Comprehensive Report on Results of the Battelle Frankfurt Containment Experiments and Analytical Verification

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Summary

The experiments performed in the model containment of Battelle Frankfurt on behalf of the Federal German Ministry of Research and Technology were the first integral tests in which loss-of-coolant accidents (LOCAs) in a multi-compartment full-pressure containment were simulated to examine the capability of the computer codes used for designing PWR containments.

The model containment was constructed similar to the full-pressure containment of a typical German PWR plant, with linear scaling of 1:4. Two experimental series have already been carried out in this facility. They were analyzed by several institutions using various computer codes, all of which are multi-node models with similar characteristics.

In the first experimental series, the C series, PWR conditions (subcooled water line breaks, interconnected compartments) were simulated for various break sizes and break locations. The analysis of these experiments showed that licensing assumptions lead to conservative results for pressure build-up in the containment. With regard to pressure differences between the compartments, subcompartment analysis has indicated that a

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more detailed description of the physical processes during a LOCA is needed. It was found that for some arrangements local inhomogeneities and flow velocities have to be taken into account and that homogeneous flow models assuming transport of a large amount of water lead to a misinterpretation of the phenomena. Code development was initiated taking account of these results, and a second experimental series, the D series, was started with simplified conditions (steam line breaks, different simple geometrical arrangements of compartments and vents). These experiments were aimed at separating the influences of different effects such as water transport, vent flow losses and heat transfer, and supporting code development.

The analysis of these experiments indicated that heat transfer between fluid and structure significantly affects pressure build-up even in the short-term range. Although this effect seems to be a particular characteristic of the model facility (large surface area to volume ratio), it has to be taken into account, because otherwise some phenomena observed in the experiments might be misinterpreted. The simplified flow conditions in these experiments enabled separate geometrical effects to be analyzed. Discharge coefficients for orifices were obtained by comparing the results of corresponding experiments with nozzles and orifices. In addition some criteria of nodalization and of the need to account for flow velocities were found.

The Battelle containment experiments have shown that the multinode models applied are suitable tools for the analysis of these integral tests, provided that appropriately averaged parameter values are available for separate effects, such as water transport, flow losses and heat transfer. Suitable combinations of such values were obtained specifically for the Battelle model containment by analyzing a large number

of different experiments; but there is urgent need for additional data from separate-effect tests to confirm these results. In addition, larger integral test facilities, such as HDR, are necessary to investigate how the importance of different physical processes changes with scaling.

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COMPREHENSIVE REPORT ON RESULTS OF THE BATTELLE-FRANKFURT CONTAINMENT EXPERIMENTS AND ANALYTICAL VERIFICATION

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BATTELLE CONTAINMENT EXPERIMENTS: FIRST INTEGRAL TESTS SIMULATING LOCA IN A MULTICOMPARTMENT FULL PRESSURE CONTAINMENT

- Observe experimentally thermo-, fluid-dynamic processes
- Verify containment codes
- Examine safety margins for licensing calculations
- Further develop codes

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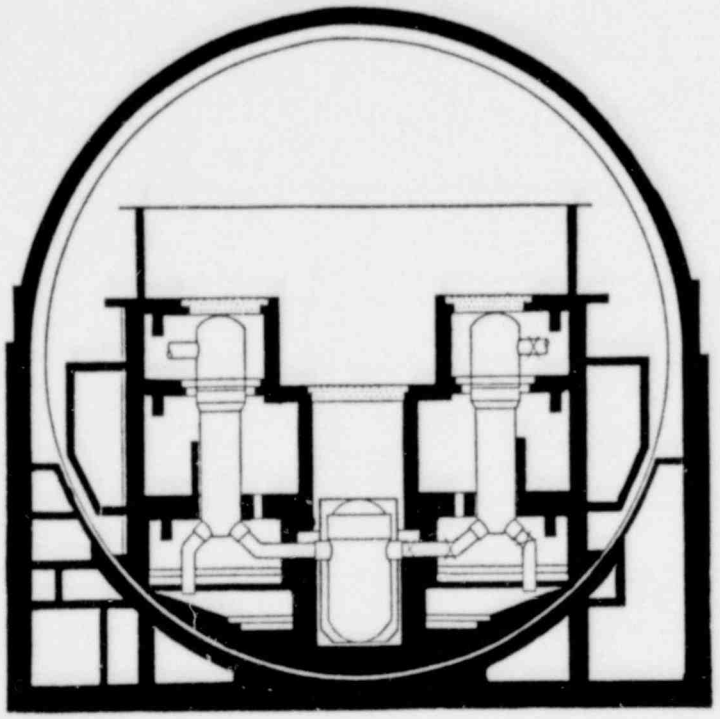
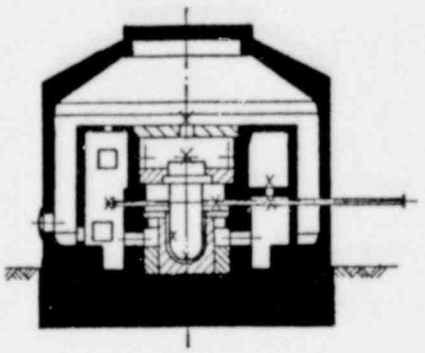
BATTELLE MODEL CONTAINMENT SIMILAR TO THE CONTAINMENT OF A TYPICAL GERMAN PWR PLANT LEADING TO TRANSFERABLE RESULTS

Real Plant



Test Facility



Linear Scale
4 : 1

475M

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1605 105

ANALYSIS OF TWO EXPERIMENTAL SERIES BY SEVERAL COMPUTER CODES WITH SIMILAR CHARACTERISTICS

- Homogeneous multinode models
- Two components (air, water)
- Two phases (air/steam, liquid)
- Model assumptions
  - Heat transfer
  - Water transport
  - Vent flow

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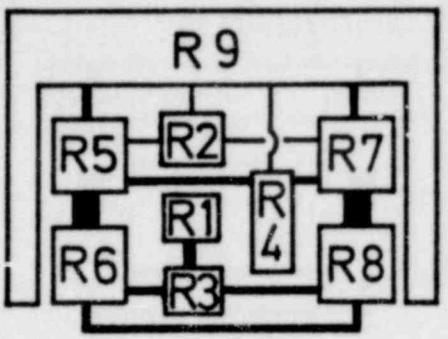
C-SERIES EXPERIMENTS: SIMULATION OF PWR CONDITIONS TO VERIFY CONTAINMENT CODES

- Network of compartments



C 13

- Water line breaks
- Different sizes and locations of the break

477M

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INTEGRAL INFORMATION ON CONTAINMENT BEHAVIOR FROM REALISTIC C-SERIES

— Licensing assumptions lead to conservative results for maximum containment pressure

— Subcompartment analysis with regard to differential pressures shows

- Great influence of water transport assumptions which dominate over other phenomena
- Local inhomogeneities which must be considered in some cases

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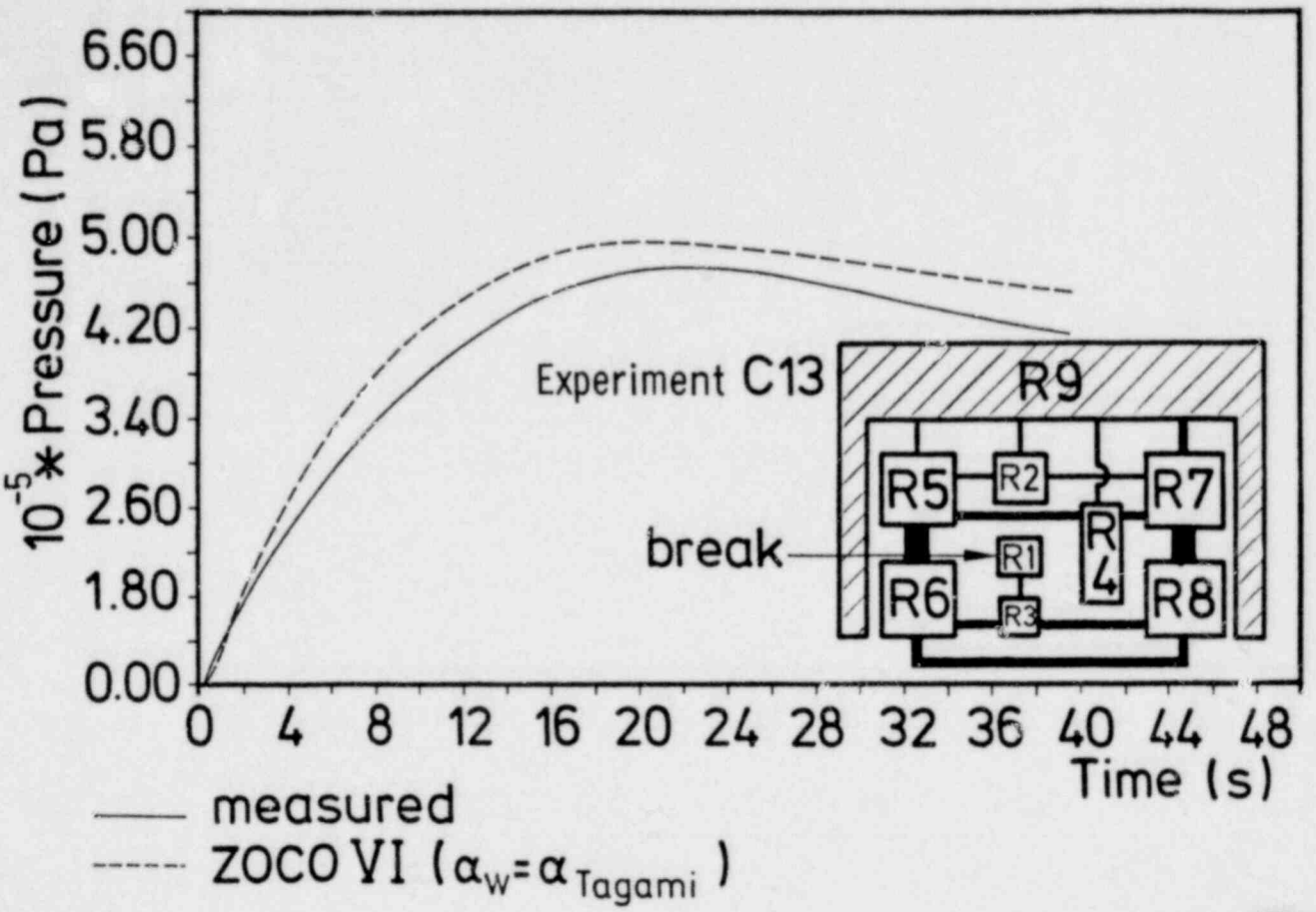
CONSERVATIVE RESULTS WITH REGARD TO MAXIMUM CONTAINMENT PRESSURE USING TAGAMI-UCHIDA CORRELATION FOR HEAT TRANSFER



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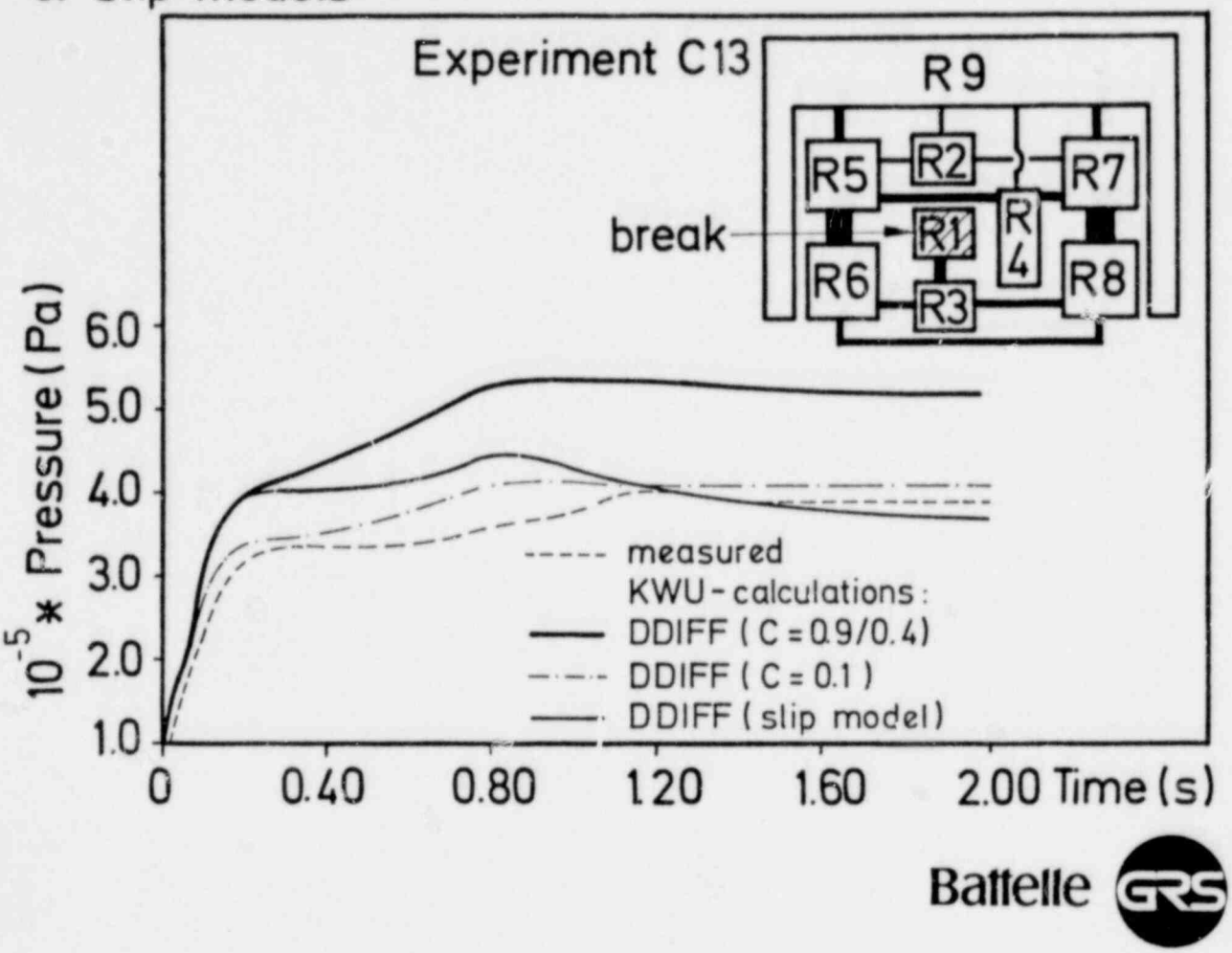
479M

MISINTERPRETATION OF PHENOMENA IN SUBCOMPARTMENT ANALYSIS BY HOMOGENEOUS FLOW MODELS WITH LARGE WATER TRANSPORT

- Improvement with limited water masses or slip models



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472M

CODE DEVELOPMENT BASED ON C-SERIES EXPERIMENTS

- Difficulties describing water transport
  → New water transport models
- Necessary subdivision of inhomogeneous compartments
  → Nonstationary momentum equation
- Influence of kinetic energy and dynamic pressure by special arrangements
  → Consideration of flow velocities

480 M

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1605 111

NEW EXPERIMENTAL SERIES TO EXPLAIN QUESTIONS OF C-SERIES STILL OPEN

Main problems:

- Water transport between compartments
- Flow losses for connections
- Heat transfer fluid ↔ walls

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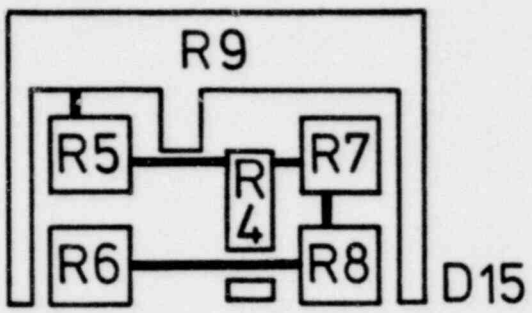
D-SERIES EXPERIMENTS: SIMPLIFIED CONDITIONS TO EXAMINE SINGLE PHENOMENA

- Chains of compartments
  → Simple flow conditions
- Steam line breaks
  → Neglection of initial water transport
- Different connecting vents
  → Information about flow losses



482 M

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1605 113

BETTER INTERPRETATION OF CONTAINMENT EXPERIMENTS BY SIMPLIFIED D-SERIES

Separation of single phenomena shows

- Importance of heat transfer for model containment

  → Key for interpretation of other phenomena (e.g. flow losses)

- Influence of geometrical arrangements

  → Differences between nozzles, orifices, and channels

  → Some criteria for nodalization and regard of flow velocities

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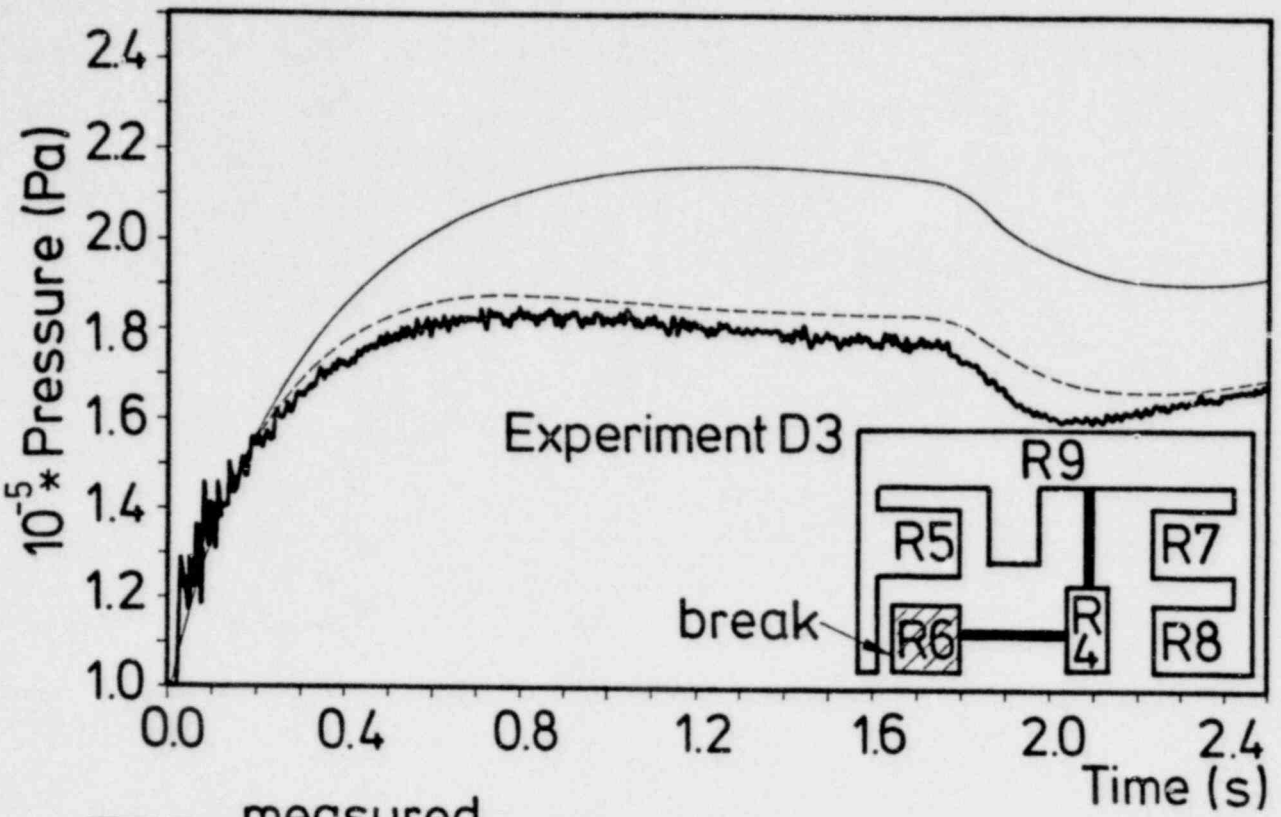
SUBCOMPARTMENT ANALYSIS OF STEAM BLOWDOWNS INDICATES LARGE HEAT TRANSFER TO WALLS NEAR THE BREAK



—— measured

—— COFLOW ($\alpha_W = \alpha_{Tagami}$)

----- COFLOW ($\alpha_W \leq 15\,000\ W/m^2 \cdot K$)

484 M

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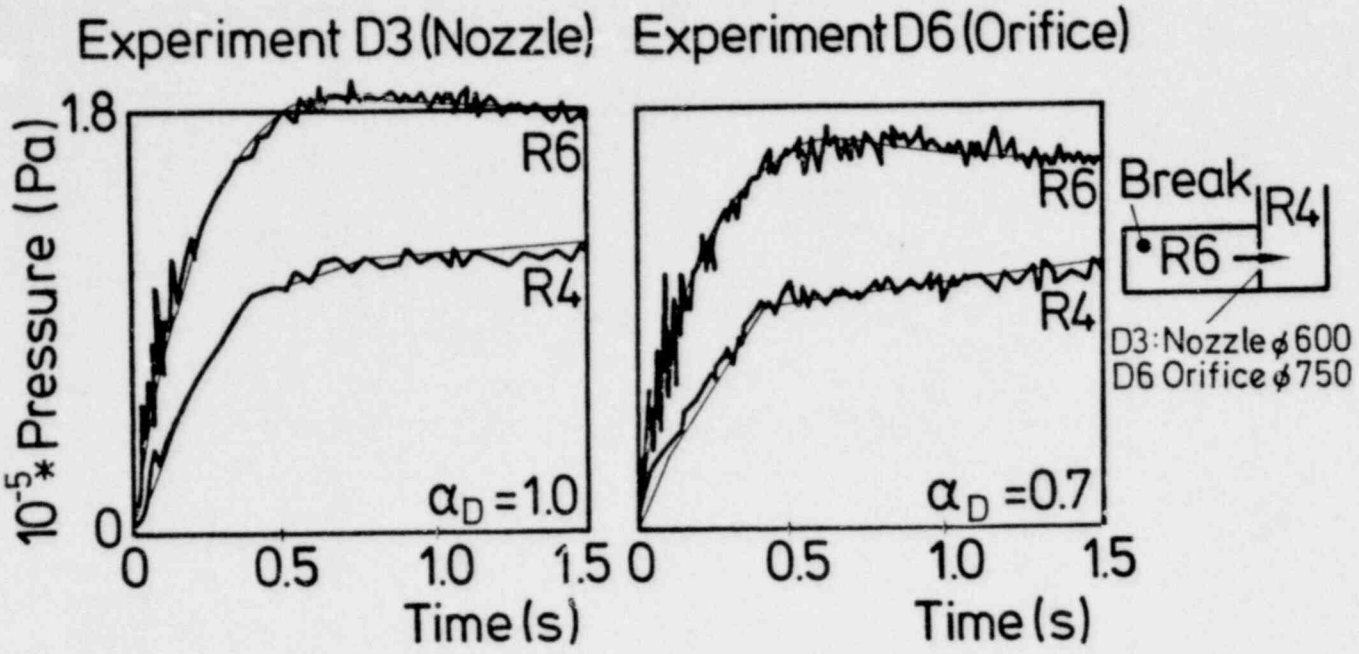
1605 115

TAKING ACCOUNT OF LARGE HEAT TRANSFER COMPARISON NOZZLES ↔ ORIFICES SHOWS SUITABLE DISCHARGE COEFFICIENTS FOR ORIFICES



—— measured
—— ZOCOVI
pressure in R4 is input

485M

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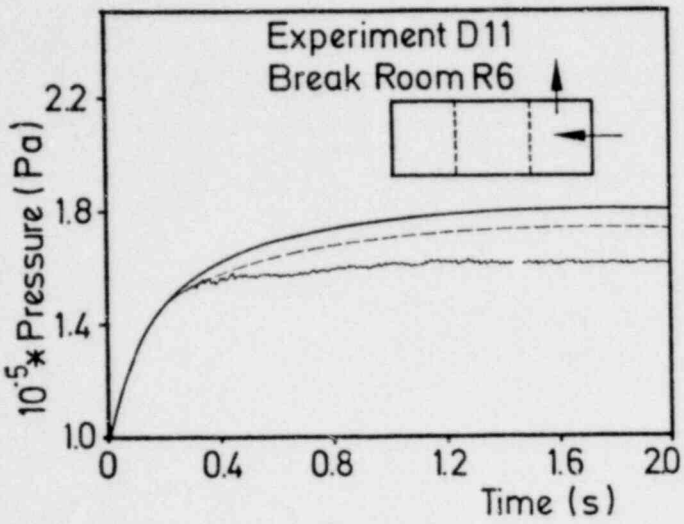
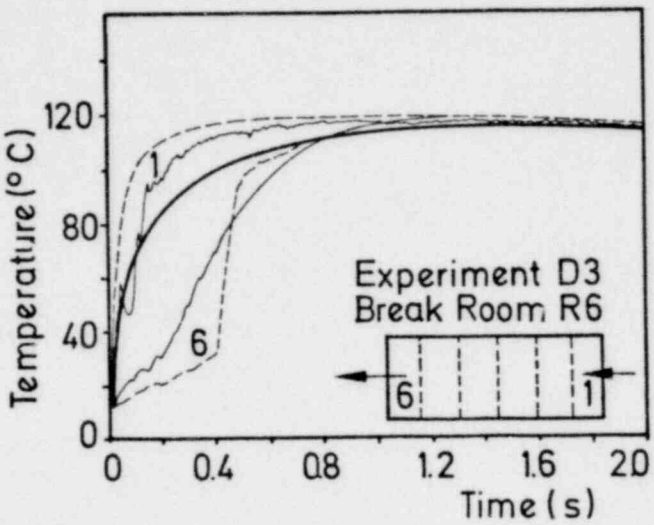
SUCCESSFUL SIMULATION OF INHOMOGENEITIES SUBDIVIDING COMPARTMENTS

Better description of

- Pressure in dead ends
- Temperature during penetration of steam front





—— measured
----- COFLOW(subdivided)
——COFLOW(not subdivided)

W 986 M

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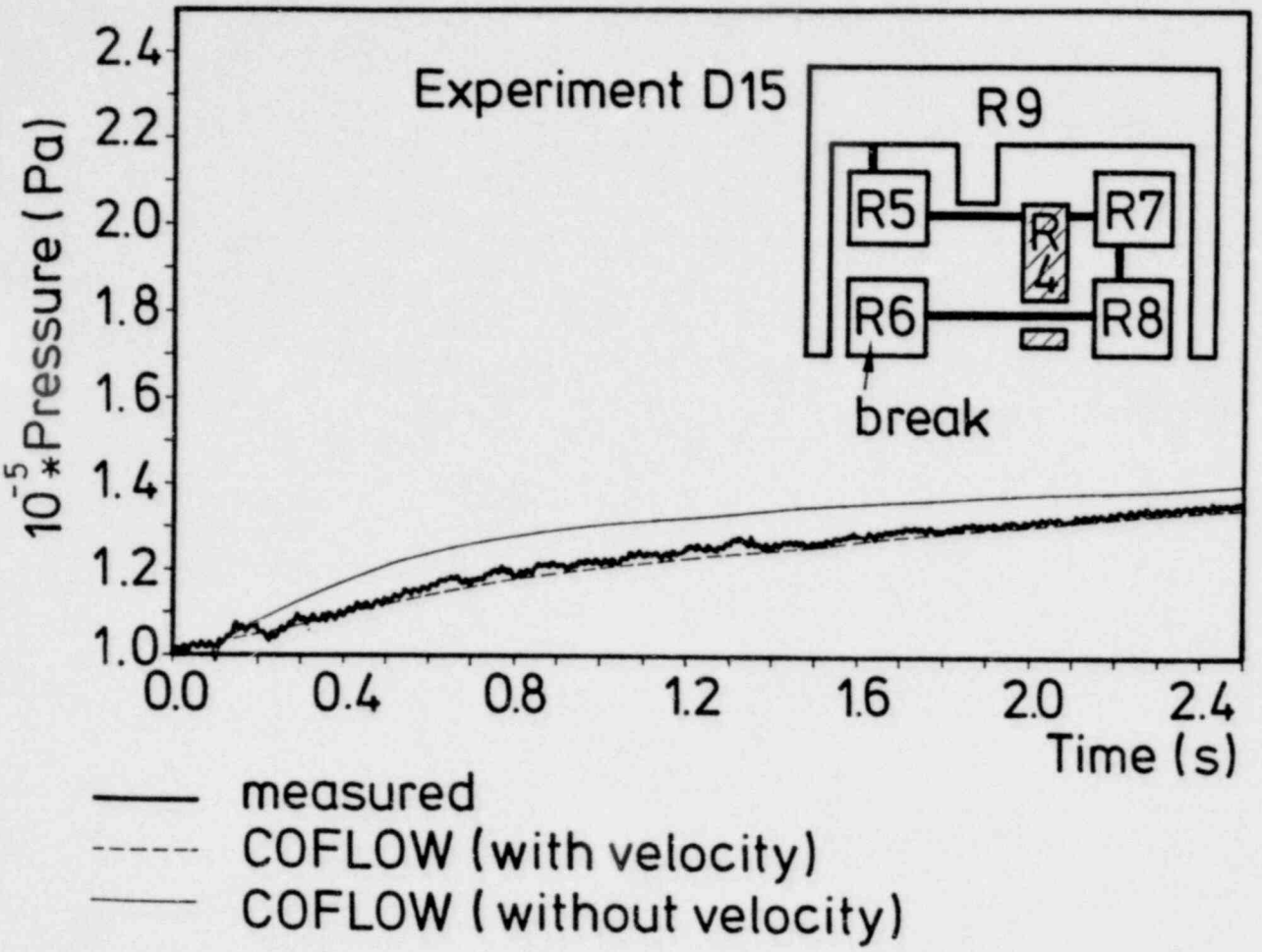
1605 117

INFLUENCE OF FLOW VELOCITIES IN SMALL COMPARTMENTS WITH TRANSVERSAL FLOW



BATTELLE CONTAINMENT EXPERIMENTS SHOW CAPABILITIES AND LIMITS OF CODES USED FOR ANALYSIS

- Multinode models are suitable tools for analysis of integral containment experiments
- Accuracy of codes depends on information about separate effects

488 M

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BENEFIT FROM SMALL SCALE EXPERIMENTS ONLY BY EXACT INTERPRETATION

To complete and confirm results obtained

- Separate effect tests → ECOTRA
- New measurement techniques for separate effects in integral tests
- Larger integral test facilities → HDR

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ANALYSIS OF BATTELLE-FRANKFURT CONTAINMENT EXPERIMENTS IMPROVE TECHNOLOGY BASE OF SAFETY EXAMINATIONS FOR PWR CONTAINMENTS

Research program has increased

- Activities in code development
- Experience in code application
- Confidence in licensing assumptions
- Information on important separate effects
- Knowledge of areas where further investigation is necessary (water transport, heat transfer, scaling)

1605 121

490M

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