WORKSHOP
"An engineering perspective on risk assessment: from theory to practice"

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SESSION I

Fundamental concepts of risk assessment and management

SESSION I / ID 01

A Scale of Risk: A Multidimensional Evaluation and Comparison of Risks

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This presentation offers a conceptual framework for ranking the relative gravity of diverse risks. The framework identifies the different aspects including moral considerations that should inform the evaluation and comparison of diverse risks and in turn shape the decisions for risk mitigation. A common definition of risk includes two dimensions: the probability of occurrence and the associated consequences of a set of hazardous scenarios. This presentation first expands the definition of consequences to include temporal aspects related to the duration of the consequences (which could be shorten by improving the resilience) and puts forward considerations on whose consequences matter. Then, the presentation expands the definition of risk to include a third dimension, namely, the source of a risk. The source of a risk refers to the agent(s) involved in the creation or maintenance of a risk. The source of a risk captures a central moral concern about risks. Finally, a scale of risk is proposed to categorize risks along a multidimensional ranking, based on a comparative evaluation of the consequences, probability, and source of a given risk. A risk is ranked higher on the scale the larger the consequences, the greater the probability, and the more morally culpable the source. The information from the proposed comparative evaluation of risks is targeted to inform the selection of priorities for risk mitigation.

SESSION I / ID 02

From Risk Analysis to Decision Support

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The role and character of risk analysis and risk assessments have undergone significant changes over the last 3-4 decades. From being mainly a procedural instrument to document that nominal risks associated with a given decision are under control and compliant with specified targets, risk analysis and risk assessments are increasingly utilized for optimizing or ranking decisions based on information on the actual risks they imply. Risk informed decision-making has attained a crucial role as an instrument for strategic, operational and tactical management both in industry, in public administration and regulation.

This development rests on increased emphasis and ability to represent systems affected by decision making in consistency with available knowledge, not least with respect to the systems performance characteristics, the uncertainties affecting these, the objectives of decision-making and the decision options whereby these may be optimized.

Building on the generic approach to risk assessment of engineered systems developed by the Joint Committee on Structural Safety, together with more recent developments in probabilistic systems representations and advances in applied decision analysis in engineering, the present contribution provides a decision analytical framework for the management of engineered systems subject to uncertainty.

The framework may be utilized to rank decision alternatives for the management of systems accounting for possible consequences to life safety and health, damages to the qualities of the environment and financial efficiency – in consistency with societal and individual preferences for their management. The framework facilitates both traditional engineering bottom up modelling as well as results of data mining and accounts for deep systemic uncertainties. The pre-posterior decision analysis, through the concept of Value of Information (VoI) analysis, is introduced as an efficient means to identify how additional knowledge may best support the management of a given system. Furthermore, in addition to risk and reliability, the system characteristics vulnerability, robustness and resilience are formulated probabilistically, providing enhanced understanding of the performances of the systems and how these may be managed optimally.

Finally, the application of the framework is discussed with reference to a selection of examples from practice and a discussion is provided on challenges and prospects for further developments.

SESSION I / ID 03

Fire Probabilistic Risk Assessment in the US Nuclear Power Industry

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Fire protection in US nuclear power plants was long regulated under a set of federal regulations called 10 CFR 50.48 Appendix R that prescribed fire protection measures. In 2001, the National Fire Protection Association issued NFPA 805, a performance based standard for fire protection at nuclear power plants. This standard, endorsed by the US Nuclear Regulatory Commission (NRC), allowed plants to transition from a prescriptive fire protection program to a performance based. Since the issue of NFPA 805, the NRC has issued additional rules allowing the use of risk assessment in support of maintenance and plant technical specifications. All of these applications require a detail risk model of the plant of which fire is a major contributor to overall risk. This presentation will give an overview of risk assessment at US nuclear power plants with a focus on fire risk assessment and the hierarchy of modeling tools used in support of the assessment.

SESSION II

The role of fire modelling in risk assessment

SESSION II / ID 04

Experiments and Modeling in Support of Nuclear Power Plant Probabilistic Risk Assessment in the USA

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For the past two decades, the Fire Research Division at the National Institute of Standards and Technology (NIST) has performed fire experiments and numerical modeling to support the transition by the US Nuclear Regulatory Commission to a performance-based, risk informed approach to fire safety. The presentation will briefly describe the various projects, including fire model verification and validation, cable fires, compartment fire dynamics, protective cable coatings, incipient fire detection, high energy arc faults, and uncertainty analysis.

SESSION II / ID 05

Treatment of uncertainty in fire safety risk analysis

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Fire safety engineering is still a rather young engineering discipline which is under a rapid development. Historically, fire safety issues have been treated by prescriptive means based on lessons learned from incidents that had occurred. The practical problem occurs when there is no reference to be used. The traditional solution has been to rely on expert judgement, often with limited evidence. The result could then lead to a costly solution as a conservative design approach would be used in order to try to fit the prescriptive specifications. But because of the introduction of performance based codes or specifications scientifically based engineering methods have become more frequent to verify a proposed fire safety solution for a facility. However, there is still a lack of consensus regarding methods to be used to not only verify a specific exposure condition, i.e. a specified scenario, but to also include the treatment of the inherent uncertainty. The presentation will focus on how, in a practical application, more or less quantitative risk assessment methods can be used in fire safety engineering verifications and what are the limitations of some of these. The presentation will also cover the relation between applied methods and the level of detail of the uncertainty treatment in the assessment.

SESSION II / ID 06

Practical approaches to QRA in fire protection engineering

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The goal of this presentation is to discuss QRA methods in the area of fire engineering from own engineering experience and from a wider fire community and literature. QRA usually involves issues such as input data and scenarios, models, uncertainty, sampling techniques and assessment criteria. All these elements are often difficult to address in practical QRA due to lack of data, knowledge or because of stochastic nature of fire events or lack of appropriate tools or models which facilitate such analysis. Typically the first difficulty is to address fire initiation i.e. its frequency and modes. Unfortunately such data is often hard to find for many specific applications. Further progress of analysis depends on the type of event modeling is selected. The least complex approaches involve fault trees, event trees, bow tie and other methods which are also popular in process safety and nuclear engineering. These methods involve some assumptions on probabilities both for protection systems and human response to characterize their performance and reliability. This stage must also include some characterization of the interactions between protection measures. All this event analysis typically requires significant amount of expert judgment. A more quantitative approach involves physical fire modeling of multiple scenarios which is based on models with complexity level that is carefully selected for the problem at hand. In such cases either the whole fire is modeled or only selected fire phenomena which are particularly relevant. Typically the central issue is design fire characteristics – fire spread rate, heat release rate, smoke generation and the resulting fire development and all related events strongly depend on fire input data and their associated uncertainty. Multiple scenario calculations accumulated using some sampling technique such as Monte Carlo can give us risk profiles which are usually more representative in terms of risk than a single scenario calculation. The last stage of QRA involves the assessment and ranking of consequences – typically in terms of human, monetary or environmental losses. A separate issue is the selection of acceptance criteria which must be established or adopted. Very often due to lack of absolute criteria some comparative criteria are used where risk levels are compared with existing standards or legally accepted solutions. Full QRA in fire engineering is a complex process and ideally it should be done using comprehensive engineering tools. Many attempts have been made in this area in fire engineering discipline but there is still a significant need for integrated analytical tools. Some existing tools will be discussed together with some own solutions.

SESSION III

Practical applications of risk assessment in process safety

SESSION III / ID 07

Quantitative risk assessment in process safety studies: an overview

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In framework of process industries (e.g., chemical and petrochemical facilities), major accidents are accidental events connected with the use of hazardous materials in an industrial site. Major fires, explosions, toxic dispersions/contaminations constitute examples of possible events leading to serious danger to human health and/or the environment. These events feature high magnitude or impact, but an extremely low expected credibility (probability), thus they are often framed as HILP (high impact – low probability) events. In order to undertake the risk assessment of HILP events, there are specific procedures and related tools, which are widely adopted in the technical and scientific literature.

The present contribution is firstly aimed at providing a summary of the currently applied tools to support QRA studies and the analysis of HILP events in the process industry; in particular, hazard identification techniques, probability and frequency assessment, consequence or impact assessment are briefly framed, highlighting key aspects and limitations. The advances in this field based on the development of simulations codes, such as computational fluid dynamics, are also remarked. Secondarily, the relevant risk metrics and indicators based on the outcomes of the previous analyses (also named “risk recomposition stage”) are discussed. The procedure for the evaluation of the more frequently used risk indexes in this framework is discussed. Examples of typical results obtained in QRA analyses are also shown.

Finally, the aforementioned risk metrics are discussed in the perspective of supporting the discussion of two relevant aspects: 1) definition and adoption of specific risk acceptance criteria, especially in the framework of land use planning around industrial process facilities; 2) application in domino effect studies, dealing with the optimization of critical protection systems. Specific examples related to the European industrial context are finally provided.

SESSION III / ID 08

ESS fire-and explosion safety programme-deterministic and probabilistic conditions – case study on acceptance criteria to open smoke hatches in the instrument building.

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A number of Swedish acts and ordinances give the basic requirements of facility safety. None of these are tailored for ESS, hence interpretation is required for appropriate application.

The Licensee shall as far as reasonable possible, based on existing technical experience and economical and social circumstances, undertake measures to limit 1) production of radioactive waste, 2) release of radioactive substances and 3) exposure to environment from ionizing radiation, ref. Radiation Protection Act (2018:396).

Applicable legislative conditions go in to the design. As an example of that is the planning- and building act which requires implementation of: e.g. fire rated partitioning, emergency lights and fire alarm. The defence-in-depth approach (DID) is derived from the radiation protection act by the ESS-0001051 "Protection against fire and explosion". The DID is an important factor of justification to keep fire and explosion at the predicted frequency and consequence. The DID for fire safety sets the deterministic foundation by; 1) preventing the start of fire by housekeeping, to apply proven electrical installation standards etc. 2) quickly detecting and extinguishing the design fires 3) preventing spread of any fire that has not been extinguished. The DID for explosion safety sets the deterministic foundation by 1) preventing explosions by minimizing formation of explosive atmospheres 2) minimizing the risk of an explosion if an explosive atmosphere cannot be avoided 3) implementing design provisions necessary to limit the consequences of an explosion.

The Swedish Radiation Safety Authority has released "Special conditions for the ESS facility in Lund", ESS-0018828. The special conditions set numeric acceptance criteria for potential risk of radiation exposure to public. For the following event classes the reference values, shall apply as a maximum limit for radiological ambient consequences for the facility. Event class:

- Anticipated events (H2) – 0,1 mSV,
- Unanticipated events (H3) – 1,0 mSv,
- Improbable events (H4A) – 20 mSv,
- Events with multiple failures (H4B) – 20 mSv,
- Highly improbable events (H5) – 100 mSv.

Fire- and explosions in the vicinity of radiation sources are initiating events with the potential to expose the environment with contaminated products.

Hence fire- and explosions have to be quantified regarding frequency and their potential consequences.

Statistics on fire and explosions from particle physics accelerators should justify probability of having a fire or explosion resulting in environmental consequences from ionizing radiation. Lack of co-ordination and assembled data makes it difficult to justify statistics on fire and explosions at particle physics accelerators. The “Future Circular Collider” project elaborated on a pilot case where statistical data based nuclear power plant statistics (a priori data from OECD FIRE Database) were applied on particle physics accelerators (a posteriori data by the use of DOE accelerator statistics).

Case study – Is it acceptable for Rescue Leader to open the smoke hatches in case of fire in the instrument building?

Smoke hatches are installed in the roof of the instrument halls. Fire modelling is performed to optimize evacuation logistics of occupants and protection of the structural steel. A full cover wet-pipe sprinkler is installed in the ceiling. In case of a severe fire scenario the sprinkler should be activated to suppress the fire before the smoke hatches are opened otherwise the sprinkler may not succeed to suppress the fire. Manual opening of the smoke hatches from a panel at ground floor is in design. In case of a severe fire scenario radioactive particles may also be dispersed with buoyance from the fire. The question is if it is acceptable to open the smoke hatches even if there is a risk of spread of radioactive particles to the atmosphere?

An early estimation included all potential ionizing nuclides inside an instrument hall during normal operation. A conservative assumption was that all nuclides are carried out through the smoke hatches by the fire. The total effective dose is 0,04 μSv to public (From inhalation 0.032 μSv and from external gamma radiation 0.012 μSv).

An unanticipated event (H3) allows 1 mSv to public. Hence any interlock of the smoke hatches should not be necessary. However if the accident originate from the target itself, the radioactive exposure may be different.

A master thesis project was performed by Ettore Carini in 2017, ESS-0190288 “Modelling and assessment of the dispersion of particles in the ESS instrument hall”. The supervisors were: Fredrik Jörud (ESS), Per Nilsson (ESS), Bjarne Husted (LTH), Anders Schmidt Kristensen (Aalborg university). The scenario set up is based on explosion in target area resulting in further fire in electronics and combustible shielding inside the instrument building. The scenario is regarded as worst case when it comes to consider ionizing particles released in the instrument building. Probably the scenario can be regarded as a highly improbable event (H5).

The thesis provides for expected behavior of the radioactive particles and to what extent they escape from the instrument hall if the smoke hatches are open. “Ansys Fluent” is considered suitable CFD software for modelling this fire simulation.

SESSION III / ID 09

Uncertainty in the assessment of BLEVE risk in process plants and in transportation

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BLEVE explosions keep occurring from time to time in process plants, storage and transport by road or rail. Concerning the materials, the highest contribution is that from LPG and water, but many other liquids can also be involved; depending on their properties, the explosion can be followed by a fireball or a toxic cloud.

Although diverse models and methodologies have been proposed to calculate the mechanical effects from a BLEVE, this prediction is subjected to a series of uncertainties: pressure inside the vessel, amount of material contained, contributions to the energy released (vapor expansion, liquid flashing), fraction of energy released devoted to create overpressure. Another important aspect to consider is the time to failure in a situation which can lead to the explosion. Due to these uncertainties, a series of assumptions must be applied –besides the classical use of expected probabilities or failure frequencies– to perform the risk analysis. In this communication these different points are analyzed and the corresponding practical criteria are proposed, based on the analysis of two cases.

SESSION IV

Cost effectiveness and damage estimation in risk assessment

SESSION IV / ID 10

Monetary optimization and quantitative risk acceptance criteria: from theory to practice

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Fire safety codes around the world are based on two different approaches to regulate building fire safety: Prescriptive or performance-based design. The prescriptive approach, as implemented in most traditional fire safety codes, allows for a simple and effective risk control for the majority of buildings, but offers little flexibility to the designers and is difficult to apply in specific situations. Performance-based design aims at mitigating these drawbacks but raises new questions regarding the definition of safety goals and performance objectives, in particular quantitative ones. Risk assessment, optimization and quantitative acceptance criteria for decisions affecting life safety can help closing the gaps in both approaches, either by adding flexibility to prescriptive code design or by defining a quantitative framework for risk-based decision-making in the context of performance based design.

The presentation shows how the basic principles of monetary optimization and societal risk acceptance can be applied in practical fire safety design problems. Special attention will be paid to the maintenance of existing buildings in contrast to the design of new structures, and to the consideration of buildings with special features that prohibit the simple application of prescriptive design rules. The main questions and challenges will be illustrated with practical examples from the area of fire safety design, but also from other areas like e.g. natural hazards protection, as appropriate.

SESSION IV / ID 11

Quantitative fire risk assessment to optimise investments into fire safety

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Decisions concerning investments into fire safety are usually made based on the reduction of risks, whereas the costs of fire safety measures are often neglected. However, for a thorough assessment, both aspects need to be considered and a balanced ratio between costs and risk reduction should be aspired. Such an assessment leads to optimised fire safety measures.

We show how quantitative risk assessment is used in two case studies to find optimised fire safety measures. The first case study shows how to avoid business interruptions in an airport control tower due to a fire. Quantitative risk assessment in the second case study is used to justify deviations from technical standards when dealing with fire hazards that clearly deviates from the standard case. In both case studies the whole event chain of a fire is considered, starting from the modelling of fire ignition and fire spread, up to the suppression of the fire by sprinklers and the fire brigade. Since life safety issues were covered by the prescriptive fire safety measures, the optimisation focused on economic losses due to a fire. The economic losses due to a fire were accounted for damages to property as well as for the loss of business continuity after a fire. Especially when the loss of business continuity is considered, optimised measures can be found that improve also the resilience of the system.

In addition to the case studies, we provide some insights to risk modelling techniques, applied acceptance criteria and advanced uncertainty propagation techniques which allows an adequate uncertainty treatment when using computationally demanding tools.

SESSION IV / ID 12

Probabilistic seismic risk analysis in the insurance industry: the University of Naples Federico II – AXA-MATRIX approach

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State-of-the-art seismic risk assessment develops in a fully probabilistic framework due to the large uncertainties inherent to the earthquake characteristics and to the seismic response of civil structure/infrastructure. The consolidated approach is that of performance based-earthquake engineering (PBEE) in which the target is to compute the expected annual loss due to seismic damage (e.g., property damage, business interruption, fatalities, etc.) to a civil system of interest. Such a calculation is, for convenience, split in three phases the results of which eventually combined: (i) probabilistic seismic hazard analysis; (ii) seismic fragility assessment; (iii) consequence/loss modelling. The hazard is related to the seismicity of the site of interest and is only dependent on the tectonic environment; (ii) is the probabilistic characterization of the seismic vulnerability of the system of interest (e.g., a structure); (iii) is the probabilistic modelling of the value of the consequences of the seismic damage. PBEE is the rational way to compute the seismic risk and can be applied to individual buildings as well as to spatially-distributed systems (e.g., utility distribution networks). It allows to consistently and quantitatively account for all the uncertainties involved.

The talk, will be devoted to illustrating the basic concepts of probabilistic seismic risk analysis and how it is going to find its way into the insurance industry. In particular, the Fragility-based Rapid seismic Risk AssessMEnt (FRAME) approach, developed by the University of Naples Federico II and funded by AXA-MATRIX Risk Consultants, is discussed. The main objective of FRAME is the world-wide assessment of structure-specific seismic risk, based on seismic hazard and fragility functions, for a number of structural typologies. To this aim, it relies on worldwide seismic hazard estimates, an expandable fragility curve inventory and damage-to-loss relationships, allowing to translate the structural damage into an expected loss for both direct damage and business interruption.