Safety research
Perspectives and priorities
in Europe and at IRSN,
In the post Fukushima context

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USNRC/RIC 2014

The post-Fukushima context in Europe

- Medium term opt out in several member states, whilst others continue to invest in nuclear energy
- Coordinated « stress tests » showed need to resolve identified vulnerabilities to beyond design but still plausible external hazards
- Research and innovation should target safety improvements as a first priority
- The 8th EURATOM H2020 R&D program favors integrative projects associating TSO's, R&D agencies and industry to develop innovative safety oriented solutions

In practice, 4 key nuclear R&D challenges…

- **Close identified nuclear safety knowledge gaps, including in assessment of external threats, with a view to implement solutions**
- **Improve emergency preparedness, from short to long term issues**
- **Accelerate the resolution of safety issues involving spent fuel risks**
- **Strengthen international cooperation through joint R&D programs (OECD/NEA, EURATOM R&D platforms)**

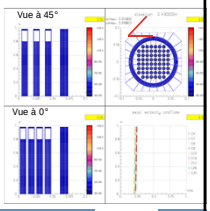
… which have required a strategic reorientation of priorities in IRSN in particular

Main priorities of nuclear safety R&D IRSN programs

- Better understand dangerous phenomena and associated uncertainties
  - Fuel behavior (LOCA, spent fuel pool)
  - External Events (seism, flooding, harsh weather, …)
  - Address issues linking safety to security
- Evaluation of possible strategies in terms of Severe accident mitigation (FP release, corium cooling)
- Better understand success or failure elements in human and organizational factors during normal or emergency operations
- Improve modeling and numerical simulation of ageing phenomena
- Focus fire R&D on malfunction of electrical components, on cables tray fire and on release of Pu during fires
- Promote international collaboration on criticality research (fuel cycle labs and plants)
- Increase efforts on the safety of deep geological disposal
- Step up emergency preparedness operational tool box

Fuel Behavior (Loss of Coolant Accident)

- Safety Issues
  - To maintain core coolability in any conditions, including in ballooned and burst fuel rod clads
  - To examine the consequences of fuel relocation and dispersion inside the Primary circuit
- PERFROI: national "post-Fukushima" program (2014-2019)
  - Experimental programs
    - Deformation of a fuel assembly
    - Cooling and reflooding of a ballooned assembly
  - Validation of dedicated computer codes (DRACCAR)
- OECD projects
  - LOCA HALDEN and Studsvick projects



Fuel Behavior (Spent Fuel Pool)

- Safety Issues
  - Understand the different possible scenarios and the involved phenomena
  - Assess mitigation strategy options
  - Elaborate post - accident strategy
  - Reactor fuel pool densification
- DENOPI: national "post-Fukushima" program (2014-2019)
  - Experimental programs
    - Mechanical properties and rupture limit of oxidized/nitrided claddings
    - Cooling of a Fuel Assembly and spray efficiency
    - Convection inside a Spent fuel pool and cooling scenarios
  - Validation of dedicated computer codes (DRACCAR; ASTEC) and CFD codes
- OECD projects
  - Participation at the SFP program (US-NRC, SNL)
  - CSNI Status Report on Spent Fuel Pool (SFP) under loss of cooling accident conditions (led by IRSN)

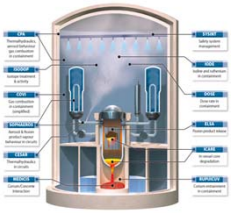
Efficiency of severe accident mitigation: the importance of experimental research

- **Fission products transport and filtration**
  - OECD STEM project operated by IRSN (with complementary investigations on paint composition and ageing effects)
  - OECD status report on Filtered Containment Venting Systems (FCVS) coordinated by IRSN
  - European PASSAM and National MIRE projects lead by IRSN
    - Improvement of existing FCVS
    - Testing the ability of innovative systems and new materials
    - Determining I, Ru and Cs long term re-volatilization (RCS, containment)
- **Management of core and corium cooling**
  - National program on in vessel debris bed cooling using IRSN large scale and pressurized PEARL facility
  - CORDEB program on the transient behavior of corium in the lower plenum (experiments performed in Russia by NITI)
  - IRSN contribution to NRC/ANL CCI tests on ex vessel corium cooling

View of EPICUR facility
Effect of irradiation

View of PEARL facility
Debris bed cooling

Efficiency of severe accident mitigation: the importance of integral codes



- **IRSN pursues efforts to capitalize international SA knowledge in ASTEC integral code**
  - Key element of SARNET (SA network of excellence), more than 30 partners involved in code assessment and models improvement
  - CESAM European project (2013-2017) for improving ASTEC use for SAMG evaluation (all European NPP types: PWR, VVER, BWR, CANDU)
    - Validation vs. experiments on most relevant phenomena in Fukushima accidents,
    - Building of reference input decks for main European NPP types,
    - Interface with atmospheric dispersal tools
  - Participation to the OECD current projects: BSAF, STEM, etc…
  - Periodic Users Clubs gathering about 35 partners in and out of Europe (next one in spring 2015)

Efficiency of severe accident mitigation: ASTEC development

- **ASTEC V2.1 (12/2014) main characteristics**
  - **Capability to simulate SA in all existing LWR and CANDU** *(in a first stage only CANDU early phase, in close collaboration with BARC in India)*
  - **State-of-the-Art models of FP behavior in RCS and containment,** *(derived from Phebus-FP, ISTP, OECD/STEM&BIP… programs)*
  - **New model of reflooding of damaged cores** *(based on PRELUDE/PEARL experiments)*
- **extension of ASTEC to other domains** *(thanks to high flexibility of the code)*
  - **SFP loss-of-cooling accidents**
  - **Lower power NPPs**
  - **SFR core-disruptive accidents** *(JASMIN European project, led by IRSN)*
  - **Nuclear fusion accidents** *(ITER and beyond)*
  - **Risks of chemical explosion in fuel cycle (unstable compounds named "red oils")**
  - **Support to emergency preparedness and management**
  - **Basic modules of DRACCAR code** *(Fuel assembly behavior in LOCA)*
  - **Extension to ITER**

Understanding external threats: Seismic, flooding

- **Seismic hazards:**
  - **Characterization of the activity of a fault, discovery of new active faults in France**
  - **Study of site effects (such as amplification of seismic movements in sedimentary basins)**
  - **Soil structure interactions, structure response (non-linear effects)**
- **Flooding hazards:**
  - **Identification and characterization of phenomena that can contribute to the flooding risk and of their dependencies**
  - **Site per site determination of the probability of events occurrence**
  - **Model improvement (such as streaming of rain water)**
- **IRSN PSA**
  - **Screening for each French site of the risk associated to all plausible external events (2013-2014)**
  - **Earthquake / PWR 900 (2015)**
  - **PSA "climatic events" (2015)**

Better understanding the influence of HOF during normal and emergency situations

- **Continuous experience feed back deep analysis from HOF point of view for a selection of incidents**
- **HOF Impact on nuclear plant safety considering**
  - **Subcontracting effects**
  - **Technological evolution (digital I/C, obsolescence)**
  - **New rules and regulations impact on HOF**
- **R&D about HOF impact on decision making process**
  - **Analysis of operating technical specifications notwithstanding**
  - **Observation and analysis of crisis exercises at national level**
  - **Detailed understanding of Fukushima accident in link with reactors situation evolution (obtained in parallel from BSAF OCDE project)**
  - **Scientific cooperation with other industry sectors**

IRSN focuses R&D on numerical simulation of ageing phenomena in order to be able to evaluate reactor life extension program

- **Development on multi-scales simulation of vessel and internals ageing**
  - Vessel : simulation of microstructure evolution considering dislocations and interaction between dislocations and atoms like C, Ni
  - Internals : development of a response law for swelling and creeping
  - Expected to be part of the European AMNOS project (Application of Material multi-scale MOdeling approach to Safe operations) expected to be launched in the frame of EURATOM (Horizon 2020 program)
- **Meso/macro scale concrete behavior modeling for:**
  - Young age ageing, mid and long term creeping, cracks opening and flow rate modeling trough cracks
  - Effect of concrete pathologies (alkali aggregate reaction (RAG) and internal sulfatic attack (ISA))

Fire remains a top priority nuclear safety R&D issue

- **Malfunction of electrical equipments**
  - Malfunction criteria of equipments are crucial data for Fire PSA and Fire Risk Analysis
  - Strong coupled effect on malfunction of heat and soot concentration
    - Measured during global tests in DIVA facility with exposed equipments
    - Need to identify and characterized the governing parameters of malfunction
  - New small scale facility DANAIDES
    - Experimental protocol will be developed in 2014 (representative of real conditions)
    - Starting experimental program by mid-2014
- **Cables tray fire (in confined conditions)**
  - Fire propagation on a tray and from a tray to a neighboring one
    - Cables types, cables density, geometrical arrangement of tray, …
    - Confined conditions (room volume and ventilation rate)
  - Improvement of modeling is a main objective
    - Simple correlations presently available to evaluate fire risk in open atmosphere for some cable trays configurations are not sufficient.
  - Complementary to NRC's CHRISTIFIRE tests in well ventilated conditions
- **Release of Pu in case of fuel plant fires**
  - Reprocessing plants (solvent fires) and labs of fuel manufacturing (Glove boxes fires)

Fire safety: IRSN continues to develop experimental facilities

- **CADUCEE (calorimeter for controlled confined atmosphere)**

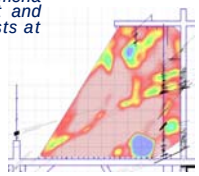
Criticality research remains critical for nuclear safety

- Assessment of criticality risk in fuel cycle (Labs, plants, transport)
  - Completion of data base for U, Pu and structure materials in the intermediate neutron energy
- Qualification/improvement of detection systems
- Post-Fukushima issues:
  - Is a criticality excursion possible with either damaged spent fuel Pool assemblies or damaged NPP core ?
  - Is there any "signature" of such an excursion ? (modification of the FP release)

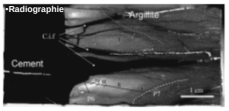
As criticality experimental facilities in CEA/Valduc (France) will be closed, future R&D programs should take place in the frame of international partnership, in particular with DOE (US) and JAEA (Japan)

Research on the safety of deep geological disposal

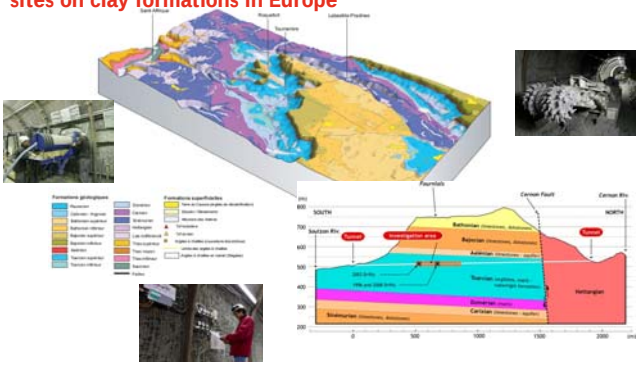
Objective 1: Understanding the main phenomena governing the safety of deep disposal at short and long term, based on simulation capacity and tests at IRSN Tournemire experimental platform



- **Containment properties of the host rock**
  - Nuclides transport properties in clay formations
  - Geophysical methods for detecting faulting in far (tectonic features) and near field (EDZ)
- **Physical and chemical disturbances**
  - Impacts of interactions between clay and exogenous materials (concrete, steel, waste package content)
  - Impact of H_2 production
  - Micro organisms induced corrosion



IRSN Platform in Tournemire (Southern France): one of the 4 R&D sites on clay formations in Europe

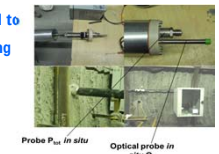


Experimental platform of Tournemire

As France moves closer to building a geological repository, IRSN R&D investigates operational safety issues

- **Thermo-hydro-mechanical disturbances**
  - Impact of excavation (EDZ)
  - Behavior of sealing devices

- **launching new programs on the monitoring of disposal during operational and retrievability phases**
  - Identification of parameters and criteria related to disposal evolution (how to collect evidence that facility remains in safe state, as expected, during operations?)
  - In situ tests of different sensors (performance, durability, sensitivity to environmental conditions,…)



Emergency preparedness: a stepped up priority for IRSN R&D

- Fast calculation codes for source term evaluation, dispersion and radiological effects
- High response mobile radiation measurement systems
- Pedagogical accident impact assessment tools for stakeholders
- Characterisation of the cost componants of a major accident with substantial radiaoctive release
- A new emergency organisation system for IRSN, matching the new national nuclear emergency governmental protocol
- Enhancing European cooperation and IAEA capability

Conclusions

- **IRSN has revisited its R&D strategy in the light of lessons of Fukushima Daichi accident, and of European strategies**
- **Efforts have been increased in five domains: HOF, Fuel safety, external events, SA (mitigation & ASTEC integral code), emergency preparedness.**
- **The development of international cooperation is more than ever a key element in order to be able to address simultaneously all main priorities**