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)

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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

a,c

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 crossectional 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 Crossectional Areas
(Typical Four Loop Plant)

Region	Area (ft^2)

a,c

Table 1-2

Effect of Thimble Volume on LOCA Analysis Results

a,c

Plant Type	Model Used	Modification	PCT (^{o}F)	Delta (^{o}F)
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	None		
		Thimble filling effect		

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[2], while the WREFLOOD version used with BART uses a more accurate conduction solution[3] 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

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.

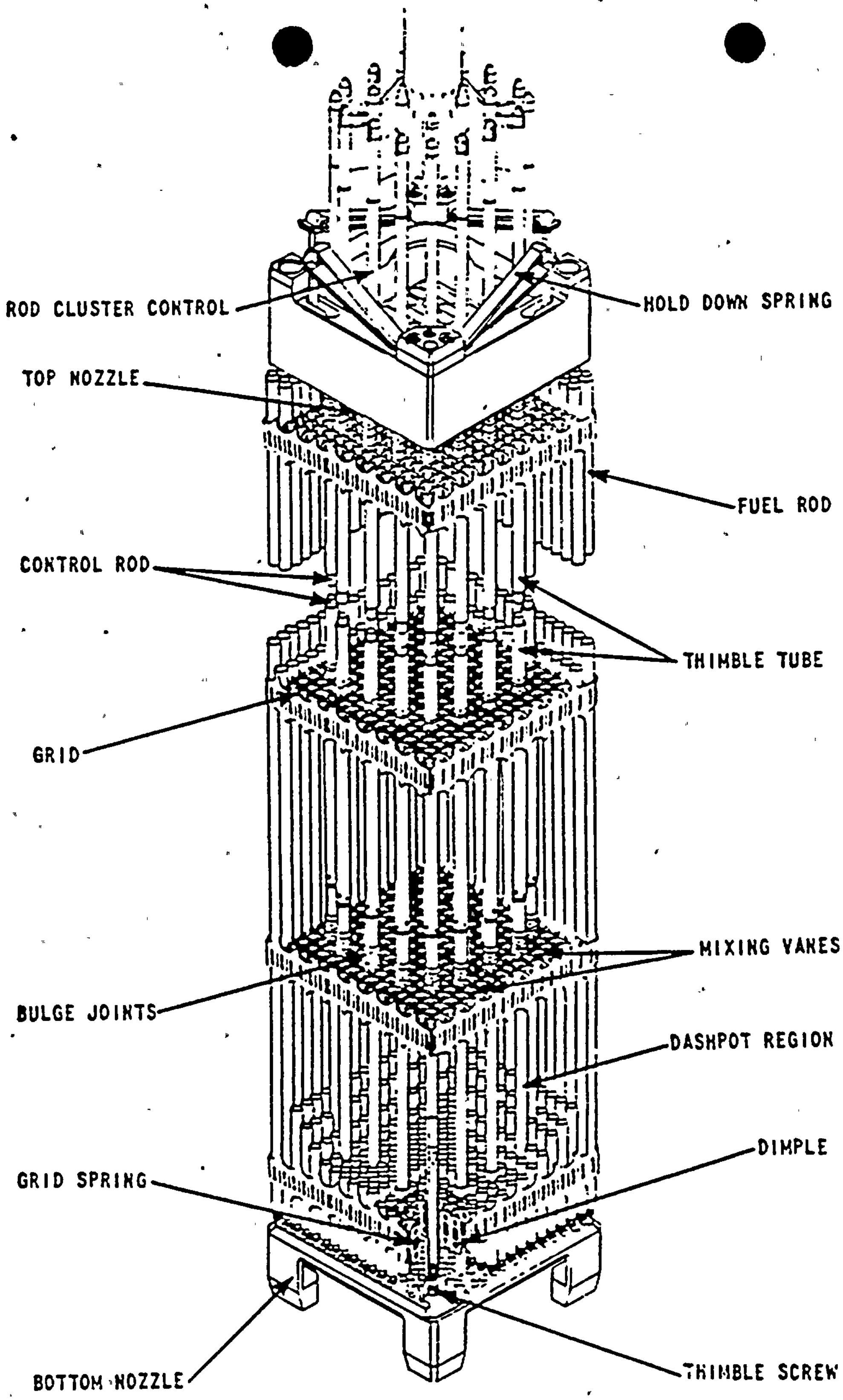

FIGURE 1-1 TYPICAL 17X17 FUEL ASSEMBLY

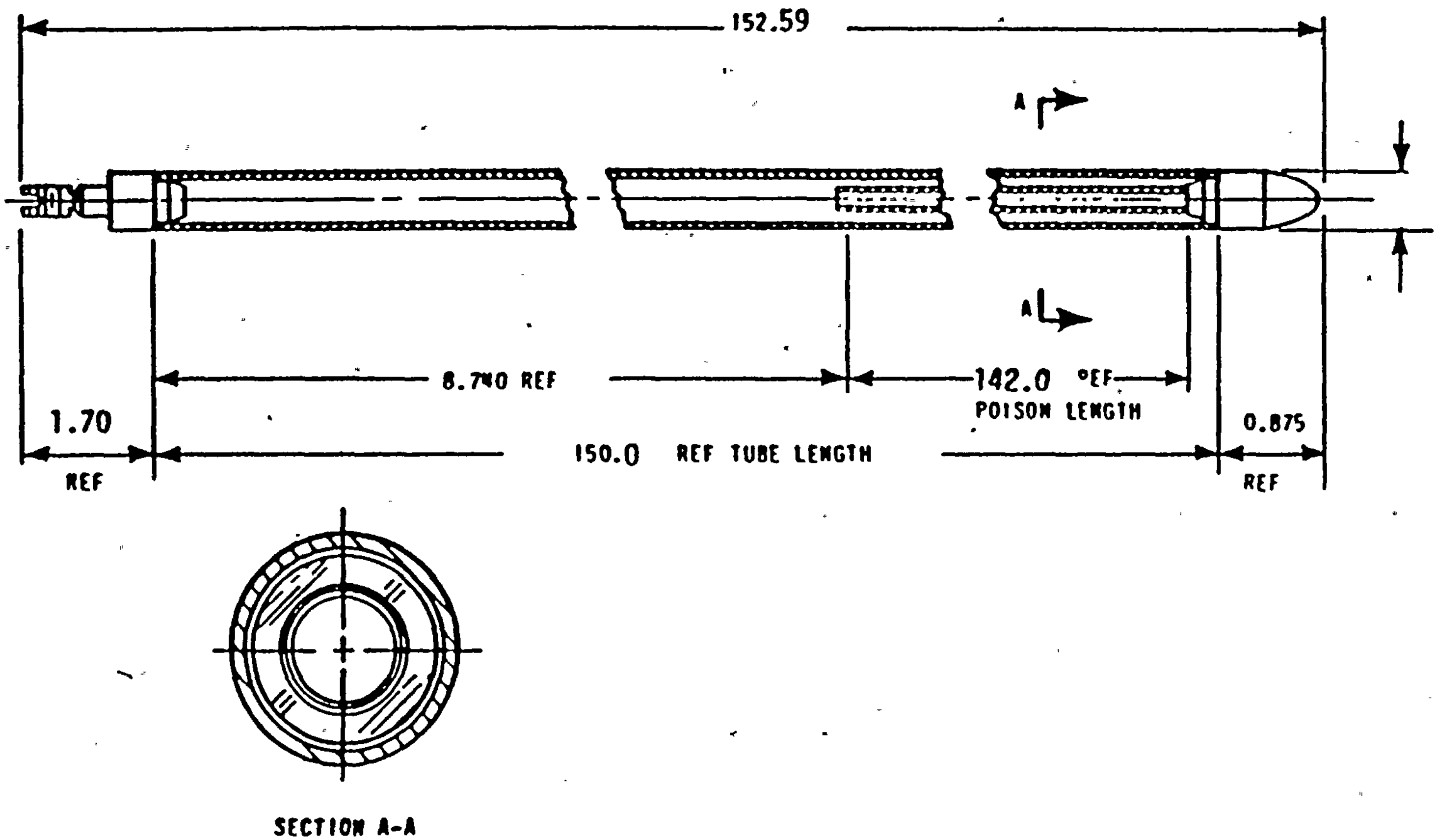

FIGURE 1-2 TYPICAL BURNABLE POISON ROD

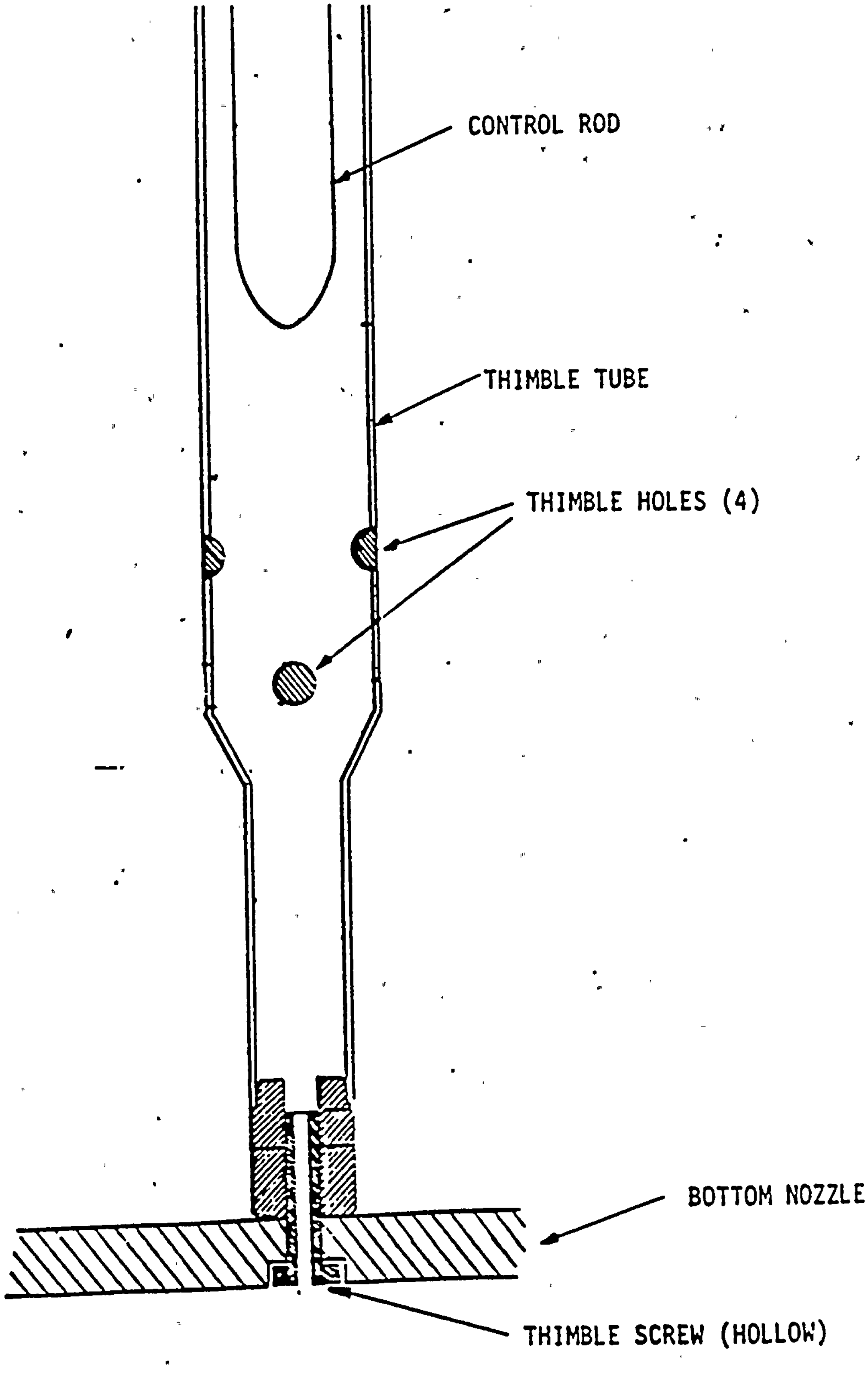

FIGURE 1-3 LOWER PORTION OF THIMBLE TUBE

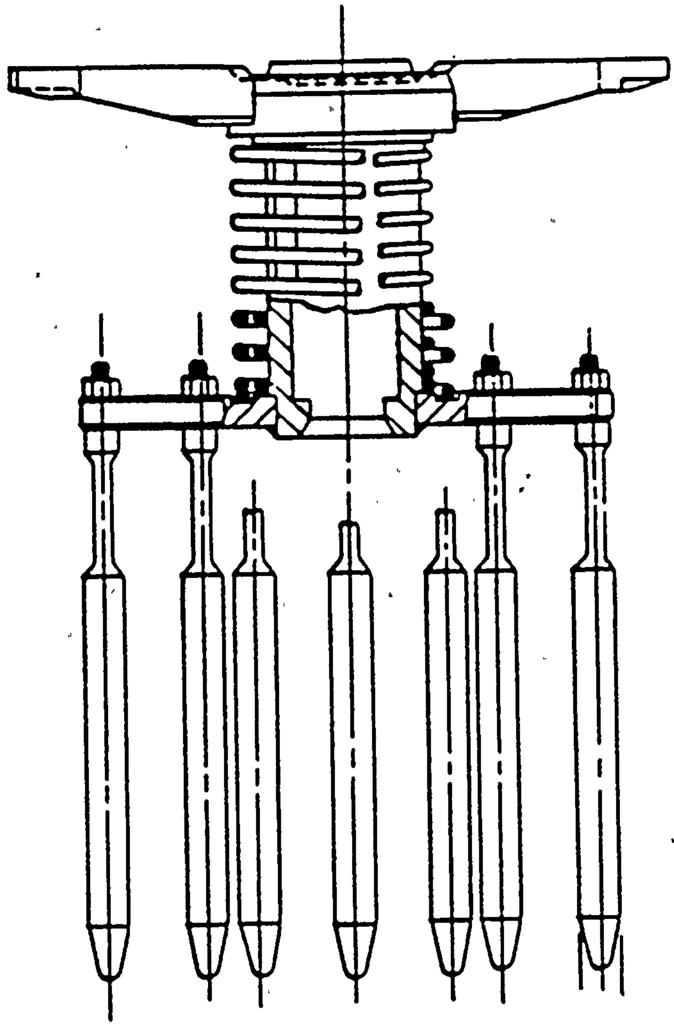

FIGURE 1-4 THIMBLE PLUGGING DEVICE

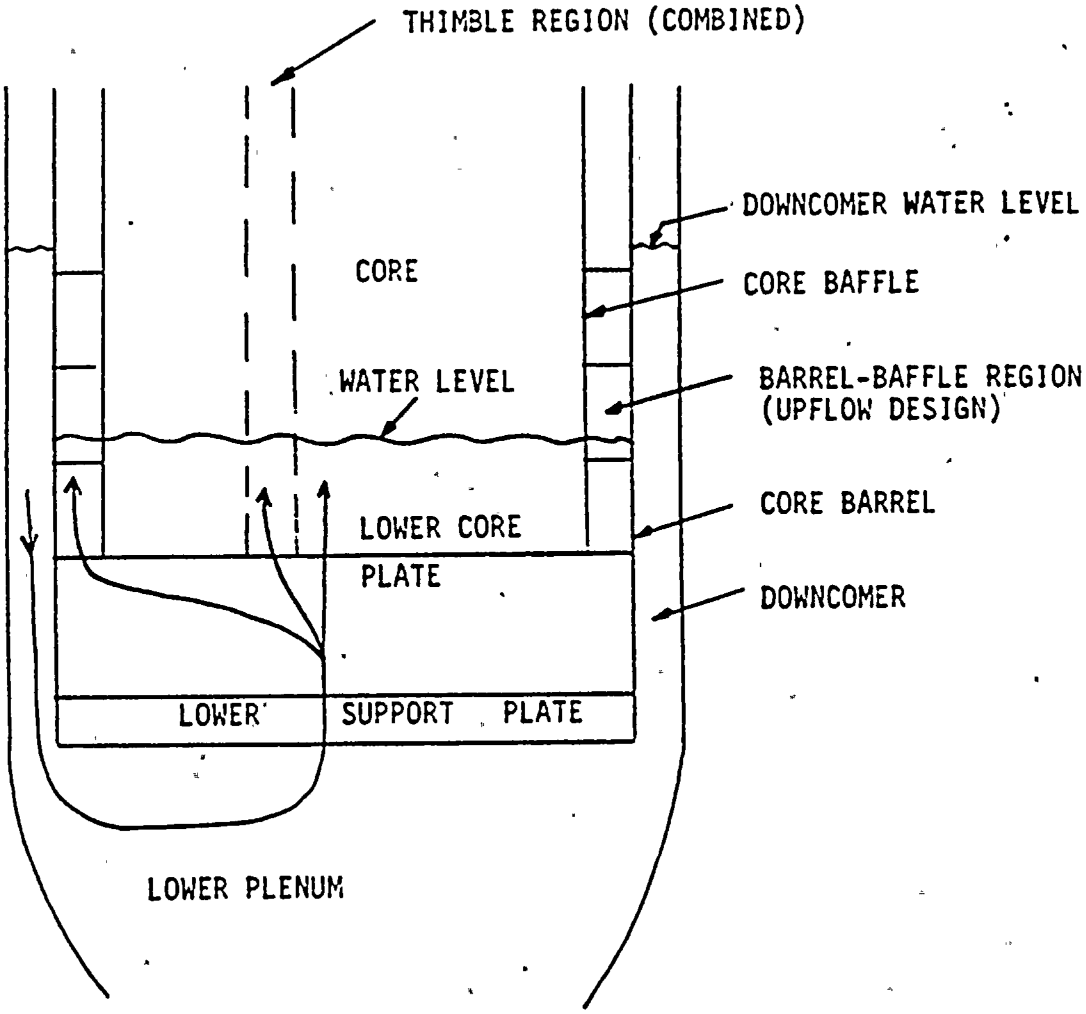

FIGURE 1-5 REACTOR VESSEL REGIONS AND POSSIBLE
FLOWPATHS FOR ECCS WATER DURING REFLOOD

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.[1,2]

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.[3] 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.[3] 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.[4,5] 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.[6]

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:

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

where Δh = change in enthalpy across ΔZ

ρV = 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:

$P_r = N_r \pi D_r = (264) \pi (.374/12)$ ft, for 17 x 17

$P_t = N_t \pi D_t = (25) \pi (.482/12)$ ft, for 17 x 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:

$$D_e = \frac{\text{4X assembly flow area}}{\text{total surface perimeter}}$$

$$= \frac{4\ A_F}{P_r + P_t} \qquad (2\text{-}2)$$

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

$$\rho V \Delta h = \frac{q''_r\ P_r + q''_t\ P_t}{P_r + P_t}\ \frac{4}{D_e}\ \Delta Z \qquad (2\text{-}3)$$

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

$$\rho V \Delta h = \frac{q''_r\ P_r}{P_r + P_t}\ \frac{4}{D_e}\ \Delta Z \qquad (2\text{-}5)$$

In terms of number of rods and rod diameter,

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

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:

$$\rho v \Delta h = \bar{q}''_r \quad \frac{4}{D_e} \Delta Z \tag{2-7}$$

where $\bar{q}''_r = q''_r \dfrac{N_r}{N_r + N_t}$ = hot assembly heat flux (2-8)

The ratio $N_r/(N_r+N_t)$ is slightly larger than the ratio $N_r/(N_r+N_tD_t/D_r)$, 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.[7] 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[8]. [

.]a,c 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[9] 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:

$$\rho V A_F \, \Delta h = (q''_r \; P_r + q''_t \; P_t) \; \Delta Z \qquad (2\text{-}8)$$

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

$$D'_h = \frac{\text{4 x assembly flow area}}{\text{total heated surface perimeter}}$$

$$= \frac{4A_F}{P_r}$$

Equation (1-8) is thus written:

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

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

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

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[9], 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 [ ]a,c 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	[ ]^{a,c}
Current Analysis	
Correct hot assembly power, retain conservatism in heat transfer information to LOCTA	
Correct hot assembly power, include [ ]^{a,c} 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 [ ]^{a,c} term in heat transfer information to LOCTA	
Use LOCBART	

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.

a,c

2.8 References

1. "LOCTA-IV Program...," WCAP-8305

2. "Westinghouse ECCS Evaluatuion 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 Evalatuion 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:

<u>1978, 1981 Models</u>

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.

<u>1981 Model with BART</u>

1. Include thimble filling effect in WREFLOOD.

2. Correct hot assembly power in BART.

3. Include [ ]^{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 [ ]a,c 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 [ ]a,c term from the fuel rod to vapor is not transferred to LOCTA from BART. In LOCBART the [ ]a,c 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.

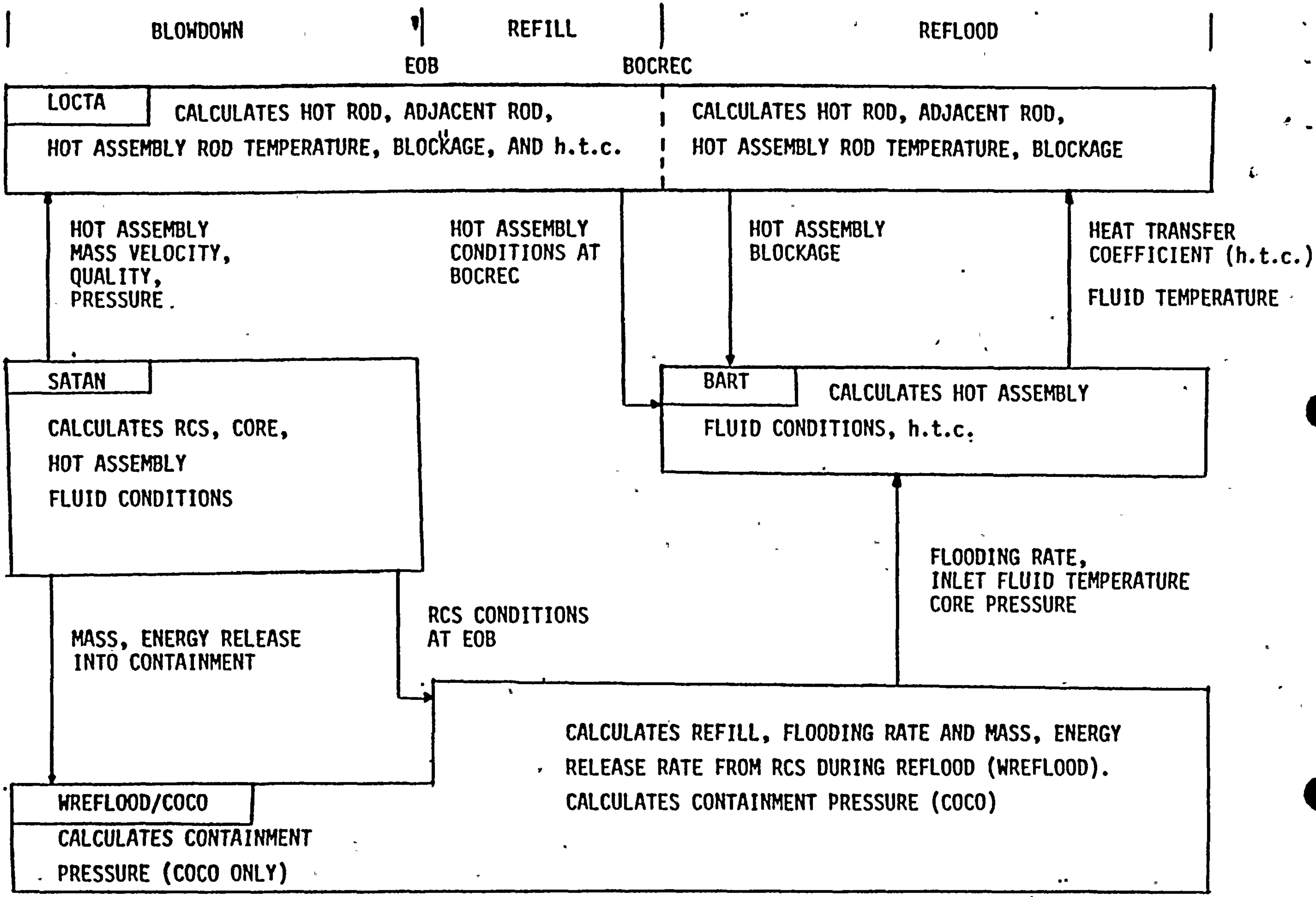

Figure A-1: Calculational Procedure Using Approved BART Model

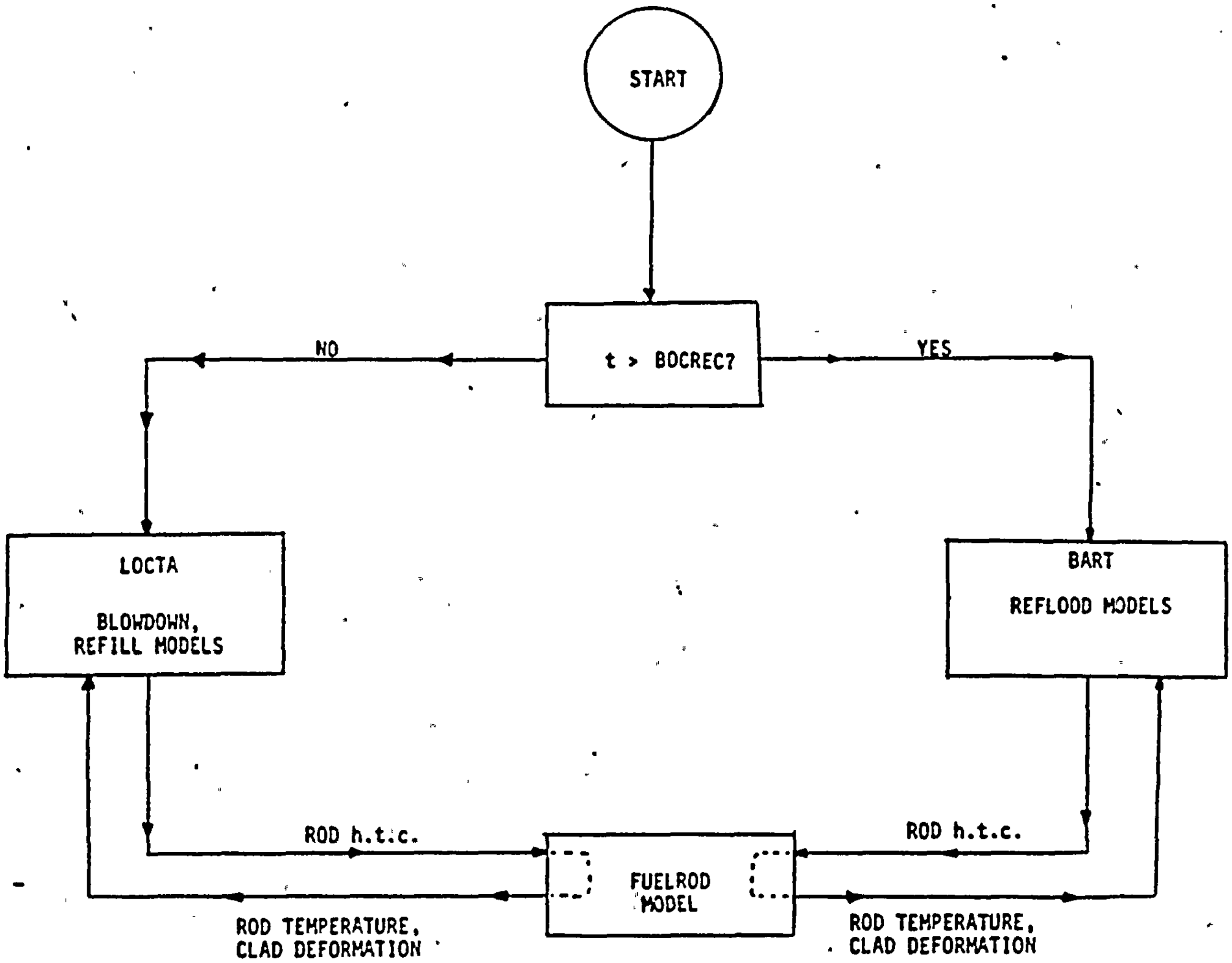

Figure A-2: LOCBART Flow Diagram

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