IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE
Faire avancer la sûreté nucléaire

Severe accidents research at IRSN: status and perspective

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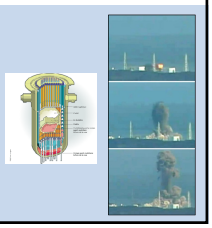
RIC 2016 - technical session W18
"What's new in the area of severe accident and off site consequence analysis"



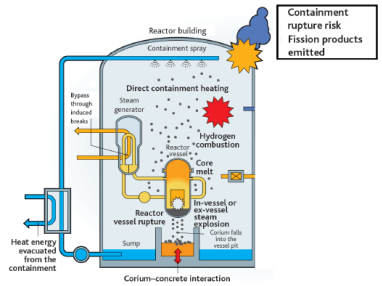
Summary

- Some preliminary considerations
- R&D on severe accident: a key topic at IRSN
  - Overview of national and international collaborations
  - In vessel corium retention
  - SFP accidents
  - Source term issues
- Conclusions

Some preliminary considerations

- Severe accident in NPPs is a complex scientific topic which study involves several domains of chemistry and physics which need to be considered all together
- Severe accident research has started for more than 40 years (1975 : the RASMUSSEN WASH 1400 report « The Reactor Safety Study » identifying the different containment failure modes)
- But the Fukushima accident reminds that severe accident may still happen, whatever improvements made, and that there are still large uncertainties in the prediction of the evolution of such accident

Some preliminary considerations



Some preliminary considerations

Situation in France

- The Safety Authority asks for continuous safety improvement: for each 10 years safety review, improvements are identified and discussed as part of the safety review process
- GIII reactors are now considered as a reference to identify as far as possible such improvements
- Severe accidents are considered as key issues for safety improvement
- As a consequence, a straight link exists between R&D progress in the domain of severe accident and safety improvements

R&D on severe accidents: a key topic at IRSN

National and international collaboration

- Large research efforts required to tackle R&D issues on SA:
  - Large concerted national effort scale promoted by the French Government following Fukushima events leading to different "ANR" projects in collaboration with CEA, EDF, AREVA and Universities
  - Projects supported by the European Commission (EC): currently PASSAM (FCVS), CESAM (ASTEC), IVMR (in-vessel corium retention), FASTNET (emergency ST tools)
  - OECD projects (soon follow-up ones: STEM2, BIP3, THAI3) and OECD status reports on relevant issues (hydrogen risk, MCCI, FCVS, SFP, FCI)
  - Specific projects under multi-lateral agreement: CCI (with EDF and ANL), CORDEB (with NITI), PARs (with Jülich),VERDON (with CEA) …

In-vessel corium retention (1/2)

On-going research:

- Experimental work on in-vessel debris bed coolability
- Theoretical work on degraded core coolability: modelling of degraded configurations, flows and heat exchanges, effects of reflooding (pressurization, H_2 production, melt stabilization)
- Experimental work on transient corium behaviour in the vessel lower head (more accurate assessment of thermal loadings on the vessel and of possibilities of external cooling)
- Theoretical work on transient corium behaviour in the vessel lower head and vessel failure modes and timing (studies including the effect of external cooling)

Perspectives:

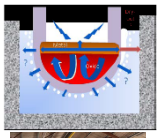
- Experimental and theoretical work on complex debris bed configurations, on metal debris oxidation in re-flooding
- Experimental and theoretical work on corium behaviour in lower head
- IVMR H2020 project for Gen.II-III reactors

In-vessel corium retention (2/2)

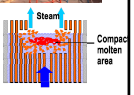
IVMR H2020 project (2015-2019) coordinated by IRSN with 23 partners, manpower 12 person.years

Objectives:

- Review the IVR existing analytical approaches for existing or under project NPPs,
- Provide new exp. results (corium in LH and vessel external cooling) to cover all corium configurations and LH geometry (VVER-1000 and BWR)
  - ✓ PEARL: extension to coolability of compact areas (reduced porosity by molten material)
- Improve IVR methodology to reduce conservatism and give more realistic safety margins (necessary for high power NPP)
- Elaborate an updated and harmonized methodology for use in Europe



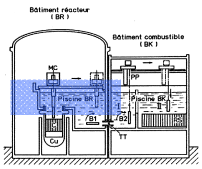
PEARL



SFP accidents

DENOPI French project (2014-2019), coordinated by IRSN with 4 partners, total of 20 person.years

Following OECD/SFP complementary experimental and theoretical studies of SFP accidents conditions:

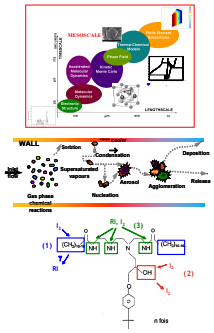


- Convection phenomena at pool scale level (two phase flow phenomena)
- Assembly scale phenomenology (temperature and water level evolution for partially exposed fuel)
- Zircaloy oxidation under air and mechanical behavior of oxidized cladding

R&D on severe accidents

Radioactive releases and mitigation (1/5)

- Multi-scale approach to describe fuel behaviour and FP release: focus on mesoscale to capture the phenomena at granular size
- Theoretical chemistry of homogeneous or heterogeneous processes: chemical reaction kinetics
- Molecular iodine and organic iodide trapping by and release from paint: phenomenological model including behaviour of specific chemical function (links with STEM2 and BIP3)



⇨ Capitalization in codes

R&D on severe accidents

Radioactive releases and mitigation (2/5)

- **On-going research on FP release from fuel:**
  - Experimental work (2012-2016) to study FP releases from high burn-up UO_2 and MOX fuel (ISTP/VERDON tests performed by CEA) and air ingress accidents
  - Development of phenomenological models for ASTEC and a fine theoretical modeling (from atomic scale to mesoscopic scale); the latter being used to widen the models applicability to non tested conditions
- **Perspectives:**
  - Experimental and theoretical work on FP release from fuel (focus on oxidant and moderate temperature conditions) to be able to predict releases for recovered sequences (before fuel melting), for spent fuel storage pool or transport accidents (collaboration with JRC/ITU)

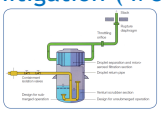
R&D on severe accidents

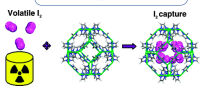
Radioactive releases and mitigation (3/5)

- **On-going research on iodine and ruthenium transport in RCS and behaviour in the containment:**
  - Experimental work in 2012-2015 to study I and Ru transport and mid and long-term behaviour in the containment (ISTP/CHIP, OECD/STEM, BIP2 and THAI2 programs)
  - Development of a theoretical modelling of kinetics of chemical reactions of iodine in the RCS, work performed in the framework of a joint research laboratory (with PC2A Lille)
  - Development of a phenomenological modelling of iodine interactions with paints, including the formation of organic iodides
  - Extension of the CHIP program for the study of the effect of control rod materials (Ag, In, Cd) on iodine transport
- **Perspectives:**
  - STEM2, BIP3 and THAI3 programs in OECD framework (focus on “delayed” source term, ST for DBA (SGTR))

Radioactive releases and mitigation (4/5)

- **MIRE French project** (2013-2018), coordinated by IRSN with 8 partners, manpower 28 person.years
- Following OECD/STEM program, new experimental and theoretical studies on systems to improve SA source term mitigation (FCVS)
  - Determine I, Ru and Cs long term re-volatilization (RCS, containment)
  - Determine I and Ru filtration efficiency for existing systems (sand filters, scrubbing systems) and long-term re-volatilization
  - Demonstrate the ability of innovative systems (zeolites, MOFs)





Radioactive releases and mitigation (5/5)

- **PASSAM EC FP7 project** (2013-2016), coordinated by IRSN with 9 partners, manpower 33 person.years
- Studies on passive and active systems towards enhanced SA source term mitigation (complementary to MIRE)
  - Improvement of existing FCVS (operation under accidental conditions, long term operation, ≠ ST compositions)
  - Test the ability of innovative systems (scrubbers and filters with new materials and combinations, acoustic agglomerators, electrostatic precipitators)

Conclusions

- Straight link, in France, between R&D progress in the domain of severe accident and safety improvements
- Large R&D programme at IRSN in the frame of national and international collaborations
- Need to accommodate, for decision making process in safety assessment of GII, GIII NPPs, with still large remaining uncertainties, i.e. for example for:
  - Core reflooding strategy
  - IVMR strategy versus ex vessel corium stabilization
  - FCVS
  - Long term releases in SA conditions