subject to a graded approach.

The TS for the NARs specifically asks in regard to the consideration of event combinations of fires to provide information on:

- *event combinations (e.g. seismic events) considered in the analysis, including the rules and/or criteria applied to consider such event combinations* (for NPPs and RRs);
- *the combinations of events considered in fire safety analysis and the rules/criteria applied to consider such event combinations* (for fuel cycle facilities);
- *event combinations considered in the fire safety analysis* (for spent fuel storage and waste installations);
- *event combinations considered in the fire safety analysis, if any* (for installations under decommissioning).

During the desktop review, the TPR Team has noted that varying information was provided related to the consideration of combinations of fires and other hazards, in deterministic and as far as applicable probabilistic fire safety analysis, but or accounted for through the design. For this reason, the topic of interest “combinations of fires with other hazards” was chosen for thorough discussion at the thematic workshop, focusing on the following subtopics:

1. Approach to define the combination of hazards to consider in the safety analyses;
2. Design, qualification and performance of fire protection features against combined hazards.

The objective of this topic of interest was to compare practices between the operators of different types of nuclear installations and get an overview of how combinations of fires and other hazards are considered in deterministic and, as applicable, in probabilistic fire safety analyses, and/or accounted for in the design to mitigate postulated events.

1. Approach to define the combination of hazards to consider in the safety analyses

The WENRA SRL 6.1 requires considering in the design credible combinations of events that may occur: this is applicable for different types of nuclear installations, subject to a graded approach.

There is relevant national and international operating experience (from both nuclear and non-nuclear installations) with respect to event combinations involving plant internal fires. Some events occur independently of the other just by coincidence. Combinations of fires and other hazards account for more than 12 % of all fire events reported from NPPs reported to the OECD NEA FIRE Database.

Different categories of hazards combinations can be identified as consequential, correlated or independent. Their combination can be assessed deterministically or screened out on a probabilistic basis, considering the characteristics of the site and of the installation.

Combinations of external hazards and fires may damage both the SSC of the installation and the surrounding infrastructure, making it difficult to operate on-site resources or to provide external support in a timely manner. Moreover, the impact of the hazards to the installation´s SSC may be different and in combination more severe than the effects of each single hazard individually.

The typical combinations considered in safety analyses by many countries include:

- various internal hazards including fire consequential or coincident to seismic hazards,
- external blast (explosion pressure wave) and consequential fire,
- long-lasting external flooding and coincidental plant internal fire,
- internal explosion and consequential fire,
- internal fire and consequential internal flooding,
- accidental aircraft crash and consequential fire,
- other transportation accidents such as railway accident or truck crash on roads or ship collision on rivers or ports, etc. and consequential internal fire.

Within deterministic fire safety analyses for the installations´ designs and updates, most countries consider combinations of seismic hazards and consequential fires (at least as a result of the Fukushima Daiichi reactor accidents and post-Fukushima stress tests) and accidental (mainly high-speed military) aircraft crash with consequential fire.

Workshop discussions highlighted the following:

- Belgium mentioned that they consider for NPPs two categories of combinations: induced or independent. For induced hazards, they carry out a deterministic approach (explosion resulting in fires, fires resulting in explosions, fires, flooding, etc.). For the independent combinations, the analyses to be performed are based on the probability of occurrence. For example, a fire in combination with a large LOCA is considered;
- Czech Republic mentioned that they have a deterministic analysis of combinations. They have also included these combinations in PSA studies;
- France mentioned that in NPPs deterministic approach, fire is considered with combination of internal explosion, lightning, extreme cold, earthquake, etc. In the analysis, e.g. for earthquake, the impact of a hazard on the fire safety equipment is analysed. For external flooding, the protection against flooding was improved, so no combination is explicitly considered;
- Slovenia mentioned that they have analysis for internal and external hazards including combinations. They evaluate relevant combinations of events and among them also fires. They perform deterministic and probabilistic analysis of those combinations;
- The United Kingdom highlighted that seismic and fire combination does not have a remarkable impact as SSC seismic qualification requirements include consideration of hazard combinations (e.g. both seismic and fire). Other events such as internal fire + explosion may have more impact on safety;
- Germany emphasized that for waste and spent fuel storage facilities, an assessment is carried out for each potential hazard, including the associated fires;
- Italy mentioned that for the research reactor TRIGA Mark II, different hazards are considered, and a matrix of possible combinations is created, selecting the most credible scenarios based on expert judgment;
- Spain indicated that the following combinations of events are considered in the deterministic analyses for NPPs: flooding caused by fire protection systems; earthquake plus fire has led to the requirement of a seismically qualified fire protection system; large commercial aircraft crash is considered as an enveloping event leading to loss of large areas in the facility; and the HEAF is also analysed in the fire PSA.

It was confirmed during the workshops that the most credible combinations in the deterministic approach are identified based on engineering judgement. Almost all countries identify most penalising scenarios and perform dedicated deterministic analyses.

Detailed FSA for hazard combinations are typically carried out only for a few non-reactor installations. A few countries, including France, Germany, Italy, Slovenia, and Switzerland, specifically consider scenarios involving aircraft crashes on spent fuel storage facilities, followed by fires involving aircraft fuel. These analyses consider varying assumptions about the aircraft type (military or commercial) and the amount of fuel involved. For example, Slovenia considers the largest fuel load from a commercial aircraft to verify that the effects of a fire on spent fuel casks remain limited. Italy and Switzerland also assess the effects of a military airplane crash on waste storage facilities and verify compliance with established radiological objectives in case of a consequential fire involving aircraft fuel load.

For installations under decommissioning, some countries consider that there is no need for FSA considering hazard combinations. However, a few countries still consider such combinations as far as applicable.

Very few countries mentioned performing a comprehensive identification and a systematic screening of such hazard combinations, mainly for PSA purposes:

- The Netherlands reported "*Furthermore, within the scope of HFR PSA, a Combination of Hazards (CoH) analysis has been performed. It is conceivable that the simultaneous occurrence of hazards can have a more severe impact on the nuclear plant compared to the hazards occurring individually. With this CoH analysis, these possible hazard combinations are addressed and analysed. Initiating events occurring in the plant may result from the impact of an individual hazard or a combination of hazards. Internal fire hazard has been considered within this analysis as a hazard initiating a secondary hazard, as a hazard initiated by a primary hazard and as a hazard occurring individually and randomly with another hazard";*
- During workshop discussions, the Netherlands provided more information about the analytical approach for combined fire events in the HFR research reactor. In the approach, three categories of combinations (consequential, correlated and independent) are considered in the probabilistic safety assessment. A comprehensive identification and highly systematic screening of single hazards and combinations of hazards which are in principle possible to occur at the site and installation specifically, are conducted. For all hazards (including hazard combinations) remaining after qualitative (credibility) and quantitative (criterion on core damage frequency <10^{-9}) screening stages, detailed analysis within PSA is to be performed for all plant operational states;
- Slovenia reported comprehensively in the NAR the approach (deterministic and probabilistic) that is considered for the combination of hazards for all the installations. In particular, they consider three groups (consequential, correlated or independent from fire), as follows:
  - Fire and consequential event,
  - Event and consequential fire,
  - Fire and independent event.

  Credible combination of fire and other events are defined based on qualitative or quantitative criteria as described in the NAR;
- Germany reported that "*Event combinations are taken into account in the design of the installations and their operation and are considered accordingly in the deterministic and probabilistic fire safety analyses. Combinations of a fire with another anticipated event are assumed if the events to be combined are causally related or if their simultaneity has to be considered due to the probability and the extent of damage*. […) *According to KTA, it has to be investigated site- and plant-specifically if event combinations with fire need to be analysed*." Germany mentioned that they use qualitative screening criteria (KTA 2101.1) based as well as quantitative criteria based either on the occurrence frequency or the damage frequency. As a result, all the combinations of fires and other hazards have been screened out for the FRM research reactor by frequency.

The discussions also confirmed that seismically induced fires may occur simultaneously at different locations inside the installation, representing a combination of different fires correlated by the seismic hazard. FSA generally consider one single fire scenario, which may not fully account for seismically induced fires occurring in multiple areas simultaneously.

2. Design, qualification and performance of fire protection features against combined hazards

According to IAEA SSG-64, the fire protection features must be designed to fulfil their required functions in the event of combinations of fires and other events, particularly earthquakes as the most well-known combinations (consequential or coincident) with fires.

It is essential to ensure the availability, reliability and robustness of fire detection, and alarm systems and fire extinguishing provisions in the event of seismic hazards. If active fire protection systems fail to fulfil their required functions, a fire consequential to a seismic hazard may develop without being detected and/or suppressed in a timely manner, and safety functions could ultimately be inadmissibly impaired.

The combinations of hazards are mostly considered in the analysis but can also be accounted for through the design. For higher risk installations (NPPs, RRs), seismically induced fires are not analysed in most of the countries due to the qualification against earthquake of structures and systems. Otherwise, a FSA analysis is usually conducted. In many countries, fire protection systems installed to protect safety-related equipment are qualified to perform their function in case of seismic events.

In relation to fires potentially induced by flooding, some countries adopt dedicated physical protections (barriers) for fire protection features (e.g. France).

It was also reported by several countries that in relation to fire protection systems relevant to ensure the achievement of key safety functions many verifications and, where needed, upgrading in relation to their qualification were conducted as result of lessons learned from the Fukushima event combinations including fires and explosions resulting from the earthquake and tsunami. The same occurred following the 9/11 events.

For lower risk installations, e.g. waste facilities, fire protection provisions are typically not seismically qualified. Even if combinations are not considered, Italy mentioned that storage buildings structures are seismically qualified. Some alternative measures like the use of mobile equipment may as well be implemented as well. The case of back fitting measures to qualify water supply, hydrogen piping and mobile means lodging buildings was mentioned by Spain for their FCF at Juzbado.

In relation to the firefighting strategy requiring the interventions of the fire brigade, the importance of seismic qualification of the structure housing firefighting equipment was highlighted. Additionally, the need to account for potential difficulties in gaining access to the site was raised.

Conclusion

The consideration of hazard combinations, including fires and other events, varies across countries and installations, using both deterministic and probabilistic approaches. Many countries assess credible combinations (e.g., fire with seismic events or explosions) based on engineering judgment. However, some have developed a more comprehensive and systematic screening process to identify credible hazard combinations, particularly for NPPs and high-risk RRs. Some countries also perform detailed FSAs for non-reactor installations (spent fuel or waste storage facilities) focusing on scenarios like aircraft crashes causing fires.

The combinations of hazards may be considered in the analysis but can also be accounted for through the design. For higher risk installations (NPPs, RRs), seismically induced fires are not analysed in most of the countries due to the qualification against earthquake of structures and systems. Otherwise, a FSA analysis is usually conducted. In many countries, fire protection systems installed to protect safety-related equipment are qualified to perform their function in case of seismic events. Flexible strategies, such as the use of mobile equipment, have also been mentioned for installations where fire protection systems are not seismically qualified, offering an adaptable solution to ensure fire safety in these facilities.

9. CONCLUSIONS AND RECOMMENDATIONS

ENSREG selected "fire protection" as the topic for this Topical Peer Review, recognising fire as a significant risk to many nuclear installations. Operating experience from nuclear facilities worldwide shows that fire events occur with some regularity and can contribute to complex incident scenarios. While no major fires leading to the failure of all defence-in-depth barriers have been reported within the EU in recent decades, several serious fire events have occurred in the past. Fires can occur at many locations in an installation and may be capable of challenging multiple structures, systems and components (SSCs) relevant to safety simultaneously, being a possible cause of common cause failures. A fire could also involve nuclear and/or radioactive materials and lead to the release and dispersion of these. In addition to being an independent event itself, fire can be induced by other external or internal hazards or events. It can also itself induce other internal hazards (e.g. flooding, explosion). Furthermore, malfunctions or inadvertent operations of fire safety systems are also seen as relevant events, as they may compromise the installation’s level of fire protection or potentially lead to consequential damage.

In line with the Terms of Reference (ToR), the TPR team reviewed the National Self-Assessment Reports (NARs) prepared by national nuclear safety regulators. These reports were based on assessments conducted by installation operators and followed the WENRA Technical Specification. As a key component of the TPR process, the NARs provide informative insights into national practices and regulatory approaches.

The NARs demonstrate an emphasis on compliance with national fire safety requirements and international safety standards, with ongoing efforts to enhance fire protection across all installation types. Comprehensive fire protection strategies - encompassing prevention, as well as active and passive measures - are widely implemented. Fire safety analyses and regular inspections play a key role in identifying and addressing potential gaps. Proactive measures by licensees supported by regulatory oversight, effective training and exercising of fire response teams, are commonly reported as essential for maintaining fire safety. The exchange of operational feedback and best practices further strengthens fire risk management.

As part of this TPR, site visits to selected research reactors were introduced, offering peer reviewers valuable opportunities to observe the practical and operational implementation of fire protection measures. These visits complement the design and programmatic aspects covered in the NARs, providing a more comprehensive assessment. Additionally, site visits facilitated direct interaction with licensees, enabling information exchange, clarification of open issues, and a productive sharing of experiences, further enhancing the review process.

The peer review identified both good practices and challenges at the EU level, which are detailed in this report, along with national areas of good performance and areas for improvement outlined in the Country Review Reports. (See Annexes IV to VII respectively).

9.0 Main generic outcomes from the peer review

Chapter 2: Regulatory framework

National regulatory frameworks for fire protection in nuclear installations vary significantly across countries and facility types. Many countries adopt specific nuclear safety requirements to protect structures and components critical to nuclear safety, while others rely on conventional fire safety focusing on protection of people and property. Fire protection responsibilities are often shared between several authorities: nuclear safety authorities and national conventional fire safety bodies (fire rescue services, building authorities, labour inspectorates, etc).

Chapter 3: OPEX

Recording and analysing fire safety events in nuclear installations is essential for improving safety, with significant events reported to regulators. Information sharing on fire safety lessons occurs both nationally and internationally through databases, forums, etc. However, more systematic learning from fire events remains a challenge since the information is dispersed and sometimes lacks sufficient details, making the data not directly usable. Exchanging information with conventional non-nuclear industry and drawing lessons from fire events in conventional industries can also contribute to improve nuclear safety.

Participating countries mention the use of operational experience feedback to improve the fire protection systems as well as data on fire occurrences and reliability of fire protection provisions in PSA.

The **peer review** identified the following **generic findings on OPEX**:

- **Challenge:** a need for a unique repository for sharing information on fire safety-related events for all types of nuclear installation, based on defined criteria for categorisation and reporting;
- **Good practice**: implementing learning from experience feedback from fire events in non-nuclear settings.

Chapter 4: Fire safety analyses

The primary objective of fire safety analyses is to demonstrate compliance with nuclear fire protection goals—such as ensuring the plant can be safely shut down and maintained in a safe state during a fire—while also ensuring workers safety and assets. While for nuclear power plants due priority is given to nuclear safety, for other nuclear facilities the main focus is more on workers and asset protection.

Fire safety analyses include:

- deterministic analyses: various approaches, such as Fire Hazard Analysis (FHA) and Safe Shutdown Fire Analysis, are used to assess fire impacts on safety-critical systems. These approaches rely on standards with high-level objectives, on codes that simulate fire phenomena, supported by essential experimental tests, as well as on several assumptions;
- fire probabilistic safety assessment (PSA): their scope varies across countries, with some focusing only on core damage. The contribution of fire events to core damage also varies significantly, with fires accounting for a substantial percentage of core damage in some cases[32].

Fire safety analysis updates are driven by regulatory changes, plant modifications, operational feedback, and new knowledge or in the periodic safety review framework. Participating countries highlighted the key role of PSA in identifying safety improvements and prioritising their implementation.

The **peer review** identified the following **generic findings on fire safety analyses:**

- **Challenge:** development of guidelines to convert high-level objectives mentioned in the standards into detailed requirements for carrying out safety analysis, especially for some type of installations or conditions of operation;
- **Good practice**: extensive series of tests carried out to assess the effects of fire on elements (electrical equipment, fire doors, cables, seals, etc.) credited in the fire safety analyses to confirm their assumed resistance to the fire-induced phenomena.

Chapter 5: Fire Prevention

The objective of fire prevention provisions is to minimise the likelihood of fires occurring.

Fire load management and ignition source control are key aspects of fire prevention. Most countries emphasize the importance of leadership, accountability and safety culture to achieve fire loads minimisation. The use of accountancy tools, such as databases, spreadsheets or tools equipped with

[32] Within the scope of this peer review the information in the NARs did not allow to further analyse the reasons behind these variations, which exist even for similar reactor technologies. This aspect could be worthy of further study.

scanner device, was reported to support effective monitoring and control of fire loads. Managing ignition sources, such as hot work, relies on permit systems and risk assessments commonly applied but as well on the use of new technology such as thermographic cameras.

The **peer review** identified the following **generic findings on Fire Prevention:**

- **Challenge:** a need to consider new types of ignition sources (e.g. lithium-ion batteries);
- **Good practices:**
  - Thermographic cameras installed on worksites, or in case of the failure of a detector, with different detection zones and alarms;
  - A dynamic system to manage storage areas for transient fire loads and other non-combustible materials.

Chapter 6: Passive fire protection

The primary objective of passive fire protection is to prevent the spread of unextinguished fires and limit the quantity of radioactive materials involved in the fire.

To achieve this, countries have implemented a range of passive fire protection components, including penetration seals, fire doors, hydrant networks, and fire dampers. They regularly conduct a variety of inspections and testing to maintain their operability:

- penetration seals and fire doors: visual inspections and functionality tests are routinely conducted. In many countries, fire doors and seals have been replaced based on their safety significance;
- fire hydrant networks: inspections involve both visual checks and advanced techniques. Ageing degradation has led to partial or full replacement of hydrant networks in all countries, with most issues identified in underground pipes;
- fire dampers: inspections are predominantly visual, supplemented by alternative methods for areas with limited access. Some countries have established dedicated programmes to improve accessibility. Common problems, such as loss of spring tension and material degradation, often necessitate replacements.

Effective management of ventilation systems during fires is essential, requiring a balance between closing fire dampers to prevent fire spread and maintaining ventilation for safe evacuation of personnel and maintaining radiological safety.

The **peer review** did not identify any **generic findings on Passive fire protection.**

Chapter 7: Active fire protection conclusion

The primary objective of active fire protection is to quickly detect and extinguish fires, thus limiting the damage and ensuring safety through:

- fire detection strategies: these vary across nuclear installations, with some countries prioritising full room coverage and others focusing on high-risk areas identified through fire hazard analyses. Upgraded systems increasingly use addressable fire detectors, enabling precise fire location;
- fire extinguishing systems: designed to match specific risks, these systems avoid water near electrical equipment, relying instead on gas or foam extinguishers with personnel safety measures. Mitigation strategies address (i) water-related hazards such as flooding through protective barriers, elevated equipment placement, and (ii) runoff management systems to prevent potential spreading of radioactive contamination;
- firefighting operations: they are organised in multiple levels to efficiently manage fire risks. Coordination between these levels and arrangements (joint training, response plans) are vital to ensure fire response efficiency.

The **peer review** did not identify any **generic findings on Active fire protection.**

Chapter 8: Transversal topics

Fire protection encompasses transversal topics, integrating fire safety analyses alongside active and passive protection measures, such as:

- **compartmentation:** compartmentation and physical separation are fundamental to prevent fire spread. When full compartmentation is not feasible, compensatory measures, including technical and administrative methods, are employed based on fire hazard analyses;
- **fire protection throughout the decommissioning process**: fire protection measures may evolve to address changing radiological environments, fire loads, and operational risks during decommissioning. Implementing dedicated provisions, such as mobile equipment, may be required for specific operations. Deterministic fire hazard analyses are conducted to identify and mitigate specific risks associated with dismantling operations; Particular attention has to be given to the effective management of hot works;
- **combinations of hazards**: credible combinations (e.g., fire with seismic events or explosions) are identified based on engineering judgment. Their consideration may be considered in deterministic or probabilistic analyses but can also be accounted for through the design or flexible strategies, offering adaptable solutions to ensure fire safety in nuclear facilities.

The **peer review** did not identify any **generic findings** on the above transversal topics.

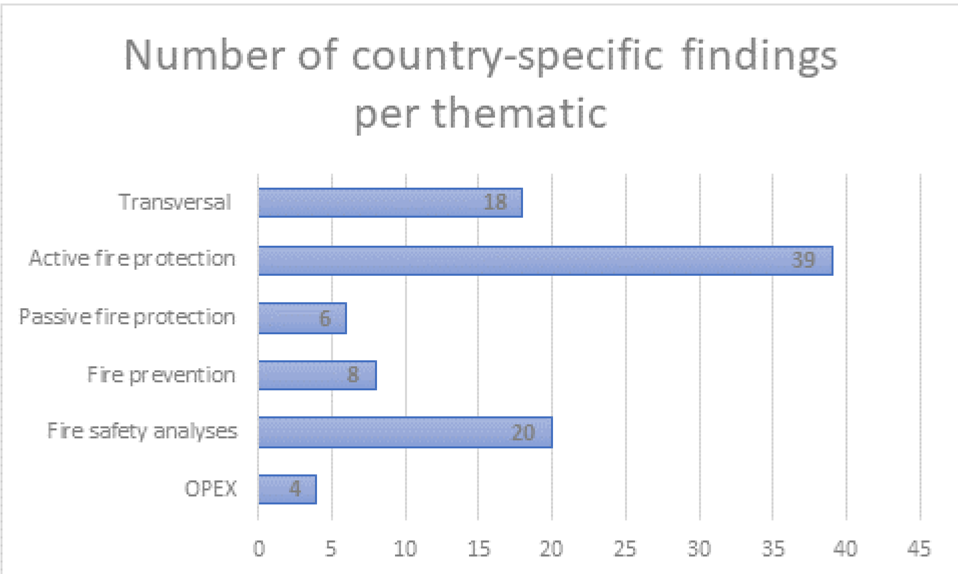
9.1 Country-specific outcomes from the peer review

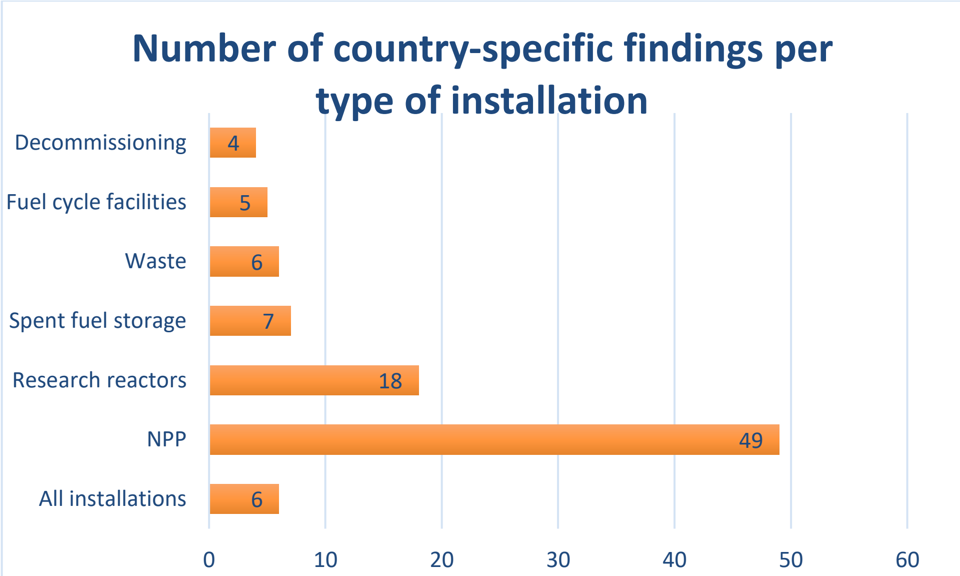
The country workshop was held to provide a comprehensive overview of fire protection approaches for the different nuclear installations in the participating countries. It focused on national experience with regard to fire protection, to enable thorough discussions on issues raised in the question-and-answer phase, and to conclude on the findings identified by the peer review, categorised as areas of good performance or areas for improvement.

At the end of the country review workshop, 95 country-specific findings were identified, distributed as follows:

- 39 areas of good performance (see Annex VI);
- 56 areas for improvement, including 43 identified by the countries during their self-assessment process and documented in their National Assessment Report (NAR) (see Annex VII).

The figures below illustrate the categorisation of these **findings** by thematic areas and types of installations.





The conclusions of this workshop are documented in the Country Review Reports (CRRs).

9.2 Overall conclusion and recommendations

The TPR review has highlighted a diverse range of approaches and solutions adopted across participating countries. While variations exist in fire protection implementation, no critical deficiencies were identified in the fire protection strategies of the installations within the TPR scope. The TPR review underscores the importance of applying all levels of defence-in-depth to ensure robust fire protection, supported by thorough fire safety analyses. Effective fire load management remains a priority, with leadership, accountability, and a strong safety culture playing a crucial role in minimizing fire risks.

The peer review identified both good practices and challenges at the EU level, which are detailed in this report, along with national areas of good performance and areas for improvement outlined in the Country Review Reports. Beyond these specific conclusions and as witnessed from the feedback received from the TPR Team, the review provided important opportunities for exchanges and learning, for regulators and operators, both at the level of national assessments, and as a result of the peer review itself.

To address the identified areas for improvement and challenges, national and ENSREG action plans should be developed.

According to the Directive, "*Member States should establish national action plans for addressing any relevant findings and their own national assessment*". The National Action Plan should address the results of the self-assessment and respond to the country specific findings (CSFs) outlined in the CRR. As stated in the TS, insights from the TPR should be transferable to the so-called "represented installations[33]". Therefore, the Board recommends that participating countries consider how insights from the TPR, in particular their CSFs, are transferable to their "represented installations" when developing their NAcP. Additionally, the Board encourages countries to examine all findings from this peer review - regardless of their categorisation (good practice, area of good performance, area for improvement) - and assess their applicability to enhance fire protection. As stated in the ToR, the actions in the NAcP shall be as specific as possible to each installation. Participating countries should inform on the progress of the implementation of the actions included in the action plan based on a follow-up schedule of at least 3 years, as defined in the ENSREG Action Plan.

[33] "*Participating countries define candidate installations that will be reported on in the individual NARs and "represented installations" refers to installations that will not be reported on in the NAR but which are similar to candidate facilities. Insights from the TPR should be transferable to these represented installations*."

The challenges identified by the peer review are areas where action at a European level, in addition to action at national level, would help build knowledge, support consistency of approaches or produce beneficial new activities to assist in enhancing fire protection at nuclear installations or the fire safety case. The Board recommends that the European Nuclear Safety Regulators Group (ENSREG) draws up an action plan to address these challenges and regularly reports on its implementation. The Board expects the action plan and the progress reports to be made available on the ENSREG website.

Additionally, further exchanges on best practices could support experience sharing and contribute to the ongoing development of standards and guidance.

In conclusion, the peer review successfully met the generic goals and objectives set out in the Nuclear Safety Directive and in the Terms of Reference established by ENSREG. It provided a valuable opportunity for participating countries to assess their fire protection provisions, share information and experience, and provided an open and transparent framework for countries to develop appropriate follow-up measures.

Finally, the Board observed that performing Topical Peer Review II has been a challenge and has required significant resources from the participating countries and the European Commission. As Topical Peer Reviews are required to be conducted at least every six years, it is of the utmost importance to learn from the experience to enhance efficiency and effectiveness in the future peer reviews. The TPR Board has compiled key insights from the TPR II experience in a separate ‘lessons learned’ document to guide improvements for future Topical Peer Reviews. A key challenge identified for future reviews is balancing a wide technical scope with a limited number of available expert reviewers, an issue that proved particularly demanding in this TPR.

10. REFERENCES

[1] WENRA Technical Specification
https://www.ensreg.eu/sites/default/files/attachments/technical_specification.pdf

[2] ENSREG Terms of Reference
https://www.ensreg.eu/sites/default/files/attachments/terms_of_reference.pdf

[3] National Assessment Reports
https://www.ensreg.eu/country-specific-reports/EU-Member-States-tpr2
https://www.ensreg.eu/country-specific-reports/other-countries-tpr2

[4] TPR II Country Review Reports
https://www.ensreg.eu/country-specific-reports/EU-Member-States-tpr2
https://www.ensreg.eu/country-specific-reports/other-countries-tpr2

ANNEX I – List of nominated experts who participated in the review

Country/Entity	Name, organisation
BE	Fabienne De Smet (FANC)
BG	Stefan Parvanov (Academy of the Ministry of Interior)
CH	Martin Buchmann (ENSI)
CH	Ralf Kaiser (ENSI)
CH	Judith Kälin (ENSI)
DE	Burkhard Forell (GRS)
DE	Christian Northe (BASE)
DE	Florian Rowold (GRS)
DE	Marina Röwekamp (GRS)
DE	Michael Schwerdtfeger (BASE)
DK	Poul Erik Nystrup (DEMA)
EC	Diego Escrig-Forano (JRC)
EC	Marc Noël (DG ENER)
EC	Miguel Peinador Veira (JRC)
EC	Kaisa Simola (JRC)
ES	Guillermo Cristóbal San Vicente (CSN)
ES	Ana Belén Fernández Domínguez (CSN)*[34]
ES	Eugenia Morgado (CSN)*
FI	Matti Lehto (STUK)
FI	Samu Rinta-Filppula (STUK)
FR	Fabien Dekeyser (ASN)
FR	Sylvain Lafont (ASN)
FR	Jocelyne Lacoue (IRSN)
FR	Yannick Ormières (IRSN)
IT	Marco Gervasi (ISIN)*
IT	Sebastian Piras (ISIN)
IT	Nadia Cipriani (ISIN)*
LT	Kęstutis Sabas (VATESI)
SE	Lars Bennemo (SSM)
SE	Per Hellström (SSM)
SI	Darko Pavlin (SNSA)
TR	Miraç Bahadir Öztemiz (NDK)
TR	Anıl Çelik (NDK)#
UA	Andrii Goroshanskyi (SNRIU)
UA	Oleksandr Kukhotskyi (SSTC)
UA	Igor Rezvik (SSTC)
UA	Oleksandr Soloviov (SSTC)
UK	Diego Lisbona (ONR)
UK	Caroline Winstanley (ONR)

[34] * indicates that the named expert was either substituted or a substitute reviewer; # indicates observer role

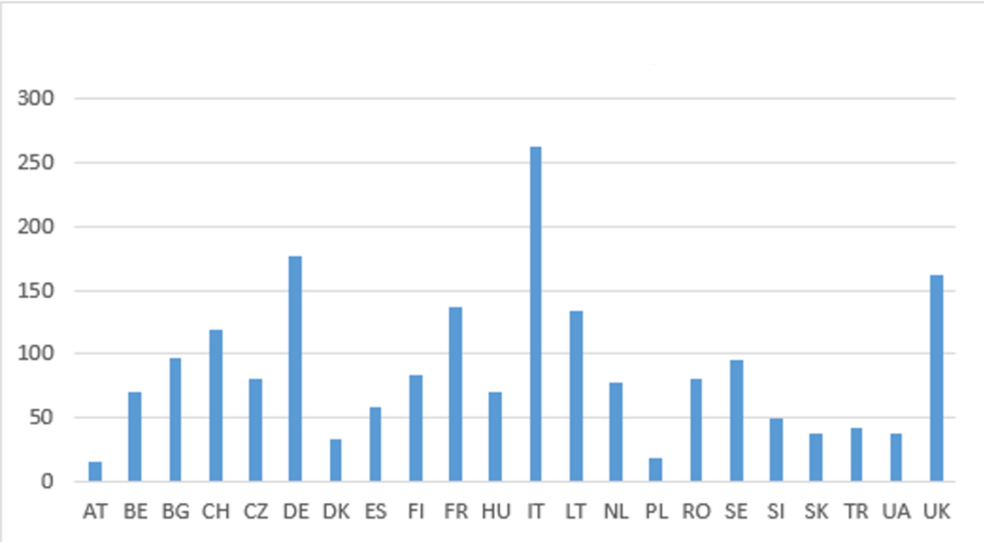
ANNEX II – Statistics about the Q&A

Following publication of the NARs in November 2023, questions were invited from all sources until 14 February 2024. The questions were compiled in an Excel table and sent to the participating countries for reply by 30 April 2024. The breakdown below comprises the questions from (i) TPR experts in the thematic teams, (ii) participating countries' regulatory authorities in ENSREG, (iii) TPR Board members and the European Commission services, (iv) external stakeholders.

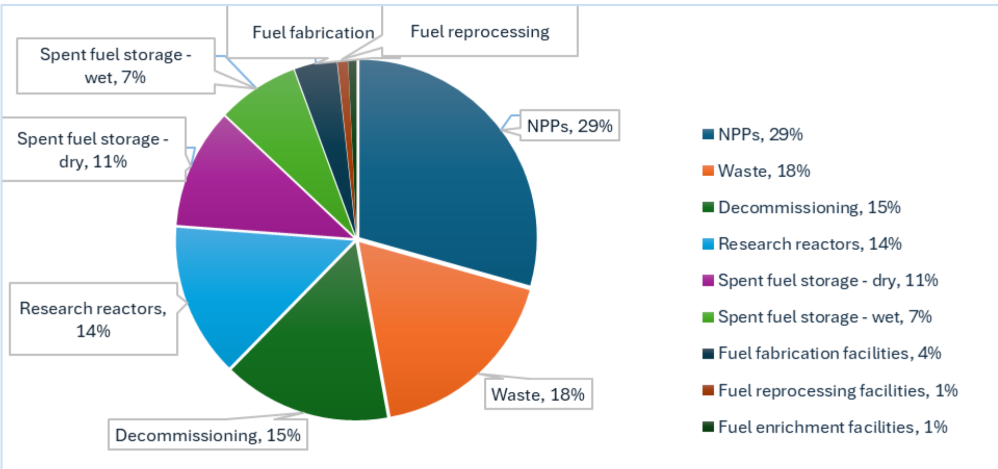
Breakdown of sources of the questions/question sets[35]

TPR experts	Participating countries	TPR Board and EC	Stakeholders	TOTAL
1941	**558**	**62**	**130**	**2691**

Number of questions/sets from TPR experts addressed to country:

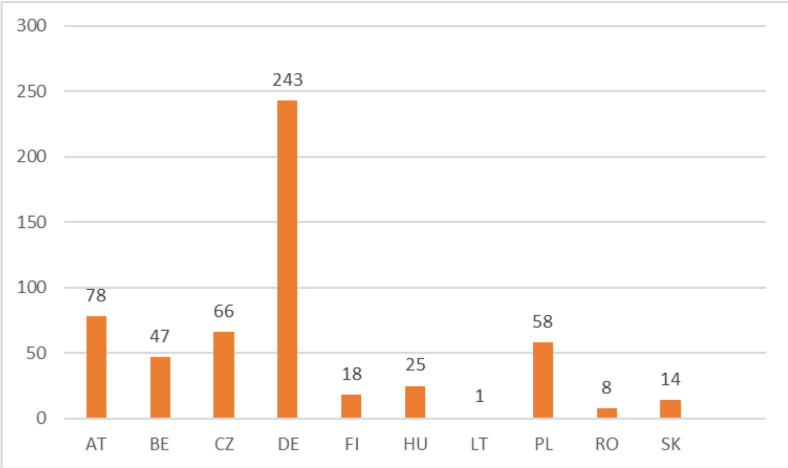


Number of questions/sets by installation type from TPR experts expressed as percentage:

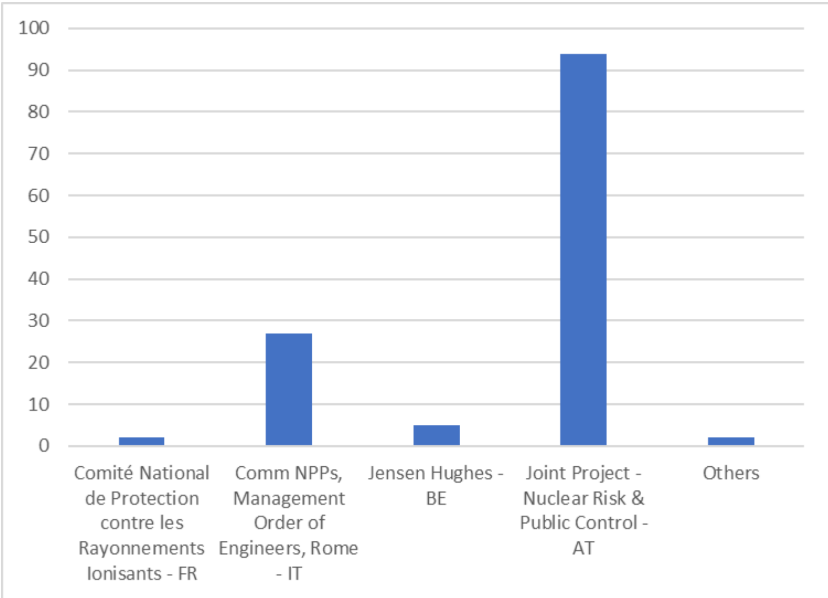


[35] Questions from the TPR team, countries and stakeholders were compiled into an Excel table. The figures represent the individual cells containing questions. In a few cases a cell contained a 'set' of questions.

Number of questions received from countries (regulatory authority):



Number of questions received from stakeholders:



ANNEX III – Definition of Good Practice, National Area of Good Performance, National Areas for Improvement and Challenge

(The TPR II definitions as presented in Annex II of the ToR):

The findings of the peer review will be categorised according to the following definitions:

- **Good Practice** which should be understood as an aspect of fire protection, which is considered by the TPR review Team to go beyond what is required in meeting the appropriate national or international standards. It is identified in recognition of an arrangement, practice, policy or programme significantly superior to those generally observed in participating countries and having a clear safety benefit. It is likely to be applicable to other participating countries with similar programmes and it is for each country to review and decide on its implementation in relevant nuclear installations to improve safety.

- A **National area of good performance** which should be understood as an arrangement, practice, policy or programme related to fire protection that is recognized by the TPR review Team as a significant accomplishment for the country and has been undertaken and implemented effectively in the country and is worthwhile to commend.

- A **National area for improvement** which should be understood as an aspect of fire protection identified by the TPR Peer Review Team where improvement is expected, considering the arrangement, practice, policy or programme generally observed in other participating countries. It may also be self-identified by the country itself (i.e. self-assessment) where improvement is appropriate.

- **Challenge (EU wide)** EU wide Challenges which should be understood as aspects in the implementation of fire protection that are considered by the TPR Peer Review Team to be common to many or all countries and are areas where action at a European level, in addition to action at national level, would help to increase available knowledge, drive consistency or produce beneficial new techniques or technology to assist in enhancing fire protection at nuclear installations or the fire safety case.

ANNEX IV – Compilation of Good Practices

Good practice 1:

‘Implementing learning from experience feedback from fire events in non-nuclear settings’ (see chapter 3)

Lubrizol fire in 2019 in France

Following the Lubrizol accident in September 2019 and the review performed upon the request of the Government to draw lessons and enhance management of fire risks, the French Government issued a circular regarding risk prevention in industrial facilities.

Similarly, ASN asked all the nuclear operators to take into account the lessons learned from this accident that happened in chemical industry. Notably, ASN required them to re-examine workers’ or subcontractors’ knowledge of the risks, and to maintain an up-to-date inventory of dangerous substances for intervention teams. Among the requests from ASN was also a reminder that non-radiological risks (direct effects of fire or explosion, chemical releases) had to be included in the safety case. The appendix of the ASN letter presented what was expected in the dangerous substances register which is mandatory for any facility.

ASN performs inspections regarding the implementation of the actions by the operators.

Grenfell tower fire in 2017 in the UK

Following the Grenfell tower fire in June 2017 involving combustible cladding in a residential building in London, ONR asked all licensees to systematically review and report the status of their buildings for any presence of the cladding products.

The licensees provided responses which were evaluated through technical triage meetings by fire specialists in the regulatory body. The information together with regulatory intelligence was used to extract learning across the sector. It was documented and shared in advice notes to inspectors, informing ONR inspections. The UK NAR documents measures taken at two sites in the UK sample where the learning included the testing of cladding materials and additional controls being introduced to reduce fire risks including by preventing the use of the materials in design.

Good practice 2:

‘Extensive series of tests carried out to assess the effects of fire on elements *(*electrical equipment, fire doors, cables, seals, etc.) credited in the fire safety analyses to confirm their assumed resistance to the fire-induced phenomena)’ (see chapter 4)

The fire project in EDF develops high-level modelling techniques an relies on excellent test facilities in terms of material, components and full-scale mock-ups. The R&D actions combine experimental approaches from small to large scale, as well as the development of in-house codes or numerical tools to perform and facilitate Fire studies and strengthen EDF’s Safety Demonstration.

The experimental activities at small scale (component or matter) are carried out on the MILONGA platform. The tests are focused on the determination of malfunction criteria that will be further used in the Safety demonstration, or on the evaluation of the behaviour of various materials under a thermal aggression. The Four650 is for instance an experimental setup that enables to heat a component to simulate a thermal aggression from an adjacent fire. It is used to determine or strengthen thermal malfunction criteria for cables or electric equipment, or to determine temperature criteria that can be used for the qualification process of new equipment. Another experimental setup can complete this approach as it enables to study the effect of smoke on electric material. Finally, a modified calorimeter cone can be used to characterize the combustion of various representative material (cable sheath for instance) at small scale and both in open and confined atmosphere. Another application is the determination of critical heat fluxes that can be used as criteria in fire safety studies.

As there is no easy transposition between small and large scale in fire scenario, EDF also invested in an experimental platform dedicated to large scale tests. This full-scale facility investigates fires that can occur at nuclear facilities. Its purpose is to provide a better understanding of fire risks and their consequences on plants. This platform, called IGNIS, is composed of different facilities that correspond to four configurations of interest:

- a calorimetric hood used to characterize the source term for various industrial combustibles,
- a room with no ventilation, but with an extraction system so that fires can be set in a confined space,
- a 12m long gallery,
- a 712 m^3 large volume facility.

The gallery and large volume facility are used for large scale tests and allow real fires to be carried out in premises representative of nuclear power plants They are mechanically ventilated and can be split into several room by building walls to study a wide range of NPP realistic configurations. The tests are used either for code validation and development or for direct observation of what happens in a realistic scenario. These facilities can be used for instance to study cable fires, to assess the efficiency of new products for fire mitigation or prevention or to understand the complex physics related to ventilated compartment fires. Flexibility is the philosophy of the platform, as the facilities are adapted to every specific need expressed by the Engineering Units.

The numerical strategy is based on a graduated approach, from zone code to advanced CDF modelling. EDF R&D has developed several widely recognised numerical codes such as:

- 'MAGIC' for characterising and modelling fires: this code is used for 90 % of the studies and benefits from an international recognition, as it is qualified by the US NRC;
- 'Saturne' (free, open-source in-house Code) for large volumes and complex geometries. It can be used when local information is needed for instance in a compartment fire scenario. It includes very detailed physics (soot formation, heat transfers…) validated on more academic benchmarks and experimental data.

Good practice 3:

'A dynamic system to manage storage area for transient fire loads and other non-combustible materials' (see chapter 5)

The licensee developed a mobile scanner device with an intuitive IT tool to efficiently manage storage areas for transient fire loads and other non-combustible materials.

The system is composed of a mobile scanner device (PDA) with an intuitive IT tool, stickers with bar code, a docking station to synchronize the mobile device and a desktop interface to set up the application. The goal of the application is to easily identify any storage area, the allowed equipment/materials stored and the owner of the area and the equipment and to ensure a dynamic monitoring and trending of the fire load storages.

The system is an interactive tool that provides a simple solution for the traceability, verification of storage area, generation of the notifications directly in the field and monitoring and trending, up to a daily basis.

The tool also provides other information as the owners of each storage area and the allowed storage materials, the maximum allowed fire load of each storage area, the contamination level etc. The bar-codes are permanently present in permanent storage locations and are installed at temporary storage locations.

The tool is similarly used for the monitoring of the radioactive material storage.

Supporting details:

- Easy to use mobile interface (personal digital assistant - PDA) with high quality barcode scanner;
- PDA's are available to all teams and also in workshops of the plant;

- Desktop interface of the tool gives many options for the postprocess of the data;
- Photos can be taken directly in the field using a Personal Digital Assistant (PDA) and instantly associated with a specific storage area or used to generate a discrepancy notification.

Benefits:

- The total heat energy can be estimated and compared with the maximum allowed value for a selected storage area;
- Regarding radiation protection, the dose is estimated and associated with the waste bag. In cases of incorrect sorting, the owner of the waste bag receives guidance and coaching;
- Regarding safety, the tool gives a dynamic global overview of the location of mobile equipment and storage area.

- Permanent storage locations
  These locations are marked with yellow/black stripes and l
  load (figure 20) and the purpose of the storage area. This
  tool and is made visible at the location (figure 21).

Figure 20: Sign allowed fire load in permanent storage location

Figure 21: Identification storage location in WESTI

- Temporary Storage locations
  The temporary storage locations are registered in the WESTI-tool and are visualised with yellow/black ribbon and a WESTI-sign.

Figure 22: WESTI-sign for temporary storage of fire load

The storage areas are frequently controlled by different stakeholders: CARE PPI (Prevention Protection Incendie), maintenance plans, Care NS (Nuclear Safety), MSL (Maintenance Service Logistique). The results of these walkdowns and controls are registered and visualised in the Fire Load Index (see next paragraph).

Good practice 4:

'Thermographic cameras installed on worksites, or in case of the failure of a detector, with different detection zones and alarms' (see chapter 5)

Thermographic cameras provide permanent monitoring of fire risk sites.

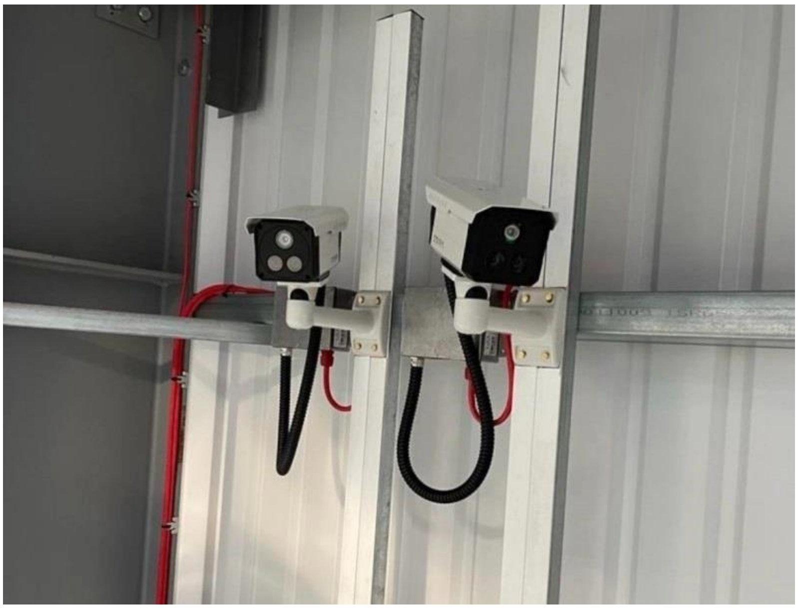
Each camera can be programmed to monitor one or more zones with specific detection criteria, assigned to each zone if an identified temperature is exceeded, the area will be alarmed. This alarm is transmitted to the Control Room, a signal and a pre-programmed message are sent (ringing, beeping, flash, etc.). The message is transmitted by the D SLAM (local ADSL, just need a phone close to the monitored area). When the alarm is given, the fire-fighting organization is engaged.

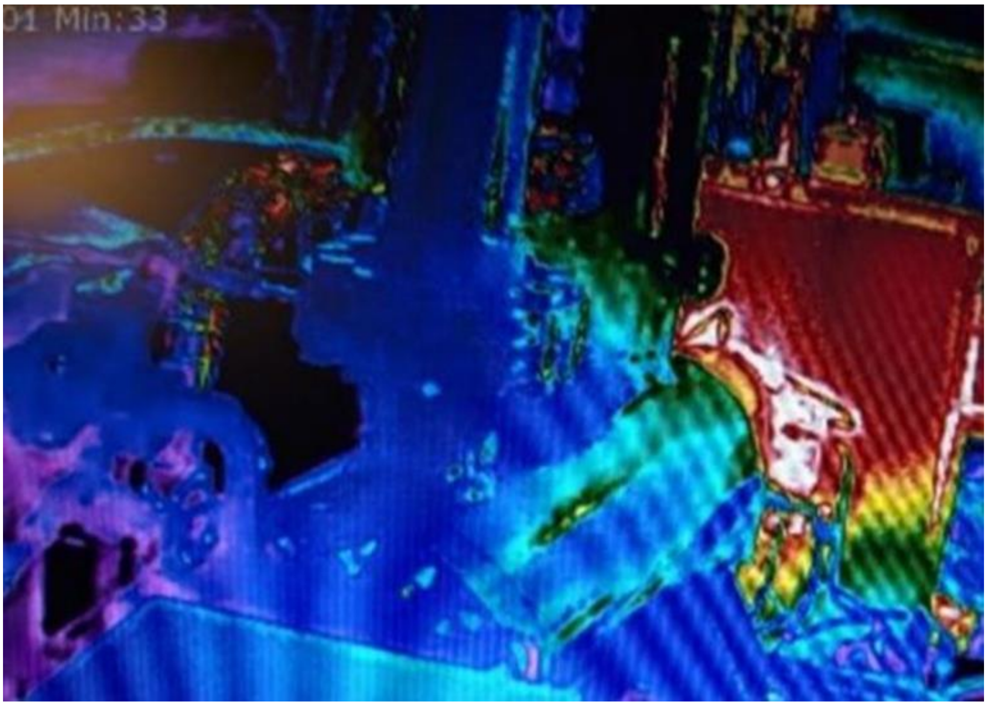
Benefits:

- Permanent monitoring of fire risk areas instead of walkdowns/round
- Anticipated detection and therefore engagement of intervention during the first phase of fire
- Possibilities of detection of "smouldering fire" that cannot be detected by naked eye

Potential other uses:

- Monitoring of sensitive equipment
- Fire team guidance on smouldering fire zone
- Monitoring of ignited gas leaks (camera can be set to negative temperatures)
- Additional compensatory means in case of detector failure
- Post-accident monitoring of areas affected by fire

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ANNEX V – Compilation of Challenges

Challenge 1:

'A need for a unique repository for sharing information on fire safety-related events for all types of nuclear installation, based on defined criteria for categorisation and reporting' (see chapter 3)

Identified gaps and challenges

Accessing operating experience and information on fire safety related events[36] and fire safety related improvements performed elsewhere, for all type of installations, is essential, especially when own/national experience is limited.

The information on fire safety related events and fire safety related operating experience are spread over various different databases (e.g. IAEA databases such as INES, IRS; OECD/NEA FIRE Database, etc.) that collect the information from the nuclear installations. These databases sometimes contain a limited level of detail, making the data not directly usable for other installations or countries.

The lack of consistent information on fire safety events and its dispersion into different databases hinder the effective use of operating experience. Enhancing the usability for operators worldwide of the existing international databases is a recognized challenge.

Recommendations for future work

The TPR II peer review acknowledged that information on fire safety-related events is spread across various databases, which often lack sufficient detail on fire safety-related events, making it challenging to apply directly to other installations and countries. To address this challenge, a need was identified for a unique international repository for sharing and accessing fire safety related events with sufficient and pertinent detail.

Future work should prioritise:

1. **Development of a guidance** providing:
   - common reporting criteria, ensuring consistency in fire-safety related event reporting;
   - instructions for coherent encoding of fire safety-related events, ensuring similar metadata for similar event;
   - type and level of details of information required, ensuring sufficient information for its direct use by other countries.
2. **Definition of the structure of the repository**, using the structure and content of existing databases, to consolidate fire safety-related events and lessons learnt (e.g. improvements) from all types of nuclear installations;
3. **Development of the fire safety related event repository.**

Establishing such a repository would improve the use of operational experience feedback on fire safety related event, contributing to enhance fire protection across the nuclear industry.

Challenge 2:

'Development of guidelines to convert high-level objectives mentioned in the standards into detailed requirements for carrying out safety analyses, especially for some type of installations or conditions of operation' (see Chapter 4)

Identified gaps and challenges

In the context of performing fire safety assessments, several standards have been developed, primarily by the International Atomic Energy Agency (IAEA), such as SRS No.8 and SSG-3, SSG-4, covering both deterministic and probabilistic approaches. However, these standards often lack details regarding the specific assumptions, methodologies, and procedural steps necessary to conduct FSAs that fully align with the high-level objectives that are described.

[36] Fire safety related events here covers not only information on fire events but also events with degradation of fire protection features

While nuclear power plants benefit from well-established methodologies, these methodologies do not easily transfer to other facility types, which encompass diverse technologies and operation conditions. Additionally, some participants highlighted gaps in existing guidelines for conducting FSAs, when an NPP is operating at reduced power or in shutdown states.

The translation of high-level objectives from existing standards into detailed safety analysis requirements remains/is a challenge, particularly for specific types of installations and operational conditions.

Recommendations for future work

To address this challenge, the TPR II peer review recommended the development of detailed guidelines to bridge the gap between high-level safety objectives and practical detailed safety analysis requirements. These guidelines should provide:

1. **Clarification on how high-level objectives should be interpreted** for specific installation types;
2. **Practical approaches for conducting FSAs** under various operating modes, including conditions such as low-power operations and shutdown states;
3. **Detailed guidance on assumptions, methods, and procedural steps**, ensuring alignment with the high-level safety objectives.

Developing such guidelines would enhance the consistency, reliability, and applicability of fire safety analyses across all nuclear facility types, improving fire risk management and protection throughout the industry.

Challenge 3:

'A need to consider new types of ignition sources (e.g. lithium-ion batteries)' (see chapter 5)

Identified gaps and challenges

The increasing presence of lithium-ion batteries in vehicles, portable and fixed electrical equipment and energy storage systems introduce new risks in nuclear installations.

In addition to introducing combustible loadings, lithium-ion batteries have thermal runaway potential posing fire and explosion hazards. Lithium-ion batteries can also act as ignition sources due to overheating, and the significance of these phenomena depend on many factors including their composition/ chemistry, location in relation to other combustible materials, age/condition, battery charge and discharge history etc. Hazards posed by lithium-ion batteries have the potential to impair SSCs important to nuclear safety, as well as the health and safety of workers and fire responders.

Traditional fixed and portable fire detection and fire extinguishing systems in nuclear installations were not originally designed to detect and suppress fires resulting from lithium-ion batteries.

The growing introduction of new technologies such as lithium-ion batteries underscores the need for effective fire prevention and protection strategies tailored to these evolving risks. The development of guidelines for the appropriate use, storage, disposal of energy storage systems, as well as for ensuring effectiveness of fire protection provisions, represent a challenge across all countries.

Recommendations for future work

The TPR II peer review acknowledged that the increasing introduction of new energy storage systems such as lithium-ion batteries underscores the need for effective fire prevention and protection strategies tailored to these evolving risks.

To address this challenge, a need was identified for:

1. **Specific guidelines** for the safe use, storage, disposal of lithium-ion batteries in nuclear installations, as well as for ensuring the effectiveness of fire protection provisions. These

guidelines should consider NFPA 855 which sets fire protection expectations for lithium-ion battery system installation;

2. **Risk assessment frameworks** which account for the introduction of new types of equipment or emerging technologies, acknowledging that effectiveness of fire detection and suppression depends on factors, such as battery chemistry, system design, and operational conditions;
3. **Routine Operating Experience (OPEX) collection**, analysis and sharing to identify and disseminate key learning on the effectiveness of fire protection measures for emerging technologies, including lithium-ion batteries and other evolving energy storage systems.

Given the expected increase in energy storage systems, it is necessary that guidelines are regularly updated to account for the introduction of emerging technologies and operational experience feedback.

ANNEX VI – Compilation of National Areas of Good Performance

Finding	Installations
Thematic: **OPEX**	
The nuclear sector-wide review of combustible cladding risks instigated by the nuclear regulator, to identify and implement any transferable learning from the Grenfell fire.	All installations (UK)
New fire-fighting procedures and training have been implemented as a result of the lessons learnt from conventional industry.	Vandellos 2 NPP (ES)
Comprehensive national review after Lubrizol (chemical industry) fire accident resulting in ASN requests and consequently in concrete actions in all nuclear installations.	All installations (FR)
Thematic: **FIRE SAFETY ANALYSES**	
High-level modelling of the effects of fire (soot, pressure effects…) to confirm the fire resistance of compartmentation elements and Structures, Systems, Components (SSCs) performance.	NPPs (FR)
Use of a semi-quantitative fire risk assessment methodology for each of the 600 rooms of the reactor building.	RHF RR (FR)
An extensive and targeted modernisation programme of fire protection equipment and systems has been undertaken at the NPPs.	NPPs (UA)
Full-scope fire PSA in all operational states for Level 1 to 3 PSA.	Borssele NPP, HFR RR (NL)
Implementation of new and modern provisions, in particular to meet the current fire protection regulations.	MARIA, Świerk (PL)
Modernisation of the facility with significant improvements (both on passive and active components) including the ones in the frame of the PSR.	RHF RR (FR)
Thematic: **FIRE PREVENTION**	
Use of a mobile scanner device with an intuitive IT tool and barcode on items to easily identify equipment or material allowed to be stored.	Tihange 3 NPP (BE)
There is an independent verification of hot work in addition to the assessment by the 'Hot Work Selected Person' and review by the 'Hot Work Controller' for enhanced control of work areas.	All installations (UK)
Implementation of thermal cameras on particular worksites providing an alarm in the main control room in order to be alerted of a fire outbreak.	NPPs (FR)

Finding	Installations
Detailed arrangements for the management of hot works are provided (covering e.g. scope of works, supervision, necessary firefighting equipment).	Cofrentes NPP (ES)
Thematic: **ACTIVE FIRE PROTECTION**	
Measures to be taken by the operators in the control room are pre-defined in written instructions (FAIOp).	NPPs (FR)
Use of a battery for powering fire valves and smoke removal valves for a period of at least 10 minutes as a compensatory measure.	Olkiluoto 3 (FI)
Measures to be taken by the operators in the control room are pre-defined in written instructions for every single fire compartment depending on the area affected. For complex spaces, intervention layouts (rooms, detectors and so on) and fire compartment layouts are complemented with specially developed intervention plans.	Ringhals 3 NPP (SE)
Implementation of a software tool to easily assess the adequacy of the fire protection measures.	Tihange 3 NPP (BE)
A large modernisation of fire detection system has been carried out with the use of new generation, multi-criteria detectors.	NPPs (CZ)
Robustness of the fire detection system against single failure.	NPPs (CH)
The design approach of the fire detection and alarm system is robust regarding the separation of redundant trains.	NPPs (SE)
Implementation of effective flooding protection of critical equipment from the harmful effects of firefighting water extinguishing system.	Almaraz and Cofrentes NPP (ES)
Gas detectors are installed in premises where diesel generators are located which signal the leakage of combustible gases from fuel tanks.	Lovisa 1, 2 (FI)
Implementation of automatic fire suppression system to transporter tug engines across the site.	Sellafield (UK)
The presence of a well-resourced on-site fire brigade contributes to responding to fires in a timely and robust manner.	Akkuyu NPP (TR)
A large professional fire brigade (FRSU) ranging from 12 to 18 depending on the NPP, is deployed on a permanent basis on the NPP site providing fire prevention, firefighting and rescue services.	NPPs (CZ)
A significant number of the staff and reactor operator personnel are certified fire safety engineers.	Budapest Research Reactor (HU)
Since 2022, a professional unit of firefighters (15 firefighters, 3 fire trucks) is deployed on a permanent basis on the Cernavoda NPP site.	Cernavoda NPP Unit 1 (RO)

Finding	Installations
Permanent presence on the site of the research reactor under decommissioning of a well-resourced on-site fire brigade.	ESSOR RR - Decommissioning (IT)
Formalised arrangements between the reactor facility and the city fire brigade contributes to an effective response in case of a fire.	İTÜ Research Reactor (TR)
A professional multi-functional fire brigade (minimum 18 staff) is deployed on a permanent basis on the NPP site. In addition, an external fire brigade is available whose intervention is planned in the event of a fire. The effectiveness of the joint intervention is verified via annual drills.	Mohovce 3, 4 NPP (SK)
There is a permanent presence of a well-resourced on-site fire brigade.	Paks NPP (HU)
The existence of first-intervention teams (composed of operators) and second- intervention teams (composed of professional fire fighters) with proper equipment and, in the case of Tihange NPP-external firefighters quartered opposite the site, ensures an appropriate response to any fire event.	Tihange 3 NPP (BE)
TRANSVERSAL TOPICS	
Fire doors and hatches which form part of the nuclear fire compartment have position monitoring that initiate an alarm in the MCR if the door is left open.	Hinkley Point C, Sizewell B and 2nd generation AGRs (UK)
A solid process is in place to manage the authorisations to have fire doors opened: the wedge to block the fire door can be collected at the Main Control Room after approval.	Tihange 3 NPP (BE)
Implementation of door-open alarms for the ones representing a safety risk (PSA based).	Tricastin 900 MWe NPP (FR)
Fire resulting from large commercial aircraft crash are considered in the design basis in the deterministic studies for storage casks for spent fuel.	Dry SFDS Krško NPP site (SI)
A systematic approach for combination of hazards is applied.	HFR RR (NL)
Fires resulting from a military aircraft crash onto waste buildings are considered at the design stage and compliance of the consequential impact with established radiological objectives verified.	OPEC2 and D2 EUREX - Waste (IT)
Fires resulting from military aircraft crash were considered at the design stage of the spent fuel storage facility and also the radioactive waste storage buildings.	Zwilag SFS (CH)

ANNEX VII – Compilation of National Areas for Improvement

Finding	Installation	Mentioned in the NAR
Thematic: **OPEX**		
Licensees to make a better use of fire operational experience database, such as 'FIRE'.	NPPs (ES)	YES
Thematic: **FIRE SAFETY ANALYSES**		
A need to enhance fire hazard analysis by further development of deterministic analyses to specifically assess the potential consequences of fire events on the performance of the safety functions.	NPPs (UA)	
Holistic Fire Safety Strategies (FSSs) covering fire objectives: nuclear safety, life safety, property protection not currently available for all nuclear facilities.	Sellafield (UK)	YES
Need for consideration of the radiological risks in the FHA	Juzbado FCF (ES)	YES
A need for a revision of the fire protection concept into an 'overarching fire protection concept' and detailed building-specific fire protection concepts.	Beznau and Gösgen NPP and Zwibez spent fuel storage (CH)	YES
There is a need to update the fire protection provisions in compliance with technical guide n. 31, in the context of the ongoing licensing process for decommissioning.	ESSOR RR, EUREX FCF - Decommissioning (IT)	YES
No obvious connection between the diverse fire analyses performed with different requirements, guidelines and scenarios depending on the fire analyses.	FCF Urenco (NL)	YES
Due to the new regulation on fire safety, the licensee will have to perform a fire safety analysis and hazard assessment. It should include justification of the acceptability of the fire protection measures including the seismic robustness of fire protection equipment.	İTÜ Research Reactor (TR)	
Need for review and upgrading of the fire safety-related systems in order to adapt to the design requirements in the new regulation on fire safety of nuclear facilities.	İTÜ Research Reactor (TR)	YES
Necessary to update and supplement the fire protection concepts and associated documentation in accordance with the national fire protection regulations.	Zwilag SFS (CH)	YES
There is a need to reassess the fire protection measures to decide whether to install new provisions (e.g. fire dampers, smoke detectors, ventilation ducts, …).	ESSOR Plant- SFS (IT)	YES
Absence of multiple spurious operation (MSO) in FHA.	Krško NPP (SI)	YES
The fire hazard analysis performed in 2013 has not been revised and updated yet. It should be updated as part of Periodic Safety Review of the RR which is currently under development. According to the TPR Team, FHA should be revised at least every 10-years as part of the PSR.	TRIGA Research Reactor in Pitesti (RO)	YES

Finding	Installation	Mentioned in the NAR
Based on the FHA results, the fire protection system for RSV TAPIRO has to be improved, in particular with regard to the fire compartmentation and to the ventilation system.	TAPIRO Fast Neutron RR (IT)	YES
The site conditions create conflicting responsibilities between the site owner and reactor operator organisation, which complicates the approval processes for certain modifications or corrective actions.	RRs (HU)	YES
Thematic: **FIRE PREVENTION**		
No inventory of the flammable materials transported into the facility (e.g. packaging materials, paints).	Budapest Training Reactor (HU)	YES
No explicit fire loading limits: a proportionate approach is needed to implement the day-to-day management of fire loading with the assessment of fire loadings in the nuclear safety case.	Dounreay Prototype Fast Reactor - Decommissioning (UK)	YES
There are two different systems to support the fire load management. It doesn't allow to get information efficiently.	Leibstadt NPP (CH)	YES
There is a need to implement a system to document the inventory of fire loads (e.g. computer system).	Risø -Waste (DK)	
Thematic: **PASSIVE FIRE PROTECTION**		
The water fire extinguishing system which protects the cable compartments is obsolete.	Dukovany NPP (CZ)	YES
There is a need to complete the replacement of external underground fire hydrants with external over-ground fire hydrants.	Interim spent fuel (SK)	YES
The need for replacement of fire detectors due to ageing management.	Kozloduy Unit 5 NPP (BG)	YES
The verification and inspection process of the seals in fire resistant concrete dals is implemented but not yet integrated in all the maintenance procedures.	Tihange 3 NPP (BE)	YES
A need for standardisation of inspections and functionality testing procedures for fire dampers. Fire dampers must be visually inspected on site for actuation condition and such a method shall be properly addressed in relevant Ignalina NPP operating and maintenance procedures.	All installations (LT)	YES
Since there are no dampers installed in the ventilation system, the fire in the building can spread through the duct system.	Hot Cell facility - Risø site - Decommissioning (DK)	YES
Thematic: **ACTIVE FIRE PROTECTION**		
There is a need to elaborate procedures for the repair, the operability and the identification of fire protection system components.	Interim spent fuel (SK)	YES
There is a need to re-evaluate the use of voice alarm in the civil structure.	Interim spent fuel (SK)	YES

Finding	Installation	Mentioned in the NAR
Improve the implementation of spray water extinguishers regarding the Labour Code requirements. Incompatibilities with the process or particular water-reactive substances should be assessed in order to not degrade the safety of nuclear installations.	La Hague (FR)	YES
A need to install additional equipment that would allow remote monitoring of the situation in SNFSF-1 from INPP main control room.	SNFSF-1 (LT)	YES
Absence of fire extinguishing blankets that could prevent fires from developing and causing damage to the infrastructure.	TRIGA Mark II Vienna RR (AT)	YES
There is a need to reassess the detection strategy in area/rooms with harsh environment, in particular high radiation, according to the FSA, and consider the adoption of appropriate fire detection solutions where needed.	All NPPs (CH)	
The fire detection alarms are not simulated in the control room simulator.	Borssele NPP (NL)	YES
In the reactor building fire detectors are located only in the ventilation ducts.	Hoger Onderwijs Reactor- HOR (NL)	
Additional work is needed to review the components and replace the cable connections of the fire detection and protection system (FDPS).	Interim spent fuel (SK)	YES
There is a need to re-evaluate the possibility of controlling important fire equipment (HVAC equipment, ventilation of protected escape routes, fire doors, power shutdown) via the FDPS.	Interim spent fuel (SK)	YES
There is a need to strengthen the fire detection provisions in the context of the planned fuel transfer into the new dry storage facility.	ITREC plant - SFS (IT)	YES
Lack of detector for an area with combustible materials temporary storage.	Paks NPP (HU)	YES
There is a need to reassess the detection strategy in area/rooms with harsh environment, in particular high radiation, according to FSA, and consider the adoption of appropriate fire detection solutions where needed.	Paks NPP (HU)	
A need to implement solutions to improve the reliability of fire detectors that are operating in hard conditions (for instance, high radiation, humidity) in Solid waste treatment and storage facilities (B3/4 project) and Solid waste storage buildings 157, 157/1.	Waste (LT)	YES
Several automatic extinguishing systems do not fully comply with the current design requirements and regulations.	Borssele NPP (NL)	YES
Fire hydrants and piping not yet installed in the Reactor Building of Unit 1.	Cernavoda NPP Unit 1 (RO)	YES

Finding	Installation	Mentioned in the NAR
In the event of fire extinguished with water, the extinguishing water has to be retained and collected within the building concerned or its immediate vicinity. For two buildings out of the eight harbouring uranium-bearing materials, part of the extinguishing water is liable to infiltrate the soil. Thus, these two buildings must undergo improvements in order to retain and recover fire extinguishing effluents. These improvements are taken into account as part of the installation's ongoing periodic safety review.	Framatome Romans fuel fabrication facility (FR)	YES
Lack of automatic extinguishing systems.	MARIA, Świerk (PO)	YES
A need to complete replacement of old CO2-gas extinguishing systems, whose design basis does not comply with today's industrial standards.	Olkiluoto 1,2 NPP (FI)	YES
The intervention time of the intervention units may be delayed due to restricted access to certain rooms.	Mochovce 3,4 NPP (SK)	YES
TRANSVERSAL TOPICS		
Insufficient physical separation between redundant safety-related components (i.e. diesel generators, ventilators).	Budapest Research Reactor (HU)	
Inadequate management and qualification of isolation valves in the reactor building.	Hoger Onderwijs Reactor- HOR (NL)	
Lack of compartmentation or compensatory measures between redundant SSCs (UPS, diesel generators).	MARIA, Świerk (PO)	
The lack of compartmentation (rooms not everywhere separated by doors and absence of floor to ceiling wall) requires complementary analysis to verify and implement, if necessary, compensatory measures to ensure that fire does not spread from between different activities.	Risø - Waste (DK)	YES
Fire preventive measures rely to a higher degree on the adherence to operational procedures than on the structural and layout features of the building itself.	Risø site (DK)	YES
Automatic fire suppression is not guaranteed in case of SSE.	Borssele NPP (NL)	
The combination of fire and earthquake events is not systematically considered and documented in all nuclear installations, as applicable.	Cernavoda NPP Unit 1 (RO)	
FSA should consider seismically induced fire.	Lovisa 1, 2 and Olkiluoto 1,2 NPP (FI)	
Fire detection systems for buildings other than the reactor and turbine buildings and water extraction plant are not seismically qualified and not independent between adjacent compartments. A risk-based justification is not provided.	Paks NPP (HU)	
Lack of systematic consideration of combined or consequential hazards assessment as part of the current safety case.	Springfields Fuels Ltd (UK)	YES
FSA should consider seismically induced fire.	Tihange 3 NPP (BE)	YES

ANNEX VIII – Abbreviations and acronyms

ALARP	As Low As Reasonably Practicable
ATEX	Atmosphères Explosives/Explosive Atmospheres
BARPI	Bureau d'Analyse des Risques et Pollutions Industrielles (France)
BWROG	Boiling Water Reactor Owners Group
CDF	Core Damage Frequency
CFAST	Consolidated Fire and Smoke Transport
CFD	Computational Fluid Dynamics
CSF	Country Specific Finding
EC	European Commission
ENSREG	European Nuclear Safety Regulators Group
EU	European Union
FDAS	Fire Detection and Alarm Systems
FDT	Fire Dynamics Tools
FHA	Fire Hazard Analysis
FSA	Fire Safety Analysis
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit (Germany)
HEAF	High Energy Arcing Faults
IAEA	International Atomic Energy Agency
IEC	International Electrotechnical Commission
INES	International Nuclear and Radiological Event Scale
IRS	Incident Reporting System
ISO	International Organization for Standardization
JRC	Joint Research Centre
KTA	Kerntechnischer Ausschuss (Germany)
LOCA	Loss of Coolant Accident
LTO	Long Term Operation
MSO	Multiple Spurious Operations
NAR	National Assessment Report (of the topical peer review)
NEIL	Nuclear Electric Insurance Limited
NFPA	National Fire Protection Association (U.S.-based international organization)
NGO	Non-Governmental Organisation
NPP	Nuclear Power Plant
NUREG	Nuclear Regulation (U.S. Nuclear Regulatory Commission)
OECD	Organisation for Economic Cooperation and Development
NEA	Nuclear Energy Agency
OPEX	Operating Experience
PIE	Postulated Initiating Event
PSA	Probabilistic Safety Assessment
PSR	Periodic Safety Review
PWROG	Pressurized Water Reactor Owners Group
RR	Research Reactor
RROWG	Research Reactor Owners Group
SRL	Safety Reference Level
SSC	Structures, Systems and Components
SSE	Safe Shutdown Earthquake
SSG	Specific Safety Guide (IAEA Safety Standards)
TOI	Topic of Interest (in the topical peer review)
TPR	Topical Peer Review
ToR	Terms of Reference (of the topical peer review)
TS	Technical Specification (of the topical peer review)
TSO	Technical Safety/Support Organisation

WANO	World Association of Nuclear Operators
WENRA	Western European Nuclear Regulators' Association