



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

OCT 22 1986

TO: All Pressurized Water Reactor Applicants and Licensees  
(Generic Letter 86-16)

SUBJECT: WESTINGHOUSE ECCS EVALUATION MODELS

Gentlemen:

In a letter dated June 2, 1986 (non-proprietary version enclosed), Westinghouse notified the NRC of the need for some additions and corrections to the ECCS Evaluation Models that contain the WREFLOOD and the BART codes. The problems with these codes were discussed at a meeting in Bethesda, Maryland, on June 23, 1986. If either of these codes were used in your ECCS analyses, then this letter is applicable to your plant(s). This letter also applies to non-Westinghouse reactor licensees who use these codes, e.g., Millstone, Unit 2.

For those plants which were analyzed with the 1978 and 1981 versions of the Westinghouse ECCS Evaluation Model, the change to the WREFLOOD code would result in a 6-12°F increase in peak clad temperature. Westinghouse has informed the NRC that the increase would not cause the peak clad temperature (PCT) in current analyses to exceed 2200°F. A new ECCS reanalysis is not required. It is our understanding that Westinghouse does not plan to modify the 1978 and 1981 ECCS Evaluation Models or use them for future ECCS analyses.

For those plants which were analyzed with the 1981 Westinghouse ECCS Evaluation Model with BART, the changes in WREFLOOD and BART could result in approximately 120°F increase in peak clad temperature. In a letter dated July 24, 1986, Westinghouse submitted an addendum to the BART code which makes the corrections identified in the June 2 letter and modifies the application of the radiation heat transfer model. We have approved the addendum to the BART code (safety evaluation enclosed) and concluded that the modifications to the heat transfer model mitigate the increase in the peak clad temperature caused by the other BART and WREFLOOD changes.

Therefore, if you used the 1981 Westinghouse ECCS Evaluation Model with BART in a current analysis, a reanalysis is not required. However, if you use an ECCS analysis to support a future licensing action, then that analysis must be performed with a correct evaluation model. It is our understanding that ECCS analyses performed with the 1981 ECCS Model with BART which support licensing actions currently under review by the NRC have already been redone with the corrected version.

Sincerely,

  
Harold R. Denton, Director  
Office of Nuclear Reactor Regulation

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INFOLTR

Enclosure: As Stated  
*Computer Listing: See packet*

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Westinghouse  
Electric Corporation

Water Reactor  
Divisions

Box 355  
Pittsburgh Pennsylvania 15230-0355

June 2, 1986  
NS-NRC-86-3130  
SED-THA-86-106

Mr. Hugh Thompson, Jr., Director  
Division of Pressurized Water Reactor Licensing - A  
U.S. Nuclear Regulatory Commission  
Mail Stop 528  
7915 Eastern Avenue  
Washington, D.C. 20555

Dear Mr. Thompson:

Enclosed are:

1. 10 copies of WCAP-9561-P-A, Addendum 3: Thimble Modeling in Westinghouse ECCS Evaluation Model (Proprietary).
2. 10 copies of WCAP-9561-NP-A, Addendum 3: Thimble Modeling in Westinghouse ECCS Evaluation Model (Non-Proprietary).

Also enclosed are:

1. One (1) copy of Application for Withholding, AW-86-044, (Non-Proprietary) with Proprietary Information Notice.
2. One (1) copy of Affidavit (Non-Proprietary).

The purpose of this letter is to inform you of the results of an assessment recently completed by Westinghouse on the effects of control rod thimbles on core hydraulics during a large LOCA. This assessment has indicated the need for some additions and corrections to the currently approved 1981 ECCS evaluation model and the 1981 ECCS evaluation model using BART.

A detailed description of the issue, its impact on current ECCS analyses, and recommended corrective actions is contained in the attached report. The effect of thimbles on flooding rate was found to have a small (6-12°F) effect on plants analyzed with the 1978 and 1981 versions of the Westinghouse ECCS evaluation model. It was also found that the metal heat model in these analyses is overly

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conservative, compared with the approved model used in the analyses using BART. If a more accurate calculation of the metal heat flow is included in the analysis, the net effect of the above changes is a reduced PCT.

It has been concluded that, since the net impact of the changes outlined above is a PCT reduction for all plants analyzed with the 1978 and 1981 versions of the ECCS evaluation model, no further action is required for these plants.

The effect of thimbles on flooding rate was found to have a somewhat larger effect on plants analyzed with BART and could not be reduced by taking credit for reduced metal heat flow. The effect ranged from 10 to 20°F. In addition, these plants were further impacted by the need to remove a hot assembly power adjustment (originally included to account for thimbles) which was found to be inappropriate for BART. The combined effect of the thimbles on flooding rate and of removing the hot assembly power adjustment was found to be offset by conservatisms currently contained in BART, resulting in a net benefit. Thus, an analysis repeated with the required model changes and with the identified conservatisms removed will result in a lower peak clad temperature than the one currently on record. However, the effect of each individual change is greater than 20°F and thus is reported here as required by regulation.

This submittal contains proprietary information of Westinghouse Electric Corporation. In conformance with the requirements of 10CFR Section 2.790, as amended, of the Commission's regulations, we are enclosing with this submittal an application for withholding from public disclosure and an affidavit. The affidavit sets forth the basis on which the information may be withheld from public disclosure by the Commission.

Correspondence with respect to the Affidavit or Application for Withholding should reference AW-86-044 and should be addressed to R. A. Wiesemann, Manager of Regulatory and Legislative Affairs, Westinghouse Electric Corporation, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

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Please contact Mr. Mike Young (412-374-5081) of my staff if you have any questions on this subject.

Very truly yours,



E. P. Rahe, Jr., Manager  
Nuclear Safety Department

MYY:sm

Enclosure(s)

cc: C. Berlinger - NRC  
R. Lobel - NRC  
J. Wilson - NRC  
File: SRC-PI-86-003

WESTINGHOUSE CLASS 3

WCAP-9561-NP-A

Addendum 3

ADDENDUM TO:  
BART-A1: A COMPUTER CODE  
FOR THE BEST ESTIMATE ANALYSIS  
OF REFLOOD TRANSIENTS  
(SPECIAL REPORT: THIMBLE MODELING  
IN WESTINGHOUSE ECCS EVALUATION MODEL)

M. Y. Young

Approved: *F. F. Cadek*, F. F. Cadek, Manager  
Safeguards Engineering and Development

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## SUMMARY

The purpose of this report is to describe the results of an assessment recently completed by Westinghouse on the effects of control rod thimbles on core hydraulics during a large LOCA. This assessment has indicated the need for some additions and corrections to the currently approved 1981 ECCS evaluation model and the 1981 ECCS evaluation model using BART.

A detailed description of the issue, its impact on current ECCS analyses, and recommended corrective actions is contained in this report. The effect of thimbles on flooding rate was found to have a small (6-12°F) effect on plants analyzed with the 1978 and 1981 versions of the Westinghouse ECCS evaluation model. It was also found that the metal heat model in these analyses is overly conservative, compared with the approved model used in the analyses using BART. If a more accurate calculation of the metal heat flow is included in the analysis, the net effect of the above changes is a reduced PCT.

It has been concluded that, since the net impact of the changes outlined above is a PCT reduction for all plants analyzed with the 1978 and 1981 versions of the ECCS evaluation model, no further action is required for these plants.

The effect of thimbles on flooding rate was found to have a somewhat larger effect on plants analyzed with BART and could not be reduced by taking credit for reduced metal heat flow. The effect ranged from 10 to 20°F. In addition, these plants were further impacted by the need to remove a hot assembly power adjustment (originally included to account for thimbles) which was found to be inappropriate for BART. The combined effect of the thimbles on flooding rate and of removing the hot assembly power adjustment was found to be offset by conservatisms currently contained in BART, resulting in a net benefit. Thus, an analysis repeated with the recommended model changes and corrections will result in a lower peak clad temperature than the one currently on record. However, the effect of each individual change is greater than 20°F and thus is reported here as required by regulation.

## 1.0 THE EFFECT OF THIMBLES ON CORE HYDRAULICS DURING LOCA

### 1.1 Background

A typical fuel assembly is shown in figure 1-1. In a 17x17 fuel assembly, there are 25 thimbles, while in a 15x15 assembly there are 21 thimbles. Thus, the typical fuel assembly is made up of approximately 10% thimbles. There are 4825 thimbles in a full core of 17x17 fuel in a four loop plant.

The thimbles have several important uses; they allow control rods to be inserted into the core to rapidly shut down core power, and they sometimes contain poison rods which modify the local fission rate within the core during normal operation. They also are used for in-core neutron detector instrumentation.

During normal operation, these thimbles are either empty, or contain burnable poison rods (figure 1-2). The number of burnable poison rods varies, from a maximum of approximately 1500 for a fresh core, to zero for a reload core with integral fuel burnable absorbers (IFBA's).

Approximately one-third of the fuel assemblies are situated under control rod assemblies. During a scram, the control rods drop into the thimbles to shut down the core power. To facilitate the insertion of the control rods, all the thimbles have a set of holes at the bottom (figure 1-3) to allow displaced water to pass through as the control rods are inserted.

All those thimbles not under control rods currently contain thimble plugging devices (figure 1-4). These devices are used to limit the amount of bypass flow (i.e., flow which does not pass directly through the core) to a low value (approximately 1% of the total core flow). Without the devices the bypass flow would be slightly higher, limited by the resistance of the holes at the bottom of the thimble.

During blowdown, in a large LOCA, the water in the thimbles will flash and drain out (a small amount of steam will flow through the thimbles due to the

pressure difference imposed on the core). Heat transfer to the thimbles by convection from the fluid, and by radiation from the fuel rods, will also occur (however, this heat transfer is not accounted for in the Evaluation Model). At the end of blowdown, the thimbles will be empty and perhaps 200°F to 300°F cooler than the surrounding fuel rods.

Because the core flowrate and pressure drop are relatively large, the resistance in the thimble tubes forces most of the fluid through the fuel channels.

When reflood begins, water entering the core will also flow into the thimbles, and into the barrel-baffle region (see figure 1-5). Because the overall core flow rate is substantially lower during reflood, hydrostatic effects dominate and the core, thimbles, and barrel-baffle regions will tend to fill at the same rate. The collapsed liquid level within each region is approximately the same. However, since substantial liquid entrainment is occurring in the core, the core inlet velocity is higher than that of the thimble or barrel baffle regions. Thus, although the barrel baffle and thimble regions may contain significant volume for liquid accumulation, the effect on the core inlet flow rate is relatively small.

## 1.2 Treatment of Barrel Baffle Region in Current LOCA Analysis

The additional barrel baffle volume which must be filled during reflood is explicitly treated in the WREFLOOD code. The detailed modelling is described in reference [1]. Briefly, there are two existing barrel-baffle designs. In the downflow design, water flows into the top of the barrel-baffle region from the downcomer (figure 1-6a). During reflood, this design will tend to fill at the same rate as the downcomer. In WREFLOOD, the downflow barrel-baffle is combined with the downcomer volume, and the barrel baffle input is set to zero. In the upflow design, water flows into the bottom of the barrel baffle region from the lower plenum, and out the top into the upper plenum (figure 1-6b). In WREFLOOD, the upflow barrel-baffle is treated separately, and is calculated to fill at the same rate as the core (the separate treatment is necessary because the core entrains liquid, while the barrel baffle region does not).

### 1.3 Treatment of Thimble Volume in Current LOCA Analyses

The additional thimble volume which must be filled is not explicitly treated in current LOCA analyses. It had previously been assumed that the plugging devices would be sufficiently tight so as to prevent the ingress of water into the thimbles during reflood. During the analysis of the effect of removal of the thimble plugging devices, it was found that plug clearances were sufficiently large and flows were sufficiently low during reflood to allow the thimbles to fill with water even with the plugs installed.

### 1.4 Modeling of Additional Thimble Volume in Current LOCA Analyses



As previously mentioned, many of the thimbles will displace water, rather than collect it, because they contain control rods or burnable poisons. A "worst case" value, bounding for all plants regardless of core configuration, can be obtained by assuming all thimbles are empty. The cross-sectional area corresponding to the empty thimbles is compared to core, barrel-baffle, and downcomer areas for a typical plant in table 1-1.

### 1.5 Impact of Model Change on Current LOCA Analysis Results

Several calculations were performed with a variety of plants using the 1981 model and the 1981 model with BART. The results are presented in table 1-2.

TABLE 1-1

Reactor Vessel Region Crosssectional Areas  
(Typical Four Loop Plant)

Region	Area (ft <sup>2</sup> )	a, c
[		]

Table 1-2

Effect of Thimble Volume on LOCA Analysis Results

<u>Plant Type</u>	<u>Model Used</u>	<u>Modification</u>	<u>PCT (°F)</u>	<u>Delta (°F)</u>
Upflow (4-Loop)	1981	None	[	]
		Thimble filling effect		
		Reduced metal heat		
BART	None			
	Thimble filling effect			
Downflow (4-Loop)	1981	None		
		Thimble filling effect		
		BART		
	BART	None		
		Thimble filling effect		

a,c

From table 1-2 it can be seen that including the effects of empty thimbles results in a small penalty, due to slightly lower flooding rates caused by the filling of the thimbles. The effects presented noted in this table are considered typical of all plants using the 1978, 1981, and 1981 + BART evaluation models.

### 1.6 Compensating Effects

A review of the metal heat transfer calculation in the version of WREFLOOD used in the 1978 and 1981 models indicated that this calculation was releasing an overly conservative amount of heat in the downcomer and lower plenum to the water which is flooding the core, lowering its subcooling and reducing heat transfer. This conclusion was reached by comparing the heat release calculated with the 1978 and 1981 model to the heat release calculated by the model used in the BART evaluation model. The reason for the difference between the two models is that the older WREFLOOD version (prior to BART) uses specified inputs to simple exponential functions to calculate metal heat release<sup>[2]</sup>, while the WREFLOOD version used with BART uses a more accurate conduction solution<sup>[3]</sup> to calculate the heat release.

Calculations were performed with the 1981 model with revised metal heat input which resulted in total metal heat release closer to (but still conservative) what the more accurate BART model version would predict. It was found that this effect more than compensated for the penalty due to thimble filling (see Table 1-2).

### 1.7 Conclusions and Recommendations

The results presented above indicate that, for the 1978 and 1981 versions of the Westinghouse ECCS evaluation model, sufficient margin exists in the current calculation of metal heat transfer to compensate for the effect of thimble filling. It is concluded that no further analysis is required for plants using these models. Because these evaluation model versions are being replaced by more advanced models (BART and BASH), it is recommended that any future calculations using the 1981 model incorporate the additional thimble

## WESTINGHOUSE PROPRIETARY CLASS 2

volume only. Although this will result in a small penalty, it is anticipated that analyses using the 1981 model will be requested only for plants which exhibit substantial margin to the 2200°F limit. Therefore, the existing conservative metal heat input can be retained.

Because the evaluation model using BART already contains the more accurate metal heat release model, the effect of thimble filling cannot be counteracted in the same way as the 1981 and 1978 models.

In addition, the BART calculations are further impacted by changes in hot assembly power, described in the next section.

A discussion of the impact of the thimble filling effect on BART analyses will be presented following Section 2.

### 1.8 References

1. "Westinghouse Emergency Core Cooling System Evaluation Model - Modified October 1975 Version", WCAP-9168, Section 2.2.
2. "Calculational Model for Core Reflooding...", WCAP-8170, Section 2.4.6.
3. "BART-A1...", WCAP-9561-P-A, pg 5-25.

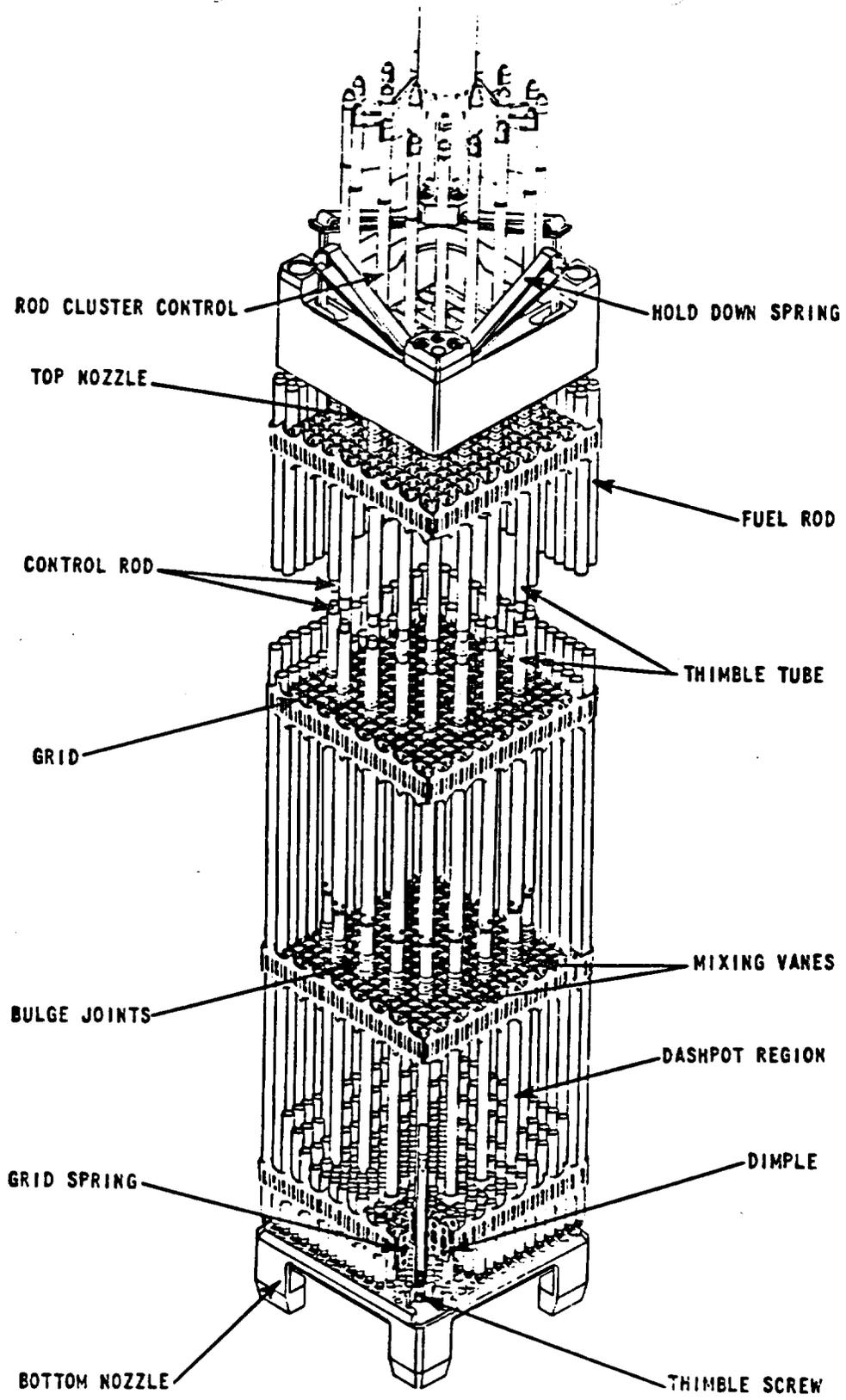
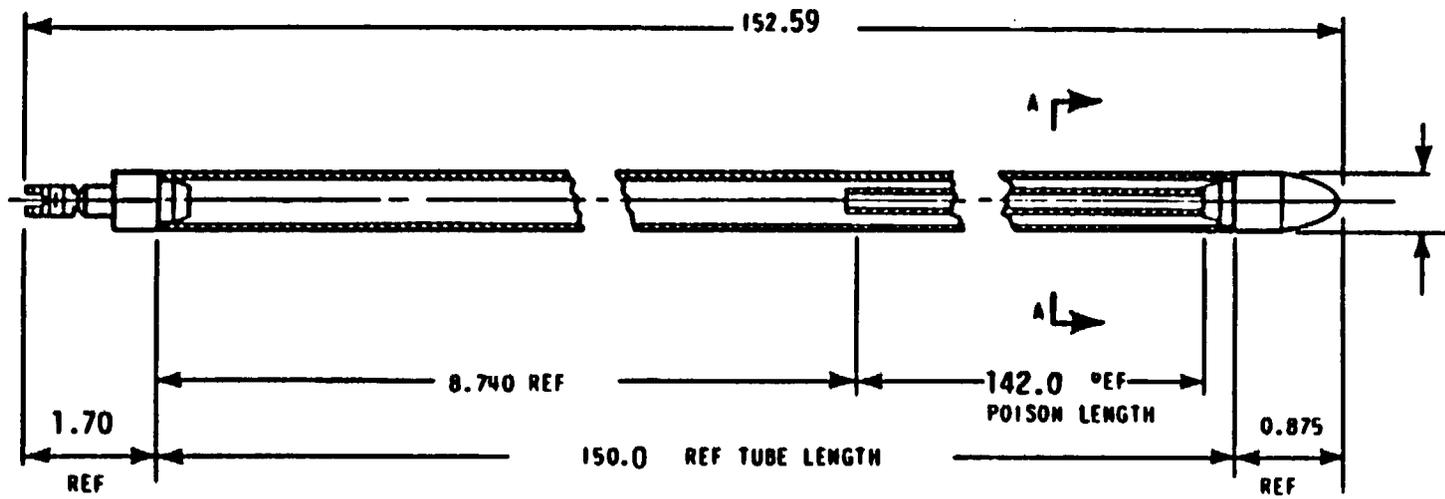


FIGURE 1-1 TYPICAL 17X17 FUEL ASSEMBLY



SECTION A-A

FIGURE 1-2 TYPICAL BURNABLE POISON ROD

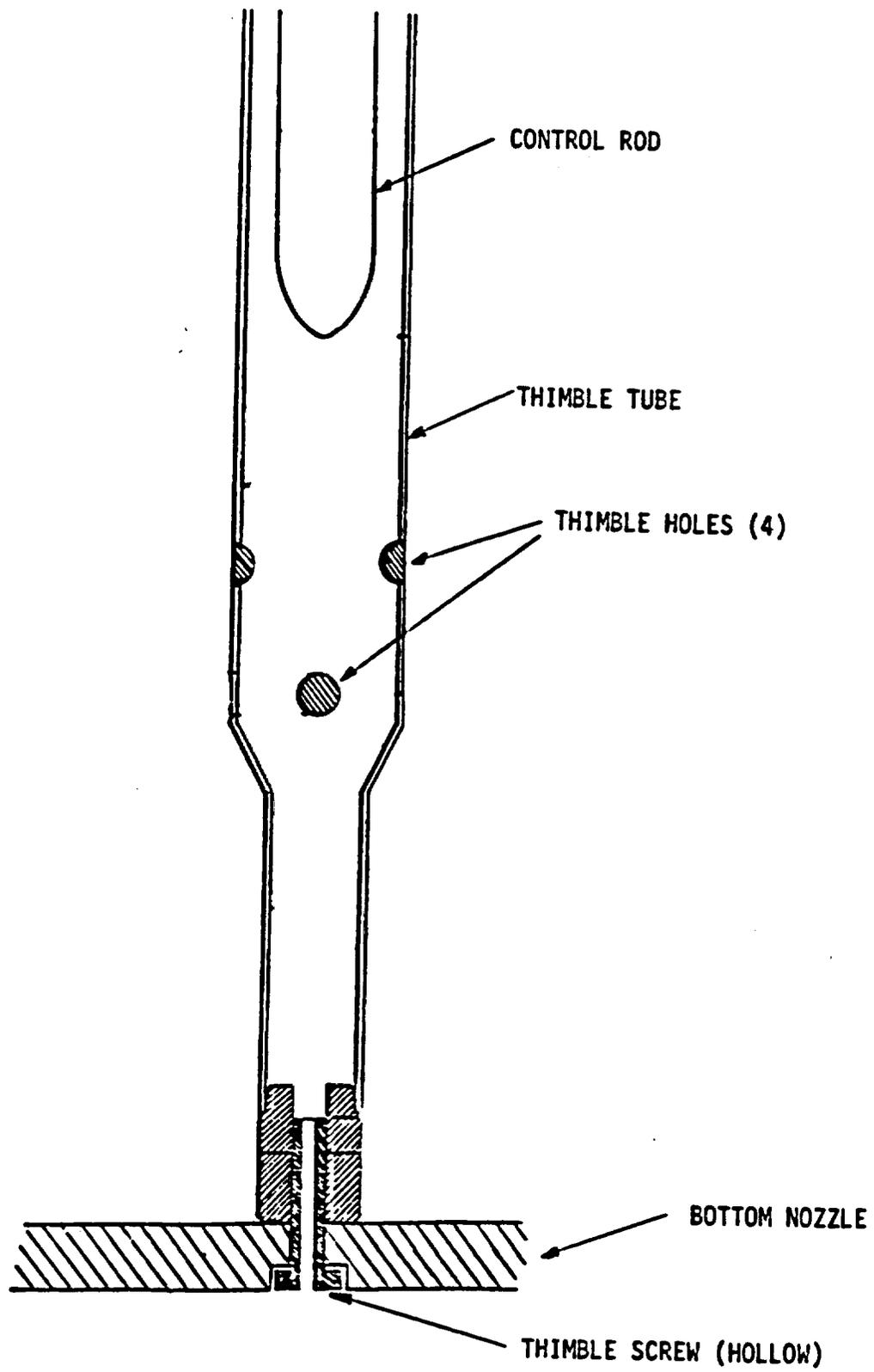


FIGURE 1-3 LOWER PORTION OF THIMBLE TUBE

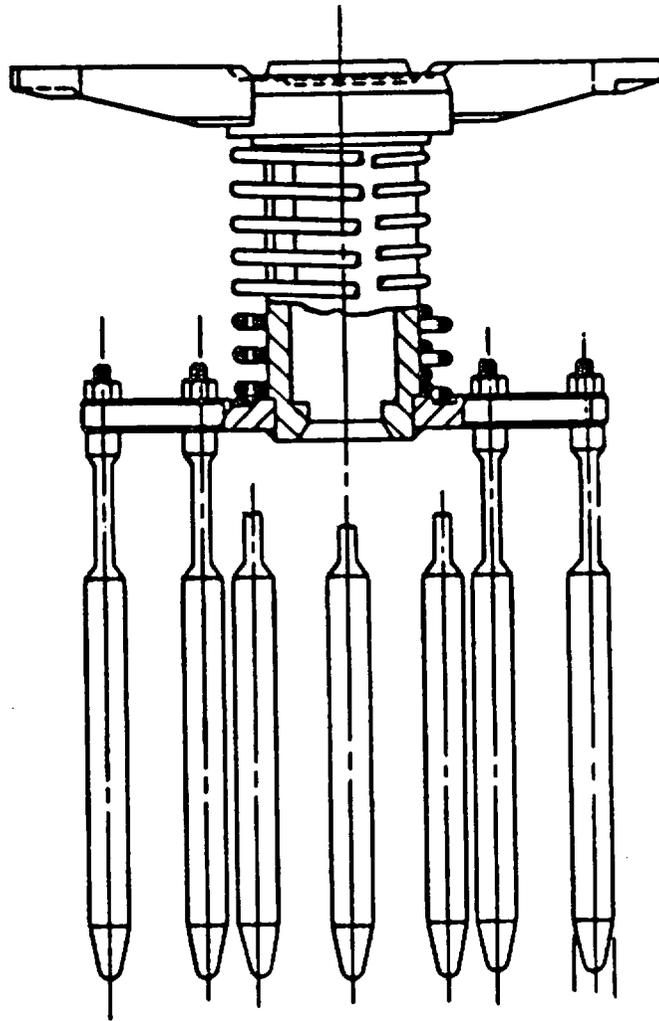


FIGURE 1-4 THIMBLE PLUGGING DEVICE

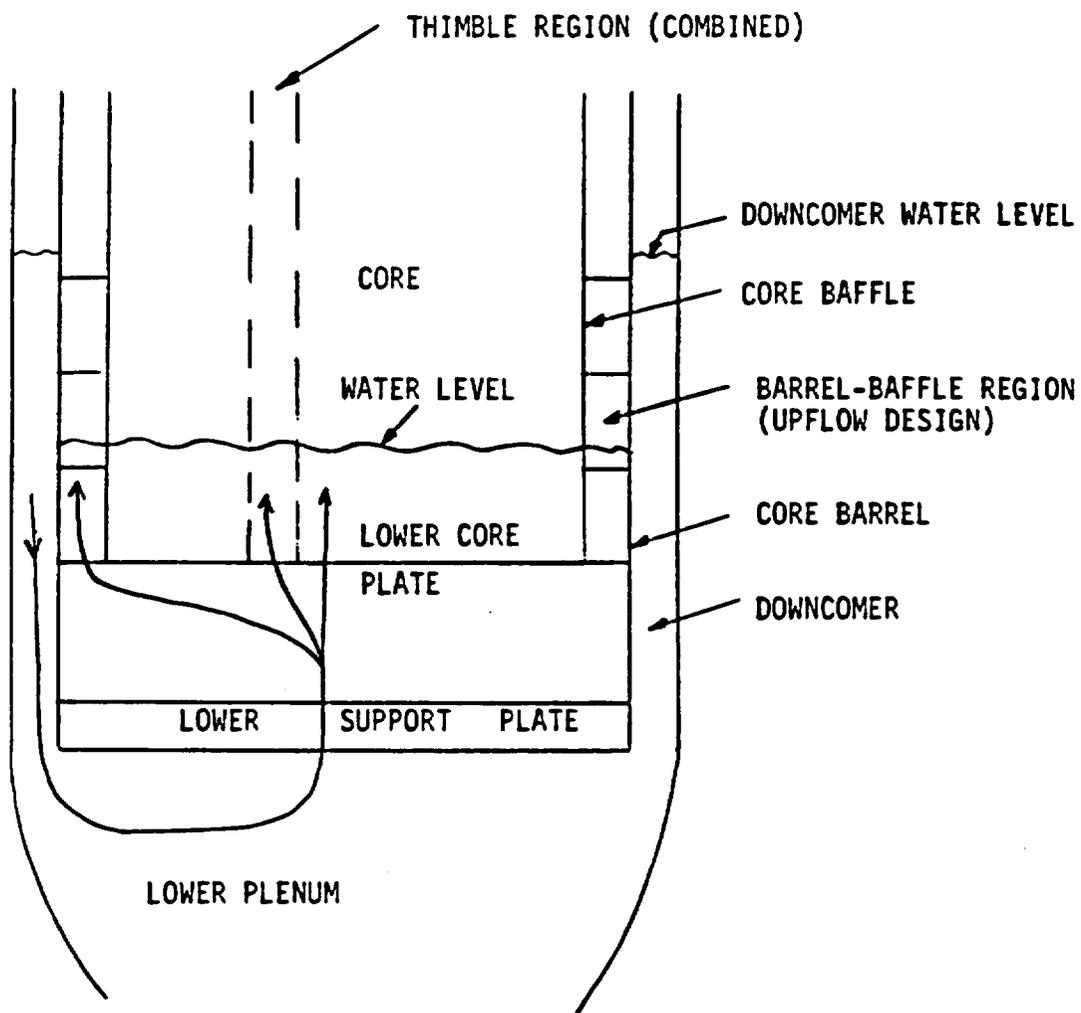


FIGURE 1-5 REACTOR VESSEL REGIONS AND POSSIBLE FLOWPATHS FOR ECCS WATER DURING REFLOOD

- a, c



FIGURE 1-6b SCHEMATIC OF UPFLOW BARREL-BAFFLE DESIGN



**FIGURE 1-6a SCHEMATIC OF DOWNFLOW BARREL-BAFFLE DESIGN**

## 2.0 THE EFFECT OF THIMBLES ON HOT ASSEMBLY HEAT TRANSFER

### 2.1 Background

Further analysis of the effect of thimbles and the way in which the thimbles are treated in the current Westinghouse evaluation model led to the identification of an inconsistency in the BART methodology concerning the power in the hot assembly.

### 2.2 1981 Model

In the 1981 version of the Westinghouse evaluation model, three fuel rods are modeled in the LOCTA heatup code.<sup>[1,2]</sup>

1. The hot rod - this is the highest power rod in the core, and is assumed to reside in the highest power assembly in the core.
2. The adjacent rod - this is a rod in the hot assembly that resides next to the hot rod.
3. The average rod of the hot assembly - this is a rod representative of the average of all rods in the hot assembly.

#### 2.2.1 Hot Rod

The hot rod is used to calculate the peak clad temperature. Its initial conditions are:

1. Maximum linear power
2. Maximum (Tech Spec) total peaking factor
3. Maximum initial stored energy

During blowdown, heat transfer coefficients are calculated in LOCTA using values of mass velocity, pressure, and quality calculated by SATAN for the hot assembly.<sup>[3]</sup> After the end of blowdown but prior to beginning of reflood (i.e., when the reactor vessel is re-filling) the heat transfer coefficient to the fluid is zero. During the refill period, radiation is allowed from the hot rod to the slightly cooler adjacent rod.<sup>[3]</sup> After reflood has begun, the FLECHT correlation is used to calculate heat transfer coefficients on the hot rod. If the flooding rate falls below one inch per second, and blockage has been calculated to occur in the hot assembly (see Section 2.2.3 below), heat transfer coefficients are calculated using a steam cooling model.<sup>[4,5]</sup> This model calculates the enthalpy rise of steam through the hot assembly, and uses a forced convection heat transfer correlation (adjusted to give the same value as the Flecht correlation in the absence of blockage) to calculate the heat transfer coefficient on the hot rod. The steam cooling model takes into account flow diversion around the blockage region.<sup>[6]</sup>

Clad swelling and rupture is calculated on the hot rod, using clad swelling models and correlations for burst temperature and pressure, and burst strain. When rupture occurs, zirconium water reaction is calculated on both sides of the cladding within a 3 inch region, as required by Appendix K.

### 2.2.2 Adjacent Rod

The adjacent rod is used during the refill period and during the steam cooling period to absorb radiation from the hot rod. Its power is assumed to be at 98% of the hot rod power. The rod to fluid heat transfer correlation used during blowdown and reflood are identical to those used for the hot rod.

Burst is calculated in the same manner as for the hot rod.

### 2.2.3 Average Rod

The average rod in the hot assembly is used to calculate the time of average rod burst, and the assembly average blockage. It is also used in the steam cooling model to calculate the enthalpy rise in the channel when flooding rates are less than one inch per second.

The power of a typical rod in the hot assembly is approximately 10% lower than the power in the hot rod. Since the average rod in the hot assembly must represent the composite behavior of the entire assembly, the hot assembly power is volume averaged to represent the power in an average subchannel. The hot assembly power is thus equal to the power of a typical rod, times the number of fuel rods, divided by the total number of rod locations in the assembly.

The enthalpy rise in an assembly comprising a mixture of heated rods and unheated thimbles can be estimated by:

$$\rho V A_F \Delta h = (q''_r P_r + q''_t P_t) \Delta Z \quad (2-1)$$

where  $\Delta h$  = change in enthalpy across  $\Delta Z$

$\rho V$  = mass velocity

$A_F$  = flow area

$q''_r$  = rod heat flux

$P_r$  = total rod perimeter

$q''_t$  = thimble heat flux

$P_t$  = total thimble perimeter

The total rod and thimble perimeters are defined as:

$$P_r = N_r \pi D_r = (264) \pi (.374/12) \text{ ft, for } 17 \times 17$$

$$P_t = N_t \pi D_t = (25) \pi (.482/12) \text{ ft, for } 17 \times 17$$

where

$N_r$  = number of fuel rods

$N_t$  = number of thimbles

$D_r$  = fuel rod diameter

$D_t$  = thimble diameter

The fuel assembly hydraulic diameter is defined as:

$$\begin{aligned} D_e &= \frac{4 \times \text{assembly flow area}}{\text{total surface perimeter}} \\ &= \frac{4 A_F}{P_r + P_t} \end{aligned} \quad (2-2)$$

Thus, equation (2-1) can be written:

$$\rho V \Delta h = \frac{q_r'' P_r + q_t'' P_t}{P_r + P_t} \frac{4}{D_e} \Delta Z \quad (2-3)$$

The thimbles may absorb heat from the fluid and fuel rods by convection and radiation, since they do not generate heat. However, they are conservatively ignored in the calculation. Thus,  $q_t'' = 0$ , and equation (2-3) becomes

$$\rho V \Delta h = \frac{q_r'' P_r}{P_r + P_t} \frac{4}{D_e} \Delta Z \quad (2-5)$$

In terms of number of rods and rod diameter,

$$\rho V \Delta h = q_r'' \frac{N_r}{N_r + N_t D_t / D_r} \frac{4}{D_e} \Delta Z \quad (2-6)$$

As described previously, the hot assembly typical rod power is reduced by the ratio  $N_r/(N_r + N_t)$  to obtain the hot assembly power. During the steam cooling calculation, the enthalpy rise is calculated by:

$$\rho v \Delta h = \bar{q}_r^* \frac{4}{D_e} \Delta Z \quad (2-7)$$

where  $\bar{q}_r^* = q_r^* \frac{N_r}{N_r + N_t} = \text{hot assembly heat flux} \quad (2-8)$

The ratio  $N_r/(N_r + N_t)$  is slightly larger than the ratio  $N_r/(N_r + N_t D_t/D_r)$ , for a slightly more conservative estimate of the enthalpy rise (the thimble diameter is larger than the rod diameter).

For the 1981 model, therefore, the enthalpy rise in the channel is calculated using the average hot assembly power  $\bar{q}_r^*$  and the hydraulic diameter,  $D_e$ . Equation 2-6 indicates that this calculation properly estimates the enthalpy rise in the channel.

### 2.3 BART Interim Reflood Model

In the BART interim reflood model, the average rod in the hot assembly is used for a more detailed calculation of thermal hydraulic conditions during reflood.<sup>[7]</sup> Using initial average rod temperature and power from a LOCTA calculation performed up to the beginning of reflood, BART proceeds to calculate fluid conditions in the hot assembly. The transfer of information from LOCTA to BART has been performed in such a way as to cause no changes in the methodologies used in LOCTA. Thus, the hot assembly average power as defined in section 2.2 has been used. The heat transfer coefficient obtained by BART is then transferred to LOCTA for a hot rod calculation and PCT determination<sup>[8]</sup>. [

] <sup>a,c</sup>

In addition, a simpler fuel rod model is used in which the clad fuel gap heat transfer coefficient is assumed constant in BART (it decreases further during reflood because of continued clad swelling) which leads to higher clad temperatures. These assumptions led to more than 100°F of margin in the BART model<sup>[9]</sup> compared to a more closely coupled calculation using the LOCBART code (see Appendix A). Although the BART fluid energy equation is more detailed than shown below, its basic form is again:

$$\rho V A_F \Delta h = (q_r'' P_r + q_t'' P_t) \Delta Z \quad (2-8)$$

In BART, in addition to the fuel assembly hydraulic diameter  $D_e$ , (which is used to calculate Reynolds Number, for example), a "heated" Diameter is defined as

$$D_h = \frac{4 \times \text{assembly flow area}}{\text{total heated surface perimeter}}$$
$$= \frac{4A_F}{P_r}$$

Equation (1-8) is thus written:

$$\rho V \Delta h = \frac{q_r'' P_r + q_t'' P_t}{P_r} \frac{4}{D_h} \Delta Z \quad (2-9)$$

Again, the heat absorption by the thimbles is conservatively ignored and equation (2-9) reduces to

$$\rho V \Delta h = q_r'' \frac{4}{D_h} \Delta Z \quad (2-10)$$

With this formulation there is no need to adjust the heat flux to obtain the proper enthalpy rise. Thus, the hot assembly rod power,  $q_r''$ , should be used in BART rather than the hot assembly power, as is used in LOCTA.

## 2.4 Description of Inconsistency in BART Methodology

The inconsistency in the BART methodology results from the application of the hot assembly power, rather than the hot assembly rod power in BART.

There are two reasons why the inadvertent application of the hot assembly power in BART was not detected sooner:

1. The inconsistency was "masked" by the conservatism inherent in the transfer of information from BART to LOCTA. It was believed that the relatively modest benefit of about 100°F using the BART methodology could be clearly accounted for by the lower powers and peaking factors of the PWR hot assembly compared with FLECHT tests, and by the improved accuracy of the BART code compared with the FLECHT correlation. Had the conservatism not been applied, then the PWR BART benefit would have been larger, and the source of the benefit would have undergone further scrutiny.
2. The inconsistency was further "masked" by comparisons between the BART methodology and a more closely coupled calculation using LOCBART<sup>[9]</sup>, which showed that the BART methodology was clearly conservative by nearly 100°F.

## 2.5 Impact of Using Hot Assembly Rod Power on BART Results

The effect of using the actual hot assembly rod power in BART was evaluated by correcting the power of the hot assembly rod in BART, and performing a LOCTA hot rod calculation. The results are presented for two plants; a four loop plant where the flooding rate remains above 1 in/s prior to PCT, and a three loop plant where the flooding rate falls below 1 in/s prior to PCT. It can be seen from table 2-1 that correcting the hot assembly power results in approximately 100°F higher temperatures.

## 2.6 Compensating Effects

As previously mentioned, there are several inherent conservatisms in the current BART calculation which can offset the negative effect of the increased hot assembly power. The effect of including the [ ]<sup>a,c</sup> is to reduce the penalty due to the hot assembly power to nearly zero as shown in table 2-1. In addition, sufficient conservatism remains in the BART model to offset the small remaining penalties due to thimble filling and hot assembly power. This is demonstrated by using the LOCBART code, which combines LOCTA and BART and avoids the need to explicitly transfer information between two codes. (LOCBART was developed for use with the BASH reflood code, but it can just as easily be used with WREFLOOD calculated flooding rates). It can be seen in table 2-1 that the calculated LOCBART result is lower than the corrected BART results.

## 2.7 Conclusions and Recommendations

It is concluded that, although the error in BART average rod power leads to a penalty in PCT, sufficient margin exists in the transfer of information from BART to LOCTA to more than compensate for this penalty. [

] a,c

Although this conservatism was retained originally to account for loose coupling of BART and LOCTA, the comparisons shown in Table 2-1 indicate that the loosely coupled methodology with corrections included still produces results which are higher than the LOCBART, or closely coupled, results. Reducing the level of conservatism in this area is therefore justified.

TABLE 2-1

HOT ASSEMBLY POWER - BART MODEL RESULTS

Analysis Method

PCT (°F)

1) Typical Four Loop Plant

Current Analysis

Correct hot assembly power,  
retain conservatism in  
heat transfer information  
to LOCTA

Correct hot assembly power,  
include [ ]<sup>a,c</sup>  
term in heat transfer  
information to LOCTA

Use LOCBART

2) Typical Three Loop Plant

Current Analysis

Correct hot assembly power,  
retain conservatism in  
heat transfer information to LOCTA

Correct hot assembly power,  
include [ ]<sup>a,c</sup>  
term in heat transfer  
information to LOCTA

Use LOCBART

[ ]<sup>a,c</sup>

It is recommended that the BART methodology be modified, as follows:

- a) Use the actual hot assembly rod power, rather than the adjusted hot assembly power, in BART.

[

] <sup>a,c</sup>

## 2.8 References

1. "LOCTA-IV Program...", WCAP-8305
2. "Westinghouse ECCS Evaluation Model-Summary," WCAP-8339, Section 4.1.1
3. "BART-A1...", WCAP-8471-P-A, Section 2.3.3
4. "BART-A1...", WCAP-8471-P-A, Section 2.3.1
5. "Westinghouse ECCS Evaluation Model - Feb. 1978 Version," WCAP-9220-P-A, Section 2.4
6. "Westinghouse ECCS Evaluation Model - Oct. 1975 Version," WCAP-8622, Section 3.0
7. "BART-A1...", WCAP-9561-P-A
8. "BART-A1...", WCAP-9561-P-A, Section 5
9. "BART-A1...", WCAP-9561-P-A, Section 5-6

a,c

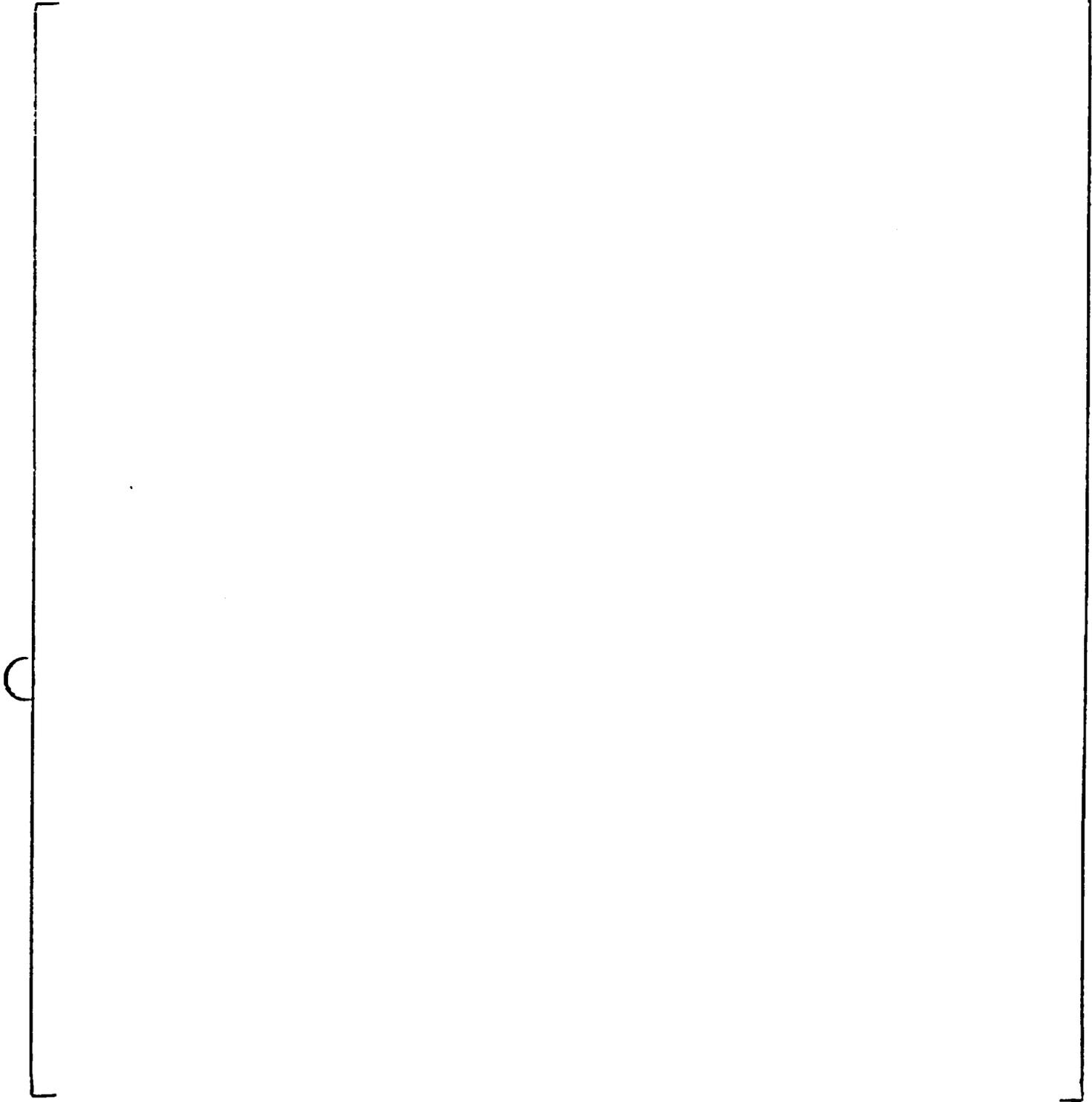


Figure 2-1. Heat Transfer Components Used in PWR Hot Rod Calculation in the BART Methodology

### 3.0 CONCLUSIONS AND PROPOSED CODE MODIFICATIONS

The effect of thimbles on core thermal hydraulics has been described, as well as a correction which is required for the BART code methodology.

Sources of margin in the WREFLOOD and BART codes have been identified which offset the penalties incurred as a result of the thimble effects and code corrections. Specifically, the following effects have been quantified:

#### 1978, 1981 Models

1. Include thimble filling effect in WREFLOOD.
2. More accurate metal heat release in WREFLOOD.

It has been concluded that a re-analysis of plants with the above changes will lead to a lower calculated peak clad temperature.

#### 1981 Model with BART

1. Include thimble filling effect in WREFLOOD.
2. Correct hot assembly power in BART.
3. Include [  $\lambda^{a,c}$  ] term in BART.
4. Additional conservatism in BART fuel rod model relative to LOCBART.

It has been concluded that a re-analysis of plants with the above changes will lead to a lower calculated peak clad temperature.

It is proposed that, for future calculations, the following changes in code methodology be implemented:

1978, 1981 Models

1. Include thimble filling effect.

1981 Model with BART

1. Include thimble filling effect.
2. Correct hot assembly power.
3. Include [            ]<sup>a,c</sup> term in BART.

The changes recommended above will lead to small (20°F) penalties in peak clad temperature when compared with the current methodology. However, the penalty is small enough that no serious loss of margin is anticipated for any plants. The changes to improve the metal heat release model and to reduce the conservatism in the BART fuel rod model (changes which would reduce calculated PCT compared with the current methodology) are not being proposed at this time because the effort required to incorporate these changes is more significant and because it is anticipated that future analyses will be performed with the BASH and LOCBART codes presently under review.

APPENDIX A  
LOCBART DESCRIPTION

The currently approved methodology uses BART to calculate hot assembly fluid conditions, and then transfers heat transfer coefficients and fluid temperatures to LOCTA, which then calculates the hot assembly average and hot rod thermal response (see Figure A-1). An iteration involving a second BART run is required if the LOCTA calculation predicts that the average rod will burst (see Section 5-2, Reference 1).

As discussed in Reference 1, the currently approved method was recognized to be cumbersome and a more streamlined method which combined both codes (without altering the basic methods of either code) was described and shown to produce similar, though slightly lower peak clad temperatures. This combined code, called LOCBART, was in a preliminary stage of verification at the time.

In the LOCBART model, BART does not generate rod temperature profiles internally (as in the BASH version of BART), but uses fuel rod temperatures provided by LOCTA at each timestep, ensuring consistency between BART heat transfer coefficients and LOCTA rod properties in the hot assembly and hot rod analysis. In addition, the blockage distribution calculated as a result of cladding swelling and rupture is automatically supplied to BART for flow redistribution calculations.

The LOCBART code is structured as shown in Figure A-2. The bulk of the LOCTA and BART subroutines are contained in separate overlays. They have a common overlay, however, which contains all the coding necessary to calculate fuel rod thermal and mechanical conditions. During blowdown and refill, the LOCTA overlay is used as the main program. During reflood, the BART overlay is

used. During the reflood calculation, the BART code calls the LOCTA fuel rod model three times for each elevation at each timestep; once for the hot rod, once for the adjacent rod, and once for the average rod. The heat flux calculated for the average rod is used to calculate thermal-hydraulic conditions in the hot assembly. These calls replace the calls to the simplified fuel rod subroutine used in the approved version of BART.

The differences between the LOCBART code and the currently approved LOCTA/BART method are as follows:

1. The fluid heat transfer calculation in LOCBART uses the more detailed fuel rod model from LOCTA. The LOCTA/BART method employs a simpler fuel rod model. The LOCBART model predicts that the gap heat transfer coefficient will become smaller during reflood as clad swelling takes place. This results in a lower clad temperature due to insulation of the clad from the fuel. Previous approved models using the FLECHT correlation and the steam cooling model took the varying gap heat transfer into account. This effect was not taken into account in the currently approved model using BART (Figure A-1) when calculating the heat transfer coefficient. (It is however, taken into account when calculating the hot rod temperature in LOCTA after the BART calculation.)
2. BART contains the modifications described in reference 2 to allow for reverse flow. In forward flow, the results predicted by the currently approved BART code and the version of BART used in LOCBART agree closely[3].
3. Since the information on clad rupture and flow blockage is available within LOCBART, a second BART run is no longer necessary if the average rod bursts.

4. To ensure conservatism in the transfer of information from BART to LOCTA, the [ ]<sup>a,c</sup> term from the fuel rod to vapor is not transferred to LOCTA from BART. In LOCBART the [ ]<sup>a,c</sup> term is used.

In all other respects, the codes, models, and methodology used in LOCBART and in the currently approved LOCTA/BART methods are identical.

#### REFERENCES

1. "BART-A1....," WCAP-9561-P-A, section 5-2.
2. "BASH....," WCAP-10266, Revision 1, section 5.
3. "BASH....," WCAP-10266, Revision 1, section 6.



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

E. P. Rahe, Jr., Manager  
Nuclear Safety Department  
Westinghouse Electric Corporation  
Box 355  
Pittsburgh, Pennsylvania 15230-0355

AUG 25 1986

Dear Mr. Rahe:

SUBJECT: ACCEPTANCE FOR REFERENCING OF LICENSING TOPICAL REPORT  
WCAP 9561, ADDENDUM 3, REVISION 1

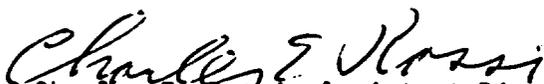
The Nuclear Regulatory Commission (NRC) staff has completed its review of Topical Report WCAP 9561, Addendum 3, Revision 1, "Thimble Modeling in Westinghouse ECCS Evaluation Model," which was submitted with your letter dated July 24, 1986. We find the report to be acceptable for referencing in license applications to the extent specified and under the limitations delineated in the report and the associated NRC evaluation, which is enclosed. The evaluation defines the basis for acceptance of the report.

We do not intend to repeat our review of the matters described in the report and found acceptable when the report appears as a reference in license applications, except to assure that the material presented is applicable to the specific plant involved. Our acceptance applies only to the matters described in the report.

In accordance with procedures established in NUREG-0390, it is requested that Westinghouse publish an accepted version of this report, proprietary and non-proprietary, within three months of receipt of this letter. The accepted version shall incorporate this letter and the enclosed evaluation after the title page. The accepted version shall include an -A (designating accepted) following the report identification symbol.

Should our criteria or regulations change such that our conclusions as to the acceptability of the report are invalidated, Westinghouse and/or the applicants referencing the topical report will be expected to revise and resubmit their respective documentation, or submit justification for the continued effective applicability of the topical report without revision of their respective documentation.

Sincerely,

  
Charles E. Rossi, Assistant Director  
Division of PWR Licensing-A  
Office of Nuclear Reactor Regulation

Enclosure: As Stated

~~SECRET~~

tp.

SAFETY EVALUATION ON CHANGES  
IN THE 1981 WESTINGHOUSE ECCS  
EVALUATION MODEL WITH BART

Introduction

In a meeting held on June 23, 1986, Westinghouse met with representatives of the staff to discuss changes in their large break ECCS Evaluation Models. These changes were necessitated by a modeling change in the WREFLOOD code and an input error to the BART code. Westinghouse estimated that inclusion of the modeling change and correction of the input error could result in an increased peak clad temperature of up to 120°F for ECCS analyses that were performed with the 1981 Evaluation Model with BART. The corrections and remedial actions are described in Topical Report WCAP 9561 Addendum 3, Revision 1, "Thimble Modeling in Westinghouse ECCS Evaluation Model," which was submitted in a letter dated July 24, 1986 (Reference 1).

The model change in the WREFLOOD code was required because the water volume which flows into the control rod guide thimbles during the core reflooding period following a large break LOCA was previously neglected. This model change was found to have the effect of increasing the calculated peak cladding temperature by up to 20°F. The BART change is an error in input which caused systematically low values of hot assembly bundle power to be used by the code. This error was found to have the effect of increasing peak cladding temperature by approximately 100°F. To offset these changes, Westinghouse will include a portion of the heat transfer model calculated by BART in the peak cladding temperature calculation of the LOCTA code. The combined effect of the thimbles on flooding rate and the error in the hot assembly power was determined to be offset by the benefit of including a portion of the heat transfer model. A net benefit was obtained for plants with high peak cladding temperatures approaching 2200°F and a small penalty was obtained for plants with lower peak cladding temperatures.

~~8609044441~~ 7pp.

## Thimble Filling

This issue affects the following Westinghouse ECCS Evaluation Models: 1) 1978; 2) 1981; and 3) 1981 with BART. This safety evaluation applies only to the 1981 model with BART. Westinghouse does not intend to correct the 1978 or 1981 models since they will not be used in the future. The control rod guide thimbles are hollow tubes within the fuel rod bundles which replace 25 fuel rods in 17x17 fuel assemblies and 21 fuel rods in 15x15 fuel assemblies. Control rods are operated within 1/3 of the thimbles. The thimbles may also contain burnable poison rods or in-core neutron detectors. The thimbles contain small flow holes at the bottom to allow water to escape during control rod insertion.

During a large LOCA, the fluid in the thimbles will flash to steam. During the reflooding period, the flow holes will allow water to reenter. In evaluating core reflooding, thimble refilling was not considered by Westinghouse in the WREFLOOD code. This tends to be nonconservative since water which would otherwise enter the coolant channels would instead flow into the thimbles. Although nonconservative, this simplifying assumption was considered to be reasonable in view of the relatively restricted flow into the thimbles compared to flow through the core and considering the effect of the thimble hole plugging devices. During analysis of the effect of removal of the thimble plugging devices, it was found that plug clearances were sufficiently large and core flow was sufficiently low during reflood that the assumption of no flow in the thimbles warranted reconsideration.

Subsequent work by Westinghouse assessed the effect of the assumption of flow through the thimbles during the reflood phase - a phase in which core flow rates are significantly lower than during blowdown and during which refill of the thimbles would tend to be at the same rate as that of the core. These subsequent studies indicated that a modeling assumption of flow in the thimbles during reflood would result in a slightly higher peak clad temperature calculation than would result from the assumption of no flow through the thimbles. For the 1981 Westinghouse ECCS Evaluation Model with BART, thimble

refilling has now been included in a conservative manner in which all thimbles are assumed to be empty at the beginning of the reflooding period and fill at the same rate as the core. This is accomplished by including the total thimble volume in an existing model of the WREFLOOD code which has been approved by the staff (Reference 2). The effect of this conservative modeling of thimble filling during reflood is small (10 to 20 degrees F) because the more significant phenomena of liquid entrainment in the core and steam binding in the coolant loops would be unchanged.

#### Hot Assembly Bundle Power

The hot assembly bundle power error in BART resulted from a confusion between similar input requirements for BART which is utilized to calculate heat transfer coefficients and LOCTA which is utilized to calculate peak cladding temperatures. The LOCTA code evaluates the thermal behavior of a single pin and the fluid conditions in the adjacent hydraulic channel. The hydraulic channel is defined by the hydraulic diameter which is a function of the wetted perimeter. The wetted perimeter includes both heated rod surfaces and unheated thimble surfaces. To account for the effect of the unheated surfaces in computing channel enthalpy rise, the total number of fuel pins plus thimbles is input to LOCTA and utilized to calculate a total surface area and an average heat flux for use in the coolant enthalpy rise calculation.

The BART code evaluates an entire fuel bundle including the thimbles. In calculating the coolant enthalpy rise the BART code correctly utilizes a heated diameter in defining the coolant channel adjacent to a fuel rod. Only the fuel rod perimeter is utilized to derive the heated diameter and not the thimble perimeter. The use of an average heat flux for both rods and thimbles is therefore not required in BART. Only the number of rods should be input rather than both rods and thimbles as in LOCTA. The same input was utilized for both codes however. This produced an under-prediction in enthalpy rise in BART and caused an over-prediction of the fuel rod heat transfer coefficient to be calculated and transferred to LOCTA. The higher heat transfer coefficient caused LOCTA to calculate a peak cladding temperature that was too low by

approximately 100°F. The error is corrected by inputting the number of fuel rods into BART rather than the number of rods plus thimbles. The staff concludes the correction is acceptable.

Heat transfer from the fuel rod surface to the fluid is a combination of convection and radiation. Evaluation of data from the FLECHT reflooding heat transfer experiments has shown that radiation represents a significant fraction of the total heat flux. Radiation heat transfer is a function of the fuel rod surface temperature to the fourth power and increases rapidly at elevated temperatures. The radiation models in the current BART code were reviewed and approved by the staff as discussed in Reference 2. In transferring the fuel rod heat transfer coefficients from BART to LOCTA for calculation of peak cladding temperature, current Westinghouse ECCS evaluations have not included a portion of the radiation heat transfer coefficient. Westinghouse deleted this heat transfer mode because it was thought to have only a small effect on fuel rod cooling and its deletion would provide additional conservatism in their ECCS Evaluation Model with BART. As discussed in Reference 1, the effect of including this portion of radiation heat transfer compensates for the identified hot assembly bundle power and control rod thimble changes in the 1981 ECCS Evaluation Model with BART. Since the staff previously approved the radiation heat transfer model (Reference 2), incorporation of this portion at this time is acceptable.

### Conclusion

As stated above, the NRC staff concludes that the changes to the 1981 Westinghouse ECCS Evaluation Model with BART, as described in Reference 1, meet the requirements of 10 CFR 50.46 and Appendix K to 10 CFR 50 and are, therefore, acceptable.

## References

1. Westinghouse letter, NS-NRC-86-3147, from E. P. Rahe to J. Lyons, NRC, "Review of WCAP-9561-P, Addendum 3, Revision 1," July 24, 1986.
2. NRC letter, from C. O. Thomas to E. P. Rahe, Westinghouse Electric Corporation, "Acceptance for Referencing of Licensing Topical Report WCAP-9561, BART A-1: A Computer Code for Best Estimate Analysis of Reflood Transients," December 21, 1983.

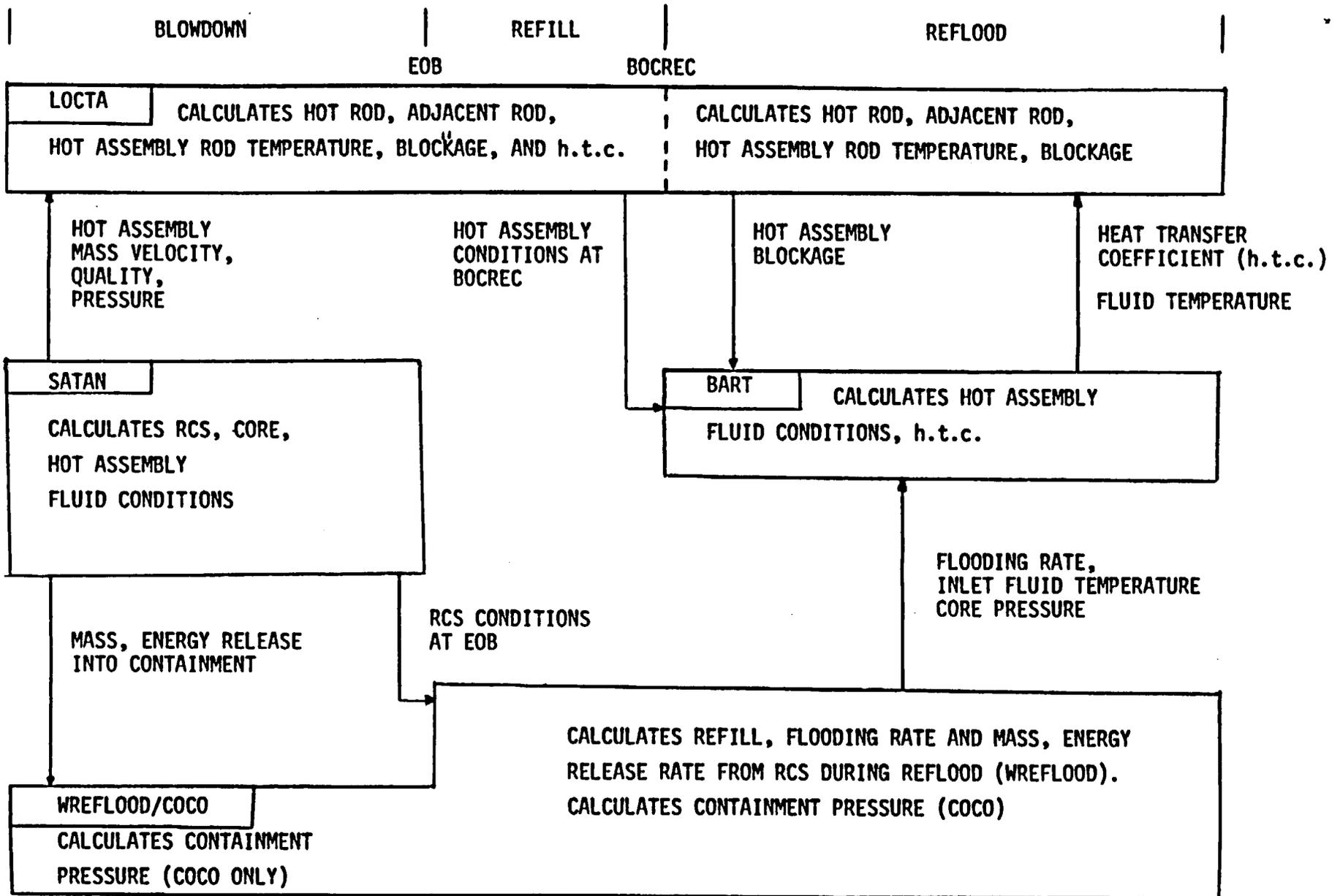


Figure A-1: Calculational Procedure Using Approved BART Model

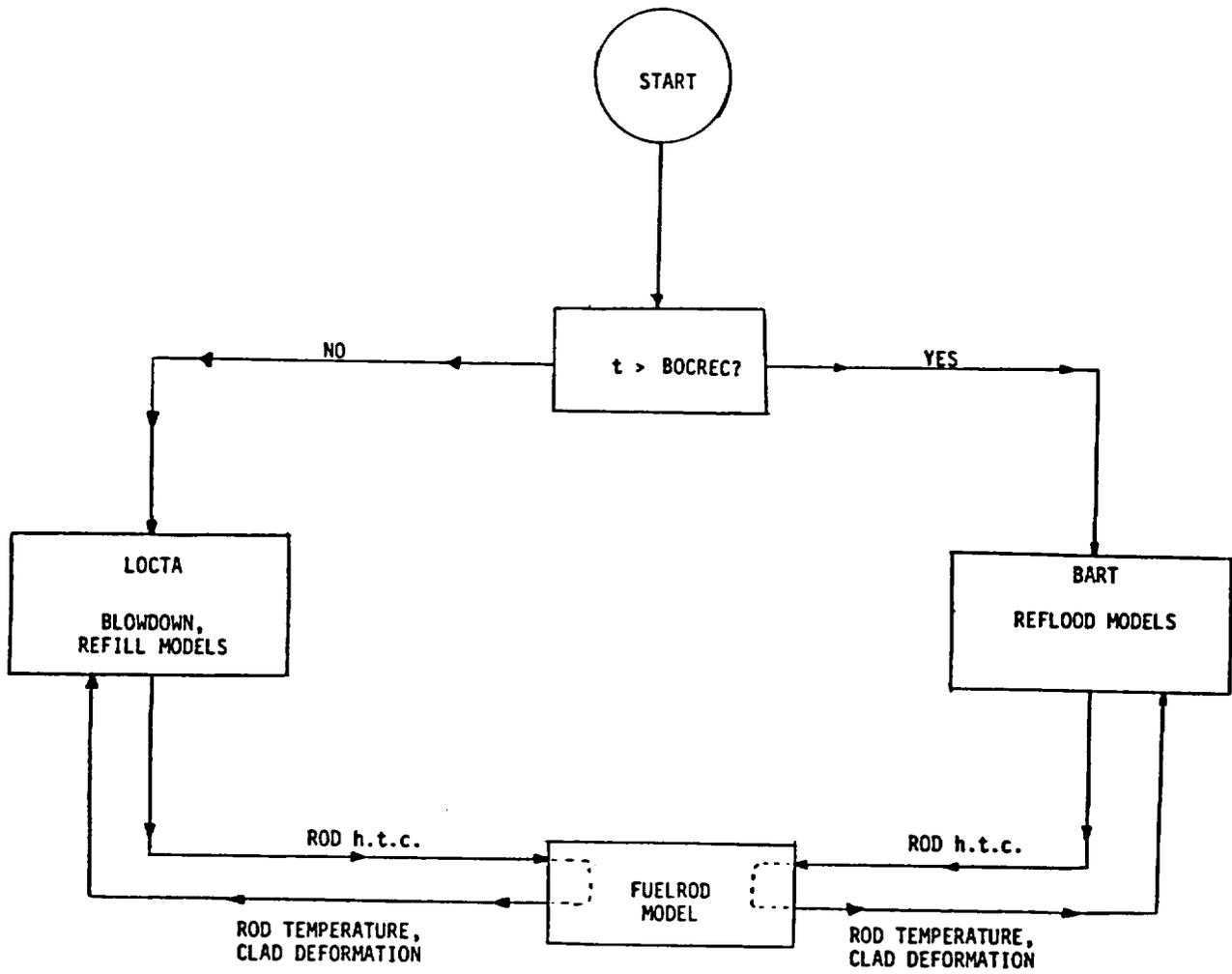


Figure A-2: LOCBART Flow Diagram

**LIST OF RECENTLY ISSUED GENERIC LETTERS**

<b>Generic Letter No.</b>	<b>Subject</b>	<b>Date of Issuance</b>	<b>Issued To</b>
GL 86-15	INFORMATION RELATING TO COMPLIANCE WITH 10 CFR 50.49, "EQ OF ELECTRICAL EQUIPMENT IMPORTANT TO SAFETY"	09/22/86	ALL LICENSEES AND HOLDERS OF AN APPLICATION FOR AN OPERATING LICENSE
GL 86-14	OPERATOR LICENSING EXAMINATIONS	08/20/86	ALL POWER REACTOR LICENSEES AND APPLICANTS
GL 86-13	POTENTIAL INCONSISTENCY BETWEEN PLANT SAFETY ANALYSES AND TECHNICAL SPECIFICATIONS	07/23/86	ALL POWER REACTOR LICENSEES WITH CE AND B&W PRESSURIZED WATER REACTORS
GL 86-12	CRITERIA FOR UNIQUE PURPOSE EXEMPTION FROM CONVERSION FROM THE USE OF HEU FUEL	07/03/86	ALL NON-POWER REACTOR LICENSEES AUTHORIZED TO USE HEU FUEL
GL 86-11	DISTRIBUTION OF PRODUCTS IRRADIATED IN RESEARCH REACTORS	06/25/86	ALL NON- POWER REACTOR LICENSEES
GL 86-10	IMPLEMENTATION OF FIRE PROTECTION REQUIREMENTS	04/28/86	ALL POWER REACTOR LICENSEE AND APPLICANTS
GL 86-09	TECHNICAL RESOLUTION OF GENERIC ISSUE NO. B-59 (N-1) LOOP OPERATION IN BWRs AND PWRs	03/31/86	ALL BWR AND PWR LICENSEES AND APPLICANTS
GL 86-08	AVAILABILITY OF SUPPLEMENT 4 TO NUREG-0933, "A PRIORITIZATION OF GENERIC SAFETY ISSUES"	03/25/86	ALL LICENSEES, APPLICANTS AND CONSTRUCTION PERMIT HOLDERS
GL 86-07	TRANSMITTAL OF NUREG-1190 REGARDING THE SAN ONOFRE UNIT 1 LOSS OF POWER AND WATER HAMMER EVENT	03/20/86	ALL LICENSEES AND APPLICANTS
GL 86-06	IMPLEMENTATION OF TMI ACTION ITEM II.K.3.5, "AUTOMATIC TRIP OF REACTOR COOLANT PUMPS"	05/29/86	ALL LICENSEES AND APPLICANTS OF CE DESIGN NSSS