UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

JAN 6 1981

MEMORANDUM FOR: Harold Denton, Director
Office of Nuclear Reactor Regulation

FROM: Robert B. Minogue, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER #108 WRAP-PWR-EM (WATER REACTOR ANALYSIS PACKAGE-PRESSURIZED WATER REACTOR-EVALUATION MODEL).

I. INTRODUCTION: OVERVIEW OF WRAP-PWR-EM DEVELOPMENT

The WRAP-PWR-EM computer code system (Ref. 1) is designed to provide NRC with the capability to perform audit calculations for Loss of Coolant Accidents (LOCAs) in pressurized water reactors. This code system is an outgrowth of, and replacement for, the original WREM system (Ref. 2) of Evaluation-Model-Audit codes. The work was performed in response to a request (Ref. 3) from the Office of Nuclear Reactor Regulation to provide a complete Evaluation Model (EM) Code package for audit capability. A companion Research Information Letter is being issued for the WRAP-BWR-EM system for boiling water reactors.

The main thrust of the system development was to use existing computer codes, each code calculating a specific facet or portion of a PWR LOCA, and provide automatic data transfer and interfacing between those codes. Doing this allows the calculation to proceed smoothly through a complete LOCA sequence. Considerable effort also went into making the system user-convenient. This included improving the input format (Refs. 4 and 5) and also providing an automatic initialization for the LOCA transient (Ref. 6).

It is worth mentioning that the Office of Nuclear Regulatory Research (RES) management of the WRAP program at the Savannah River Laboratory (SRL) was aided by the successful interaction between SRL and other groups of workers. First, NRR personnel aided in the WRAP program from the beginning. Although they could not respond in writing to all requests for review of models and interfaces, their contributions were helpful (Ref. 7). Second, the check-out and verification of the completed WRAP-PWR-EM system was performed in parallel efforts by both Savannah River Laboratory and the Idaho National Engineering Laboratory (INEL) (Refs. 8 and 9). The assistance that INEL provided to SRL throughout this project was very important.

II. DESCRIPTION OF CALCULATION SCHEME

A. CODES FORMING THE WRAP-PWR-EM PACKAGE

The WRAP system for PWR-EM analysis comprises several computer codes which have been developed to analyze individual phases of a LOCAs. These codes include GAPCON (Refs. 10 and 15) for calculation of initial fuel conditions, the SRL analog of RELAP4/MOD5 (Ref. 11) for analysis of the system blowdown and selected parameters for refill, special models for refill (Refs. 1 and 12), the FLOOD option in RELAP (Ref. 11) for analysis of the reflood phase, and the FRAP code (Refs. 13 and 14) for the calculation of the behavior of the hot fuel pin.

The GAPCON module calculates preaccident thermal conditions of the fuel rods. For a given fuel rod, GAPCON determines the gap conductance, temperatures, pressures, and stored energy as a function of the power history of the rod. These data are then used as initial conditions for the transient fuel models.

GAPCON calculations can be performed as part of the WRAP-EM modular path or stand alone from the other calculations. In either procedure, GAPCON results may be stored in a data library. The stored GAPCON data are then used as input to WRAP and FRAP calculations. The GAPCON data transferred to WRAP require only two fuel rod descriptions - an average rod for the hottest fuel bundle and an average rod for the other fuel bundles.

The PWR system blowdown is calculated by the well-known RELAP4/MOD5 code (Ref. 11). The initial WRAP system was based on RELAP4/MOD5/Version 65. The PWR-EM development program required updating WRAP to RELAP4/MOD5/Version 84 and implementing several modifications to provide an EM treatment of the PWR blowdown, refill, and reflood calculations. The latter included:

- o Vertical slip modeling modifications (Ref. 16) necessary to properly model gravity-induced velocity differences between liquid and gas phases,
- o Implemention of new PWR reflood heat transfer EM models in the FLOOD subroutine in WRAP (Ref. 17),
- o Corrections to the fuel rod plenum temperature calculations (Ref. 16).

Several other corrections (Ref. 18) were made which included the proper calculation of potential energy contributions to the junction enthalpy when flow reverses as well as other minor coding modifications.

FRAP computes temperatures, pressures, and dimensional changes for the hot pin in the core. During refill (i.e., between end of bypass and beginning of core recovery) FRAP assumes adiabatic heatup of the core. In determining the fuel rod response to a transient, FRAP models the mechanical deformation of the pin, the material properties (only oxide fuel and zirconium cladding allowed), and fill gas behavior. The transient hydraulic conditions in the core are used as boundary conditions in the form of surface heat transfer coefficients at selected axial levels. Both best estimate and evaluation model calculations are possible.

Refill analysis begins when the blowdown phase ends, which is when the net flow through the downcomer is directed into the lower plenum. This signals the onset of the refill phase and is labelled the end of bypass (EOB). At this point, the calculation exits the normal advancement of the thermal-hydraulic equations in RELAP and invokes a series of phenomenological models which describe the processes of interest.

The overall sequence is:

- o Compute input flows (accumulator + ECCS)
- o Compute refill time
- o Compute enthalpy of the fluid in the lower plenum
- o Compute core metal temperature
- o Set up additional input for the reflood calculation.

The refill time is calculated to be the sum of:

- o time to fill the cold legs one-half full,
- o free fall time,
- o hot wall delay time, and
- o time to fill the lower plenum.

A more detailed explanation of these procedures is given in Reference 1.

The reflood analysis uses the FLOOD model described in Reference 11. As implemented in WRAP-EM, the model has several new features added for user convenience. For example, a pressure initialization procedure has been added. Given a single known pressure (normally containment pressure), the pressure distribution around the entire system is computed based on head differences and pressure drops due to any initial nonzero flows. Otherwise, the FLOOD model current in RELAP4/MOD4/Version 84 has been incorporated into WRAP-EM with no alterations.

B. CODE INTERFACES FOR DATA TRANSFER

The integration of the GAPCON, RELAP, REFILL, FRAP and FLOOD modules to form the WRAP-EM system required the defining and programming of the following interfaces:

- o GAPCON/RELAP,
- o GAPCON/FRAP,
- o RELAP/FRAP,

- o (RELAP-REFILL)/FLOOD, and
- o FLOOD/FRAP.

These interfaces automate the computational steps required to perform a complete LOCA analysis from break through reflood.

In general, hot assembly and average assembly fuel pin conditions as calculated by GAPCON are transferred to RELAP via the GAPCON/RELAP interface. The fuel pin conditions for the hot pin are also transferred to FRAP via the GAPCON/FRAP interface. The (RELAP-REFILL)/FLOOD interface is a transfer of the data from RELAP at end of blowdown to FLOOD for initialization of the reflood calculation. Transient hot pin data during blowdown and reflood are passed to FRAP via the RELAP/FRAP and FLOOD/FRAP interfaces, respectively. A more detailed description of the data transferred by each interface is presented in Reference 5; short descriptions are given in Appendix I.

C. PWR STEADY-STATE PROCEDURE

The RELAP4/MOD5 code provides no explicit procedure for initializing the transient thermal-hydraulic calculation. Instead, the user is required to generate the initial system state by a series of hand calculations to produce estimates of the state variables and then short transient runs to evaluate the reasonableness of the estimates. An automatic PWR steady-state procedure has been developed to eliminate this time-consuming process.

Instead of specifying the volume variables and junction flows required by RELAP, the WRAP user specifies the following quantities:

- o Core inlet specific enthalpy,
- o Pressure and liquid level in the pressurizer,
- o Loop flow rates, and
- o Mixture level, mixture quality, inlet specific enthalpy, and pressure on the secondary side of the steam generator.

The procedure then computes the:

- o Thermodynamic state of all control volumes,
- o Flow splits within the core,
- o Pump speeds, and
- o Heat exchanger characteristics.

A detailed description of the procedure is provided in Reference 6.

D. WRAP-PWR-EM ANALYSIS SEQUENCE

The PWR-EM analysis scheme is shown in Figure 1. The calculation proceeds along two paths, one for thermal/hydraulic analysis and the other for fuel rod response analysis. This scheme has been reviewed by NRR personnel (Ref. 20).

At selected times during the calculation, information is passed from the thermal/hydraulic analysis to the fuel rod response analysis. Initial fuel conditions are calculated as a function of burnup by the GAPCON module. Selected parameters are passed to FRAP and RELAP for initialization of the transient fuel models. The blowdown phase of the LOCA is calculated by the RELAP module and transient results are used to provide hydraulic conditions for the hot pin analysis by the FRAP module.

During the refill phase, the thermal-hydraulic equations used in the blowdown calculation are not solved. Instead, a series of special models are invoked to represent the discrete processes of interest (for example: heat transferred to the ECCS water in the lower plenum, hot wall delay time in the downcomer, etc.). The time required to fill up the lower plenum and the state of the fluid in the lower plenum are the ultimate quantities of interest for the refill phase. After the refill time is computed, the normal heat conduction equations in WRAP are advanced from the end of bypass (EOB) to the end of refill. Adiabatic boundary conditions are used for the core heat slabs.

At the end of refill, the system is renodalized by the RELAP-FLOOD interface routine and the reflood phase of the accident is calculated by the FLOOD option in RELAP. The time at EOB, the time at beginning of recovery and selected coolant conditions in the core are transferred to FRAP for use in the hot pin analysis.

III. WRAP-PWR-EM RESULTS

Calculations to verify the capability of the WRAP-PWR-EM system were performed on the Zion Plant (Ref. 21) and were also compared with test data from Semiscale Test S-06-3 (Ref. 22) and LOFT Test L2-3 (Ref. 23). In addition to these system calculations, separate verification of the FLOOD option in RELAP was made by comparing calculations with reflood data from FLECHT LFR Cosine Test 4831 and SEMISCALE Test S-03-2 (Ref. 24). All calculations were performed at SRL, with automatic interfacing between the separate codes, and with the same code versions at INEL (Refs. 8 and 9) with hand interfacing between codes. The latter procedure was used to uncover and correct coding and input errors.

The FLOOD option in WRAP, FLOOD/SRL, was checked out (Ref. 24) by comparing FLOOD/SRL to two calculated test problems generated by INEL as well as the test data for the experiments modeled in the problems. In general, the computed maximum rod surface temperatures were higher than the experimental data while the computed quench times were later than those measured, as required for a conservative evaluation model calculation (Fig. 2). The results calculated by FLOOD/SRL duplicated those computed by FLOOD/INEL except during the interval of quenching. During that time, the FLOOD/INEL results demonstrated a much more gradual temperature decrease than FLOOD/SRL for one of the test problems (FLECHT).

The results for the SEMISCALE test case are displayed in Figure 3. For this test case, the computed results are conservative in all respects and much more so than in the FLECHT test case. This is not very surprising because the correlations in FLOOD are based on FLECHT data, and one would expect relatively close agreement with experiment in that case.

WRAP-PWR-EM calculations of the blowdown phase of the Semiscale S-06-3 test (Ref. 25) indicated unexpected behavior in the prediction of the peak rod surface temperature. The WRAP-PWR-EM prediction of the rod surface temperature turned out to be less conservative than the corresponding best estimate prediction also performed with WRAP, and also less conservative than the experimental data for the test (Fig. 4).

The best-estimate (BE) calculation gave higher cladding temperatures than the EM calculations because of two combined effects: First, the effective core flows are lower in the BE calculation than in the EM calculations. Second, for similar flows and qualities, the EM heat transfer correlations generally give higher heat transfer coefficients than are calculated by the BE heat transfer correlation.

For the EM cladding temperatures to equal or exceed the BE cladding temperatures, it would require that the EM core flows be somewhat smaller, not larger (as at present) than the BE flows. This can be accomplished by using a smaller break discharge coefficient than the value used thus far. A reduction of the discharge coefficient (allowed by the Appendix K rules, Ref. 26) will reduce the EM break flows and hence the core flows. These results have been reported previously to NRR (Ref. 27).

The WRAP calculation for S-06-3 was continued through refill and into reflood, as reported in Reference 22. The calculation was ended at 12 seconds into the reflood phase following the beginning of quenching in the bottom of most core slabs, since all trends had been established.

This nonconservative finding is not an indication of failure of the WRAP-EM system, nor should it be considered as indicative of a major breakdown in the applicability of the 10 CFR Part 50, Appendix K rules which govern EM calculations. Rather, the nonconservative results should be interpreted as a reflection of the special EM modeling that was assumed for the Semiscale calculation. The models were not in direct compliance with all of the Appendix K rules. The rules concerning reactor initial overpower, decay overheat, stored energy, initial power peaking, gap conductance, etc., were not obeyed since Semiscale is an electrically heated facility. Similarly, the ECC systems were fully operational, as in the test. Only those rules pertaining to EM calculational controls, such as specification of the discharge model and the post CHF heat transfer models, were directly obeyed.

WRAP-PWR-EM calculations were performed for the LOFT L2-3 test extending through the reflood and quench phases (Ref. 23). The calculated results were suitably conservative, predicting higher clad temperatures and later quench times than the data.

To demonstrate the WRAP-PWR-EM system, a LOCA analysis was performed for the Zion Plant. The accident model represents a double-ended guillotine pipe break on the primary pump outlet side in one of the cold legs. The analysis was performed in parallel with an identical calculation at Idaho National Engineering Laboratory as part of the code checkout effort. The results are reported in Reference 21. In general, the agreement between the two calculations was very good.

The intent of this study was to verify that the code models and interfaces in the WRAP-PWR-EM system were functioning correctly, by comparing WRAP calculations to calculations run by INEL using codes with the same models. To ensure a "clean" comparison, identical input data were used in both analyses. All phases of a large break LOCA (blowdown, refill, and reflood) in a 4-loop PWR plant were analyzed. The initial steady state was computed by INEL and the results used by both SRL and INEL for their blowdown calculations. SRL also independently calculated a steady-state to check out the WRAP automatic initialization procedure. Most input data for the refill and reflood calculations were transferred automatically by WRAP interfaces. INEL transferred data by hand. Any input discrepancies were resolved by adjusting WRAP input, since the INEL calculations were run prior to the WRAP calculations.

Calculation of a hot pin (FRAP) was included in the WRAP analysis even though no INEL data were available for direct comparison. After correcting input and logic errors, WRAP agreed quite well with INEL's Zion calculations, thus demonstrating that the WRAP models and interfaces were working as intended.

IV. RECOMMENDATION FOR WRAP-PWR-EM USE BY NRR

Development and verification of the WRAP-PWR-EM system is now complete and it is recommended for use by NRR. In early CY80, the WRAP system was made operational on the Harry Diamond Laboratory computer, located in a Maryland suburb of Washington, and a special remote terminal was installed in Bethesda so that NRR personnel could perform their own calculations with WRAP. An indoctrination class in the use of WRAP was also held in Bethesda by SRL personnel in early CY80. However, most of the NRR use of WRAP is now being performed at SRL.

As a result of the WRAP-PWR-EM verification studies, NRR personnel are currently examining the conservative model used for flooding rate in

RELAP/FLOOD and for the heat transfer calculations in FRAP-T4/LACE. RES intends to supply maintenance of the WRAP system over the next few years, to improve modelling and to solve any coding problems that are identified by NRR use.

R. B. Minogue

Robert B. Minogue, Director
Office of Nuclear Regulatory Research

Enclosures,
1. Appendix I
2. Figures 1-4

cc: O. F. Ross, NRR
P. Check, NRR
T. Speis, NRR
G. W. Knighton, NRR
R. Audette, NRR

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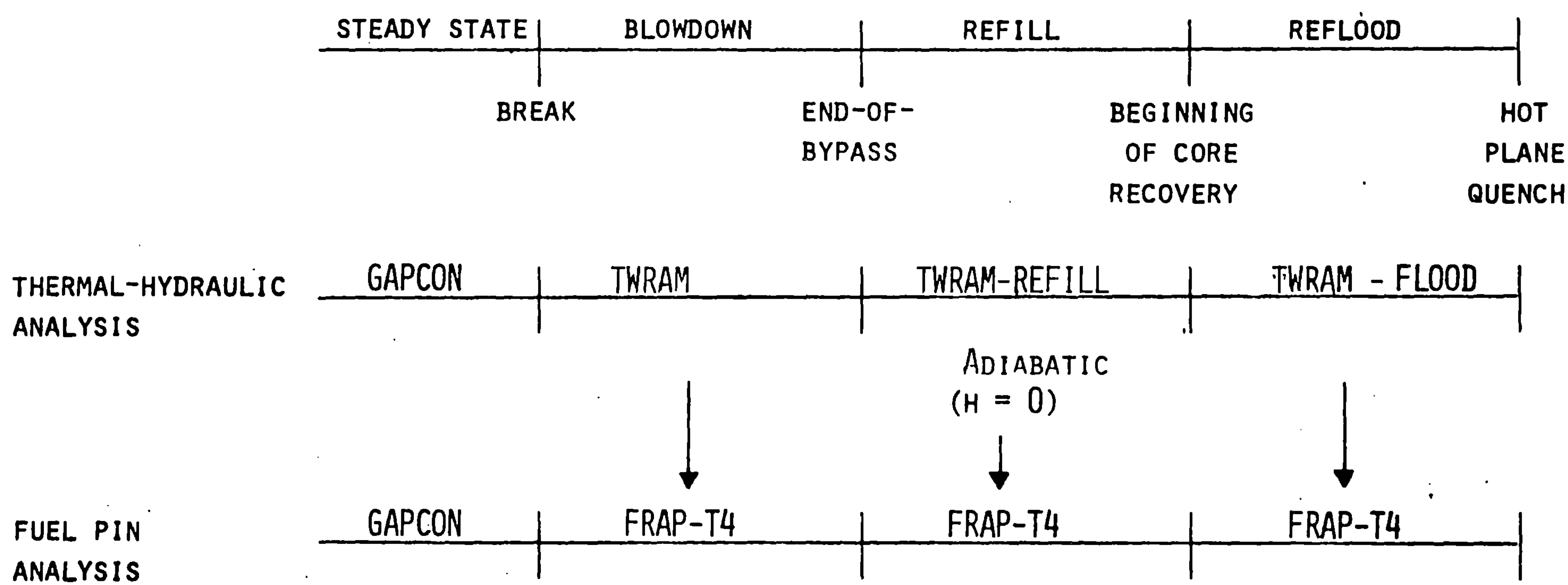
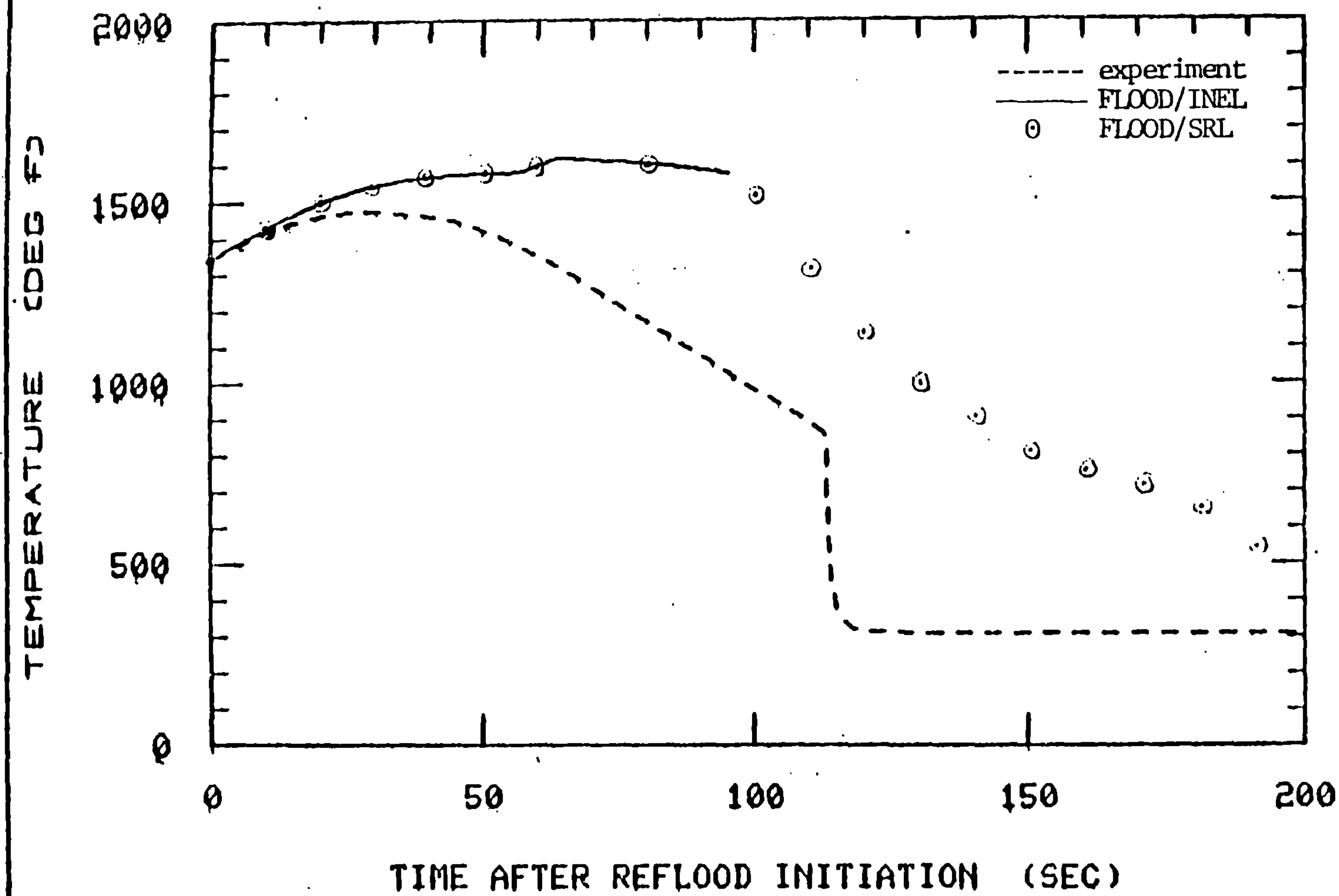
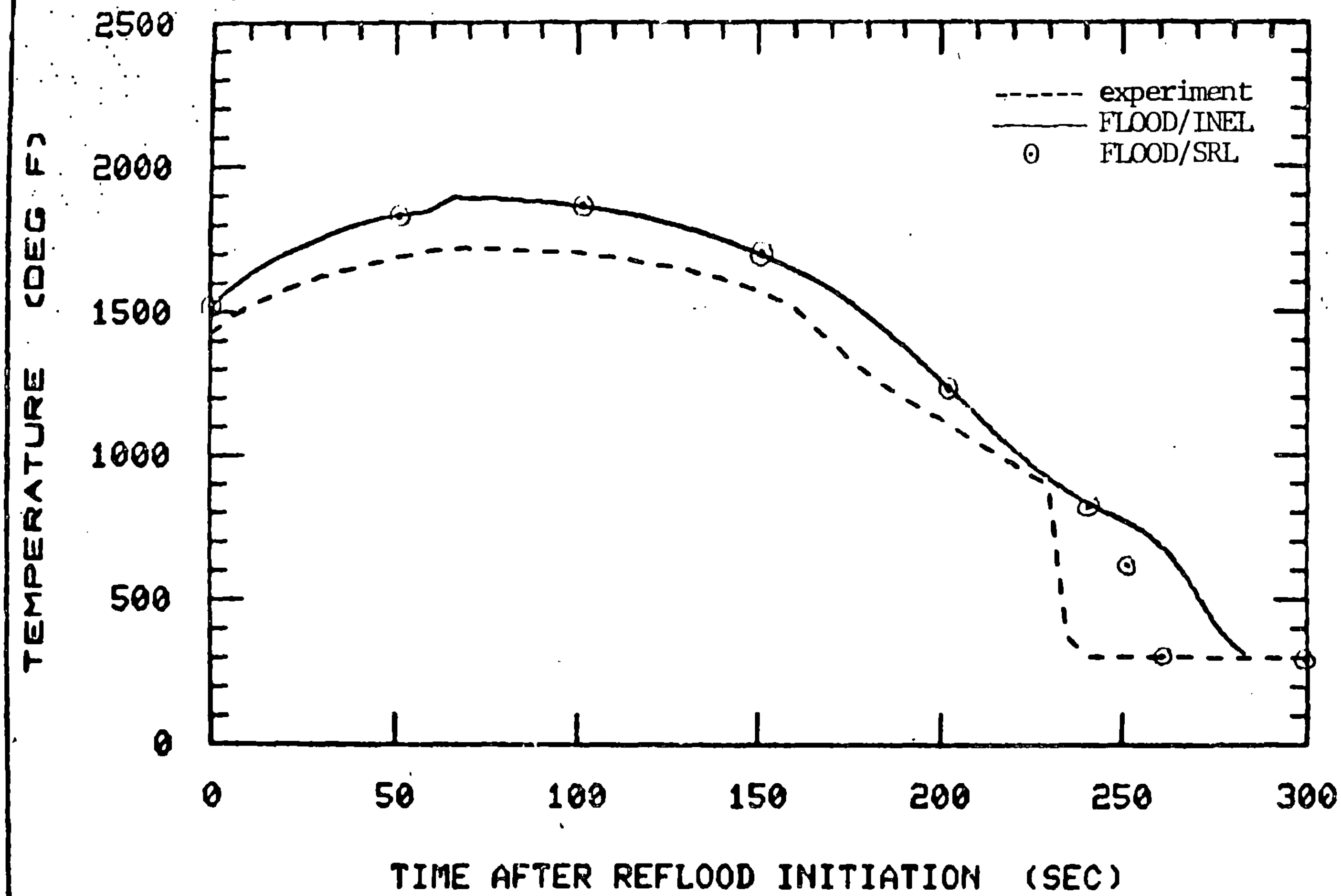
FIGURE 1 PWR ANALYSIS SCHEME





SEMISCALE TEST S-03-02

FIG. 3 ROD SURFACE TEMPERATURE AT 33 IN. ELEV.



FLECHT LFR COSINE TEST 4831

FIG. 2 ROD SURFACE TEMPERATURE AT 7 FT. ELEV.

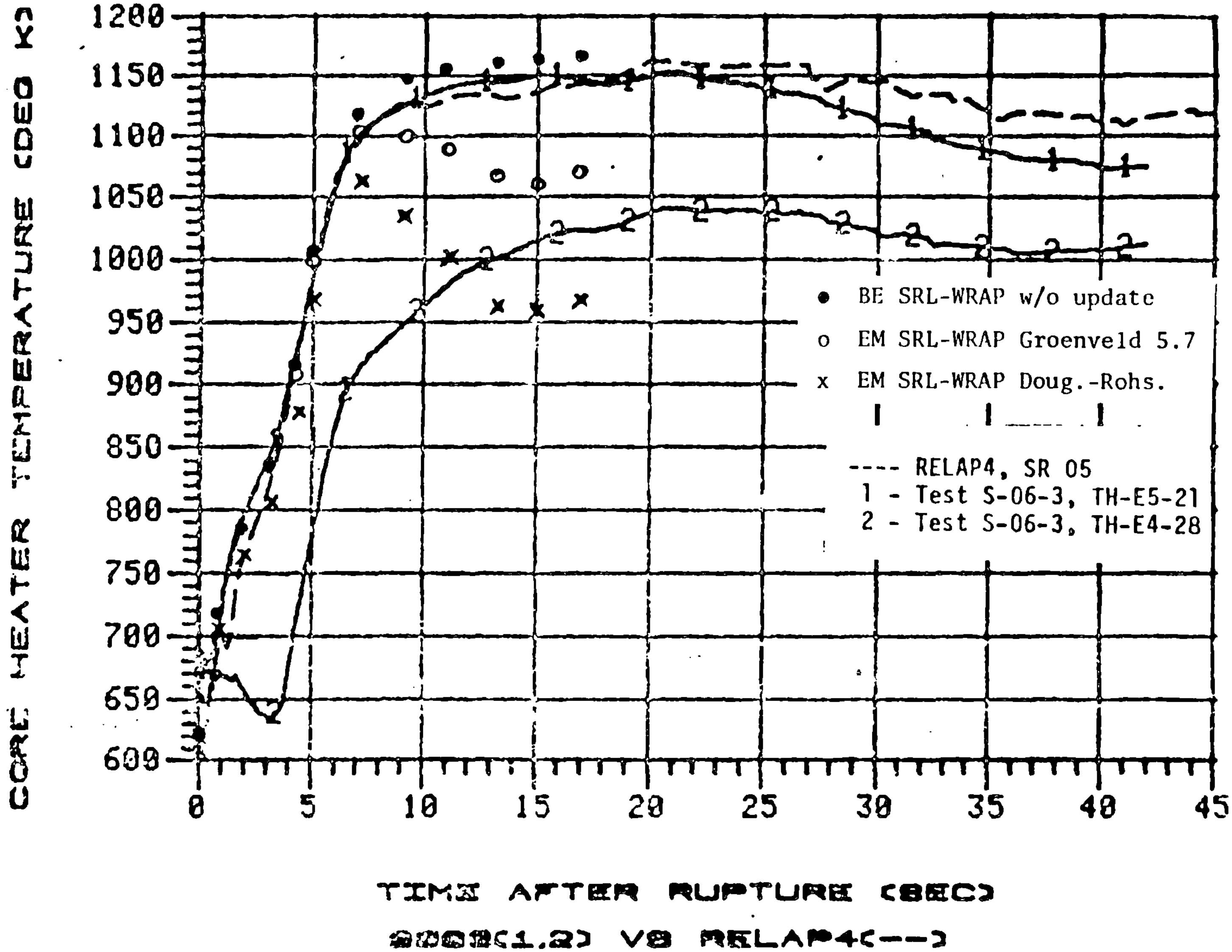


FIGURE 4 Comparison of INEL-BE and SRL-BE and EM Calculated Hot Channel Cladding Temperatures. This figure is taken from Reference 1. The EM calculations assume a break discharge coefficient = 1.0.

APPENDIX I: DESCRIPTION OF CODE INTERFACES

A. GAPCON/WRAP

In the WRAP-EM computational system, GAPCON is used to determine fuel rod conditions at the beginning of the LOCA analysis. These initial conditions are functions of power level, burnup, fill gas pressure, etc. The data from the GAPCON calculation are transferred via the GAPCON/RELAP interface to RELAP which calculates the blowdown phase of the LOCA.

The data transfer between GAPCON and RELAP is not straightforward because the fuel models in the two codes differ. For example, GAPCON models a single fuel pin allowing up to 20 axial nodes for detail. RELAP, on the other hand, models the complete core as one or two (or possibly three) stacks of heat slabs. One stack may represent the hot bundle while the other models the remainder of the core. Thus, the data transferred from GAPCON to RELAP must be collected, stored, and interpolated by the interface before being used in RELAP.

Data transferred between GAPCON and RELAP are specified for a given pin(s). For example, hot channel and average channel heat slab conditions may be determined by "typical" hot rod and "typical" average fuel rod calculations done with GAPCON. In the interface, the GAPCON "typical" pin data may be scaled by the number of fuel rods per stack to obtain RELAP heat slab data. The data transferred by the interface includes the fuel rod geometry (before and after burnup), power, fuel density, and gap heat transfer factors including fission gas composition and gm-moles of fission gas. Where GAPCON data do not coincide with the axial mesh locations used in RELAP, the RELAP heat slab data are linearly interpolated from the GAPCON data.

B. GAPCON/FRAP

Cold state fuel pin dimensions are passed from the GAPCON data base to FRAP which modifies the data to model the appropriate hot state. This eliminates the need to duplicate input data for the two codes and ensures consistency of data in GAPCON and FRAP. Options used in the two codes are checked for consistency and flagged if not identical.

GAPCON results which are transferred to FRAP include power specifications at the time of the accident (e.g., average linear power and axial power distribution) and burnup dependent data (e.g., average burnup, amount of gas in the gap, and the composition of the gas). Also, any fission-induced swelling in the fuel and clad creep strain is transferred for each axial level.

C. WRAP/FRAP

Core hydraulic conditions during the blowdown are transferred to FRAP to be used as boundary conditions for the hot fuel pin thermal analysis. Two options are available to select the parameters to be passed. The first option passes the time dependent coolant pressure, temperature, and enthalpy for the upper and lower plena and each hot channel volume used in the blowdown calculation. From these parameters, FRAP calculates the axially dependent surface heat transfer coefficients. The second option transfers only the coolant pressure and temperature for each hot channel volume and the surface heat transfer coefficient for each heat slab modelling the hot pin in the blowdown calculation.

Regardless of the option chosen, the power history of the hot pin during blowdown is also transferred. All data are transferred from the plot tape generated during blowdown. The number of data points passed is selected by the user.

D. WRAP/REFILL-FLOOD

The refill model picks up its data from the end of bypass (EOB) database. There is no external interface as such since the refill calculation and the blowdown calculation are both performed in the same module. The required data transfer is carried out based on the user's identification of the specific volumes of interest: the cold leg, the downcomer, and the lower plenum. As needed, flow areas, loss coefficients, hydraulic diameters, volumes, enthalpies, elevations, saturation temperatures, densities, specific heats, slab temperatures, thermal conductivities, volumetric heat capacities, and liquid inventories are extracted from the database.

The reflood interface consists of a few automated features in the input processing module WRAPIT which can be invoked for a FLOOD calculation. The containment pressure may be extracted from the database with the remaining system pressures then calculated by marching around the system, as described in Section IIA above. Volume temperatures are initialized to the corresponding saturation temperatures. As needed, the user may specify that the database extract the lower plenum subcooling temperature, the clad surface temperatures, the fraction of channel blockage, and the core outlet enthalpy. In general, a renodalization is carried out in going from the blowdown/refill calculation to the reflood calculation. In part, this renodalization is supported by the renode module RENPRE. This is a semiautomatic interface due to the complex nature of the renodalization.

E. FLOOD/FRAP

This module is based on the FLOOD/FRAP interface developed at INEL. The time-dependent parameters passed are (1) core inlet coolant temperature, (2) reflood rate, (3) core pressure, and (4) collapsed liquid level. Since these values can oscillate rapidly during the flooding process, a data-smoothing routine was added by INEL to the data transfer module (Ref. 19). FRAP uses this data in the FLECHT correlation to predict heat transfer coefficients during the reflood stage.

results are reported in Reference 21. In general, the agreement between the two calculations was very good.

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Thomas E. Murley, Acting Director
Office of Nuclear Regulatory Research

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	LS		CEJ for LST	
CRESS	RSR=ADB	RSR=ADB	RSR	RES
1SHOTKIN/H	LShotkin:mw	SFabic	LSTong	TEMurley
10/01/80	10/15/80	10/16/80	10/23/80	10/ /80

See note on next page

RES LARKINS

RELAP/FLOOD and for the heat transfer calculations in FRAP-T4/LACE. RES intends to supply maintenance of the WRAP system over the next few years, to improve modelling and to solve any coding problems that are identified by NRR use.

Robert B. Minogue

Robert B. Minogue, Director
Office of Nuclear Regulatory Research

Enclosures,
1. Appendix I
2. Figures 1-4

cc: O. F. Ross, NRR
P. Check, NRR
T. Speis, NRR
G. W. Knighton, NRR
R. Audette, NRR

This RIL was discussed with R. Audette of NRR, who is currently using the WRAP-PWR-EM system to perform audit calculations. He agrees that the work has reached the stage for issuance of a RIL.

See next page for Concurrence

CRESS	RSR=ADB	RSR=ADB	RSR	RES
1SHOTKIN/H	LShotkin:mw	SFabic	LSTong	TEMurley
11/20/80	11/ /80	11/ /80	11/ /80	11/ /80
	RES	RES		
	JLarkins	RBMinogue		
	11/5/80	11/6/80		