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BWR CORE MELT PROGRESSION PHENOMENA— EXPERIMENTAL ANALYSES*

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Abstract

In the BWR Core Melt Progression Phenomena Program, experimental results concerning severe fuel damage and core melt progression in BWR core geometry are used to evaluate existing models of the governing phenomena. These include control blade eutectic liquefaction and the subsequent relocation and attack on the channel box structure; oxidation heating and hydrogen generation; Zircaloy melting and relocation; and the continuing oxidation of zirconium with metallic blockage formation. Integral data have been obtained from the BWR DF-4 experiment in the ACRR and from BWR tests in the German CORA exreactor fuel-damage test facility. Additional integral data will be obtained from new CORA BWR tests, the full-length FLHT-6 BWR test in the NRU test reactor, and the new program of exreactor experiments at Sandia National Laboratories (SNL) on metallic melt relocation and blockage formation. An essential part of this activity is interpretation and use of the results of the BWR tests. The Oak Ridge National Laboratory (ORNL) has developed experiment-specific models for analysis of the BWR experiments; to date, these models have permitted far more precise analyses of the conditions in these experiments than has previously been available. These analyses have provided a basis for more accurate interpretation of the phenomena that the experiments are intended to investigate. The results of posttest analyses of BWR experiments are discussed and significant findings from these analyses are explained. The ORNL control blade/canister models with materials interaction, relocation and blockage models are currently being implemented in SCDAP/RELAP5 as an optional structural component.

The BWR Core Melt Progression Phenomena Program at ORNL is Involved in Pretest and Posttest Analyses of BWR Core Melt Experiments

- DF-4 test (SNL)
- FLHT-6 test (PNL)
- CORA tests (KfK)
- Ex-reactor tests (SNL)

Experiment-Specific Features Dramatically Influence Test Behavior

- Must consider test geometry when interpreting the data
- Difficult to control boundary conditions (especially heat losses)
- Additional phenomena must be treated

Experiment Structural Thermal Response Must Be Accurately Modeled

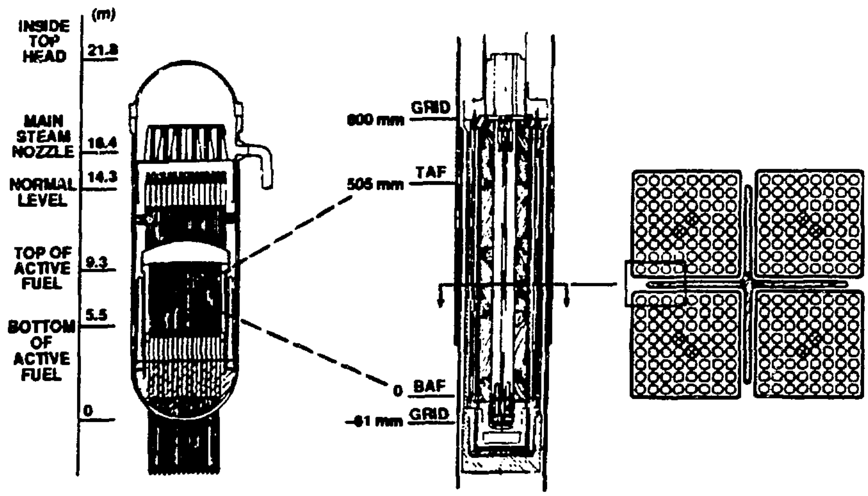
- Requires very detailed approach
  - To predict phenomena after melting begins
  - To interpolate between data points
  - To extrapolate when thermocouples fail at high temperature
- System codes represent the reactor core and do not adequately represent the experimental structure

By Excluding Extraneous Considerations Experiment-Specific Modeling and Analysis Yields

- Thorough understanding of key phenomena of interest
- Data with reduced uncertainties
- A verified database that can be used to formulate and validate models for the system-level codes

ACRR DF-4 Experiment

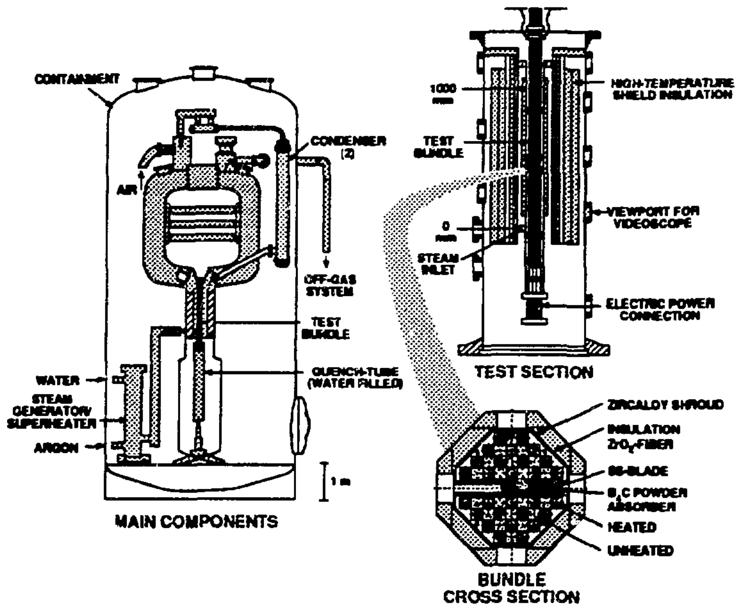
- Constant system pressure
- Constant superheated steam feed
- Emphasis on tip of control blade



Important Results from the Experiment-Specific Posttest Analyses of the DF-4 Experiment

- Close model agreement with experimental results through early phase melt relocation
  - Structural temperatures within ±25K
  - Timing of structural relocation within ±10s
- Control blade models must allow for reduction of the absorber tube liquefaction temperature
- Urbanic/Heidrick oxidation kinetics provide best agreement with experimental data
- Candling heat transfer coefficients in the 2200-3400 W/m^2K range provides reasonable agreement with data
- At 10 bar pressure, the gaseous stream acts as a gray interacting medium

CORA Severe Fuel Damage Test Facility



Important Results from the Experiment-Specific Posttest Analyses of the CORA BWR Experiments (Previously Reported)

- **Excellent model agreement with experimental results**
- **Confirmation of separate effects studies, NIELS results and the DF-4 experiment, which demonstrated that control blade models <u>must</u> allow for stainless steel/B4C interaction**
- **The gaseous coolant at 2.2 bar should be treated as a transparent non-interacting medium**
- **Spacers should be treated explicitly in the experimental analyses**
- **Proper accounting for the local power generation (in CORA) requires consideration of the fuel electrical conductivity**

Important Results from the Experiment-Specific Posttest Analyses of the CORA BWR Experiments (Previously Reported) (continued)

- Available solid-state Zircaloy oxidation kinetics[1] give good agreement with the experimental results
- Cladding strain must be included in the fuel rod modeling
  - In CORA, concurrent strain and oxidation in the β phase regime occurs
  - The effect is enhanced oxidation

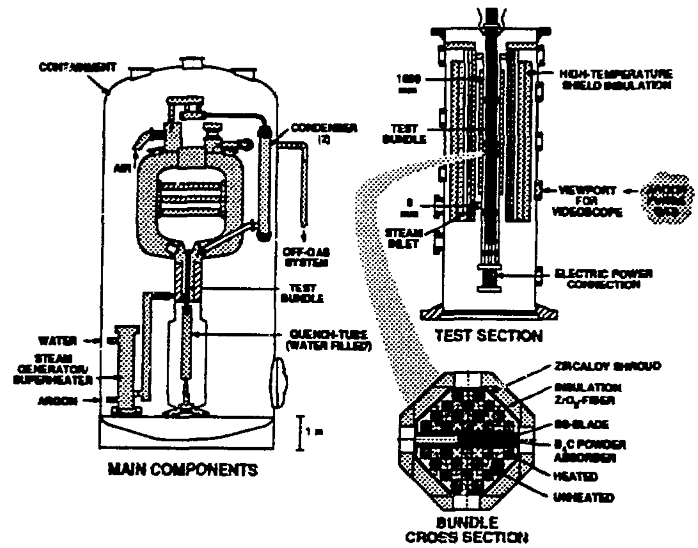
[1]Haste, Harrison and Hindle, "Zircaloy Oxidation Kinetics in the Temperature Range 700-1300°C", IAEA-TC-657/4.7, September 1988

BWR Core Melt Progression Phenomena Program Activities in 1991/1992

- Provided KfK pretest computational support for CORA-31 and CORA-28
- Providing technical support for SNL ex-reactor experiments
- Continued analyses of available CORA BWR tests
  - Effect of Argon purge flow
  - Blockage/materials interaction models

Argon Purge Gas Cools and Clears the Viewports for the Videoscopes

- ~ 1/10 – 1/8 of test section argon flow
- Small but not insignificant effect on the core thermal response during the transient



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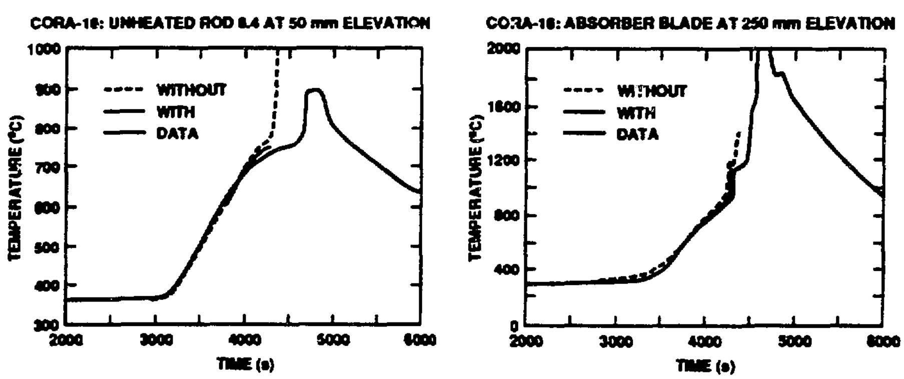
Argon Purge Gas Appears to Enhance Structural Cooling in the Lower Portion of the Bundle



- At elevations ≥350 mm, negligible effect
- This region of the BWR core is the recipient of melting and relocating materials
- Blockages occur here

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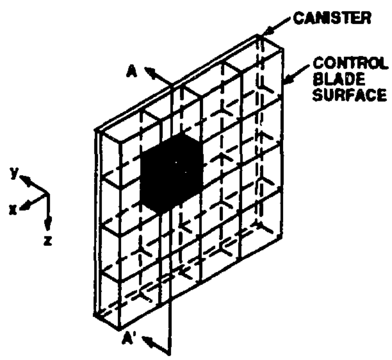
Materials Interaction, Relocation and Blockage Models

- Interaction models
  - KFK separate effects studies (P. Hofmann)
    - Stainless steel/B_4C
    - Stainless steel/Zircaloy
- Relocation
  - Film flow with freezing and remelting
  - Flow allowed in x-y-z directions



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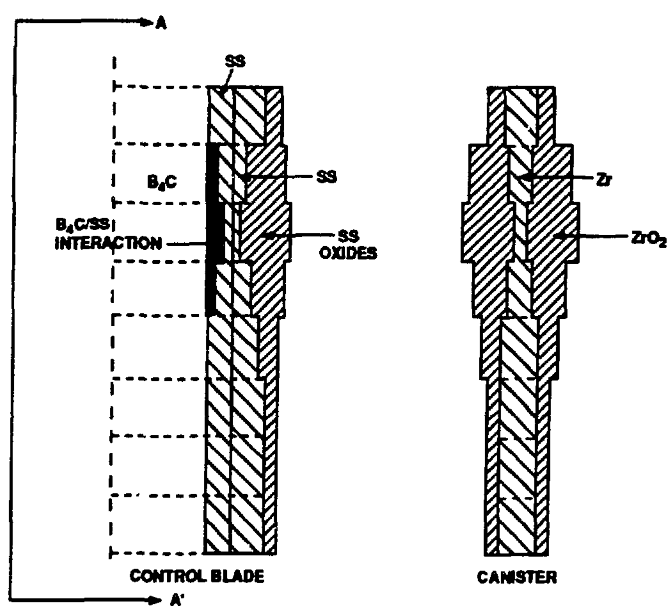
Conceptualization of Structural Liquefaction, Material Dissolution and Eutectic Relocation for the BWR Control Blade/Canister



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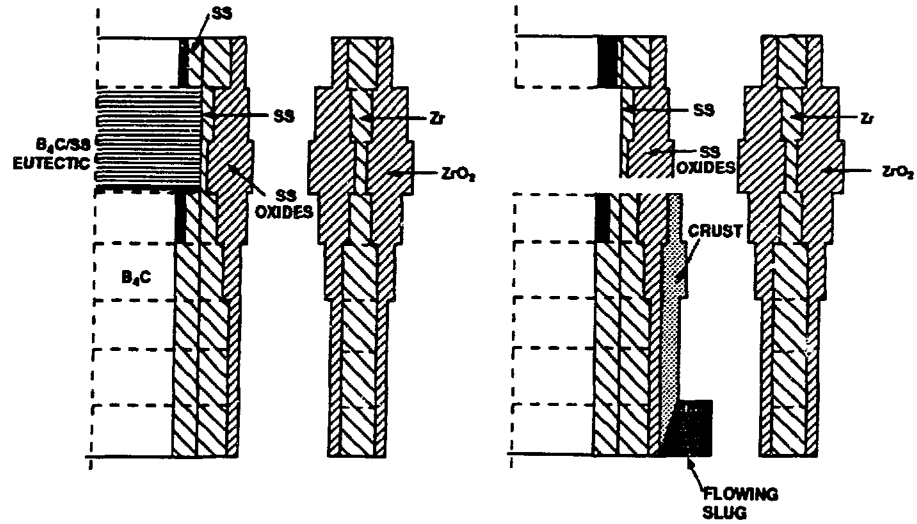
ABSORBER TUBE LIQUEFACTION | **SS/B4C EUTECTIC RELOCATION WITH FREEZING**



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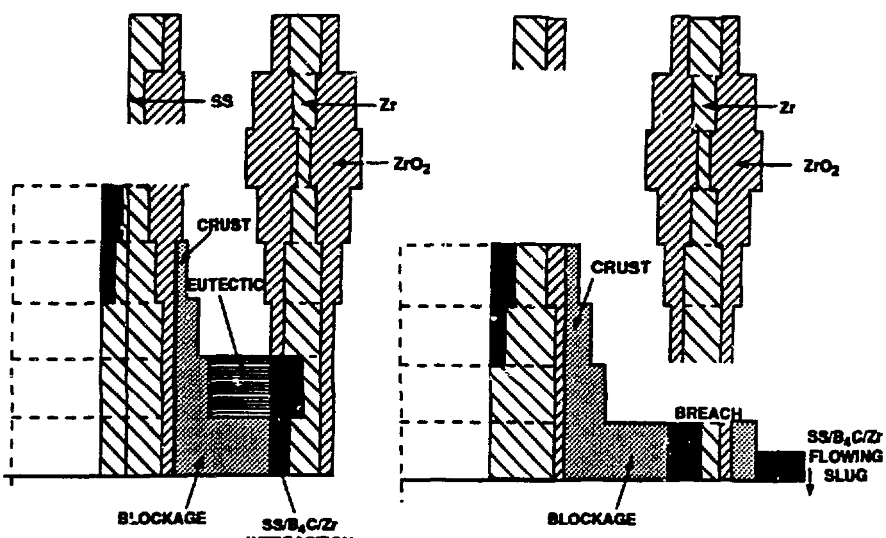
BLOCKAGE WITH SS/B4C/Zr INTERACTION | **CANISTER BREACH WITH SS/B4C/Zr EUTECTIC RELOCATION**



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Materials Interaction, Relocation and Blockage Models

- Implemented in CORA/BWR

CORA/BWR Control Blade/Canister Models with Materials Interaction, Relocation and Blockage

- Being implemented as an optional structural component in SCDAP/RELAP5 at ORNL
- ORNL letter report (F.P. Griffin, L.J. Ott, May 1992)

A Major Role of Experiment-Specific Analytical Simulation Is to Provide Physics Guidance to Integrated Code Development

- Not biased by geometric modeling considerations
- Clarifies the experimental phenomena and timing of events
- Indicates what needs to be modeled and what does not, or which models work and which do not
- Provides a platform for developing and validating models that can be incorporated into integrated codes