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Summary of ETSON strategic orientations on research activities.

ETSON Research Group activity

EUROSAFE 2017

Context

- Six years after publication of the ETSON “Position Paper of the Technical Safety Organizations: Research Needs in Nuclear Safety for Gen 2 and Gen 3 NPPs”, the need appeared to update it to account for the progress of many R&D international projects in diverse frames and the progress made by ETSON partners:
  - OECD/NEA/CSNI,
  - Euratom (FP7 and H2020),
  - Analysis of the Fukushima-Daiichi severe accidents,
  - NUGENIA roadmaps in 2013 and 2015 on research on Gen.II and III NPP, including safety aspects.

Process of ranking of R&D priorities (1)

- Basis of the list of R&D issues from the 2015 NUGENIA R&D roadmap that covers the 6 following topical areas:
  - Plant safety and risk assessment,
  - Severe accidents,
  - Improved reactor operation,
  - Integrity assessment of systems, structures and components,
  - Fuel development, waste and spent fuel management and decommissioning,
  - Innovative LWR design and technology.
- Selection of issues (among 150) focusing on the safety aspects and avoiding the topics where significant R&D is ongoing in an international frame.

Process of ranking of R&D priorities (2)

- The results indicated some scattering of issues but also the possibility to identify issues with a majority of votes ⇨ 8 issues were underlined as highest priority *(no order of priority among them, see the following slides)*.
- The following slides summarize very shortly, for each of them, the importance of the issue for safety, the state of knowledge and the remaining gaps, and the international context.
- Note that, as requested, the selected issues do not cover important issues already addressed in current projects, such as for instance on severe accidents : In-Vessel-Melt-Retention in H2020 (IVMR project) or source term in OCDE frame (STEM2, BIP3, THAI3 projects).

Improved thermal-hydraulics evaluation for the existing plants (1)

- NPP response represents a complex interplay of the processes and phenomena in the subsystems ⇨ Large-scale integral experimental facilities and simulation system codes are thus essential or NPP safety analyses.
  - Need to maintain the integral facilities (see CSNI review: some were dismantled, but some remain as LSTF, MOTEL, or ACME)
- In complement, need of experimental and numerical studies of separate effects at smaller scales.
  - Single-phase flow experiments and CFD codes are a mature field,
  - Two(multi)-phase field is much more difficult to address, with detailed 3D flow models that still rely on (semi)empirical closure relations which must be carefully considered for each particular geometry and phenomenon.

Improved thermal-hydraulics evaluation for the existing plants (2)

- Most important research directions for TSOs is upgrading of system codes with (quasi)3D modules for 3D components, especially the reactor vessel:
  - These coarse grid models can be tuned with CFD results and high-resolution experiments.
  - Need of coupling with 3D neutronic models and more detailed description of the heat transfer and mixing in the core region.
- More attention should be paid on integral scale studies, typically much more expensive, and that can be seen as critical infrastructures to maintain (integral facilities, equipment, knowledge and experts).

Spent fuel pool accident scenarios (1)

- Importance of SFP safety, as underlined by the Fukushima Daiichi accidents, with possible large radiological consequences on-site and off-site if the accident cannot be prevented or mitigated.
- Identification of main knowledge gaps in a recently completed CSNI activity, led by IRSN, with participation of several ETSON members, including a PIRT on loss-of-cooling and loss-of-coolant accidents:
  - Cladding chemical reactions with mixed steam-air environments and in low temperature range,
  - Thermal-hydraulics and heat transfers for the coolability of partly or completely uncovered fuel assemblies,
  - Thermal-hydraulic behaviour and large-scale natural circulation flow pattern, with fuel assemblies covered with water,
  - Spray cooling of uncovered spent fuel assemblies.

Spent fuel pool accident scenarios (2)

- A few experiments, specifically targeted to SFP accidents, are underway or planned in Europe,
  - In particular within national projects focusing on SFP issues that are addressed by several ETSON members (e.g. in BelV, IRSN, LEI, SSTC-NRS etc.)
- Improvements of models and computer codes are still necessary, and validation will continue against the produced data.

Methodologies for beyond design basis assessments

- With update of IAEA requirements, the analysis of DEC that include multiple failure events without nuclear fuel melting, as well as severe accidents, becomes an intrinsic part of the plant safety assessment, and appropriate safety features for preventing such conditions or mitigating their consequences are required to be included in the NPP design.
- Individual aspects of the methodology for BDBA are reflected in national regulations of ETSON member states but still some questions are to be addressed : e.g. how to ensure that all relevant scenarios are considered, what is the extent of failures to be considered, how the uncertainties shall be identified and accounted for ? ⇨ TSO need to get unified detailed guidelines that cover all BDBA stages.
  - It should include the incorporation of up-to-date results of R&D on phenomenology, validation of computer codes and models and procedure for treatment of inherent uncertainties.

Corium thermophysical and thermodynamic properties (1)

- For SA analysis, thermodynamic models are required to predict the corium behaviour, the fission product releases and the residual power within the corium different phases ⇨ Need to know the composition of the phases present in the corium and its physical-chemical properties,
- Many past projects in Euratom, ISTC and OECD (MASCA…) frame,
- Two main bases are internationally used: NUCLEA/MEPHISTA (French IRSN and SIMAP) and TAF-ID (in OECD frame),
  - Link with recently launched OECD/NEA project “Thermodynamic Characterisation of Fuel Debris and Fission Products” (TCOFF) project, led by Japan, aiming at improving these bases for SA scenario analyses, particularly the Fukushima-Daiichi accident.

Corium thermophysical and thermodynamic properties (2)

- Main gaps of knowledge in databases
  - Interactions between molten U-Zr-O and iron/steel within the vessel due to their impact on the heat flux to the vessel (failure conditions or IVMR), and extension to MOX fuel,
  - Impact of stainless steel oxide components on thermochemistry of the corium-concrete mixtures, with need of new experiments,
  - Activity coefficients of the Ag-In-Cd control rod elements in the melts, as main contributors of source term in terms of mass of aerosols release (Ag and Cd very reactive with iodine).
- There is a strong link with the issue of development of severe accident integral codes since the latter will strongly benefit from new data on material properties.

Development and validation of severe accident integral codes (1)

- Key role of SA integral codes (such as mainly MELCOR and ASTEC for ETSON, but also MAAP used by the industry), storing all knowledge developed in the last decades, for evaluating SA progression and supporting SAM.
  - Essential field of applications in next years: need to improve SAM guidelines.
- Several past projects in Euratom (SARNET, CESAM…) and international benchmarks underlined the following modelling improvements in priority:
  - Coolability of the degraded core and IVMR strategy,
  - Coolability of corium during Molten-Core-Concrete-Interaction in the NPP cavity after a possible vessel failure,
  - Mitigation of potential source term (I, Ru…), in particular use of FCVS and accident long term situation.

Development and validation of severe accident integral codes (2)

- Other subjects for future improvements:
  - More systematic coupling with uncertainty estimation,
  - More “crosswalk” activities (e.g. code-to-code exercises involving developers’ teams),
  - Coupling with specialized codes to predict the impact of the source term in the environment (release, transport, dispersion),
  - In order to reduce the users’ effect:
    - Users’ training programs, led by international recognized experts,
    - Well-defined international cooperation platforms of research activities for developers/users exchange of opinions, methods…. (NUGENIA/SARNET, CSARP/MCAP, OECD/NEA ISP….),
    - Advanced Graphical User Interfaces to support the users in the input-deck preparation and make easier the post-processing.
- And obvious need of continuous process of validation vs. experiments (and application to Fukushima accidents)

Impact of single or multiple external events (1)

- The EU FP7 ASAMPSA_E project (2013-2016) *(see the EUROSAFE-2017 paper)* aimed at supporting a systematic extension of PSA to all potential natural or man-made external and internal hazards ⇨ Guides for European stakeholders in conducting extended PSAs and ensuring that all dominant risks were identified and managed.
  - Led by IRSN with participation of many ETSON members,
  - Discussion under way to perpetuate the activities of this "network" in NUGENIA frame.
- Needs also covered by the NARSIS H2020 current project (concomitant external events, fragility of SSCs, combination of risk integration with uncertainty quantification….)

Impact of single or multiple external events (2)

- A few identified areas for future developments from the ASAMPSA_E conclusions:
  - External flooding hazard: lack of site-specific data and limitations of spatial modelling and downscaling methods, quantification of uncertainties for common-cause failures, integrated modelling of hazard internal/external impact assessment, etc.
  - Meteorological hazards: quantifying the correlation mechanisms between extreme weather events, estimation of the impact of climate change, development and validation of downscaling methods and tools for analysing and characterizing spatially distributed extreme data, etc.
  - Seismic hazards: reduction of aleatory and epistemic uncertainties in derivation of seismic hazard and fragility curves, methods for deriving conditional probabilities of seismically induced consequential events such as fire and flood.

Ageing/degradation mechanisms, modelling and materials properties for metallic components (1)

- In the frame of NPP LTO extension, need to take thoroughly into account the ageing/degradation mechanisms, through e.g. knowledge of materials properties and computational modelling, in particular on metallic components such as for vessel or internal structures.
- “Time limited ageing analysis” (TLAA) done on basis of temperature and stress distributions across the components; computation with heat transfer and structural mechanics analyses (typically FE codes) with results as input data for the degradation propagation analyses. For local flaws, e.g. cracks, these analyses are carried out applying fracture mechanics and empirically derived crack growth correlations.

Ageing/degradation mechanisms, modelling and materials properties for metallic components (2)

- Main gaps of knowledge: modelling of irradiation embrittlement, thermal fatigue, SCC and mechanical wear as well as joint action of degradation mechanisms.
- Current active research in Euratom frame with participation of some ETSON members:
  - SOTERIA on irradiation embrittlement,
  - INCEFA+ on joint action of corrosion and fatigue,
  - ATLAS+ (led by VTT) on thermal fatigue and fracture mechanics based modelling of degradation mechanisms.
- But, despite this intensive activity in Europe, this issue selection underlines the very high importance given by TSOs on such issue.

Small modular reactors (1)

- Revival of SMRs is driven by the potential for enhanced safety and security while reducing capital costs and thus investment risks, through design simplification,
  - Improved technologies and methods will be implemented, thus contributing to the demand of higher safety and reliability without sacrificing the LWR long-lasting operation experience,
  - The ETSON priority concerns are LWR-type SMRs, and the basis for further success is the progress of knowledge, which also includes validated simulation tools.
- Several international activities were initiated in IAEA and OECD/NEA frame, as well as in the UK and in Germany (by GRS).

Small modular reactors (2)

- Tools and facilities:
  - Existing codes are good basis for SMR simulation but will need efforts for further development and validation,
  - Requested new “component-level” experiments with advanced (two-phase flow) measuring techniques,
  - Request also of integral tests (e.g. on mutual interaction of different passive safety systems) but several facilities are available in Europe (INKA, PANDA, HCSG).
- Main subjects for future improvements:
  - Fuel: advanced fuel patterns, innovative designs, increase of enrichment and burn-up, boron-free cores,
  - New working fluids with extended scopes,
  - Passive safety systems and their mutual interactions, natural circulation and flow instabilities,
  - Innovative heat exchanger designs,
  - 2D/3D models for simulation of temperature and velocity fields in large water pools.

Conclusions and perspectives

- These R&D highest priority issues correspond mostly to the objectives of the new 2014/87 Euratom Directive on the safety of nuclear installations, as shown in the ETSON EUROSAFE-2015 paper (in particular defence in depth and avoiding radioactive releases outside a nuclear installation).
- Most of them were also identified in the ETSON 2011 position paper.
- This ranking will first serve as basis for new potential research projects, either to be performed by ETSON partners only, or as a basis to be proposed in a larger frame such as NUGENIA or H2020. The ranking will also serve as the ETSON input to future roadmaps or international R&D projects.