

ANALYSIS OF SMALL BREAKS
IN THE
REACTOR COOLANT PUMP DISCHARGE PIPING
FOR THE
B&W LOWERED LOOP 177 FA PLANTS

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1. Introduction

On April 14, 1978, B&W reported that previous small break analyses had not been based on the worst break location. This report indicated that the worst case break had now been determined to be at the reactor coolant pump discharge. A spectrum of small breaks has been examined for the B&W 177-FA lowered loop plants using the small break evaluation model described in BAW-10104, Rev 3, "B&W's ECCS Evaluation Model." These results show that it is necessary to use operator action during the early stages of the postulated accident, to effectively mitigate the accident consequences and meet the criteria of 10 CFR 50.46. Operator action is used to achieve sufficient and balanced flow through all four HPI injection lines. This report shows that operation up to at least 2568 MWt is possible within the criteria of 10 CFR 50.46 and Appendix K.

2. Evaluation

2.1. Method of Analysis

The analysis method used for this evaluation is that described in Chapter 5 of BAW-10104, Rev 3, "B&W's ECCS Evaluation Model." Specifically, the model, except for break size, break location, and core power, is the same as utilized in Appendix C of BAW-10103A, Rev 3, "ECCS Analysis of B&W's 177-FA Lowered-Loop NSS." The analysis uses the CRAFT2 code to develop the history of the reactor coolant system hydrodynamics. The CRAFT model uses 19 nodes to simulate the reactor coolant system, two nodes for the secondary system, and one node for the reactor building. A schematic diagram of the model is shown in Figure 1 along with the node descriptions. Control volumes (nodes) in and around the vessel are all connected by a pair of flow paths to permit counter-current flow. The break is assumed to be located at the bottom of the cold leg piping between the reactor coolant pump discharge and the reactor vessel. The Wilson, Grenda and Patterson average bubble rise model is used for all nodes. Within the core region, however, a multiplier of 2.38 is applied to the calculated bubble rise velocity.

Appendix F of BAW-10104 demonstrates that a multiplier of 2.38 in CRAFT2 gives a mixture height within $\pm 2\%$ of that predicted by FOAM. Thus, no FOAM analysis will be needed if the CRAFT2 mixture level remains above the core by 2% of the active length.

The following assumptions are made for conditions and system responses during the accident:

- a. The reactor is operating at 102% of the steady-state power level of 2568 MWt. For breaks greater than 0.1 ft, the analysis utilized a power level of 102% of 2772 MWt.
- b. The leak occurs instantaneously, and a discharge coefficient of 1.0 is used for the entire analysis. Bernoulli's equation was used for the subcooled portion of the transient, while Moody's correlation was used in the two-phase portion.
- c. No offsite power is available.
- d. The reactor trips on low pressure at 1900 psia.
- e. The safety rods begin entering the core after a 0.5 second delay from the time the reactor trip signal is reached.
- f. The RC pumps trip and coast down coincident with reactor trip.
- g. One complete train of the emergency safeguards system fails to operate, leaving two CFTs and only one HPI and one LPI system available for pumped injection to mitigate the consequences of a cold leg break.
- h. The auxiliary feedwater (FW) system is assumed to be available during the transient. Its main function is to remove heat from the upper half of the steam generator during the initial stages of the transient. When the secondary side of the steam generator becomes a source of heat to the primary system, the assumption of auxiliary FW maximizes the energy that must be relieved.
- i. ESFAS signal error band is considered in the analysis to signal the actuation of the HPI system.
- j. The peak linear heat generation rate in the hot pin is the maximum allowed by the Technical Specifications at the 10.5 ft level.
- k. Operator action is taken to increase the HPI flows to the intact cold legs at 10 minutes following the ECCS initiation signal. This assumption is explained more fully below and in section 3.

As most of the breaks evaluated in this spectrum showed core uncover, temperature calculations were necessary. Once core uncover occurs a spatial swell distribution analysis is necessary to assure that only the core covered by mixture is included in the swell level. B&W uses the FOAM code. The code was utilized under the same assumptions as described above with the following additions:

1. The power shape shown in Figure 6 was used but implemented with a radial peaking factor of 1.0. This represents the average channel condition which is appropriate for use in swell level calculations.
2. Steam production due to heat from the primary metal, core and lower plenum flashing, was conservatively underpredicted. Although the CRAFT model accurately predicted these effects, full credit was not included in the FOAM simulation as a conservative computational convenience. This simulation, therefore, underpredicts both the swell level and the steaming rate. Consequently, more core uncover and lower coolant flow are used in the heat-up evaluation.

The heat-up calculation was performed using the THETA code in the manner described in section 5 of BAW-10104. The following additional assumptions are utilized in the THETA evaluation:

1. The power shape of Figure 5 was used with a radial power factor of 1.8. This maximizes steam superheating and sets the peak local power at 10.5 ft at the technical specification LOCA limit.
2. Coolant flow and mixture level were taken directly from the FOAM calculations.
3. End of life pin pressures were used to conservatively predict the incidence of fuel pin rupture.

2.2. High Pressure Injection System Performance

The previous arrangement of the HPI system allowed for one pump to inject into the reactor coolant system (RCS) at two locations. As one injection point could be in the region of the break, 50% of the one HPI flow could fail to penetrate the reactor vessel. This flow would, therefore, not be available to provide core cooling. The proposed operator action, section 3, will provide four points of penetration of the RCS. Therefore, only 25% of the HPI flow would be lost.

Since the flow from one HPI pump will now be distributed to four injection points and to assure conservatism in allowing for injection line loss differences, this analysis assumes 30% of the HPI is injected into the broken cold leg. The implemented action starts at 5 minutes after an ECCS signal and is concluded 15 minutes after the signal. The resultant HPI flow can be conservatively represented as a linear ramp from 5 to 15 minutes. This

was simulated in our present CRAFT code as a step function at 650 seconds (600 seconds for action, 50 seconds for ECCS signal). This is illustrated in Figure 7.

2.3. Break Spectrum and Results

All evaluations reported in this analysis assume the high pressure injection performances as described in section 2.2. Breaks of 0.3, 0.2, 0.15, 0.1, 0.07, and 0.04 ft² were evaluated. The evaluation of a 0.5 ft² break was reported in BAW-10103A, Rev 3, and shows complete core coverly at all times and thus no temperature excursion. The 0.5 ft² break results are independent of HPI flow and remain valid.

Figure 2 shows the RCS pressure transient for each break. As shown, each accident initiates CFT flow within 2000 seconds except for the 0.04 ft² break.

Figure 3 shows (CRAFT) mixture height as a function of time for each break of the spectrum. As can be seen, breaks of approximately 0.3 ft² and larger than approximately 0.04 ft² uncover part of the core. Various uncover levels and times are observed but all trends are consistent throughout the spectrum.

The 0.04 ft² break achieves a match up of effective ECCS (the HPI injected into the intact cold legs) with the core decay heat and the RCS metal heat at 2500 seconds. After 2500 seconds the mixture level will rise in the core due to excess HPI injection. As the 0.04 ft² break has a level of 14 feet at this time the core never uncovers and no temperature excursion occurs. For breaks smaller than 0.04, the match up will occur at approximately the same time and the core mixture levels will drop slower; thus, for all smaller breaks the core will remain covered.

Figure 4 shows the time duration of uncoverly for four core elevations as a function of break size. These results are from CRAFT. As can be seen, the maximum degree of uncoverly and the maximum time of uncoverly occur for the 0.15 ft² break and is the worst case break. This break can thus be identified as the worst case. A similar uncoverly occurs for the 0.1 and 0.07 ft² breaks. The 0.07, 0.10, and 0.15 ft² breaks were analyzed for temperature response. The results are shown in Figure 5 and are well within the criteria of 10 CFR 50.46. They provide positive assurance that all breaks of the spectrum are within acceptance criteria.

The 0.2 ft² break was not evaluated for three reasons:

1. The uncover time is approximately 2/3 of that for the 0.15 ft² break.
2. The depth of uncover is only 1/2 of that for the 0.15 ft² break. The minimum core level is only 11 feet as compared to 10 feet for the 0.15 ft² break.
3. The decay heat rate will be approximately the same as for the 0.15 ft² break.

Thus, the 0.2 ft² case is well bounded by the 0.15 ft² case.

Local metal water reaction is shown below the temperature curves on Figure 5. The highest value is 2.8% for the 0.15 ft² break. This value is well below the local oxidation limit for the large breaks utilized in BAW-10103 for the whole-core metal-water reaction calculation. Thus, the whole-core metal-water reaction results given in section 8 of BAW-10103 is conservative for small breaks. The degree of clad damage is bounded by the large break results which produce higher clad temperatures. Thus, all criteria of 10 CFR 50.46 are met. This analysis is conservative for many reasons as detailed in the write-up and meets all evaluation criteria. This analysis shows that all 177 lowered loop plants meet the criteria of 10 CFR 50.46 if operated at or below 2568 Mwt power and in conjunction with the specified operator action.

3. Operator Action

The ECCS analysis used as a basis for this report assumes that the operative HPI train (one train is lost due to a single active failure) provides emergency core cooling water to the RC loop containing the break. It is conservatively assumed that the break is on the lower portion of the reactor coolant pump discharge piping resulting in the total loss to the system of 50% of the available HPI flow. Acceptable mitigation of the accident requires more than the 50 % of this flow from one HPI pump. If, following the LOCA, it is assumed that one train of HPI does not start it is necessary to take operator action to achieve a flow split wherein no more than 30% of the remaining pump's flow goes into the cold leg containing the break. The following is a description of the action required for a typical plant.

1. Upon ESFAS signal check for flow through both HPI trains.

2. If no flow in one train:
 - open pump header cross-connect valves
 - check HPI valve position and open if closed
3. Secure flow through normal makeup line if flow is indicated
4. Throttle HPI valves as required to balance flow and meet run out limits

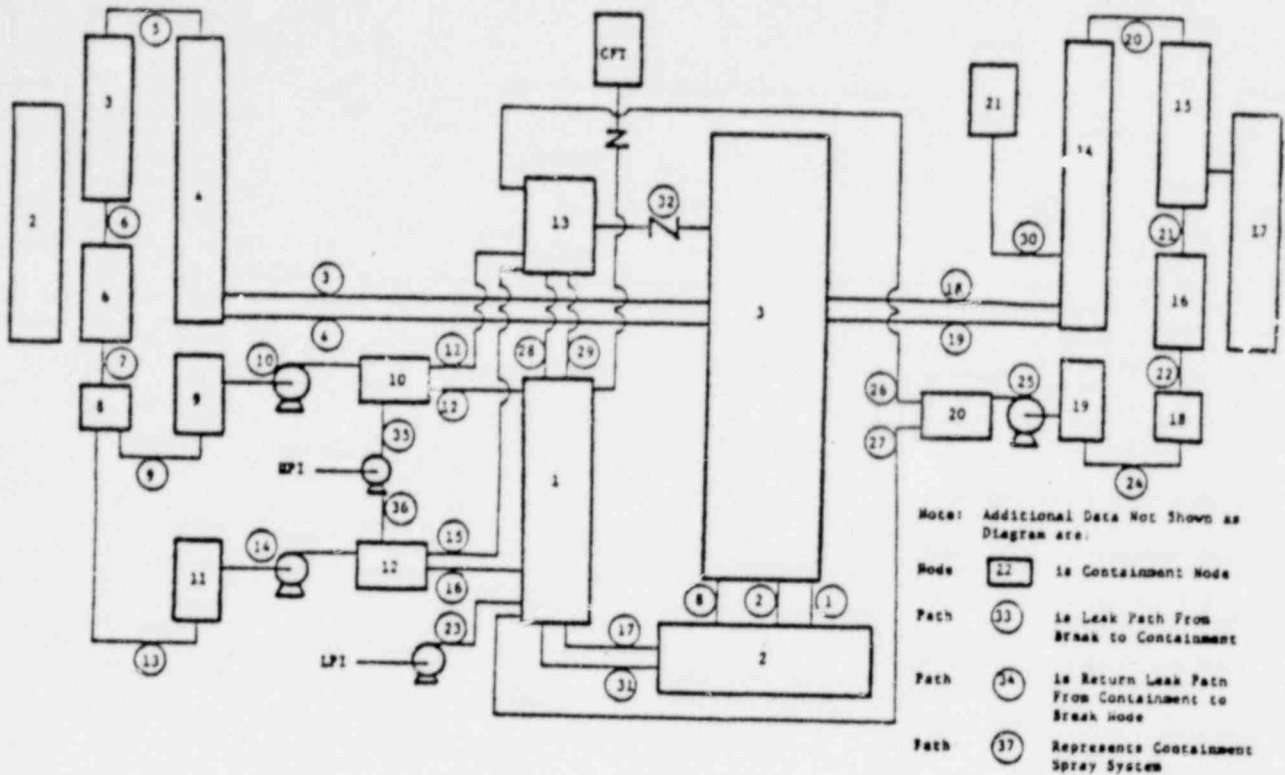
The above actions initiated at five minutes and completed within 15 minutes subsequent to the ESFAS actuation ensures adequate HPI flow for accident mitigation. In the analysis, credit is taken for the HPI flow as the HPI injection valves are opened. Figure 7 shows the calculated HPI flow for a typical plant as a function of time for a 10 minute valve opening. As shown in Figure 7, the majority of the HPI pump capacity would be delivered with a partial valve opening. For the small break analysis, a linear flow versus valve position response was simulated by a step function increase, 10 minutes after ESFAS actuation.

4. Evaluation of Other B&W Supplied Plants

- a. Davis-Besse - The DB-1, 2 and 3 Plants have been analyzed for a spectrum of small breaks at the RCP discharge in accordance with an approved small break evaluation model. This analysis is reported in BAW-10075A, Rev 1, March 1976. In addition, the Davis-Besse 1, 2, and 3 units have a split high pressure injection and makeup system design. The Davis-Besse HPI pumps, therefore, have considerably higher capacity at the system pressures experienced.
- b. 205 and 145 FA - These plants have been analyzed for a spectrum of small breaks at the RCP discharge in accordance with an approved small break evaluation model. These analyses are reported in BAW-10074A, Rev 1, and BAW-10062A, Rev 1, March 1976. In addition, the 205 and 145 FA HPI systems contain cross connects between the two HPI trains downstream of the HPI injection valves. These cross connects effectively achieve the same flow split as the operator action assumed in the current 177 FA lowered loop analysis and the flow split is achieved when the HPI pump is started.

c. All B&W supplied plants except the 177 FA lowered loop plants have raised loops and thus do not trap a large volume of coolant in the cold leg. The raised loop design allows this coolant to drain into the core for core covering and cooling by boiloff.

Figure -1. CRAFT2 Noding Diagram for Small Break



| Node No. | Identification | Path No. | Identification |
|----------|---|-------------------|-------------------------|
| 1 | Downcomer | 1,2 | Core |
| 2 | Lower Plenum | 3,4,18,19 | Hot Leg Piping |
| 3 | Core, Core Bypass, Upper Plenum, Upper Head | 5,20 | Hot Leg, Upper SG Tubes |
| 4,14 | Hot Leg Piping | 6,21 | SG Lower Head |
| 5,15 | Steam Generator Upper Head, SG Tubes (Upper Half) | 7,22 | SG Lower Head |
| 6,16 | SG Tubes (Lower Half) | 8 | Core Bypass |
| 8,18 | SG Lower Head | 9,13,24 | Cold Leg Piping |
| 9,11,19 | Cold Leg Piping (Pump Suction) | 10,14,25 | Pumps |
| 10,12,20 | Cold Leg Piping (Pump Discharge) | 11,12,15,16,26,27 | Cold Leg Piping |
| 1 | Upper Downcomer (Above the G of Nozzle Belt) | 17,31 | Downcomer |
| 21 | Pressurizer | 23 | LPI |
| 22 | Containment | 28,29 | Upper Downcomer |
| | | 30 | Pressurizer |
| | | 32 | Vent Valve |
| | | 33,34 | Leak & Return Path |
| | | 35,36 | HPI |
| | | 37 | Containment Sprays |

FIGURE 2. PRESSURE

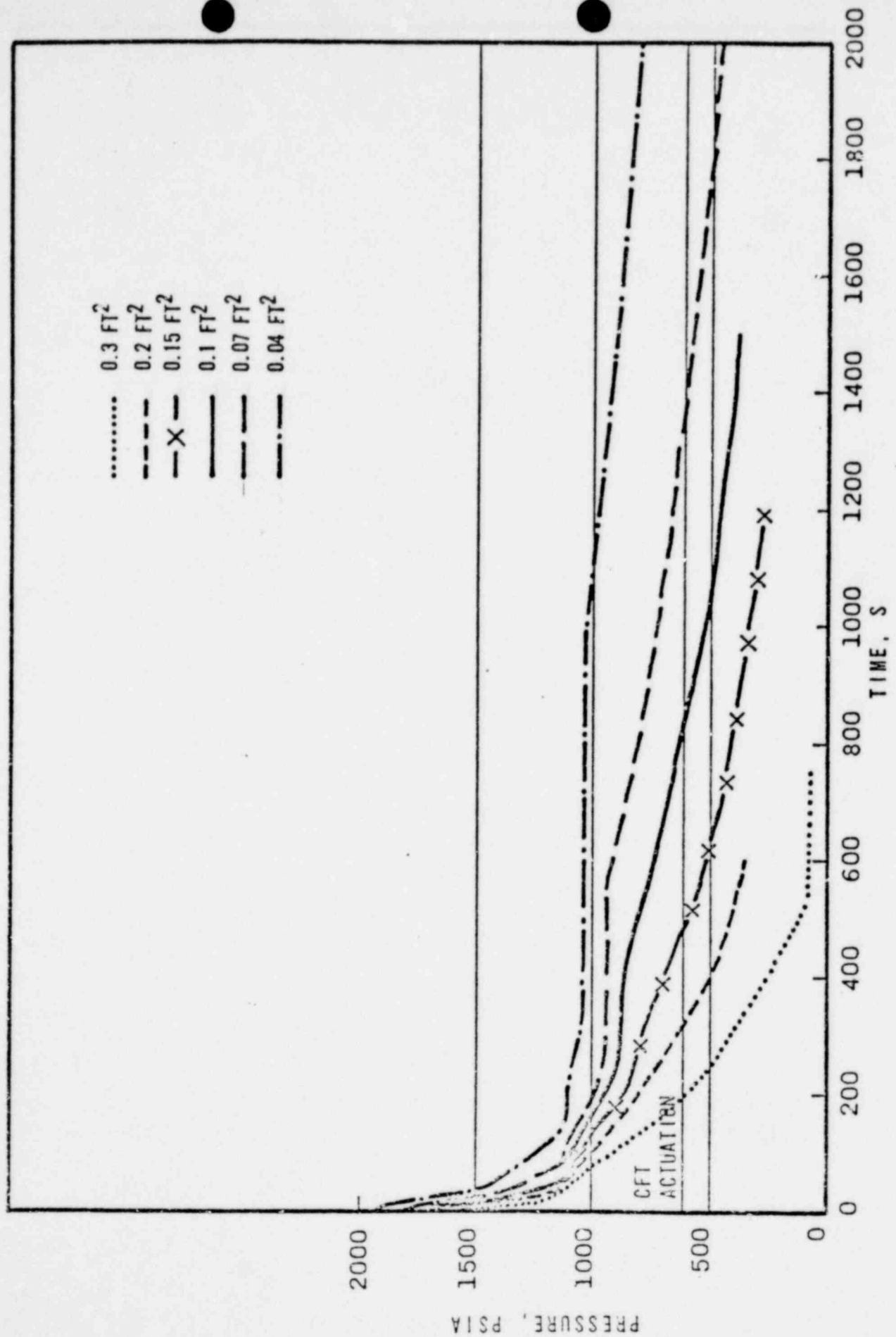
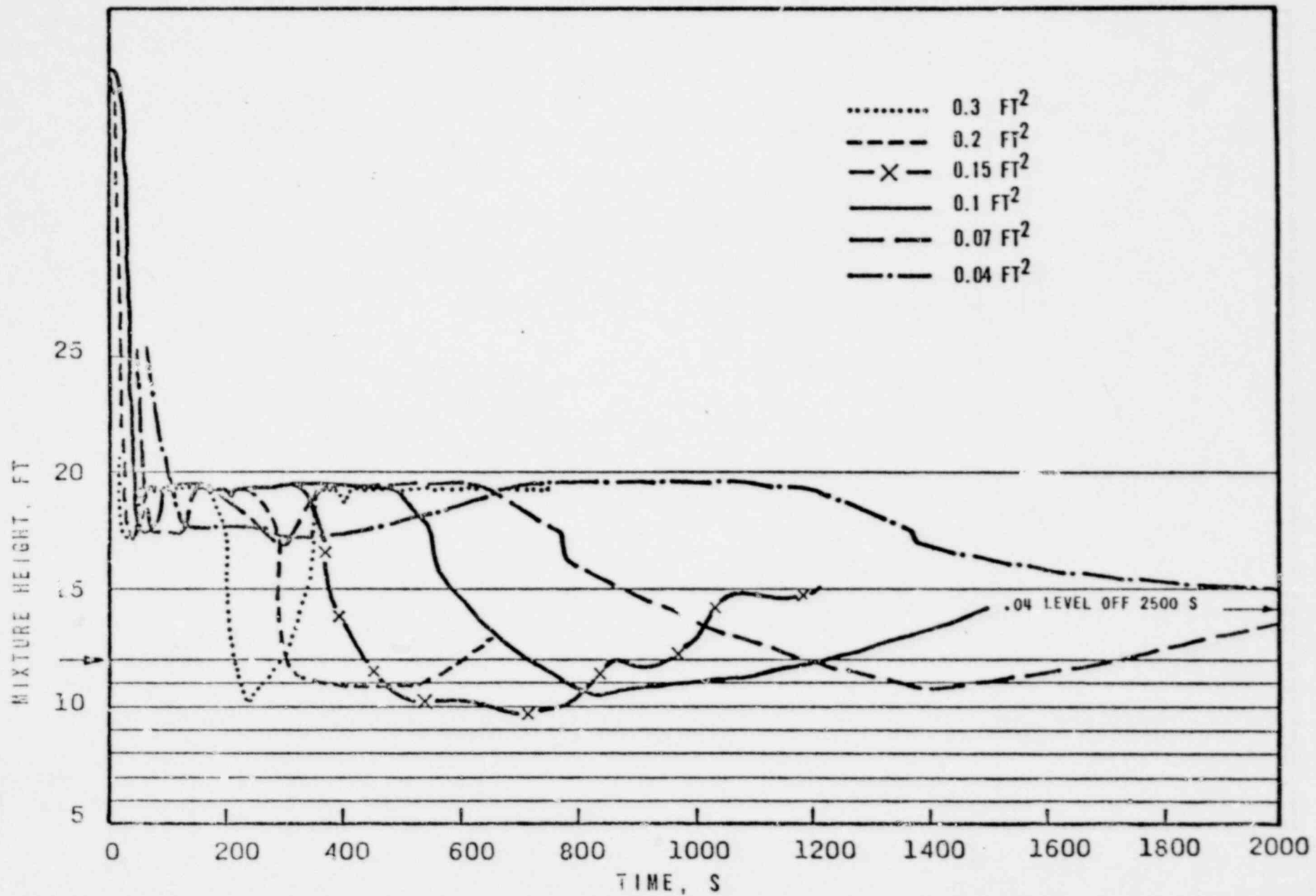
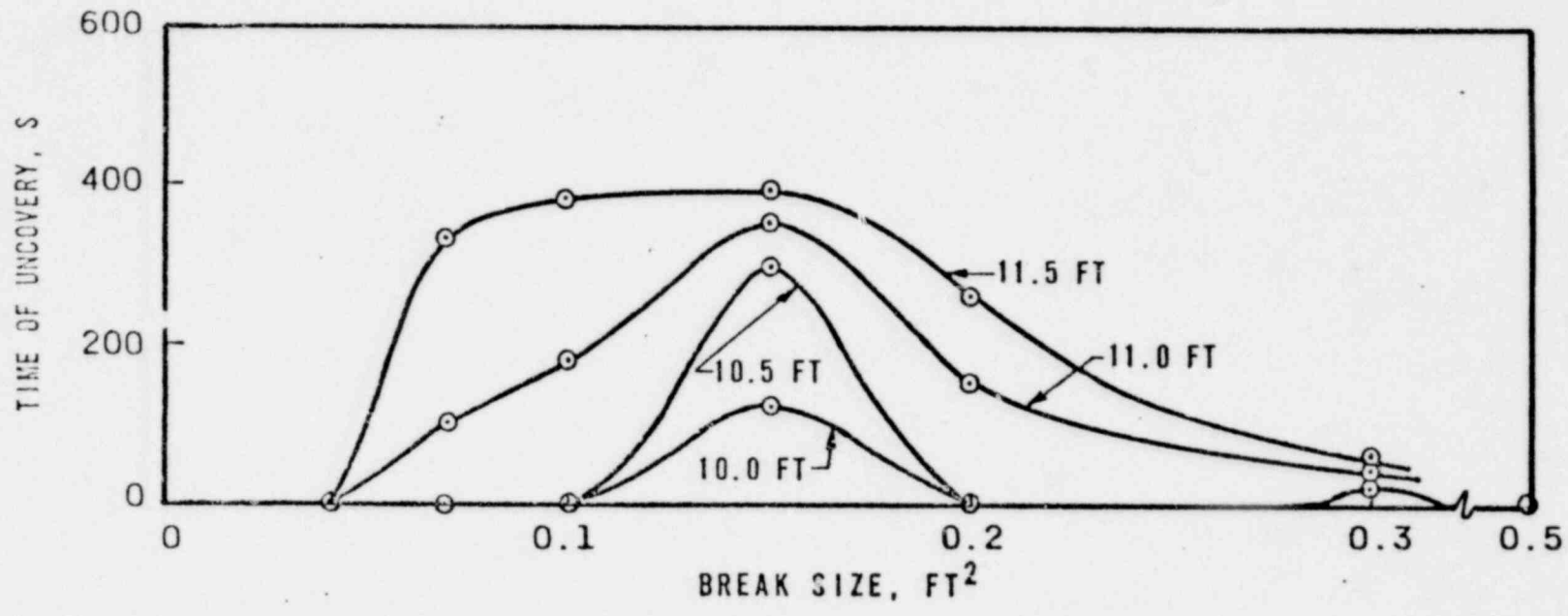


FIGURE 3. CORE MIXTURE HEIGHT
(CRAFT)



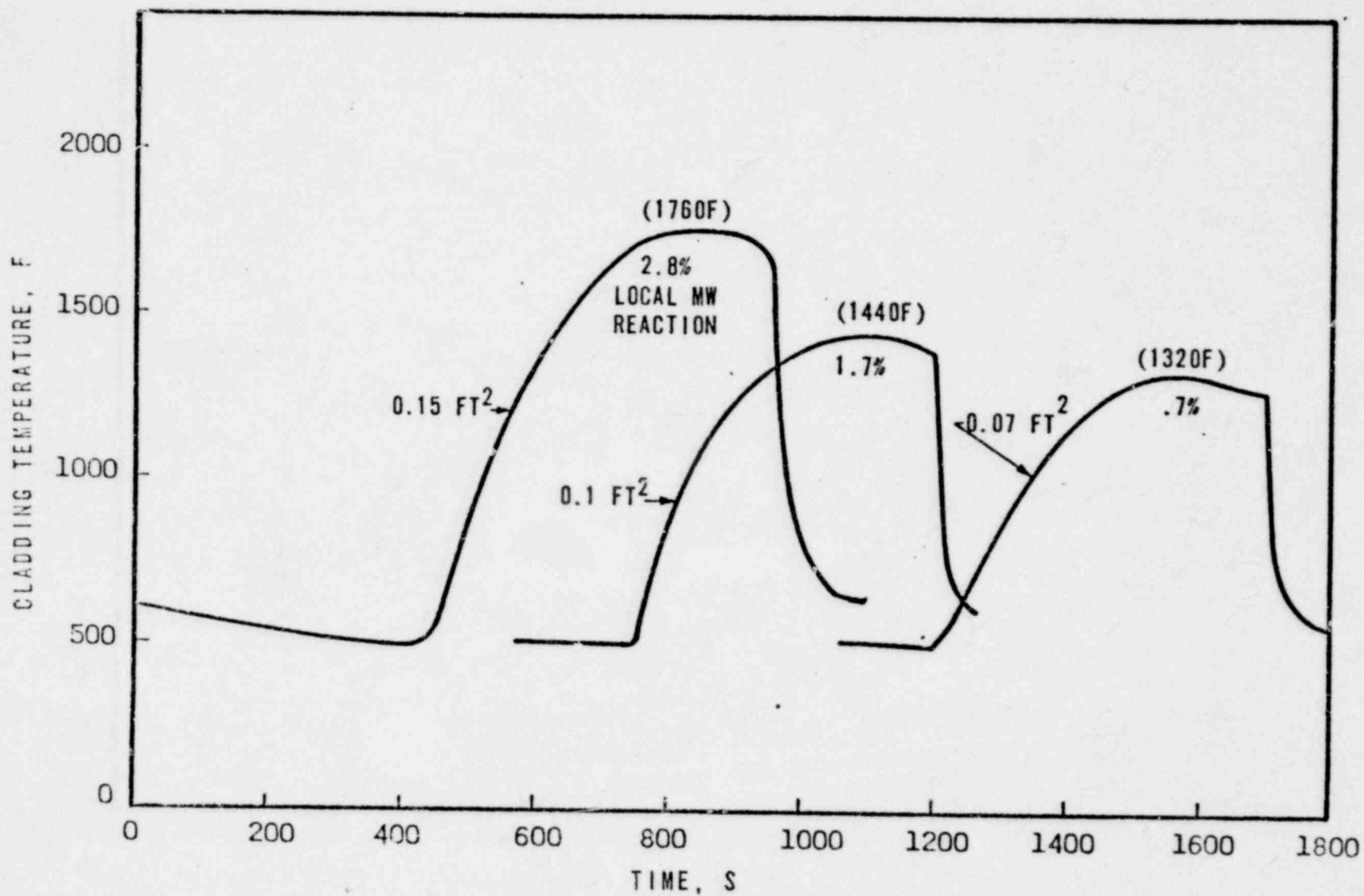
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FIGURE 4. CORE UNCOVERY TIMES VERSUS BREAK SIZES



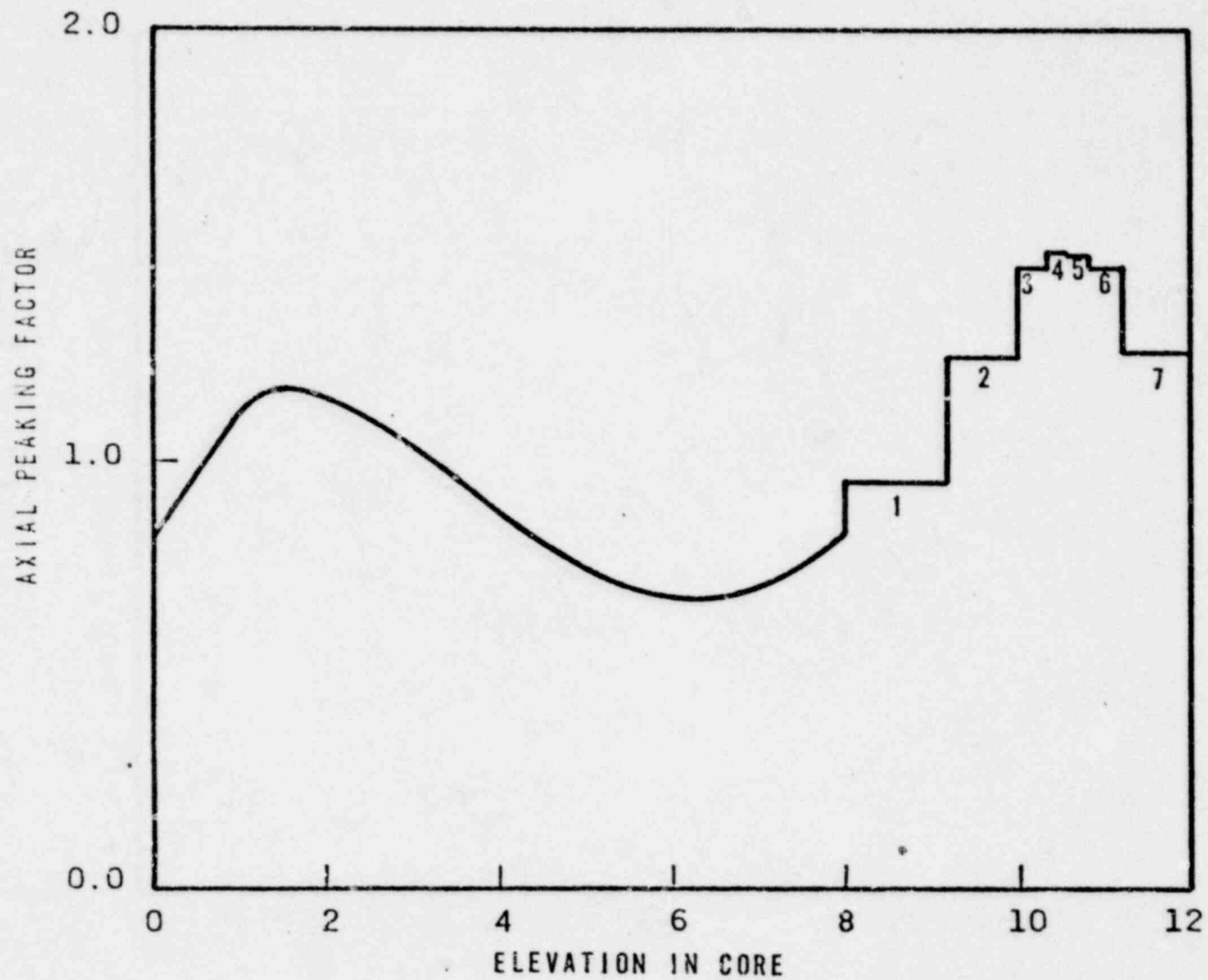
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FIGURE 5. PEAK CLADDING TEMPERATURE



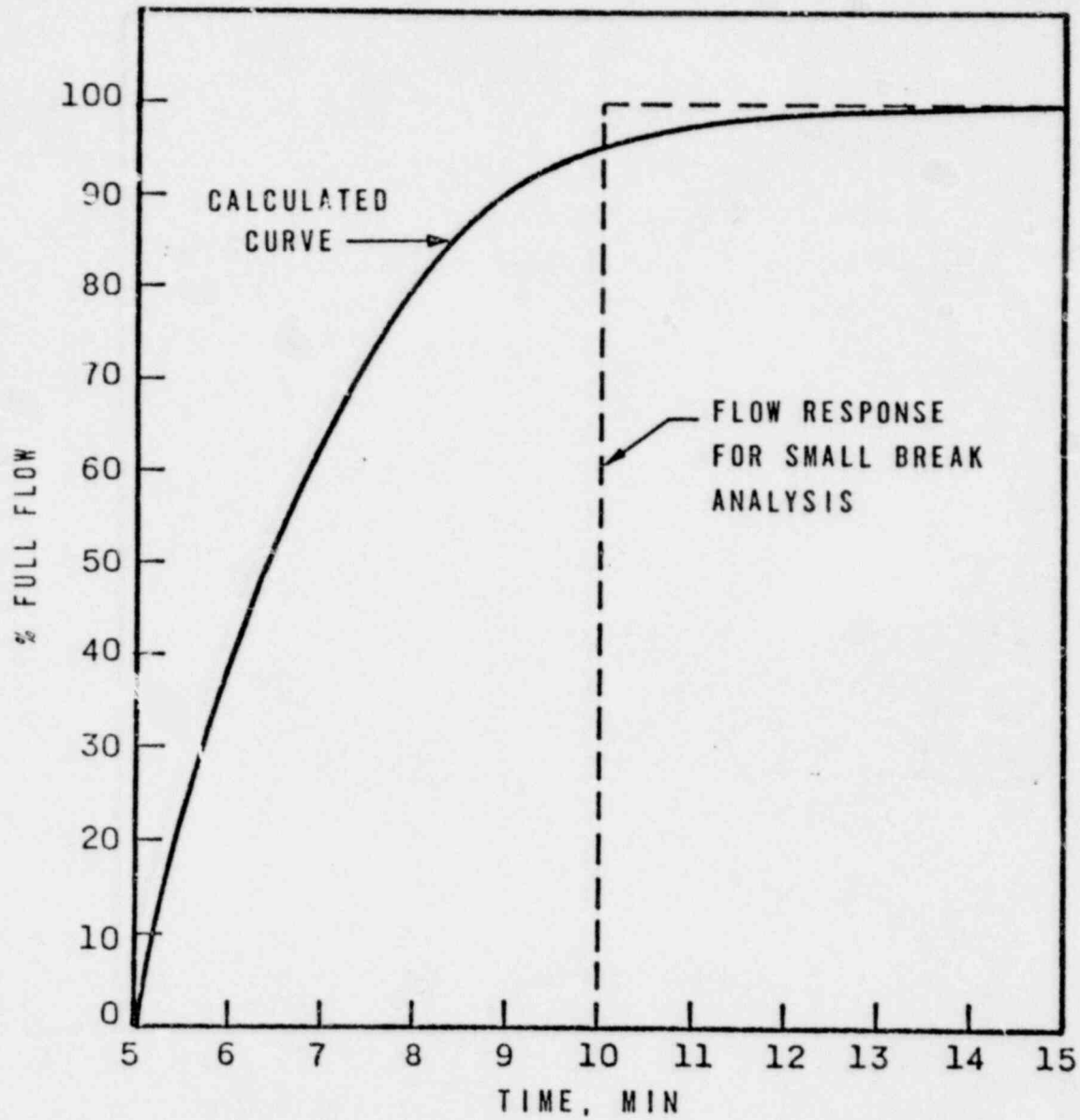
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FIGURE 6. AXIAL POWER SHAPE



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FIGURE 7. FLOW VS VALVE POSITION
(Based on Actual C_v VS Valve
Position for Ocone HPI Valves)



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