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CORCON: A Computer Program for Modelling Molten Fuel/Concrete Interactions*

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MASTER

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ABSTRACT

A computer program modelling the interaction between molten core materials and structural concrete is being developed to provide a capability for making quantitative estimates of reactor fuel-melt accidents. The principal phenomenological models, inter-component heat transfer, concrete erosion, and melt/gas chemical reactions, are described. A code/test comp~~ressi~~arison calculation is discussed.

SUMMARY

The CORCON (core/concrete interaction) computer code is being developed at Sandia Laboratories under sponsorship of the Fuel Behavior Research Branch, NRC, as part of the combined experimental/analytical Molten Fuel Concrete Interactions Study. The objective of the modelling effort is to develop and verify a molten fuel/concrete interaction code capable of providing quantitative estimates of pertinent phenomena, e.g., the nature and rate of gas evolution, and the rate and direction of melt penetration, suitable for risk assessment of light water reactors.

CORCON contains the mass and energy transport and chemical reaction models necessary to describe the interaction process. The principal components of the system are the concrete crucible or container, the molten pool and the atmosphere above the pool. These are cast in a two-dimensional, axisymmetric geometry as illustrated in Figure 1. Additional features of the code are listed in Figure 2.

The initial concrete cavity may be either a flat or hemispherically based right circular cylinder or an arbitrary shape defined in terms of n body points. Three "default" concrete compositions, specified in terms of 12 species, are included in the code. These are representative of LWP basaltic aggregate and limestone aggregate concretes, and a generic southeastern United States concrete (the so-called CRBP concrete). The pool is treated as a multi-layered structure ranging from a single one-phase or heterogeneous mixture layer to separate oxidic and metallic layers surmounted by a coolant layer. Each layer is treated as isothermal in bulk (well stirred) and the relative orientation of the layers is determined by the bulk layer densities. The atmosphere above the melt is modelled as an isothermal mixture of reacting gases. The code treats the conservation of mass and energy throughout the system including the interaction with the surroundings. Inter- and intra-component mass and energy transport and generation are described using phenomenological models obtained from the literature, the majority of which are based on empirical or semi-empirical correlations. Chemical equilibrium is assumed within each component.

The phenomenological models having the greatest impact on the interaction process are those dealing with heat transfer within the melt and across the melt/concrete interface, concrete erosion and cavity shape change, and melt/gas-phase chemical reactions.

Heat transfer across the pool/concrete interface is described using applicable gas-film models (see Figure 3). The Taylor instability model for a horizontal surface is employed along the cavity bottom, up to a local surface inclination angle of 15°, at which point the bubbling of concrete decomposition gases into the pool ceases. At higher surface angles, i.e., around the sides of the pool, laminar and turbulent continuous gas film heat transfer models similar to those developed for film boiling are utilized. When coupled together with appropriate transition regions, these models provide a continuous description of the pool/concrete interface heat transfer around the periphery of the pool. A representative heat transfer coefficient variation is given in Figure 4.

Heat transfer from the interior of the melt to its periphery and across pool layer interfaces is strongly affected by the gas flow into the pool from the decomposing concrete. Enhanced heat transfer as a result of the gas driven circulation may be categorized as either indirect (bubble agitation), for surfaces across which there is no gas flow, e.g., steeply inclined surfaces, or direct (gas injection), for surfaces through which there is gas flow, e.g., bottom and top of the pool, and layer interfaces (see Figure 5). The associated heat transfer coefficients are modelled using empirical correlations for gas driven circulations faired into standard turbulent natural convection correlations as the injected gas flow approaches zero. For typical melt material properties and concrete erosion rates, these range in magnitude from approximately 10^3 to 10^5 W/m^2K.

Concrete erosion is described using a quasi-steady, one-dimensional ablation model applied at each point on the melt/concrete interface at each time step. Values of the concrete "heat of ablation" required for this model were obtained for the three "default" concretes from experimental investigations of the thermal decomposition behavior of these representative types. The concrete ablation model is coupled to a two-dimensional, axisymmetric shape change procedure which utilizes the local surface recession values to define a new cavity shape at each time step.

Melt/gas-phase chemical reactions are treated thermodynamically for the following two subsystems: gas-metal phases and gas-oxide phases. Each subsystem is assumed to reach chemical equilibrium during each time step, but they are not in equilibrium with one another. The method employed is to minimize the free-energy of a reacting chemical system at constant temperature and pressure subject to the mass balance constraint. This is accomplished using a first order, steepest descent minimization technique. Its main advantages are that neither the reactions nor their order of occurrence need be known and that convergence is guaranteed. The principal disadvantages are that although the solution follows the phase rule it does not do so completely, and that trace species in the melt are not accurately determined.

The initial version of CORCON is assembled and is currently being debugged and checked out on a sample problem. A topical report/users manual to describe the content and operation of the code is in preparation. It is anticipated that a draft version of this report will be completed by the end of the calendar year.

The first application of CORCON is to perform prediction calculations for the Sandia code comparison test. The initial and boundary conditions for this test will be supplied to the various code evaluators during November 1979. Each will be provided the same and sufficient information about the test to facilitate the comparison calculations. The test results will be suppressed until all calculations have been completed. A number of specific interaction phenomena and events are to be predicted. Resuls available prior the the meeting will be summarized.

GEOMETRY - 2-D, AXISYMMETRIC
MULTILAYERED POOL - 1 TO 4 LAYERS
- ISOTHERMAL CORE
MELT ATMOSPHERE - ISOTHERMAL, REACTING GAS MIXTURE

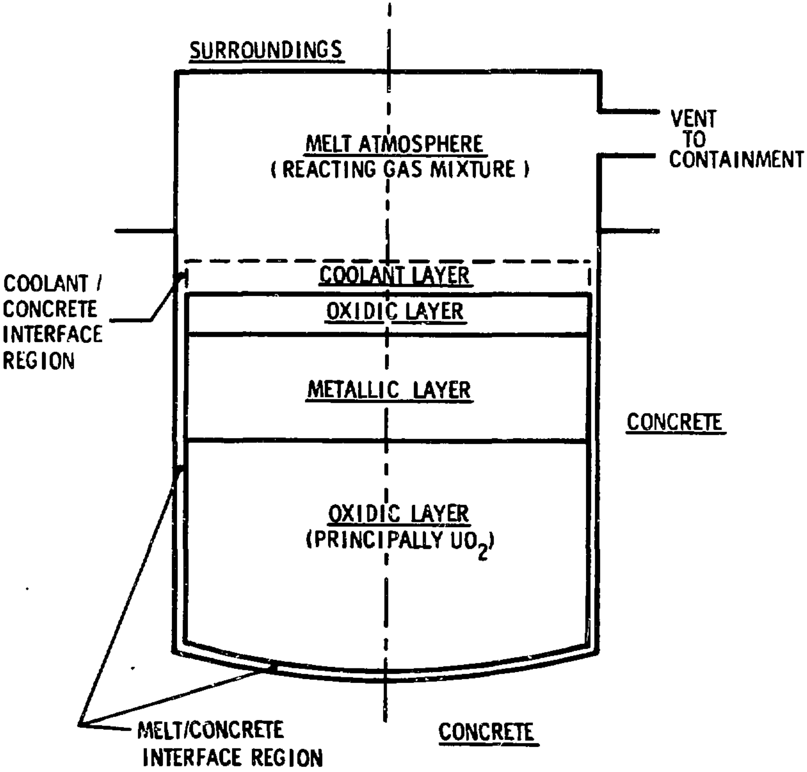


FIGURE 1. CORCON - PRINCIPAL FEATURES I

INSTANTANEOUS DEPOSITION OF MELT INTO CAVITY

MELT/CONCRETE INTERFACE -
- FLOW CONFIGURATION }
- HEAT AND MASS TRANSFER }

VARIABLE AROUND POOL

MASS AND ENERGY CONSERVATION -
- TRANSPORT - MELT/CONCRETE INTERFACE
  - BETWEEN POOL LAYERS
  - FROM POOL SURFACE - ATMOSPHERE
    - SURROUNDINGS
  - ATMOSPHERE TO SURROUNDINGS
  - VENTING TO CONTAINMENT
- SOURCES/ SINKS - CONCRETE DECOMPOSITION
  - CHEMICAL REATIONS
  - FISSION PRODUCT DECAY HEAT
  - ABLATION OF SURROUNDINGS

CONCRETE EROSION - 1-D, STEADY-STATE ABLATION
- 2-D, AXISYMMETRIC CAVITY
- CONCRETE DECOMPOSITION DATA

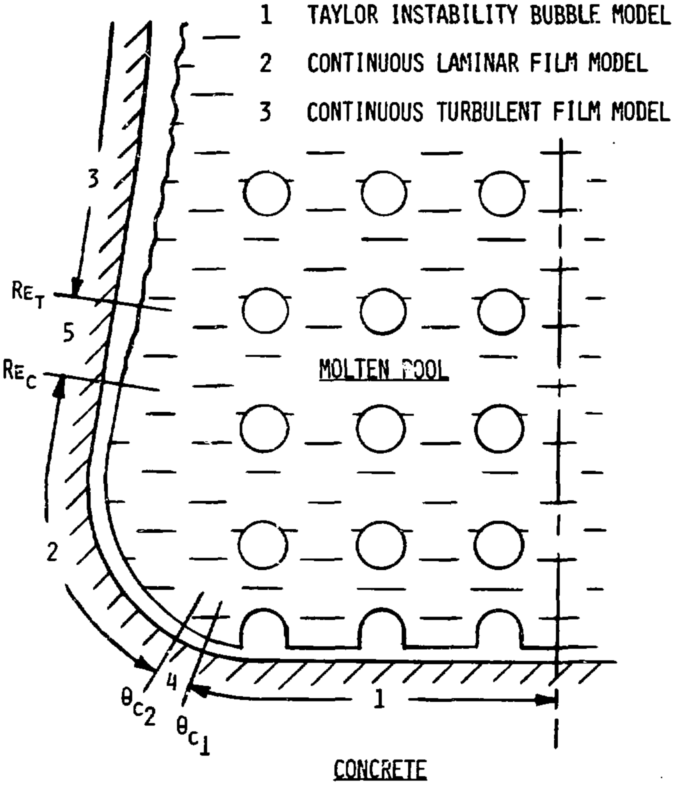
CHEMICAL REACTIONS - OXIDATION - METALLIC LAYER
- REDUCTION - OXIDIC LAYER
- EQUILIBRIUM - GAS PHASE

IMPROVED MATERIAL PROPERTY DATA

POOL VOID FRACTION AND LEVEL SWELL

IMPROVED NUMERICAL TECHNIQUES

FIGURE 2. CORCON - PRINCIPAL FEATURES II



1 TAYLOR INSTABILITY BUBBLE MODEL

2 CONTINUOUS LAMINAR FILM MODEL

3 CONTINUOUS TURBULENT FILM MODEL

4 TRANSITION REGION, $\theta_{c_1} - \theta_{c_2}$, FROM BUBBLE TO LAMINAR FILM MODEL

5 TRANSITION REGION, $R_{E_C} - R_{E_T}$, FROM LAMINAR TO TURBULENT FILM

FIGURE 3. POOL/CONCRETE INTERFACE HEAT TRANSFER

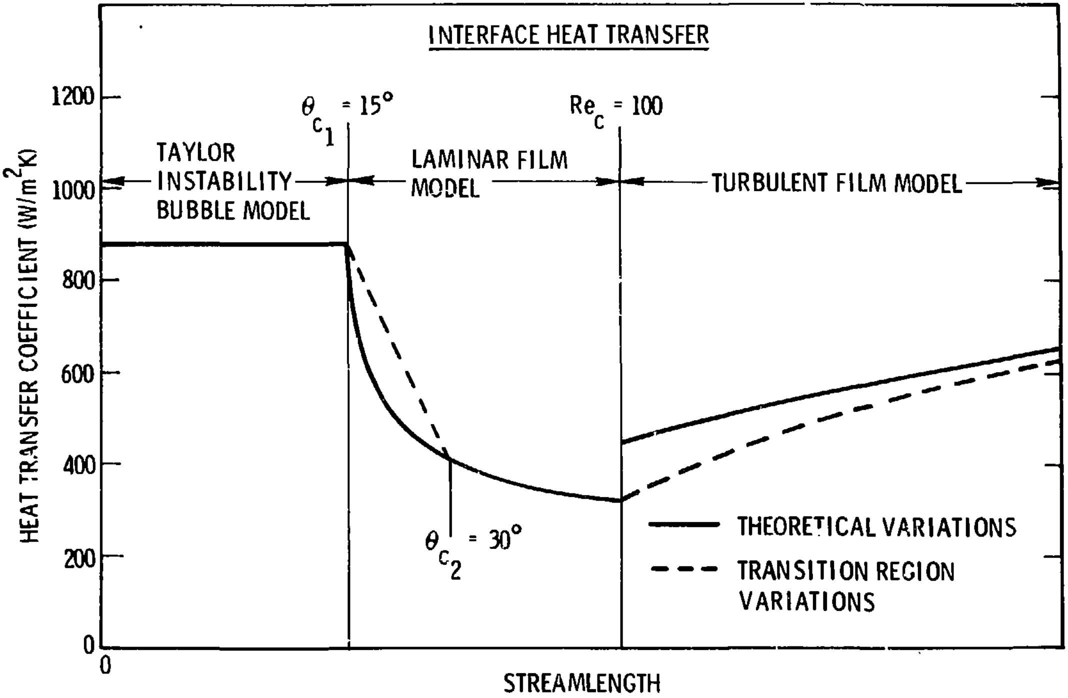
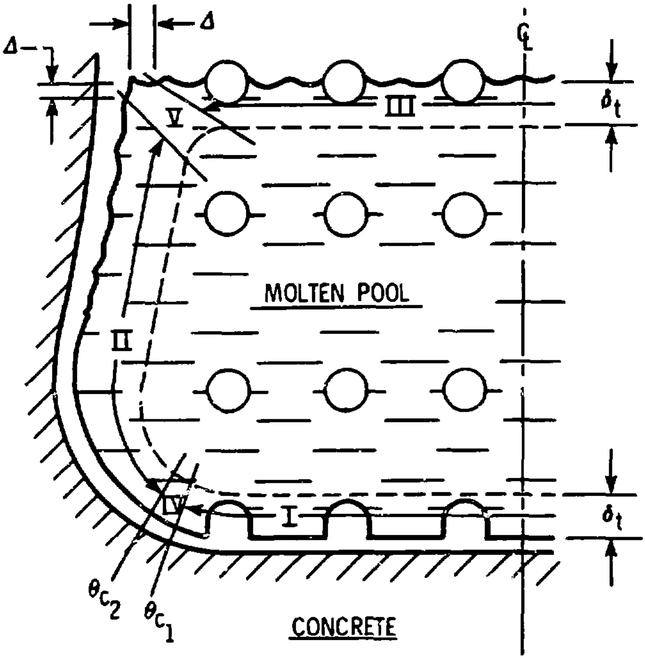


FIGURE 4. REPRESENTATIVE INTERFACE HEAT TRANSFER COEFFICIENT VARIATION AROUND PERIPHERY OF POOL



REGION	CONDITION
I, III	SURFACE WITH GAS INJECTION
II	SURFACE WITH BUBBLE AGITATION
IV, V	TRANSITION REGIONS

FIGURE 5. POOL INTERIOR/EXTERIOR HEAT TRANSFER