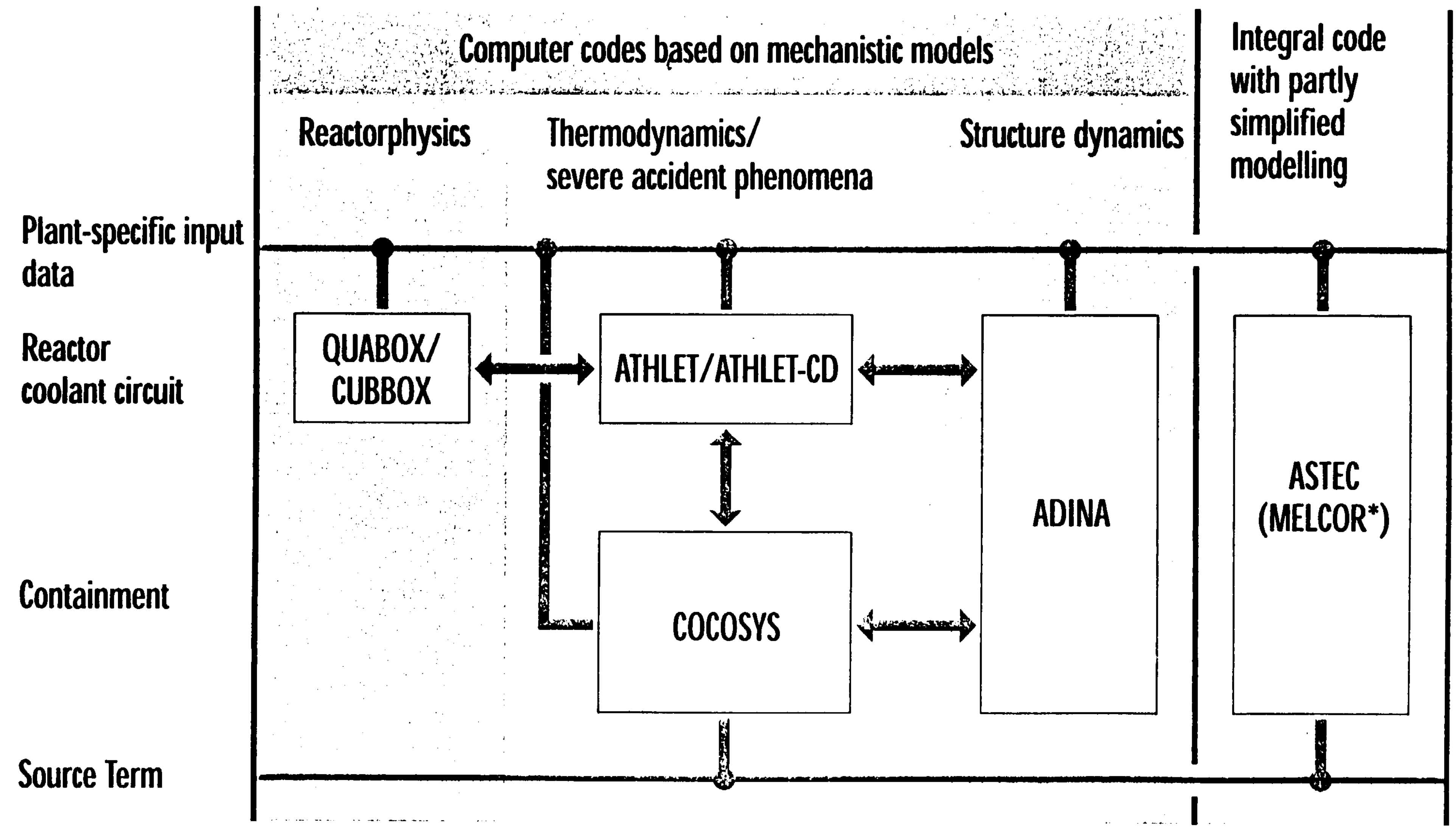
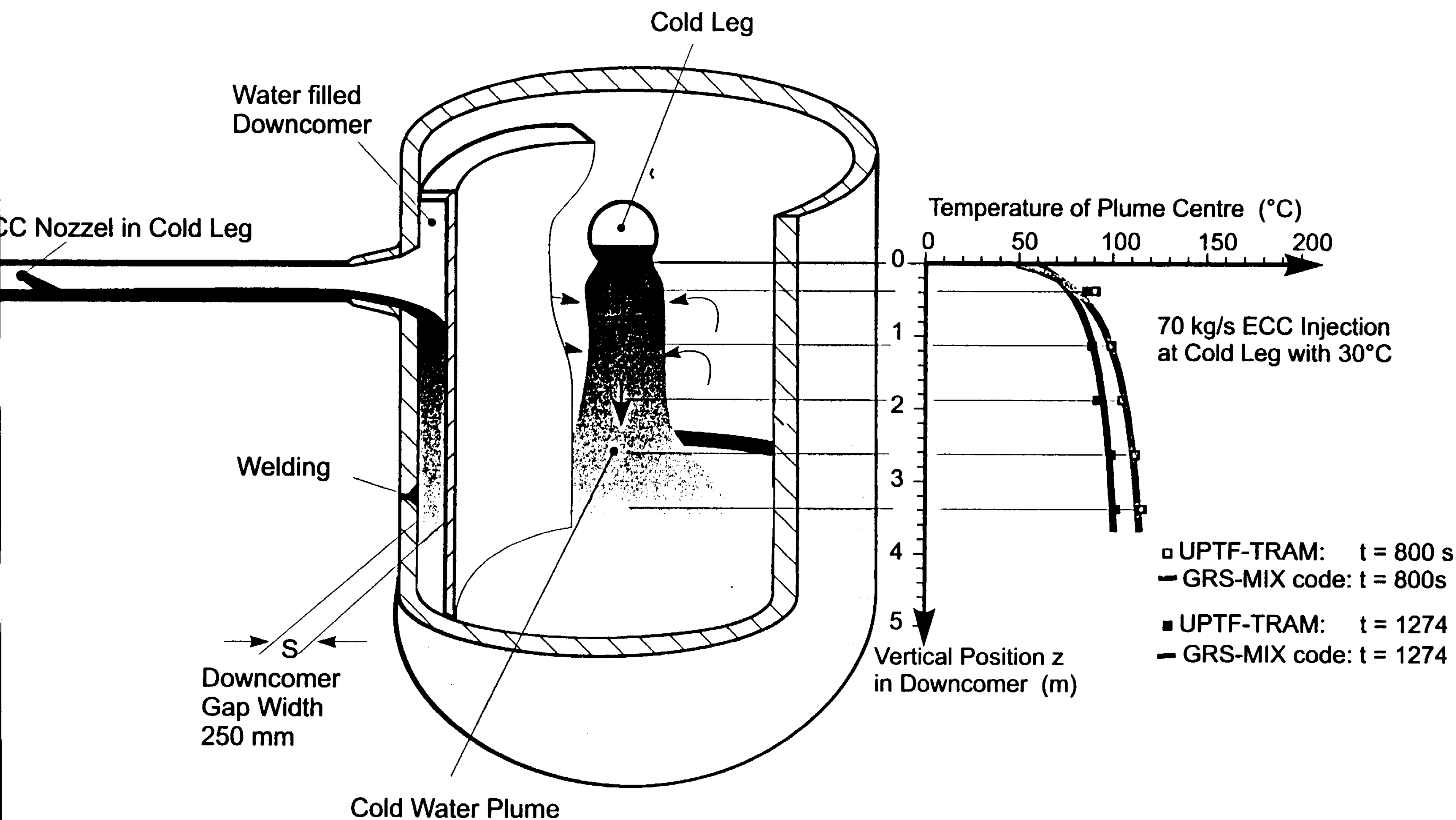
System of GRS-Codes for the Analysis of Accidents and Severe Accidents in LWR's

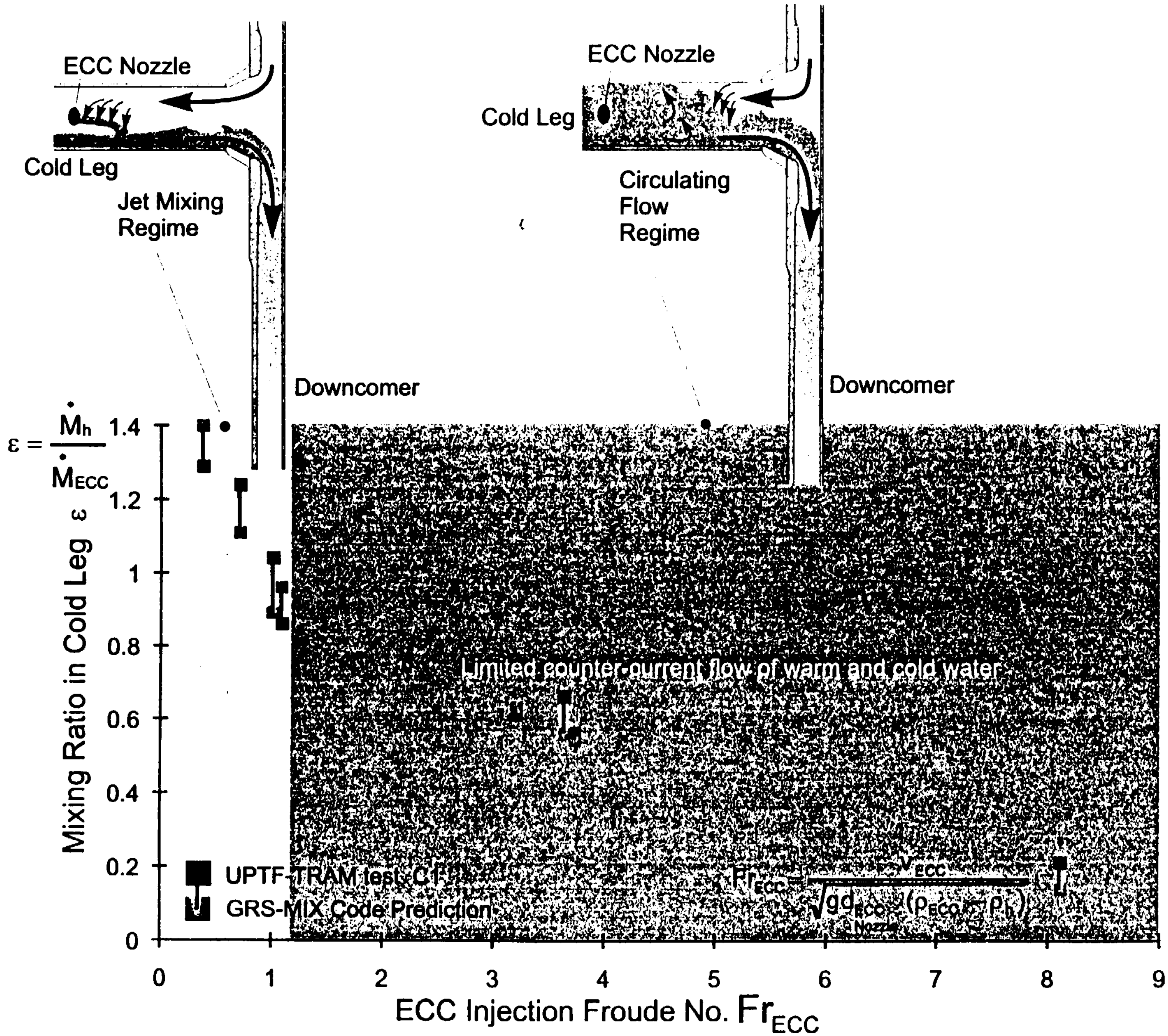


*only complementary until an ASTEC-version incl. "front end" modelling is available

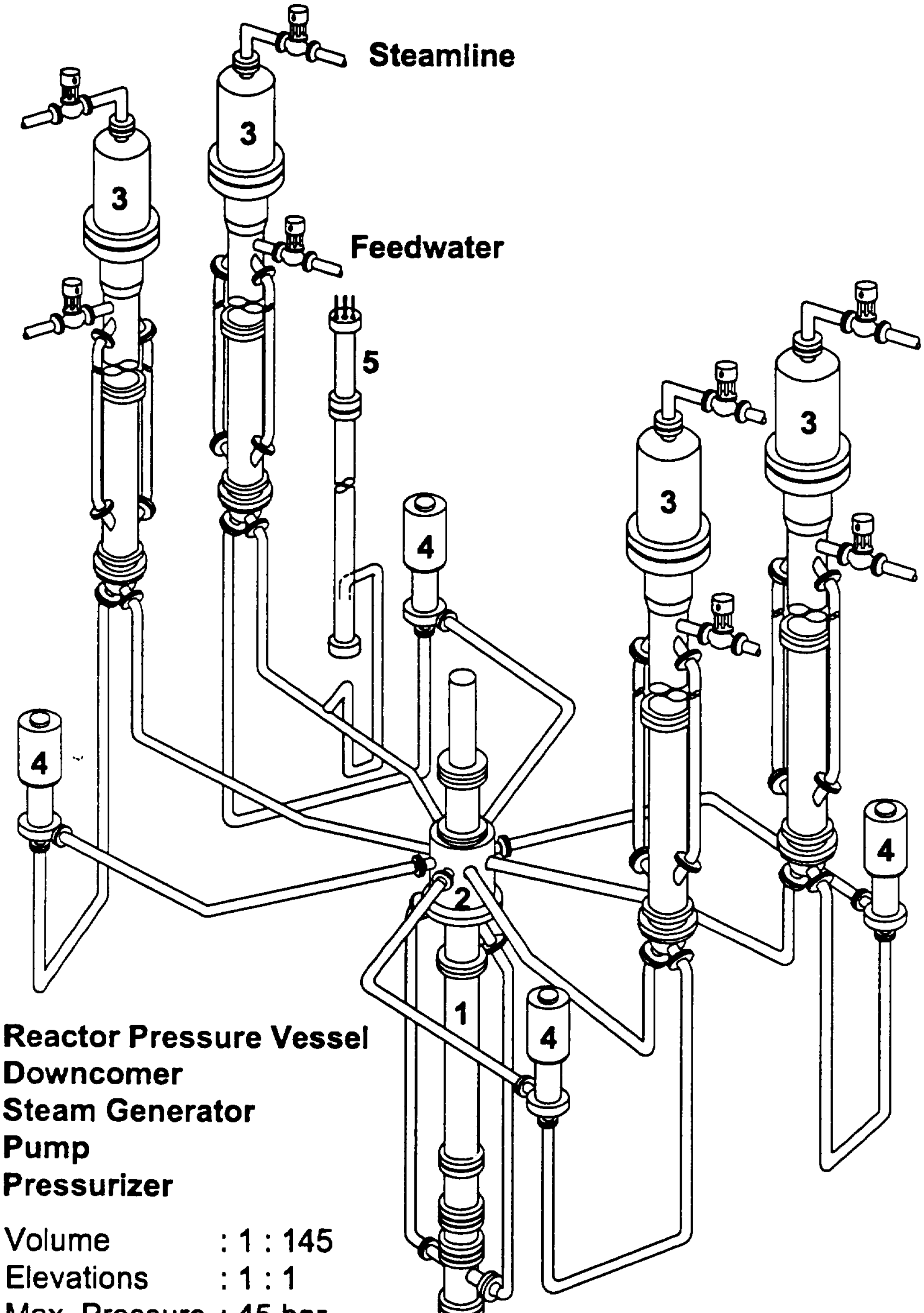
9611201



UPTF-TRAM: Full Scale Investigation of Thermal Mixing in Downcomer



UPTF-TRAM Test Result for ECC Mixing in Cold Leg



1 Reactor Pressure Vessel
2 Downcomer
3 Steam Generator
4 Pump
5 Pressurizer

Volume	: 1 : 145
Elevations	: 1 : 1
Max. Pressure	: 45 bar
Max. Power	: 2,5 MW (10%)

PKL III Test Facility Primary Side

KWU NT31/Gü
09.10.98
OECD/Fo02.dsf

PKL Program within the SETH-Project

- It is planned to include the PKL program (together with the PANDA program) from the beginning of 2001 on in an international OECD project (SETH)

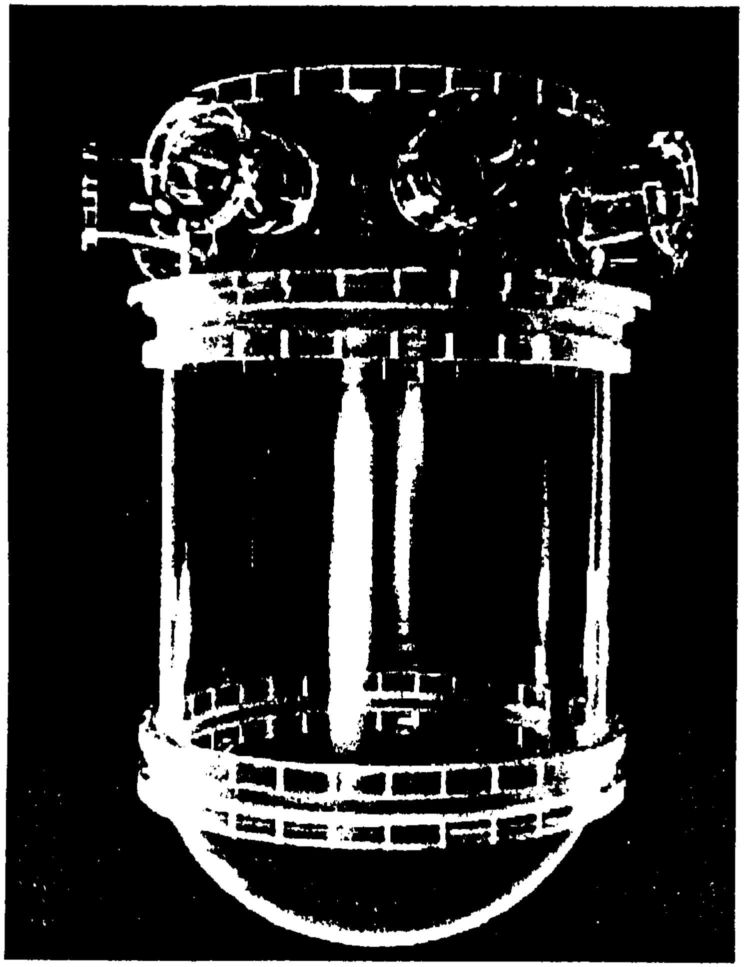
- The proposed PKL program is scheduled from 01/2000 to 06/2003 and includes four extensive experiments

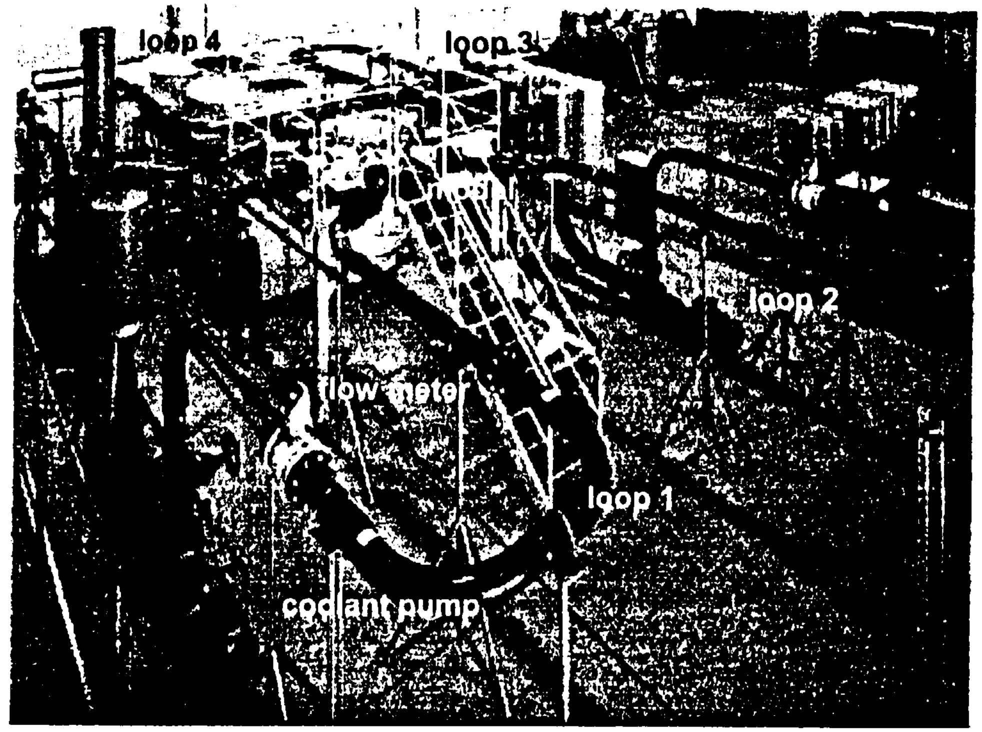
- The PKL experiments will focus on PWR issues, which are currently receiving great attention within the international reactor safety community, i. e.:
  * Boron dilution accidents
    → Systematic investigation of restart of natural circulation under SB-LOCA conditions and transport of low borated water into the RPV
    → With use of boric acid and by employing specific instrumentation for the determination of boron concentration

  * Accidents under shutdown conditions
    → Efficiency of preventive accident management (AM) measures in case of failure of the RHRS during mid loop operation with already opened RCS

- The common OECD project will
  - provide important experimental data concerning current topics of international relevance
  - provide an important experimental database for code validation
  - contribute towards guaranteeing the availability of the test facility and the preservation of the competence/skills of the research team in the future

ROCOM: Rossendorf Coolant Mixing Test Facility



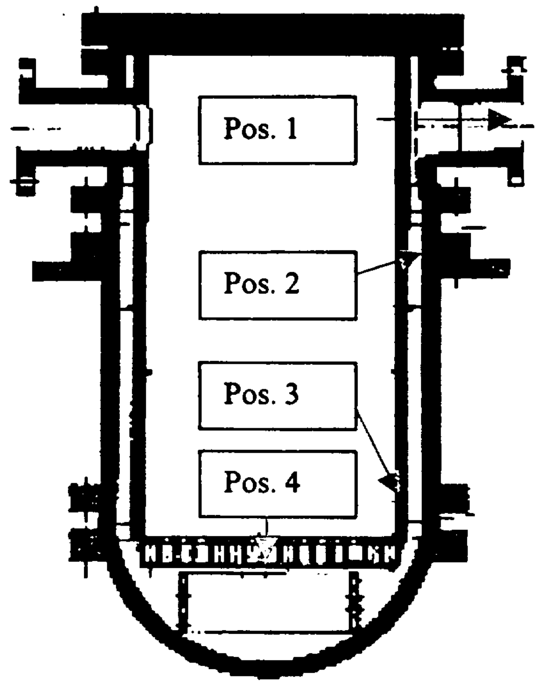


- scaled test facility (1:5) of the PWR Konvoi (Siemens KWU)
- injection of salt water plugs to simulate the deboration or overcooling
- four loops with separately frequency controlled coolant pumps
- 4 wire mesh sensors for salt concentration measurements (over 1000 measurement points)

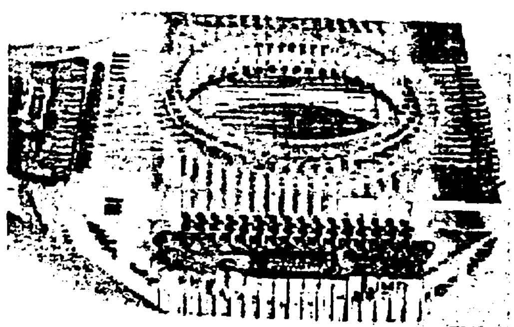
Conductivity Measurement: Wire Mesh Sensors

Technical Data:

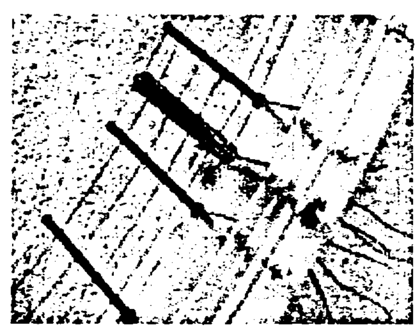
- Working Mode: 200 Hz sampling
- Conductivity Range: 10-500 µS/cm
- Resolution:
    - 15x15 Core Inlet
    - 16x16 Inlet Nozzle
    - 16x16 (upper Downcomer)
    - 16x16 (lower Downcomer)



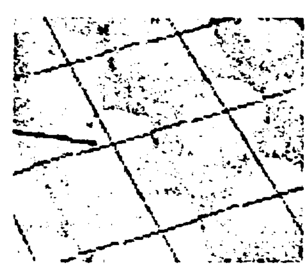
Wire Mesh Sensor Inlet Nozzle (Pos. 1)



Wire Mesh Sensor Downcomer (Pos. 2 +3)



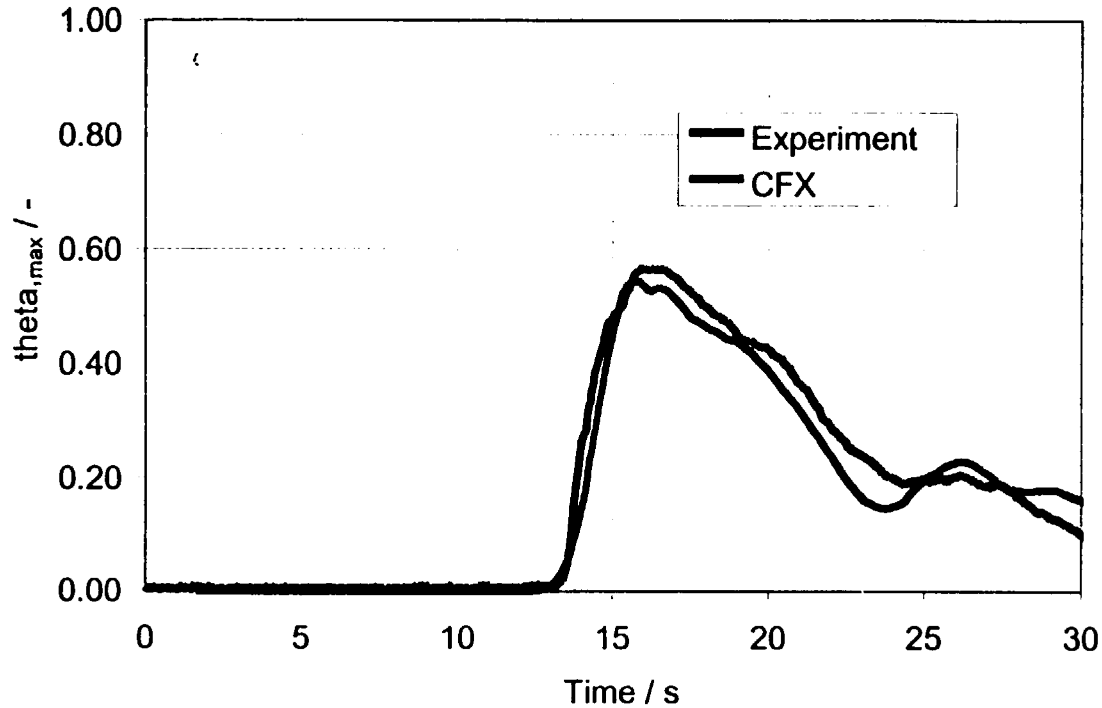
Wire Mesh Sensor Core Inlet (Pos. 4)



Forschungszentrum Rossendorf
Institut für Sicherheitsforschung

Start of the first MCP into stagnant fluid

Streamlines showing the flow field (numerical simulation)



Time behavior of the normalized maximum salt concentration at the core inlet - comparison between CFD-calculation and experiment

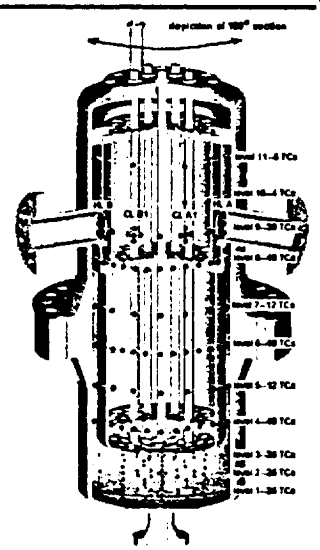
$$\Theta_{x,y}(t) = \frac{\sigma_{x,y}(t) - \sigma_{reactor}}{\sigma_{plug} - \sigma_{reactor}} = \frac{c_{B,\max} - c_B}{c_{B',\max} - c_{B,\min}}$$

CFX-TASCflow

- **Mathematical model:**
  - 3D RANS + energy equation,
  - k-ε Turbulence model,
  - Conjugate heat transfer.
- **Numerical method:**
  - Discretization 2nd order in space and time,
  - Block-coupled pressure-momentum solution,
  - Algebraic multi-grid solver.
- **Numerical grid:**
  - Hexahedral flux elements,
  - Body-fitted,
  - Block-structured.

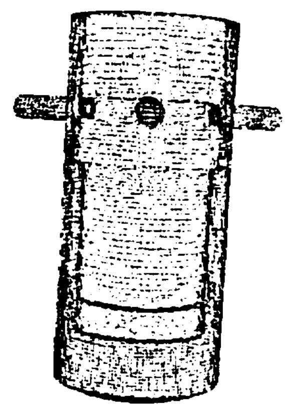
ISP 43 Experiment

- Rapid Boron dilution by actuation of pump
- Test case A:
  - Mixing of cold water front (large volume)
  - Open system
- Test case B:
  - Mixing of cold water slug (limited volume)
  - Closed System
- http://chemnuc-149.umd.edu

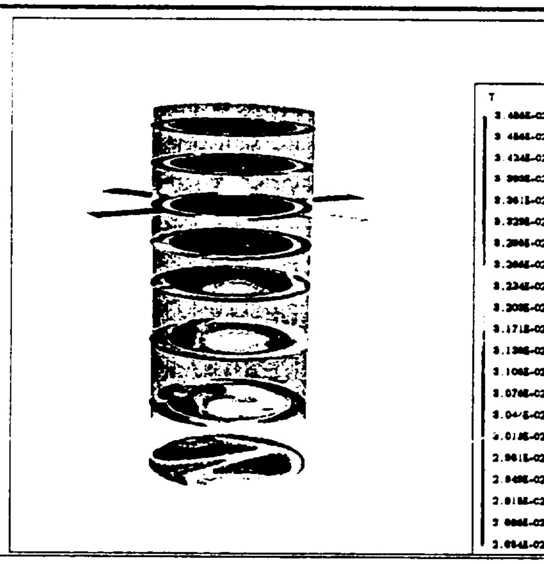


Problem Description

- Geometry: IGES surface model
- Grid generation: Powermesh (ICEM)
- Numerical grid: 470 000 elements
- Porous core: ΔP = 1500 Pa
- Water filled system: T = 74 ºC
- Transient calculation for 62 s
- Adiabatic walls.

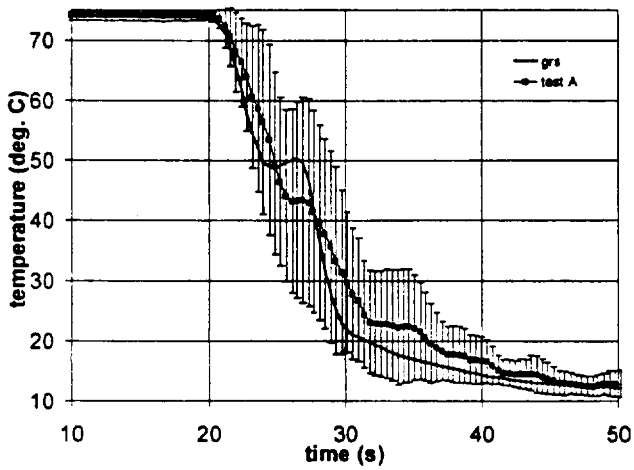


Temperature distribution, time = 28 s



Transient temperature distribution

level 4 average



Problems

- Transient calculations on large grids:
  - High demand on storage and CPU time.
  - Efficient convergence.
- Complex physical phenomena.
- Lack of experiments for validation of local phenomena.

CFD-Research Proposal

- Increased use of CFD-tools requires:
  - Parallel computing.
  - Improved models:
    - Turbulence models: Buoyancy, heat transfer.
    - Two-phase flow models.
- Better and more complete experimental data.
- Establishment of Best Practice Guidelines:
  - Documentation of simulation process.
  - Quality assurance.
  - Establishment of guidelines for judgement of numerical results.

Summary on CFD-codes

- Potential of CFD Codes for detailed simulation.
- Adaption of CFD tools for 3D single- and two-phase flows in the reactor coolant system.
- Proposed research areas.

Fuel Behaviour during LOCA and RIA (1)

- ECC acceptence criteria in RSK guidelines are the same as the US rule (10CFR50.46) plus one additional criterion:
  The number of ruptured rods must not exceed 10% of all rods.

- This core damage criterion dominates in today's plant applications.

- A new core damage analysis is required for each new core load.

- The criteria on peak clad T (1200°C) and oxidation depth (17%) are to be reviewed with respect to new cladding materials and high burn-up.

- During fast power transients (RIA) high burn-up fuel shows specific features, e.g. fission gas release from the rim.

Fuel Behaviour during LOCA and RIA (2)

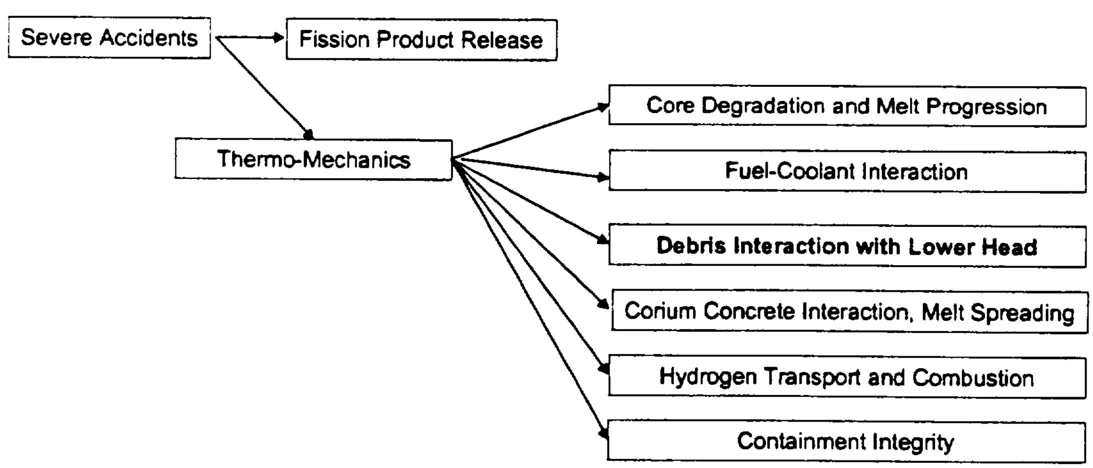
R&D actions required:

- Core damage during LOCA should be assessed using a fuel rod behaviour code (TESPA) with correlations for oxidation, creep, rupture etc. for new cladding materials implemented.
- Thermal-hydraulic LOCA calculations for peak cladding temperatures should be best-estimate with uncertainties quantified.
- Fuel behaviour for RIA will make use of TRANSURANUS to account for burn-up history and will include improvements in SCANAIR for transient behaviour.
- Experimental data for RIA are expected from the CABRI programme.

Severe accident molten core behavior: cooling in the lower head

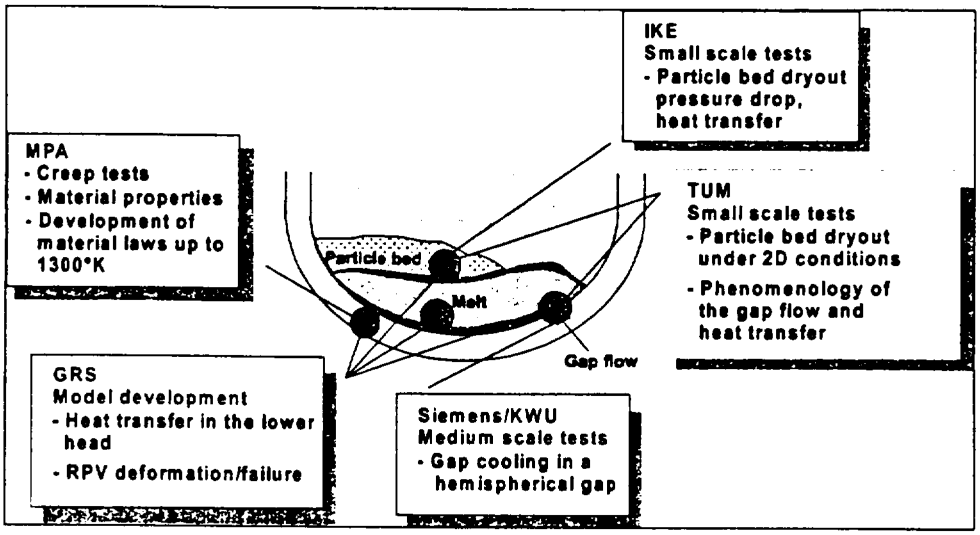
- Relation of the current issue to severe accident research
- Phenomena under investigation
- Re-interpretation of TMI-2 results
- Joint German research program
- Integral simulation module AIDA
- Mechanism of gap cooling
- Evaluation of RASPLAV and MASCA experiments

Relation to Severe Accident Research



Joint German BMWi Research Program: Debris Lower Head Interaction 1995-2000

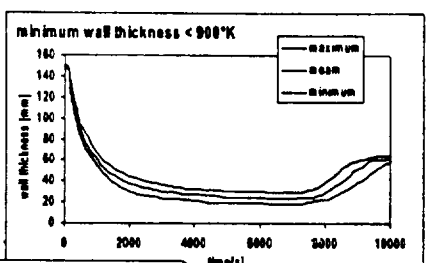
GRS

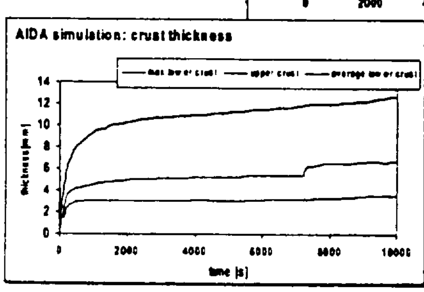


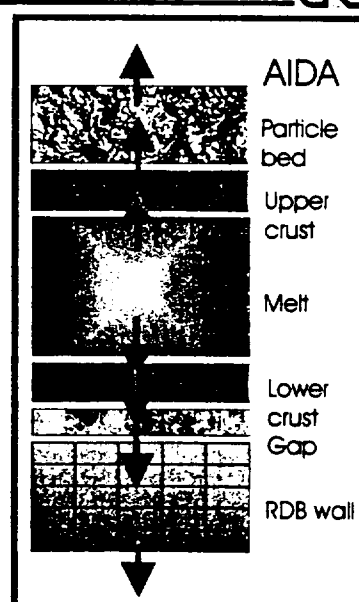
AIDA: Analysis of the Interaction between Core Debris and the RPV during Severe Accidents

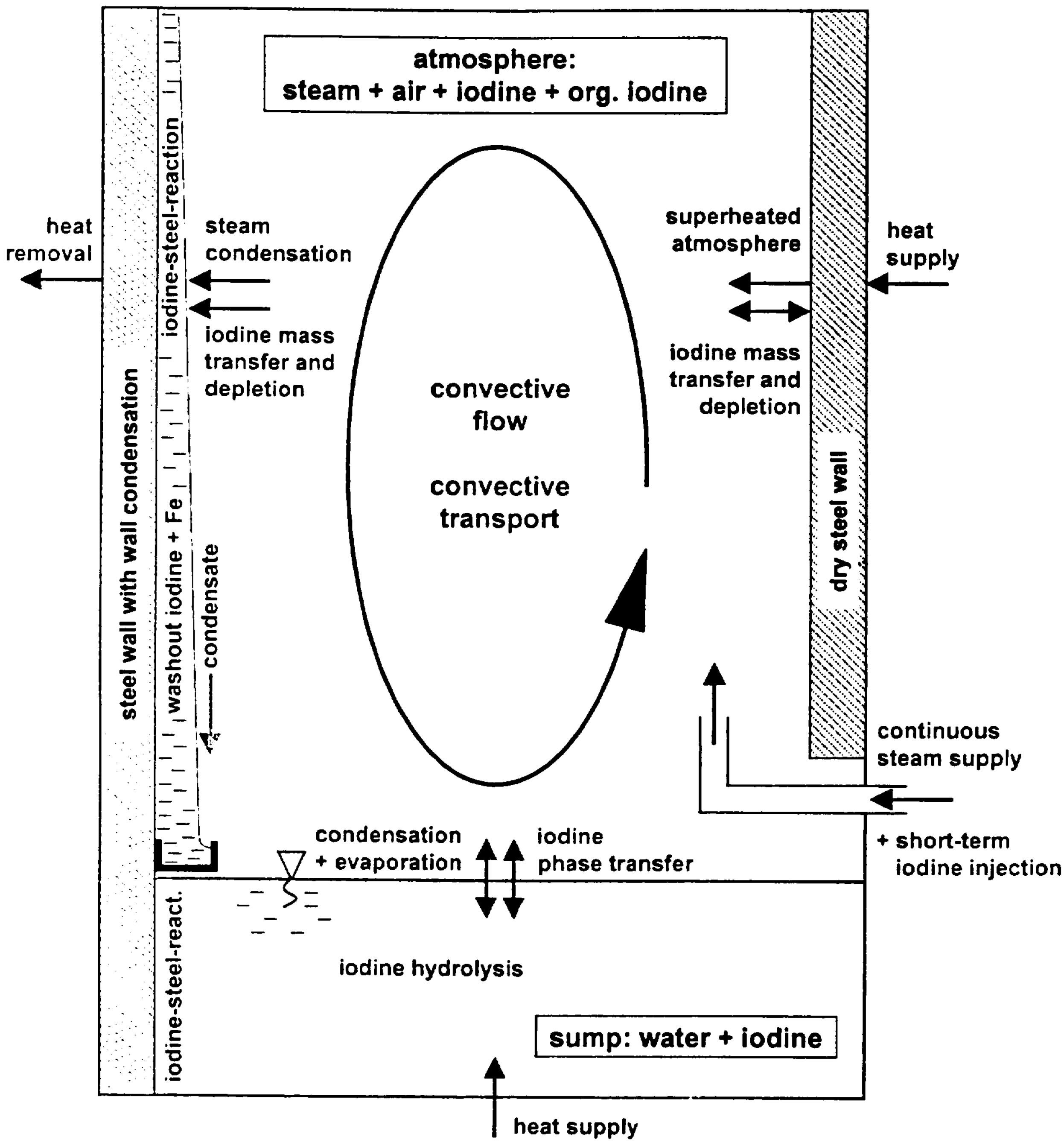
GRS

- Application:
- Scoping calculations
- Uncertainty analysis
- Sensitivity analysis
- Safety analysis









Thermohydraulic and iodine phenomena

GRS Method

- All potentially important uncertain parameters can be included
- Variation of all parameters simultaneously per computer code run
- Results:
  - **Uncertainty range** of code results
  - **Sensitivity measures** about influence of uncertain input parameters

    ⇒ **Ranking** of parameters **as result of the analysis**

Number of code calculations – Wilks' formula (1)

- Independent of **number of uncertain parameters**
- Dependent on **tolerance limits for the uncertainty statement of the code results**
- Smallest number of code runs n
  - upper statistical tolerance limit (one-sided):

$$1 - \alpha^n \geq \beta$$

α % is the desired **probability content** (fractile),

β % is the **confidence limit** (taking into account the possible sampling error due to limited number of code calculations)

Number of code calculations – Wilks' formula (2)

- **Minimum number of code runs** to calculate limits which are not to be exceeded with **95% probability** (95%-fractile):

  59 at 95% confidence level,
  45 at 90% confidence level,
  32 at 80% confidence level,
  14 at 50% confidence level.

Summary and Conclusion

- Reactor safety research in Germany comprises several topics that we consider as potentially interesting for co-operation with the US.

- In the areas of thermal-hydraulics and severe accidents Germany is performing both anaytical and experimental R&D.

- Experiments adressing fluid/fluid mixing have been performed in 1:5 scale loop facility ROCOM and in the 1:1-scale UPTF. Integral system tests in the 1:145-scaled PKL 4-loop facility will be performed within the SETH project of OECD/NEA.

- Other topics of interest are: uncertainty analysis, fuel behaviour under LOCA and RIA, in-vessel melt cooling, and fission product behaviour in the containment.