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Challenges Faced by Technical and Scientific Support Organizations (TSOs) in Enhancing Nuclear Safety and Security: Ensuring Effective and Sustainable Expertise

Overview of ETSON modelling and experimental capabilities for R&D on nuclear safety

ETSON Research Group activity

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Foreword

R&D objectives

- Develop and maintain expertise based on safety research
- Access to research and experimental facilities and to up to date scientific information, state of the art codes and methodologies
- Support international community to achieve safety objectives

→ **Develop networking with other TSO**

ETSON Research Group

- Identify needs
- Ranking priorities
- Orienting research
- Sharing information
- Launching initiatives

→ **R&D is driven by specific regulatory needs**

Introduction

- **ETSON addresses most technical domains relevant for safety**
  - Experienced experimental and modelling teams
  - Operators of experimental research facilities
  - Developer's team of simulation codes and/or teams that perform their verification and validation
- **Principal domains**
  - Thermal-hydraulics; material testing reactors and fuel behavior; reactor physics and criticality; materials, mechanics, chemistry and corrosion; severe accidents, emergency preparedness and response; uncertainty methods and probabilistic safety assessment; hot laboratories with irradiated materials and research reactors; fires and explosion; waste disposal

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ETSON experimental facilities and simulation codes

A few illustrative examples

Thermal-hydraulics (1)

- **Many system codes are used by the ETSON partners**
  - A majority apply TRACE and RELAP5 (distributed by USNRC)
  - A few apply CATHARE (developed by CEA and jointly owned by EDF, Framatome and IRSN)
  - A few apply ATHLET and COCOSYS (part of AC^2 code system developed by GRS)
  - SEC-NRS uses the internally-developed computer code Rainbow-TPP
- **CFD codes**
  - Used to provide more detailed calculation of specific phenomena
  - Interest in the further development of CFD tools has increased: e.g. GRS, is developing OpenFOAM solvers for nuclear safety applications
- **Main use of the codes**
  - Audit & confirmatory calculations, development of code models and input decks
  - Identification of shortcomings in licensing analyses and accident procedures
  - Get insights of potential improvements of accident procedures
  - Strengthen the TSO safety position
  - Support to analytical and experimental activities in international projects

Thermal-hydraulics (2)

- **Experimental facilities**
  - ENEA runs the SPES large-scale facility
  - IRSN runs the THEMA platform for mitigation of reactor accidents (LOCA, SFP)
  - All other members rely on the few facilities that still exist in Europe like PKL (in Germany) and PSB-WWER (in Russia) or in Asia like LSTF/ROSA (in Japan) and ATLAS (in Korea)

- **Challenges for the future**
  - **Maintain knowledge and experts in the field**
  - **Further develop the codes, establish couplings between codes to improve multi-scale and multi-physics capabilities**
  - **Continue to operate the large integral facilities which are difficult to maintain**

SPES Integral Facility, courtesy of ENEA

Severe accidents, emergency preparedness and response (1)

- **Two ETSON members are developing SA simulation tools**
  - AC² consisting of ATHLET, ATHLET-CD, COCOSYS and ATLAS (GRS)
  - ASTEC integral code, considered as a reference code in Europe due to the continuous capitalization of knowledge acquired in Europe (today by IRSN)
  - MC3D multiphase multi-dimensional code for fuel coolant interaction (IRSN)
  - → A large majority members apply the IRSN ASTEC code, and several use AC^2
  - → All ETSON members except IRSN use MELCOR for performing safety studies
- **Main use of the codes**
  - Assess the influence of the plant safety upgrade on meeting SAMG
  - Strengthen the capability for independent severe accident safety assessments
  - Results in support to the review of licensing safety analysis, planning of the emergency response, improving Level-2 and Level-3 PRA methodologies and the source term for the consequence analysis
  - Support to analytical and experimental activities in international projects

Severe accidents, emergency preparedness and response (2)

- **Two ETSON members are developing EP simulation tools**
  - SESAME code system for evaluation of source term released to the environment (IRSN)
  - C3X platform for evaluation of transfers in the environment and of the doses received by the population as a function of meteorological conditions (IRSN)
  - FaSTPro Fast Source Term Prognosis tool for decision-making during emergency situations → Input for the RODOS transport and consequence calculation tool used by the German Office for Radiation Protection (GRS)
- **Main experimental facilities**
  - CHROMIA platform: on chemistry and radiochemistry of fission products (in particular iodine and ruthenium) in severe accidents conditions (IRSN)
  - THEMA platform: PEARL facility devoted to the reflooding of debris beds, at a relatively large scale; and ENACEFF facility on explosion of combustible gases such as hydrogen (IRSN)
  - CERES facility: to test the heat transfer capabilities in case of molten corium in the vessel bottom (MTA-EK)
  - ETSON members participate/ed in OECD projects where facilities like THAI (in Germany), PANDA (in Switzerland) and MISTRA (in France) have been used

Severe accidents, emergency preparedness and response (3)

- **Main challenges**
  - **Despite progress in research, and efforts to capitalize knowledge into integral codes such ASTEC or MELCOR, modelling phenomena for conditions expected in the SA domain are still subject to great uncertainties.**
  - **It is extremely important that the simulation codes and methods are validated for their intended purposes and key research infrastructures still support the reduction of the uncertainties in the phenomena.**

PEARL facility, courtesy of IRSN

Conclusive Remarks (1)

- **As a whole, ETSON covers all safety issues with experienced teams and capabilities and can address further R&D challenges**
  - Large and small scale facilities, often unique
  - Development of simulation codes, some being international reference
  - Experienced experimental and modelling capabilities
- **Trainees can be accepted on case by case basis**
- **ETSON allows to concentrate resources, focus on topics of main interest and avoid duplication of efforts**

Conclusive Remarks (2)

- **ETSON is able to keep a high level of competences and expertise**
  - Based on advanced and detailed scientific information
  - In most of the technical domains relevant for safety
  - In a challenging scientific context in continuous evolution
- **ETSON can address further R&D challenges**
  - New materials, fuels, safety systems

R&D is fundamental to support independent and informed safety positions

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Thank you for your attention

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Back-up slides

MTR and Fuel behaviour

- **CABRI research reactor**
  - Owned and operated by CEA mainly for IRSN and EDF, in particular for OECD R&D projects (mainly to study RIA).
- **Simulation tools for fuel safety**
  - SCANAIR (RIA) and DRACCAR (LOCA) developed by IRSN
  - TESPA-ROD developed by GRS
  - Most used code: TRANSURANUS (EC JRC), some use FEMAXI and FRAPTRAN

  →Normal operation, anticipated operational occurrences, fragmentation, relocation and dispersal phenomena
- **With the changes in fuel design and operation (e.g. new materials, higher burnup levels, power uprate, load following, etc.), guaranteeing an acceptable level of safety will require testing and analysis for the most challenging conditions such as LOCA and RIA.**

Reactor physics and criticality

- **GRS, IRSN and Wood are developing simulation tools**
- **MCNP code is used by a majority of ETSON members**
- **Reactor physics**
  - Core power distribution governs the plant behaviour and determines operating safety margins
  - Linear heat rate dependency on burnup is a key parameter for safety analyses such as in the case of large break LOCA and control rod ejection studies
  - No single code is capable of covering all phenomena involved in the nuclear safety field

  → **Coupling reactor physics codes with tools of other disciplines is needed to carry out reliable safety analyses**
- **Assessments of criticality**
  - **Needed for fuel storage, waste disposal, new reactor systems and transport of nuclear material**

Materials, mechanics, chemistry and corrosion

- Wood has unique facilities for materials testing in support of nuclear power plant operation (material and corrosion laboratories)
- IRSN runs two experimental platforms
  - ODE: to study concrete pathologies linked to ageing of NPP containment
  - MAESTRO: for the characterization of materials
- GRS is developing the following codes
  - PROST: assessment of structural reliability of piping and vessels
  - WinLeck: calculation of leak areas and discharge flow rates
  - ASTOR: simplified tool for the determination of failure times of RPV and piping loaded under internal pressure and high temperatures due to SA
- **Aim: maintaining the capabilities and progress in R&D**
  - **There are still gaps in modelling of irradiation embrittlement, thermal fatigue, Stress Corrosion Cracking (SCC) and mechanical wear as well as joint action of degradation mechanisms**

Uncertainty methods and PSA

- **Two ETSON members develop PSA tools:**
  - GRS: SUSA for uncertainty and sensitivity analyses; XSUSA for nuclear cross section uncertainty and sensitivity analysis; and MCDET for Monte Carlo event tree analysis for probabilistic assessment of consequences of (S)A scenarios
  - IRSN: SUNSET for uncertainty and sensitivity analyses; and KANT, a probabilistic code for level 2 PSA

  → Several European TSOs use the RiskSpectrum code by Lloyds Register, RATEN ICN uses WinBUGS and NRA uses WinNUPRA

- **Main challenge for the future application of PSA related to**
  - **Improved probabilistic software tools**
  - **Methodologies extending the scope of existing PSA**
  - **Status of geosciences for assessing natural hazards and quantitatively addressing severity and frequency of both single and correlated natural initiated events**
  - **Solutions to develop fragility analysis and to develop plant response analysis generally, including severe accident progression**

Hot laboratories with irradiated materials and research reactors

- Several hot laboratories and facilities for irradiated materials are available: 2 at Wood, 1 at JSI, 3 at PSI, and 1 at VTT
- TRIGA reactors are run at RATEN ICN, JSI and ENEA
  - e.g. In RATEN ICN, the TRIGA SSR - 14 MW and TRIGA ACPR research reactors are unique facilities at national level, providing irradiation of nuclear fuel and structural materials, radioisotopes production, analysis services for neutron activation, prompt gamma spectrometry, neutron dosimetry, determination of irradiated fuel burn-up.
- **Main challenges**
  - **While fundamental because of their unique multidisciplinary capabilities, operation and maintenance can be challenging especially for research and training reactors.**
  - **The main issues are connected to lack of full utilization, ageing, staff requirements and funding.**
  - **IAEA has several programs on those subjects.**

Fires and explosion

- Two ETSON members are developing simulation tools
  - IRSN: SYLVIA system code for a simplified simulation of fire scenario in a nuclear facility with a mechanical ventilation; ISIS CFD for detailed simulation of a fire in a room of a nuclear facility; and PR^{2}MICS CFD for detailed simulation of a gas explosion in a compartment of a nuclear facility.
  - GRS: COCOSYS containment response code that includes a pyrolysis model.
- GALAXIE platform: only experimental facility with the aim of improving fire safety in nuclear facilities (IRSN)
- In 2017, the majority of ETSON members took part in a joint benchmark exercise using simulation tools to model experiments on hydrogen explosion in NPP containment.
- **Fires can be an important contributor to core damage frequency and other plant damage states of NPPs (e.g. see results of PRISME OECD project), thus confirming the interest in further research on the subject.**