BASH DOWNCOMER BOILING/ LOCBART TRANSIENT EXTENSION

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Purpose

To describe the method that has been developed to address the effects of downcomer boiling in the 1981 Westinghouse Large Break LOCA Evaluation Model with BASH (BASH-EM)[1]. Per Reference 2, this method was reported pursuant to 10 CFR 50.46 as a Discretionary Change to the Westinghouse Evaluation Model.

Outline

1. Background
2. Downcomer Boiling Sequence of Events
3. BASH Downcomer Modeling
4. LOCBART Transient Extension
5. Expected Effect on Results

1. Background

- As discussed in Reference 3, CCTF and UPTF tests indicated that a realistic treatment of a PWR reflood transient would need to include effects such as downcomer boiling and entrainment.
- Based on CCTF results, it was estimated that modeling these phenomena would only add ~25°F to the calculated PCT.
- Reference 3 concluded that downcomer boiling and entrainment did not represent a significant safety issue for PWRs.

- To allow for conclusive termination of BASH-EM transients, a method has been developed to extend the LOCBART calculation beyond the point at which downcomer boiling is encountered in BASH.
  - Based on a method developed by MPR[4].
  - Uses a void fraction correlation developed by Sudo[5] to estimate the average void fraction in the downcomer during boiling, which is then used to calculate an equivalent void height.
  - Reduction in downcomer driving head is used to calculate a reduction in the flooding rate, which is conservatively assumed to remain constant and is used to extend the LOCBART calculation.

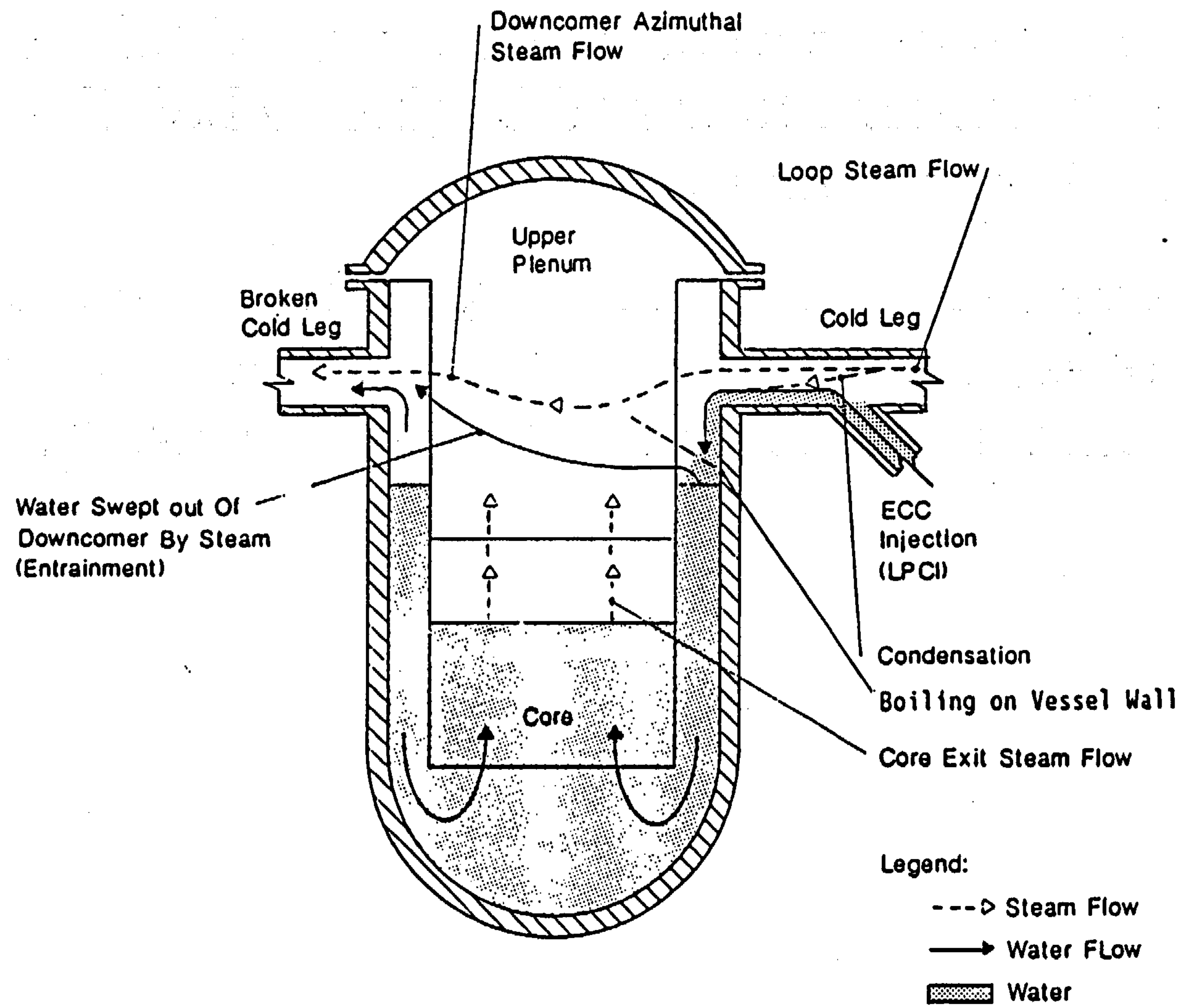
2. Downcomer Boiling Sequence of Events

The following describes the expected behavior of ECCS water in the downcomer and lower plenum during a PWR LBLOCA transient, based on: (1) phenomena observed at the CCTF and UPTF facilities, as described in Reference 3; and, (2) best estimate calculations performed by Westinghouse using WCOBRA/TRAC.

- At end-of-bypass, the vessel is nearly empty of liquid, and ECCS water from the accumulators is calculated to penetrate the lower downcomer. At this time, the vessel quickly fills with water which is approximately 120-150°F, usually filling the lower plenum and downcomer either completely or to within a few feet of the bottom of the cold legs.

- During the accumulator injection period, which typically lasts about 5 to 15 seconds into reflood: water has partially filled the core; entrainment has begun; and, flooding rates drop to a relatively low value on the order of 1 inch per second.
- After the accumulators have emptied, pumped injection water continues to enter the vessel. When minimum safeguards are assumed, condensation of steam in the intact cold legs causes the water to reach saturation before entering the vessel. As illustrated in Figure 1, this water forms a warm layer above the colder accumulator water.

Figure 1[3]


Downcomer Azimuthal
Steam Flow
Loop Steam Flow
Upper
Plenum
Broken
Cold Leg
Cold Leg
Water Swept out Of
Downcomer By Steam
(Entrainment)
ECC
Injection
(LPCI)
Condensation
Boiling on Vessel Wall
Core Exit Steam Flow
Core
Legend:
Steam Flow
Water FLow
Water

- At the beginning of reflood, the reactor vessel walls, thermal shield, and core barrel represent a significant source of stored energy, which heats up the accumulator water and begins to boil the warmer safety injection water.
- As the stored energy is removed from the vessel structures, the heating rate is reduced. Eventually, the accumulator water will also reach saturation.

3. BASH Downcomer Modeling

- Older evaluation models using the WREFLOOD code (e.g., Reference 6) assume that the water in the downcomer does not boil after reaching saturation. The calculated reflood transient therefore proceeds without a significant change in the flooding rate.

- BASH-EM[1] uses the BASH code to calculate the raw core inlet flooding rate, which is then smoothed into two or three constant segments for use in LOCBART. This process was developed during the licensing of BASH-EM to help ensure a conservative prediction of hot channel heat transfer during reflood and is illustrated in Figures 2 through 5 for a sample BASH-EM calculation.

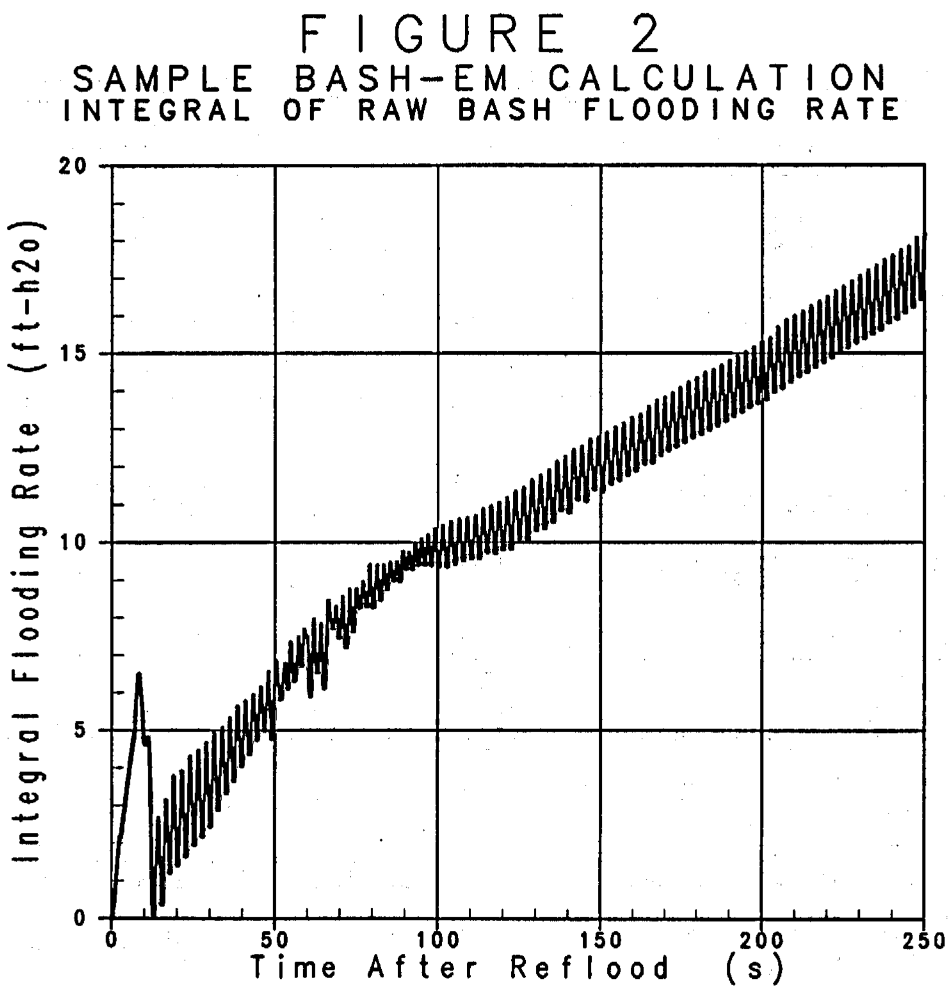


FIGURE 2
SAMPLE BASH-EM CALCULATION
INTEGRAL OF RAW BASH FLOODING RATE
Integral Flooding Rate (ft-h2o)
0
5
10
15
20
0
50
100
150
200
250
Time After Reflood (s)

FIGURE 3
SAMPLE BASH-EM CALCULATION
SMOOTHED FLOODING RATE INTEGRAL

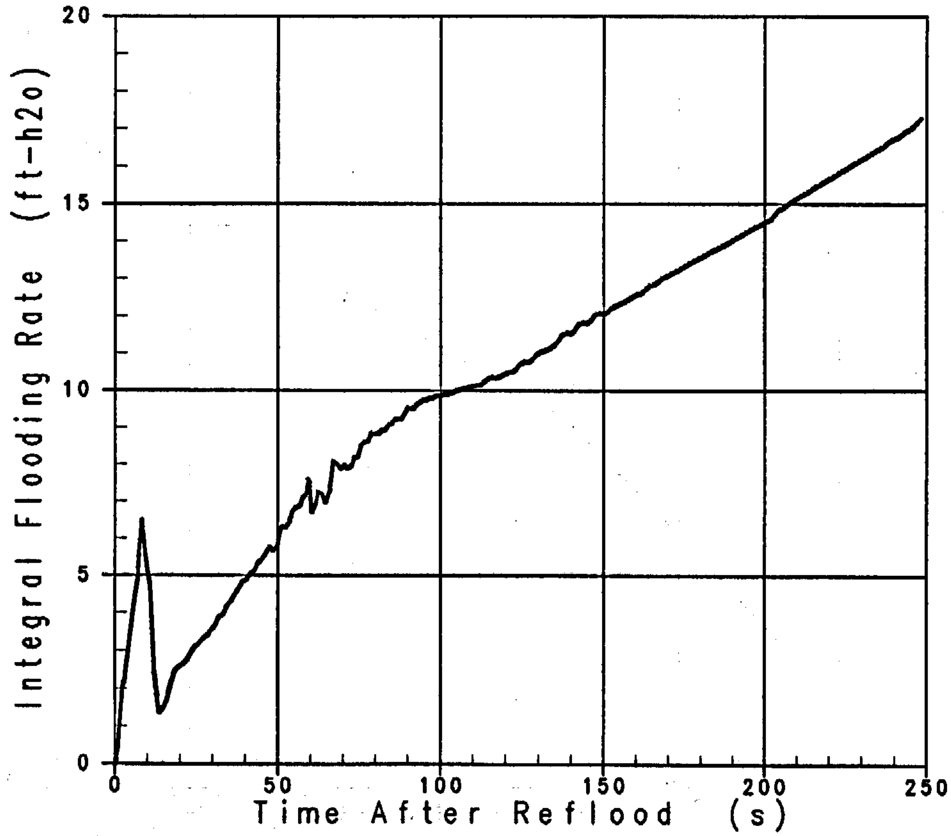


FIGURE 4
SAMPLE BASH-EM CALCULATION
FINAL FLOODING RATE INTEGRAL

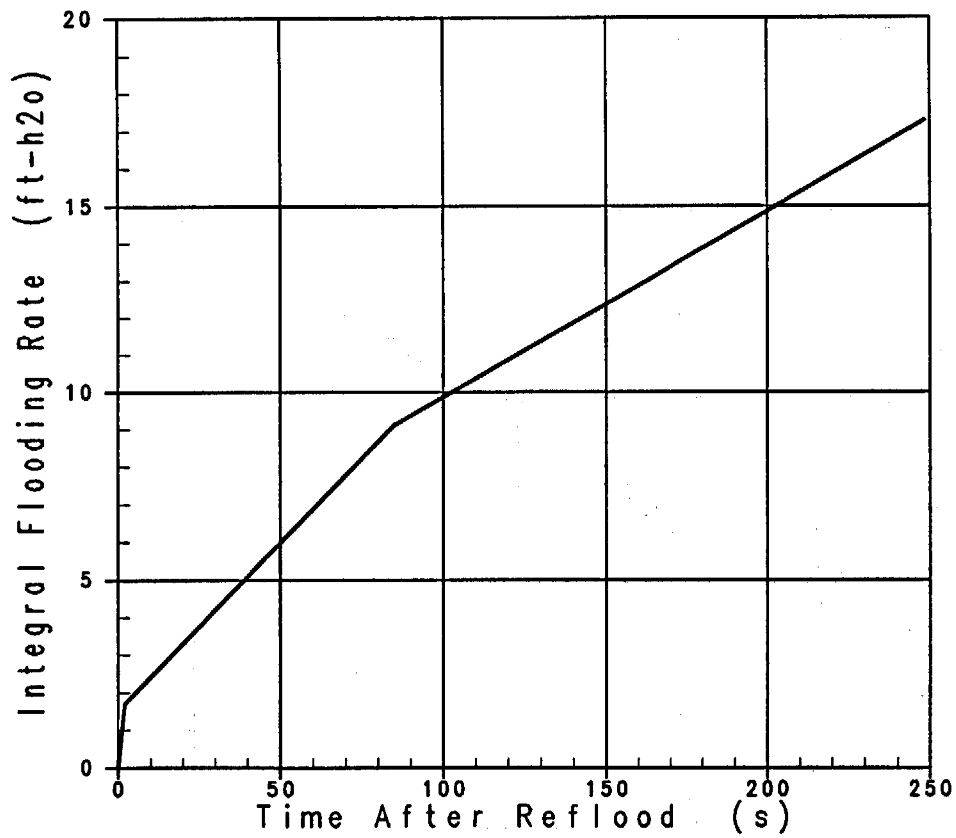
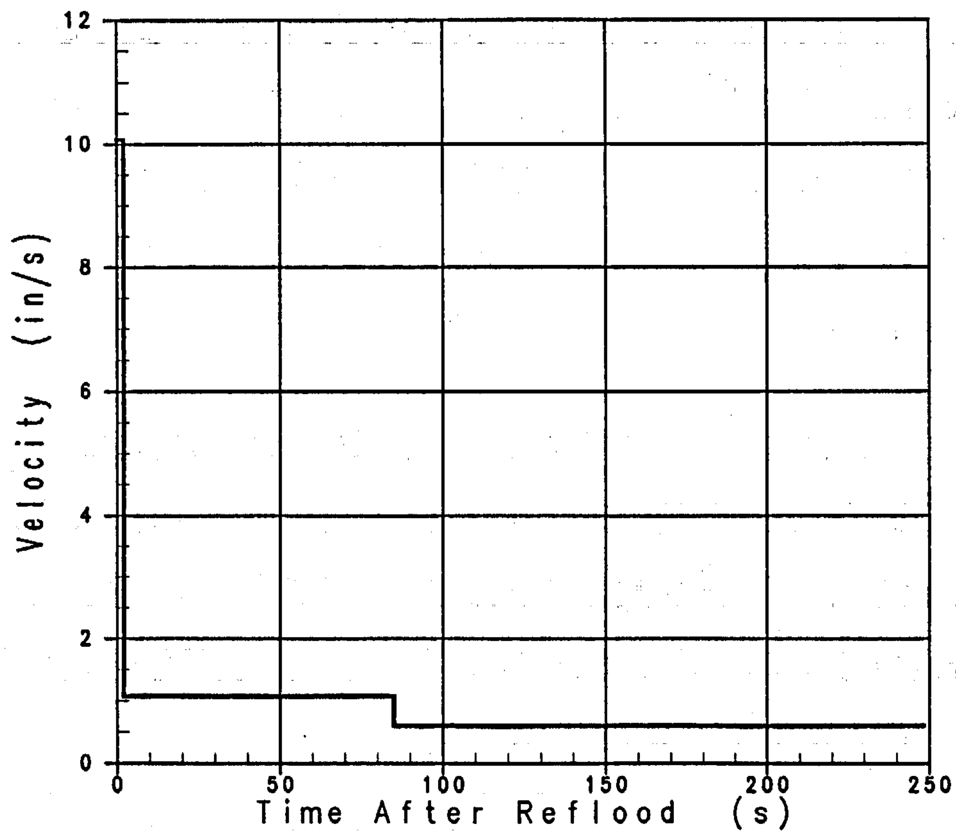


FIGURE 5
SAMPLE BASH-EM CALCULATION
FINAL FLOODING RATE

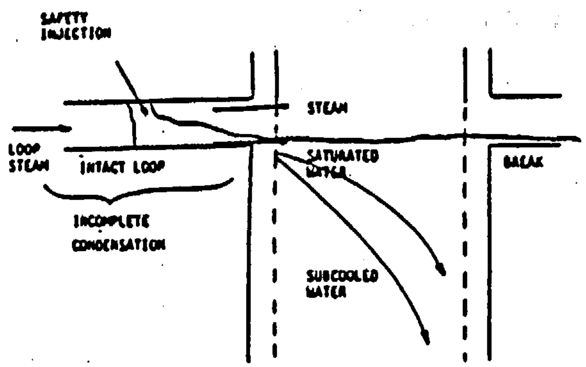


- The downcomer modeling in BASH is illustrated in Figure 6 and consists of a lower liquid volume and an upper vapor volume. These volumes could be made to exchange mass by appropriate correlations but cannot simulate the layer of warmer water at the top of the downcomer or model the buoyancy-driven flows which cause only portions of the downcomer to boil at a time.

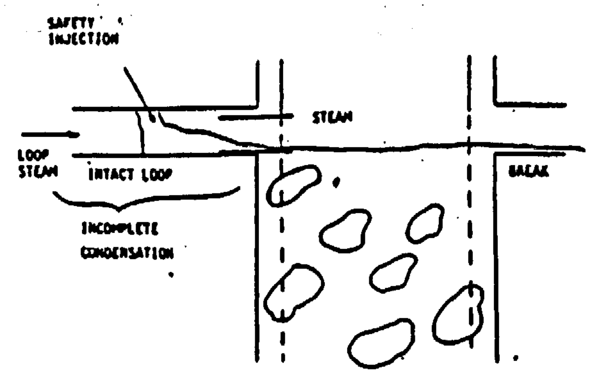
- Due to the complexity of the associated phenomena, an accurate treatment of downcomer boiling and entrainment in a PWR reflood transient requires a level of detail comparable to the two-fluid model that is used in WCOBRA/TRAC.

Figure 6

BASH Model

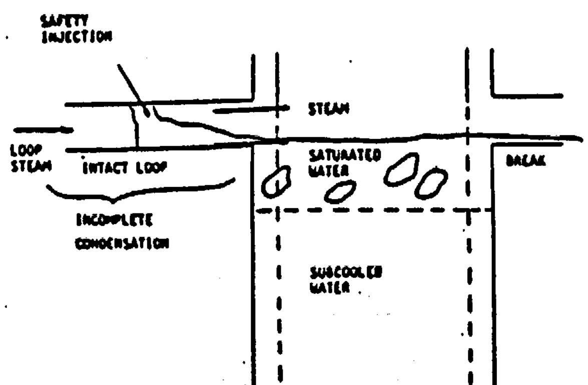


Early Reflood: Complete Mixing Keeps Downcomer Subcooled, but Heats Water More Rapidly

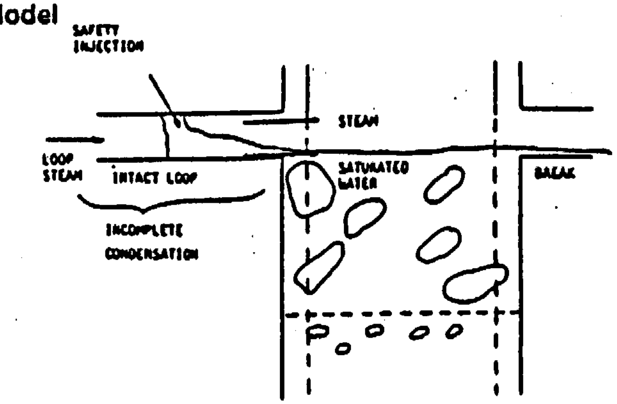


Late Reflood: Entire Downcomer Starts Boiling at Once

Realistic Model



Early Reflood: Warm SI Water Remains on Top, Boils Sooner



Late Reflood: Boiling of Accumulator Water Delayed, Reduced

4. LOCBART Transient Extension

The following example illustrates the application of the LOCBART transient extension method.

1. [

]$^{(a,c)}$

(a,c)

2. [

]$^{(a,c)}$

3. **Compute the resulting void fraction using the Sudo correlation, which can be expressed as:**

$$\alpha = \frac{Y}{AX^{m}}$$

where:

$$X = \left(\frac{\mu_g j_g}{\sigma g_c}\right)\frac{\left(\frac{\mu_f}{\mu_g}\right)^{.82}}{\left(\frac{\rho_f}{\rho_g}\right)^{.2}} \qquad Y = \frac{\left(\frac{\sigma g_c}{\rho_f g D^2}\right)^{.064}}{\left(\frac{\mu_f}{\mu_g}\right)^{.125}}$$

Regime	A	m
$X \le .0005$	.00523	-.704
$.0005 < X \le .004$	.093	-.325
$X > .004$	.54	0

For this example D (downcomer gap width) = 0.8 ft, and [ ][(a,c)].

4. [

]$^{(a,c)}$

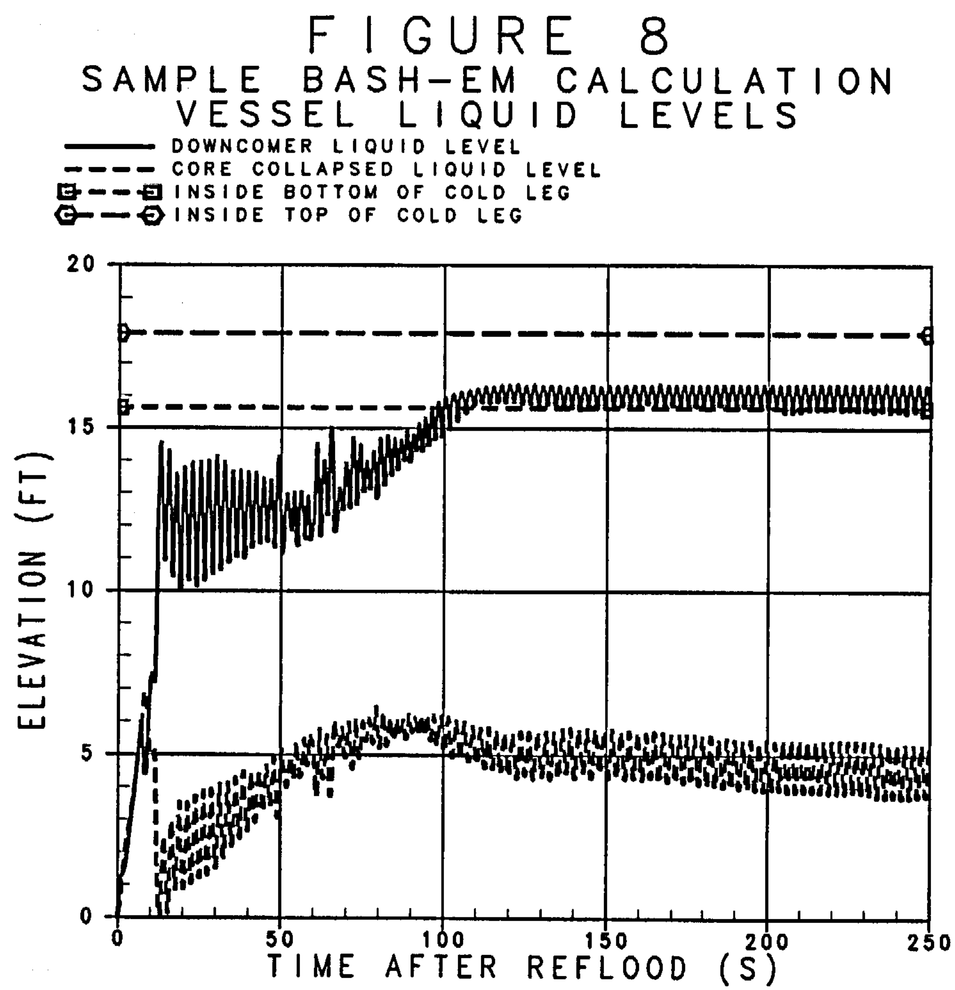


FIGURE 8
SAMPLE BASH-EM CALCULATION
VESSEL LIQUID LEVELS
DOWNCOMER LIQUID LEVEL
CORE COLLAPSED LIQUID LEVEL
INSIDE BOTTOM OF COLD LEG
INSIDE TOP OF COLD LEG
ELEVATION (FT)
TIME AFTER REFLOOD (S)
0
5
10
15
20
0
50
100
150
200
250

5. [

]$^{(a,c)}$

[

]$^{(a,c)}$

(a,c)

5. Expected Effect on Results

For most calculations, it is expected that the PCT that was calculated prior to the onset of downcomer boiling will remain bounding. If not, the cladding temperature transient will already have leveled off sufficiently that any further increase in PCT should be relatively minor.

References

1. "The 1981 Version of the Westinghouse ECCS Evaluation Model Using the BASH Code", WCAP-10266-P-A Revision 2, March 1987.
2. "1999 Annual Notification of Changes to the Westinghouse Small Break LOCA and Large Break LOCA ECCS Evaluation Models, Pursuant to 10 CFR 50.46 (a)(3)(ii)", NSBU-NRC-00-5970, May 2000.
3. "Reactor Safety Issues Resolved by the 2D/3D Program", NUREG/IA-0127, July 1993.
4. "Summary of Results from the UPTF Downcomer Separate Effects Tests, Comparison to Previous Scaled Tests, and Application to U.S. Pressurized Water Reactors", MPR-1163, July 1990.
5. Sudo, Y., "Estimation of Average Void Fraction in Vertical Two-Phase Flow Channel Under Low Liquid Velocity", Journal of Nuclear Science and Technology, 17(1), pp. 1-15, January 1980.
6. "BART-A1: A Computer Code for the Best Estimate Analysis of Reflood Transients", WCAP-9561-P-A, March 1984.