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ETSON views on R&D priorities for implementation of the 2014 Euratom Directive on safety of nuclear installations

New Euratom Safety Directive (1/2)

- The safety of nuclear energy production in the EU is the primary responsibility of NPP operators supervised by independent national regulators ⇨ Importance of EU-wide approach to nuclear safety because a nuclear accident could have negative consequences for countries across Europe and beyond.
- Following the Fukushima-Daiichi accident in 2011, the Council Directive 2009/71/Euratom that established a Community Framework for the safety of nuclear installations was reinforced in July 2014 through the 2014/87/Euratom amending Directive.
  - Its scope covers most nuclear installations (NPP, nuclear fuel fabrication plant, spent fuel storage facility….),
  - It applies to nuclear installations with licence after August 2014, but reference for timely implementation of reasonably practicable safety improvements for existing nuclear installations.

New Euratom Safety Directive (2/2)

- The fully new article 8 addresses some ERG (ETSON Research Group) closely related issues:
  - *Objective to prevent accidents and mitigating its consequences, avoiding:*
    - *Early releases requiring off-site emergency measures but with insufficient time to implement them*
    - *Large radioactive releases requiring protective measures that could be limited in area or time*
  - *Defence-in-depth to ensure:*
    - *Minimizing the impact of extreme natural and unintended man-made hazards*
    - *Preventing abnormal operation and failures*
    - *Controlling abnormal operation and detecting failures*
    - *Controlling DBA*
    - *Controlling severe conditions, incl. prevention of accident progression and mitigation of SA consequences*

2011 ETSON Position paper

- This document, released in October 2011, prioritized the research needs according to their relevance-to-safety,
  - Accounting for preliminary lessons from the Fukushima-Daiichi NPP accident,
  - Used for ETSON contribution to the NUGENIA R&D roadmap.
- These R&D highest priority needs are still valid and correspond mostly to the objectives of the Article 8 of the 2014 EU Directive,
- In the following, for each main Art.8 above objective, ETSON R&D priorities are reminded and the ETSON TSOs involvement is illustrated through some examples of on-going or planned new R&D projects (it is not an exhaustive list).

Extreme natural and unintended man-made hazards (1/2)

- General comments:
  - Lack of an integrated approach to hazards assessments in general, which applies to external natural hazards as well,
  - Possible close link between internal and external hazards (e.g. seismic event can cause fire and flooding) and protection against both needs to be considered together,
- Main needs for future work:
  - Integration of natural external hazards in plant safety case and PSA,
  - Development of hazards PSA requirements,
  - Hazard combinations,
  - External events modelling,
  - Fire and smoke (propagation, modelling…,)
  - Human reliability for hazards PSA,
  - Simulators extension (for operator training).

Extreme natural and unintended man-made hazards (2/2)

- Some R&D projects with participation of ETSON members :
  - EC FP7 ASAMPSA-E (“Advanced Safety Assessment Methodologies: extended PSA”), led by IRSN, for extending the PSA scope to all potential natural or man-made external hazards and developing guidance documents,
  - Activities of OECD/NEA WGRISK (Working Group on Risk Assessment) and of other groups such as for instance the Task Group on Natural External Events,
  - PRISME2 (“Fire Propagation in Elementary, Multi-room Scenarios") OECD/NEA, led by IRSN, on fire experiments and modelling,
  - New proposal AMENOFIS (“Advanced Methods for the Evaluation of Noxious consequences Of Fires on Installations Safety”), led by VTT, for the next H2020 call, on new and improved methods, recommendations and guidelines to support Fire-PRA and the performance-based design of fire safety.

Preventing abnormal operation and failures, controlling abnormal operation and detecting failures

- Prevention of abnormal operation and failures needs to address instrumentation, I&C and regulation systems, maintenance of equipment and systems, and operators‘ actions ⇨ *here focus on electrical power supply systems.*
- Main R&D recent activities in OECD/NEA/CSNI through ROBELSYS (ROBustness of ELectrical SYStems) Task Group, led by IRSN, based on the former DIDELSYS projects ⇨ recommending CSNI to establish a permanent working group on electrical systems.
- Some actions were recommended that imply R&D, among which some below concern more TSOs:
  - Conduct a Hazard Review to determine the plant-specific range of possible voltage surge transients.
  - Review the impact of voltage surge transients propagating through power supplies, with detrimental effects on safety system loads

Defence in depth (1/3)

- Defence in depth concept should be improved at two levels (IAEA Safety Standard Series SSR-2/1 2012):

  (1) Prevention of (severe) accidents through decay heat removal from the reactor core and the spent fuel pool

  (2) Protection of the integrity of the containment (last barrier before release of reactivity to the environment in case of severe accidents)

- Passive Safety Systems (PSS) have the potential to create options and extra time in accidents characterized e.g. by loss of power and loss of cooling water:

  - The function of PSS is based on physical phenomena (gravity, convection, condensation and/or evaporation) independent of operator actions,
  - Therefore lower failure rates are attributed to passive safety systems,

Defence in depth (2/3)

- Different PSS definitions impede the development of assessment methodology and acceptance criteria, comparison of active / passive safety systems:
  - **IAEA** (TECDOC-626): Cat. A – D
  - **EPRI** (Advanced Light Water Reactor Utility Requirements)
  - **National regulations** (e.g. German KTA rule 3301)
- Selected open R&D issues:
  - Behaviour under deviating, unexpected or extreme conditions,
  - Testing of PSS, evaluation of the reliability when a PSS can be neither tested, inspected or maintained,
  - Influence of aging,
  - Assessment of parallel operation of mutual interactions of redundant trains,
  - Evaluation of the mutual influence of different PSS,
  - Requirements for analytical / experimental proofs,

Defence in depth (3/3)

- Planned European R&D proposals for the next H2020 Call with participation of ETSON members :
  - ***NUSMoR*** (NUgenia Small Modular Reactor)
    - Screens and comparatively evaluates relevant safety feature designs of existing SMR (e.g. SCOR, FLEXBLUE®) and innovative new ideas
    - Use of the ocean as ultimate heat sink
    - Breakthrough in nuclear because it enables an infinite decay heat removal without any need for electricity of external input
  - ***REPASS*** (REtrofitting of PAssive Safety Systems)
    - Investigates and develops PSS for residual heat removal from the reactor coolant system or from SFPs, in particular for retrofitting to existing NPPs

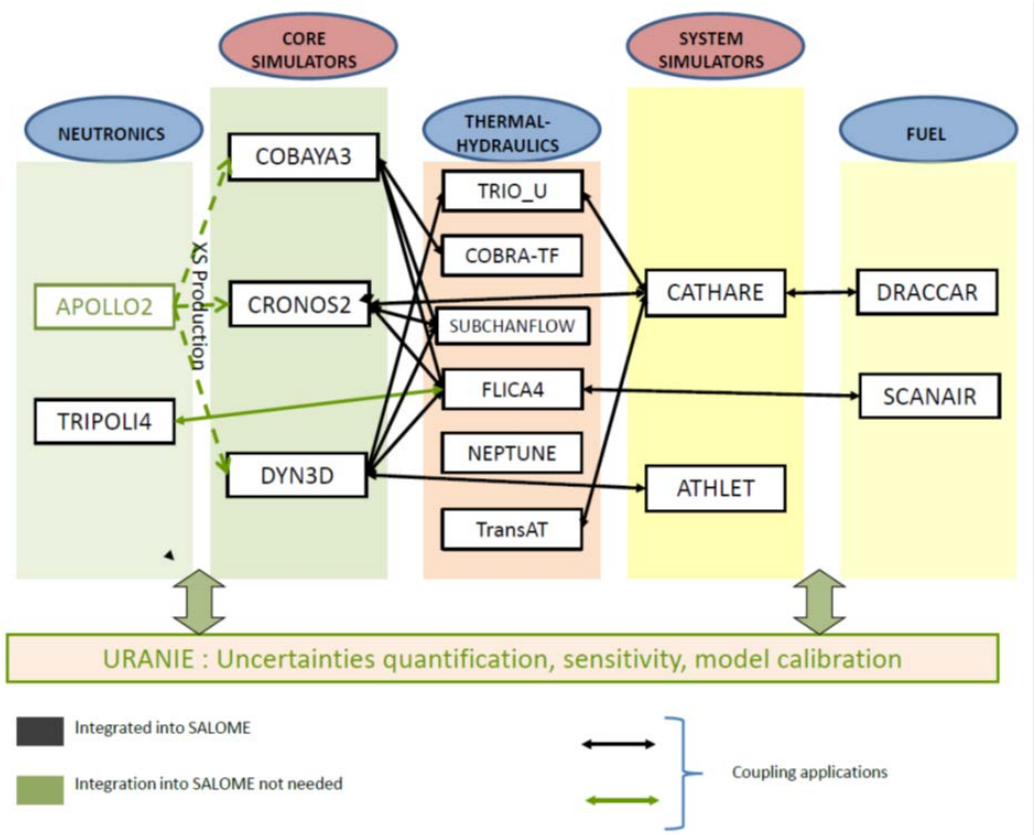
Controlling DBA (1/2)

- Main general R&D needs: safety margins methodology (which comprehensively combines the advantages of deterministic and probabilistic approaches), multi-physics and multi-scale tools, and uncertainties
- In more details, some high priority topics:
  - Coupling between thermal-hydraulics and neutronics codes
  - Effects of gas intrusion or release in reactor coolant system
  - Passive system behaviour
  - Containment thermal-hydraulics
  - Safety assessment through benchmarking and experiments
  - Coupling of system thermal-hydraulics and CFD codes
  - Mixing in pools and vessels at low flow rates
  - Stratification in pools and vessels
  - Water hammer assessment

Controlling DBA (2/2)

- Main R&D activities with participation of ETSON members :

NURESAFE (2013-2015), led by CEA with contribution of several ETSON members on reliable software capacity for safety analysis needs, delivery of multi-physics and fully integrated applications on some safety relevant “situation targets”



Controlling severe conditions, incl. prevention of accident progression and mitigation of SA consequences (1/4)

- Most activities in Europe in recent years took place in the frame of SARNET network (Severe Accident Research NETwork of excellence) (2004 to 2013 in Euratom FP6-FP7)
  - Coordinated by IRSN with a strong involvement of the ETSON members (both in technical and management aspects),
  - Now integrated in the NUGENIA Association
- Update of ranking of priorities in 2012-2013 by a group of SARNET experts:
  - Accounting for the preliminary lessons from Fukushima accidents,
  - Accent put more on SAM than knowledge of phenomena (as in the past) and on BWR (past R&D was done mostly for PWR),
- Unique opportunity of Fukushima accident for gaining more information on severe accident progress and mitigation.

Controlling severe conditions, incl. prevention of accident progression and mitigation of SA consequences (2/4)

- Main R&D needs oriented towards severe accident mitigation:
  - In-vessel accident progression: efficiency of degraded core cooling, In-Vessel Melt Retention (corium/debris behaviour in vessel lower head and vessel external cooling),
  - Early containment failure risks: steam explosion (in particular the premixing phase) and gas combustion in the containment (deflagration/detonation, efficiency of recombiners…),
  - Ex-vessel phenomena that could lead to late containment failure: coolability of corium by water injection during Molten-Core Concrete Interaction,
  - Source term: decrease of iodine and ruthenium release into the environment by trapping or filtration (FCVS, pool scrubbing), including the accident long term situations.

Controlling severe conditions, incl. prevention of accident progression and mitigation of SA consequences (3/4)

- Need to continue the improvement of codes for simulation of SA scenarios and their management:
  - In particular the ASTEC integral code, jointly developed by IRSN and GRS, that has capitalized the SARNET and international knowledge
  - ASTEC is used by most ETSON members

Controlling severe conditions, incl. prevention of accident progression and mitigation of SA consequences (4/4)

- Euratom projects (FP7 or H2020) with participation of ETSON members :
  - IVMR (led by IRSN) on applicability and technical feasibility of IVMR strategy to high power existing and future reactors,
  - PASSAM (led by IRSN) on passive and active systems on SA source term mitigation (in particular on FCVS),
  - CESAM (led by GRS) on ASTEC integral code improvements to simulate SAM for the various European NPPs.
- OECD/NEA/CSNI projects with participation of ETSON members :
  - BSAF (Benchmark Study of the Accident at Fukushima),
  - And three new projects to start in 2016, STEM2 on source term mitigation, THAI3 on containment thermal-hydraulics, hydrogen risk, aerosols and iodine and BIP3 on iodine behaviour.

Spent Fuel Pools accidents (1/2)

- Loss of cooling accidents may lead to fuel uncovery and heat-up, and, without appropriate measures, fuel rod cladding oxidation by air and steam might cause an exothermic runaway reaction leading to fuel rod degradation and release of radioactive materials.
- Need of more R&D on the following issues:
  - Air ingress process during SFP boil-down, considering SFP configuration (deep shaft, shallow pools), circulation modelling, possible 3D convection patterns etc…,
  - Improvement of computational tools: adaptation of codes used for NPP accidents (t/h system and severe accident codes) and use of CFD codes, in particular for 3D effects (heterogeneous fuel arrangement and boundary conditions),

Spent Fuel Pools accidents (2/2)

- Main R&D projects with participation of ETSON members:
  - In the recent years, CSNI Sandia Fuel Project (2009-2013) with integral tests,
  - International projects:
    - Current task “AIR-SFP” in the NUGENIA+ FP7 project, mainly on benchmarking of severe accident codes for SFP,
  - Proposal of OECD/NEA/CSNI Phenomena Identification and Ranking Technique (PIRT) for SFPs,
  - National projects:
    - New DENOPI IRSN project (with Bel V) from 2014 with experiments on SFP t/h behaviour, fuel assembly t/h before and after fuel uncovery, and Zr clad oxidation by air/steam mixture.
    - Projects in Belgium (Bel V), Lithuania (LEI) and Ukraine (SSTC NRS)

Conclusions

- Many R&D highest priority needs that were identified in the 2011 ETSON position paper already contribute to the objectives of the new 2014 Euratom Directive on the safety of nuclear installations.
- Besides, the ETSON members have been strongly involved for many years in R&D projects related to the improvement of safety of the European NPPs (e.g. SARNET) and this situation was even reinforced after the Fukushima-Daiichi accident in 2011.
- To date they are involved in many R&D projects, either international (FP7/H2020 Euratom or OECD/NEA/CSNI) or in a national frame, aiming at preventing accidents through defence in depth and at avoiding radioactive releases outside a nuclear installation ⇨ This will help to better answer the main objectives of the 2014 Directive.