Ranking of Severe Accident Research Priorities in the Frame of SARNET

(Session 5 – Paper 5.1)

Bernd Schwinges, GRS

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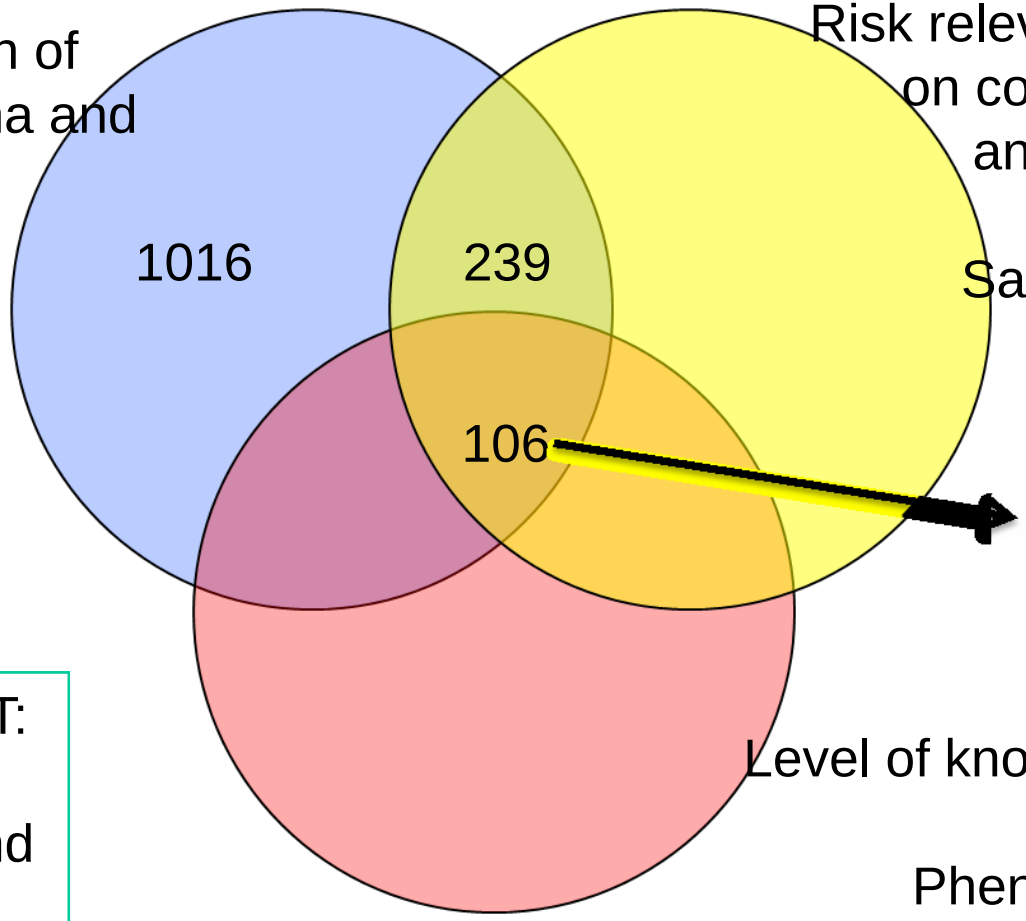
- Results of EURSAFE
- Decisions procedure to re-evaluate the EURSAFE Research Items and new items/reorientation
- Re-evaluation of Issue Prioritisation and new proposals for future research
- End User Comments
- Summary and Concluding Remarks

Bottom-up approach for the definition of needed research items



Combined to **21 ERI - issues**

EURSAFE PIRT: Phenomena Identification and Ranking Table

PIRT implication

- Starting from 1016 phenomena reduced to 106 with high importance ratio **+** significant lack of knowledge
  (52 with first priority, ***7 bimodal with first priority***, 47 with second priority)

- The PIRT implication included
  - Defining R&D needs in terms of objectives and priorities
  - Identifying required R&D tasks in terms of experimental programmes & codes
  - Reviewing the European facilities and codes which could be used for these tasks, taking into account the existing and planned programmes

- Individual phenomena integrated to items with same R&D orientation
  - **➔ 21 EURSAFE Research Items**

EURSAFE bottom up approach: from more than 1000 phenomena to 21 items for needed research

Number of entries	In-vessel	Ex-vessel	Dynamic loading	Long term loading	Fission products	Sum
Phenomenon identification	162	149	461	116	128	1016
Selected due to high importance for safety	43	48	82	36	30	239
Selected due to significant lack of knowledge + safety importance	24	28	26	10	18	106
Integrated items for needed research	6	4	5	1	5	***21***

Decisions procedure to re-evaluate the EURSAFE Research Items – based on the methodology developed in EURSAFE –

Creation of a Template with the following steps:

a. Recall descriptions and evaluation from EURSAFE

b. Rationale for the decision to be taken

c. Evaluation by means of knowledge, test facility, model development

d. Review and assessment by means of safety and risk significance

e. Review of decision, inform GB

f. Publication on ACT and ask SARNET and End User for comment

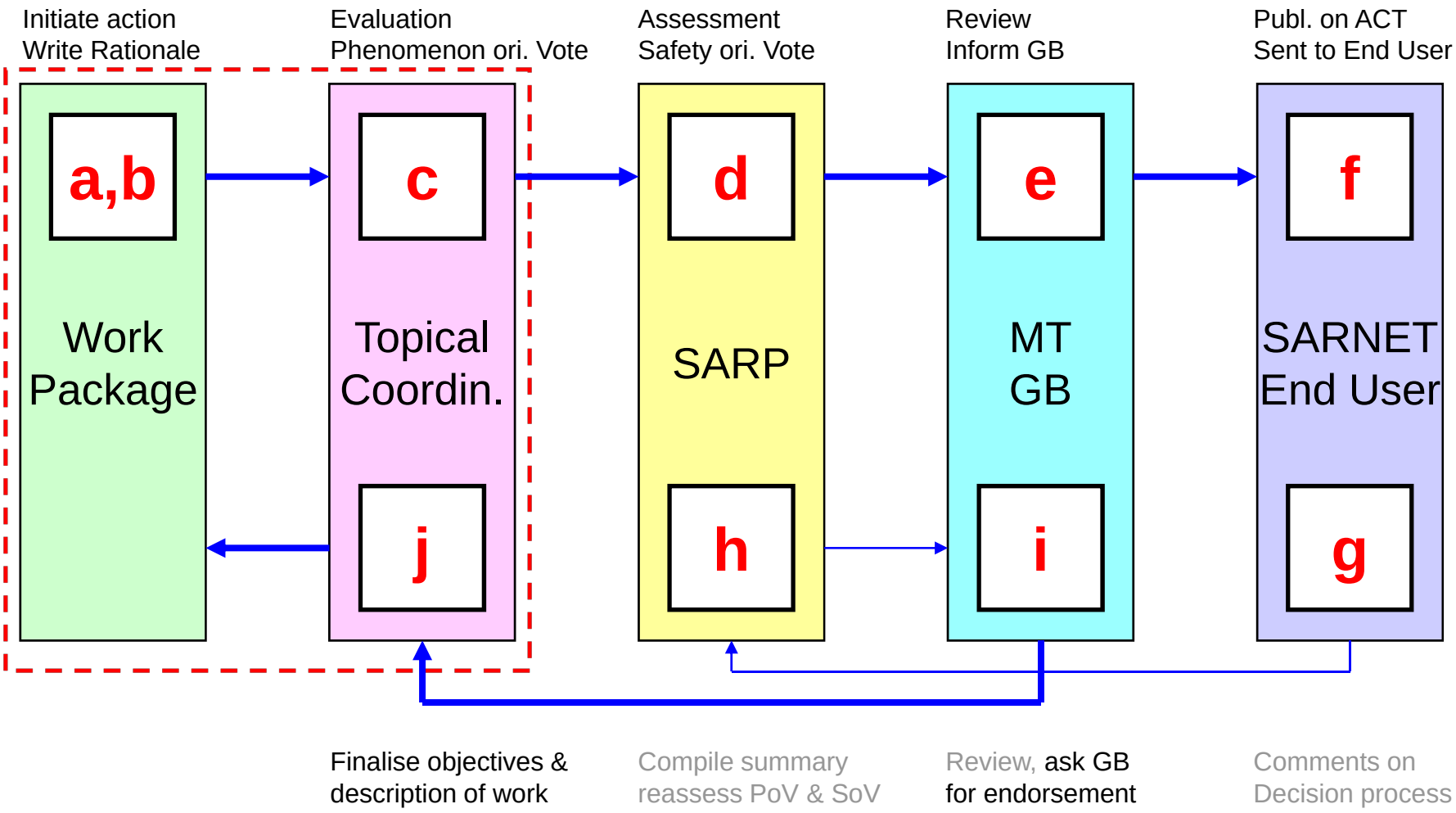
g. Comments from SARNET community and End User

h. Compile comments and reassess PoV and SoV

i. Review of decision, ask GB for endorsement

j. Final description of objectives, experimental programme, and codes

Decisions Procedure for the Reorientation of Research Item



Results from SARP meeting Febr. 2006 on re-evaluation of current + new research items: Evaluation of 7 proposed Research Items

- CORIUM
  - New cladding material => issue of design basis accidents
  - MCCI/spreading after radial erosion => SAM to be assessed.
- CONTAINMENT
  - Effect of mitigation sys. on H2 distribution => minor reorientation of WP
  - DCH: combustion of H2 jets => minor changes (extended item) of WP
- SOURCE TERM
  - Resuspension in the circuit => covered by existing WP, check data base (sticky deposits)
  - Iodide decomposition in PARS => Calc. & small scale tests (new)
  - Ruthenium behaviour in the containment => Review data, SETs

Results from 3rd+ 4th SARP meeting 2007 on Issue Prioritisation

- Detailed discussion (*now Top-Down approach*) of the research priorities along the list of the 21 EURSAFE Research Items with the objectives to reduce the number of open issues by means of
  - Merging of items with similar R&D objectives
  - Consideration of progress, improvement of knowledge
  - Re-evaluation of risk significance
    - ★ Integrity of reactor pressure vessel / reactor cooling system
    - ★ Integrity of containment
    - ★ Source term potential
  - New findings from PSA

With reference to the individual research priorities in the existing PIRT Implication Table

EURSAFE Research Issue on Containment Integrity

- ERI 1,1 treated in WP 9-1 & WP 10-1
  Hydrogen generation with metal rich mixtures during reflood and during melt relocation into water of lower head
  (EURSAFE Reference Number: 1,2,021; List 1 and 1,3,040; List 2)
  - ★ Rapid generation of hydrogen which may not be recombined by re-combiners; increases the risk of early containment failure. Improve knowledge about the magnitude of hydrogen generation, uncertainties are tool large.
  - Issue remains open with medium priority
    - ★ Medium priority, because research for confirmation/validation of models
    - ★ But high risk significance
    - ★ Optimisation of the implementation of the hydrogen mitigation measures such as PAR (very plant specific)

EURSAFE Research Issue on In-Vessel Melt Retention

- ERI 1,2 treated in WP 11-1
  Core and debris coolability and thermal-hydraulics within particulate debris during reflood of a not totally degraded core
  (1,2,***033 List 1b*** 1,2,060/061/***062***/080; 1,3,011/061/080/081/091/093/161)

  ★ Reflooding of core can terminate an accident while maintaining RCS integrity. Increase predictability of core cooling during re-flood.

  – Issue remains open with high priority

  ★ Improve the predictability of codes for a better assessment of AM measure reflooding and the risk of RPV lower head failure; possible reduction of vessel failure frequency in PSA

EURSAFE Research Issue on In-Vessel Melt Retention

- ERI 1,3a treated in WP 10-1 **&** WP 11-1
  Corium pool coolability in lower head
  (1,1 ,200; 1,3,010)
  - ★ Improve predictability of the thermal loading on RPV lower head to maintain its integrity (***important for BWRs***).
  - — Issue remains open with medium priority
    - ★ In-vessel processes of corium coolability are less significant then ex-vessel
    - ★ To be considered in conjunction with external RPV cooling (ERI 1,4)

EURSAFE Research Issue on Ex-Vessel Melt Coolability

- ERI 1,3b
  Corium coolability in external corium catcher
  (2,5,120)
    - ★ Improve predictability of the thermal loading on core catcher device to maintain its integrity (Heat transfer at corium pool boundaries similar to in-vessel situation).
    - ★ No experimental activities in SARNET
  - – Issue could be closed due to second priority
    - ★ Issue closed for EPR
    - ★ for future reactors out of scope of SARNET

EURSAFE Research Issue on In-Vessel Melt Retention

- ERI 1,4 treated in WP 10-2
  Integrity of RPV by external vessel cooling (1,3,145)
  - ★ Need to improve data base for critical heat flux and external cooling conditions to evaluate and design AM strategies of external vessel cooling for in-vessel melt retention; dependent on local conditions in plant.
  - Issue remains open with medium priority
    - ★ Possibility for low power reactors (e.g. WWER440)
    - ★ Influence of lower head penetrations (e.g. BWR) on external convection
    - ★ To be treated in conjunction with melt pool coolability in LH
    - ★ More important for BWR

EURSAFE Research Issue on Source Term Potential

- ERI 1,5
  Integrity of RCS
  (1,1,040; 1,4,023)
  - ★ Improve predictability of heat distribution in the RCS to quantify the risk of RCS failure and possible containment bypass due to thermo-mechanical loads on SG tubes
  - ★ No experimental activities in SARNET
  - – Issue closed due to second priority

EURSAFE Research Issue on Corium Displacement

- ERI 1,6 treated in WP 10-2
  Corium release following vessel failure
  (1,3,168; 2,1,040/041/042)
  - ★ Improve predictability of mode and location of RPV failure to characterise the corium release into the containment.
  - — Issue could be closed due to second priority
    - ★ Information on break location sufficient
    - ★ no solution for break size, but not significant due to hole ablation during outflow (break size significant for DCH)
    - ★ but material investigations in ISTC projects to be continued
      item important for BWR (see ERI 3,1 & 3,2)

EURSAFE Research Issue on Containment Integrity

- ERI 2,1 **&** 2,2 treated in WP 11-2 **&** WP 11-3
  MCCI: ex-vessel molten pool configuration and concrete ablation **&** Ex-Vessel corium coolability, top flooding
  (2,2,052/053/060/070/072; 2,3,045; 2,5,010/020/030/033)
  - ★ Improve predictability of axial versus radial ablation up to late phase MCCI to determine basemat failure time and loss of containment integrity
  - ★ Increase the knowledge of cooling mechanisms by top flooding the corium pool to demonstrate termination of accident progression and to maintain containment integrity

— Issue remains open with high priority due to risk significance

- ★ PSAs treat differently the risk significance
- ★ Reduce large uncertainties to diminish conservatism for basemat penetration time in PSA

EURSAFE Research Issue on Containment Integrity

- ERI 2,3 **&** 2,4 treated in WP 11-2 **&** WP 11-3
  Ex-Vessel corium catcher: corium ceramics interaction and properties **&** coolability and water bottom injection
  (2,3,020; 2,4,020/060/062; 2,5,070/082/100/101; 2,6,021)
    - ★ Demonstrate the efficiency of specific corium catcher designs by improving the predictability of the corium interaction with corium catcher materials
    - ★ Demonstrate the efficiency of water bottom injection to cool corium pool and its impact on containment pressurisation (Porosity formation)
  - Issue closed due to improved knowledge
    - ★ further investigation for plant specific geometrical conditions
    - ★ some analytical effort to keep knowledge for GEN III – IV should be continued

EURSAFE Research Issue on Containment Integrity

- ERI 3,1 **&** 3,2 treated in WP 13-1
  Melt relocation into water and particulate formation **&**
  FCI including steam explosion (ex-vessel: melt into water)
  (1,3,033;2,2,050/052/100;2,5,041/043; 3,1,***011***/012/***013***/014/***015***/ 022/026/***067/*** 068/ 072/400/410/420/432)

  - ★ Determine characteristics of jet fragmentation, debris bed formation and debris coolability towards maintaining containment integrity.
  - ★ Increase the knowledge of parameters affecting steam explosion energetics during corium relocation into water and determine the risk of containment failure
  - ★ *Is very important for BWR: corium slump into cavity*

- — Issue remains open with high priority due to risk significance
  - ★ Answers expected from SERENA-OECD project, more analytical effort is needed
  - ★ Ex-vessel findings will be transferred to in-vessel situation

EURSAFE Research Issue on Containment Integrity

- ERI 3,3
  FCI including steam explosion in weakened vessel
  (2,1,031)
  - ★ Investigate the risk of failure of a weakened vessel during reflooding of a molten pool in the lower head.
  - ★ No experimental program in SARNET
  - — Issue closed due to improved knowledge
    - ★ According to current state of knowledge:
      very low probability for high energetic in-vessel steam explosion
    - ★ Further activities in the ex-vessel field

EURSAFE Research Issue on Containment Integrity

- ERI 3,4 treated in WP 12-1 **&** WP 12-2
  Containment atmosphere mixing and hydrogen combustion and detonation
  (3,3,022/029/043/094/102/109/112; 4,1,070/071)
  - ★ Identify the risk of early containment failure due to hydrogen accumulation leading to deflagration or detonation and to identify influence of counter-measures (PAR, spray).
  - ★ DDT not treated in SARNET

  – Issue remains open with high priority due to risk significance
  - ★ Work to be continued
  - ★ Flame acceleration, ignition by recombiners are of specific interest
  - ★ Link to DCH → hydrogen generation, ignition source

EURSAFE Research Issue on Containment Integrity/Source Term

- ERI 3,5 treated in WP 15
  Dynamic and static behaviour of containment, crack formation and leakage at penetrations
  (3,5,044/047/059/067/068; 4,3,071)
  - ★ Estimate the release of fission products through leakages to the environment. Problem: shape and size of cracks
    FP depletion in cracks → ERI 5,3
  - ★ No experimental actions in SARNET for structure mechanics
  - — Issue was already second priority, now low priority
    - ★ Release might be significant in case of longer lasting P > $P_{Design,}$
      e.g. if AM measure 'containment filtered venting' fails,
      low probability for longer overpressurisation due to AM measures

EURSAFE Research Issue on Containment Integrity

- ERI 4,1 treated in WP 13-2 **&** WP 10-2
  Direct containment heating
  (4,2,013/030/031/060/063/070/071)

  ★ Increase the knowledge of parameters affecting the pressure build-up due to DCH and determine the risk of containment failure.

  – Issue partially closed (EPR, VVER1000) still open for KONVOI

  ★ Large experimental database, CFD code for analysis available

  ★ Hydrogen combustion model to be improved

  ★ Analytical approach for initial hole size and hole ablation necessary => hole size has direct influence on melt ejection rate

  ★ AM measure: reduce RCS pressure, but DCH also with lower RPV pres.

  ★ Continue at reduced effort with **medium priority**

EURSAFE Research Issue on Source Term Potential

- ERI 5,1 treated in WP 14-1 **&** WP 9-3
  Oxidising environment impact on source term
  (1,1,111/233/243; 5,1,026)

  ★ Quantify the source term, in particular for Ru,
  under oxidation conditions or air ingress for HBU and MOX.

— Issue remains open with high priority due to risk significance

★ Issue is covered by ISTP, continue the planned work

★ High priority issue for Ru behaviour due to risk significance

EURSAFE Research Issue on Source Term Potential

- ERI 5,2 **&** 5,4 treated in WP 14-2 **&** WP 9-2 **&** WP 16
  RCS high temperature chemistry impact on source term **&**
  Containment chemistry impact on source term
  (5,1,041; 5,2,014; 5,5,021/023/024/025/030/040/043/047/048/04C)
  - ★ Improve predictability of iodine (Ru) species exiting RCS to provide the best estimate of the source into the containment.
  - ★ Improve the predictability of iodine chemistry in the containment to reduce the uncertainty in iodine source term.

— Issue remains open with high priority due to risk significance

- ★ Issue covered by ISTP and other projects, continue the planned work
- ★ High temperature iodine chemistry less important for RCS, but significant for BWR containment

EURSAFE Research Issue on Source Term Potential

- ERI 5,3 treated in WP 15 & WP 9-2
  Aerosol behaviour impact on source term
  (5,2,042/050; 5,4,060; 5,5,080)
  - ★ Quantify the source term for containment bypass (aerosols not hold back by the secondary side of steam generator), leakage through cracks in the concrete containment wall, and the source into the containment due to revolatilisation in RCS.
  - Issue could be closed after completion of the current activities
    - ★ Issue covered by ISTP, ARTIST and other projects
    - ★ AM measure: reduction of RCS pressure
    - ★ AM measure: isolation and filling of affected steam generator
    - ★ AM measure: reduction of containment pressure (filtered venting)
    - ★ Low priority considering successful AM

EURSAFE Research Issue on Source Term Potential

- ERI 5,5
  Core re-flooding impact on source term
  (5,1,***050***)
    - ★ Characterise and quantify the FP release during core re-flooding.
  - — Issue remains open with low priority
    - ★ Issue covered by ISTC VVER QUENCH Project, to be continued
    - ★ Low priority with respect to risk significance
      (according to PSA2 not a dominant effect)

Summary 1/4

- 6 issues remain open with **high priority**
  - ERI 1,2: research on coolability of not totally degraded core during reflood and debris cooling
  - ERI 2,1 **&** 2,2: Combined research on ex-vessel melt pool configuration during MCCI **&** ex-vessel corium coolability, also by top flooding
  - ERI 3,1 **&** 3,2: Combined research on melt relocation into water **&** ex-vessel FCI
  - ERI 3,4: Research on hydrogen mixing, combustion in containment (flame acceleration), H2 mitigation measures
  - ERI 5,1: Research on oxidising impact on source term (Ru oxidising conditions or air ingress for HBU and MOX fuel elements)
  - ERI 5,2 **&** 5,4: Combined research on iodine chemistry in RCS **&** in containment

Summary 2/4

- 4 issues remain open with **medium priority**
  - ERI 1,1: Research on hydrogen generation during reflood and during melt relocation in vessel
  - ERI 1,3a: corium coolability in lower head
  - ERI 1,4: Research on integrity of RPV by external vessel cooling
  - ERI 4,1: Research on direct containment heating

Summary 3/4

- 5 Issues remain open with **low priority** and could be closed after finalizing the related activities
  - ERI 1,3b: Research on corium coolability in external core catcher
  - ERI 1,6: Research on corium release following vessel rupture
  - ERI 3,5: Research on dynamic and static behaviour of containment, crack formation and leakage at penetrations
  - ERI 5,3: Research on aerosol behaviour impact on source term (steam generator and containment cracks)
  - ERI 5,5: Research on core reflooding impact on source term

Summary 4/4

- 3 Issues **could be closed** due to low risk significance or sufficient knowledge,
  further experimental programs seem not necessary
  - ERI 1,5: Research on heat distribution in the reactor coolant system and its integrity
  - ERI 2,3 **&** 2,4: Research on ex-vessel core catcher and corium-ceramics interaction **&** on the cooling of the melt by water bottom injection
  - ERI 3,3: Research on in-vessel FCI inclusive steam explosion in weakened vessel

Research Proposals

- In the field of corium coolability
  - ★ Reflooding + coolability of a not totally degraded core (multi-D effect)
  - ★ Remelting of debris, melt pool formation and coolability
  - ★ Ex-vessel debris formation and coolability
  - ★ Bringing research results into reactor application
- In the field of MCCI
  - ★ Effect of the concrete properties on 2D ablation profiles
  - ★ Role of the metallic layer on the MCCI
  - ★ Efficiency of water cooling to terminate the ablation of concrete
  - ★ Transfer of R&D results to the reactor scale

Research Proposals

- In the field of containment
  - ★ Contain. atmopshere mixing, H2 combustion, H2 mitigation measures
  - ★ Ex-vessel FCI (jet fragmentation, debris bed formation, coolability)
  - ★ Ex-vessel debris formation and coolability
  - ★ Direct containment heating (improve the models)
- In the field of source term
  - ★ Effect of oxidising atmosphere on Ru + air ingress for HBU and MOX (FP release from fuel, Ru oxide transport/behaviour in RCS + containment)
  - ★ Iodine behaviour/transport in circuit + containment
  - ★ Bringing research results into reactor application

End User Comments

- Utilities/manufacturer end users main interest in research results which are useful for development of AM measures
- More on realizable applications than on knowledge oriented research
- Risk informed ranking by PSA2 results: *would not be uniform, because PSA2 results are plant specific;*
  regarded by assessing the generic risk relevance (influence on source term)
  - For SARP2 proposal is to invite additional PSA specialists and experts from utilities/ manufacturers as members

Concluding remarks

The evaluation of research priorities is an ongoing process; it will be continued in SARNET2, when new discussions on the priorities of the issues are reasonable on the basis of progress of knowledge.

The author thanks all members of the SARP and MANAGEMENT team, and the TOPICAL leaders for their valuable contributions.