ATTACHMENT I

INEL
Idaho National Engineering Laboratory

March 11, 1992

Dr. Joram Hopenfeld
U.S. Nuclear Regulatory Commission
Washington, DC 20555

DRAFT RESULTS OF STEAM GENERATOR TUBE RUPTURES CONCURRENT WITH STEAM LINE BREAK OUTSIDE CONTAINMENT CALCULATIONS - LWW-05-92

Dear Dr. Hopenfeld:

The attached report prepared by C. Heath summarizes the results of the calculations performed as you requested to determine the expected behavior of a Westinghouse RESAR III plant after a steam line break concurrent with a steam generator tube rupture. The calculations performed led to prediction of refueling water storage tank depletion (RWST) in a period of three to eight and a half hours depending on the number of tubes ruptured. It should be emphasized that the time to exhaust the RWST could vary substantially due to operator action, thus the predicted times are not absolute and are useful as scoping calculations only.

Please note an NPA mask was developed as part of the analysis should you desire to see the results displayed on the DEC 5000. Also, I have included, as a second attachment, a copy of the critical flow equations we discussed. If you have any additional questions or comments please call me at 492-3688 or Chris Heath at 492-3691.

Sincerely,

Dr. Leonard L. Ward
INEL Program Manager
for NRR Projects

Enclosures:
As Stated

cc: P. Norian
G. Berna (EG&G Idaho, Inc.)

9212040339 921124
PDR ADOCK 05000344
P PDR

Attachment 1

STEAM GENERATOR TUBE RUPTURE CONCURRENT WITH STEAM LINE BREAK OUTSIDE CONTAINMENT

Prepared by: C. Heath

INTRODUCTION

At the request of Dr. Joram Hopenfeld of the USNRC, Office of Research, scoping calculations were performed for a double-ended rupture of a main steam line, outside of the containment, concurrent with multiple failures of steam generator tubes. The failed steam generator tube break areas evaluated in this study included sizes equivalent to 1, 2.5, and 5 double-ended guillotine ruptures. A RESAR III Nuclear Steam Supply System model was used for the evaluation.

The results of these calculations show that without operator intervention, a steam line break, outside of the containment, concurrent with the double-ended rupture of a single steam generator tube in the failed generator results in depletion of the refueling water storage tank (RWST) in 8.5 hours. The double-ended rupture of five steam generator tubes results in exhaustion of the RWST inventory in about three hours. With operator action to throttle Emergency Core Cooling System (ECCS) injection flow, exhaustion of the RWST with five failed tubes is delayed to 7.7 hours. While operator actions can significantly delay exhaustion of the RWST, timely accident management strategies such as those to replenish the RWST with borated water would be needed to prevent the accident from progressing to a core melt. Because the secondary pressure of the failed steam generator decreases to near atmospheric conditions due to the large steam line rupture, operator actions to reduce reactor coolant system (RCS) pressure to a value below that of the failed steam generator secondary (to terminate the RCS break flow) may not be timely enough to prevent exhaustion of the RWST.

The results of the scoping calculations are discussed below.

DISCUSSION

The SCDAP5/RELAP5/MOD3 code, version 7(o), was used in the calculations. The calculations were performed on a DEC 5000 computer for a four loop RESAR III PWR at a thermal power of 3400 MW_t. The RELAP5/MOD3 nodalization diagram is presented in Figure 1. The model consists of two separate loops. The single loop contains the failed steam generator with the broken steam line and failed steam generator tubes while the other loop combines the three remaining loops. The calculations were carried out to one hour into the event at which time the primary and secondary pressure responses achieved a near quasi-steady state condition.

Three steam generator tube failure cases were evaluated consisting of break areas equivalent of 1, 2.5, and 5 double ended guillotine ruptures. The main steam line break size included a double-ended guillotine failure, outside of the containment, with an area of 4.9 ft^2. With a steam line break outside of the

containment concurrent with a multiple failure of the steam generator tubes, exhaustion of the RWST inventory can potentially occur which could lead to a possible core melt. With the break located outside of the containment, exhaustion of the RWST cannot be followed by a switch in ECC alignment to the recirculation mode of cooling. From an accident management perspective, the time to exhaust the RWST inventory is therefore of particular interest since in the event of no additional actions, core uncovery and melt could occur.

Table 1 presents a summary of the results of the scoping calculations. The time to exhaust the RWST inventory for the three steam generator tube rupture sizes varies from 8.5 hours for one failed tube to 3.1 hours for five failed tubes. For illustrative purposes, no operator actions were assumed for these first three cases.

In estimating the time to exhaust the RWST, the capacity of the tank was assumed to be 350,000 gallons, which is approximately the minimum allowable technical specification value. Clearly, any additional borated water would lengthen the amount of time to drain the RWST. Also, the time to exhaust the RWST is based on the injection flow at one hour into the event, which consisted of high pressure safety injection and charging flow. Low pressure safety injection was never initiated in our calculations and the safety injection tank (SIT) contributions were insignificant by this time for all cases. While RCS and secondary pressure has stabilized at this time, use of the injection or break flow at one hour results in minimizing the drain time for the RWST since break flow is expected to decrease during the latter portion of the events. Since decay heat generation decreases with time, the operator could continue to throttle ECC flow to minimize RCS pressure and the resulting break flow, while maintaining a minimum of subcooling.

The last case presented in Table 1 shows the effect of the operator actions to delay drainage of the RWST. These actions included throttling the ECC flow to maintain a minimum of subcooling in the RCS, while cooldown of the RCS by opening the atmospheric dump values (ADVs) in the intact steam generators was also initiated. As mentioned earlier, with the double-ended steam line break, cooldown of the RCS with the objective of reducing RCS pressure below that of the broken steam generator requires many hours since the failed steam generator depressurizes to very low values early in the event. Table 1 shows that throttling ECC flow to maintain a minimum of subcooling results in delaying exhaustion of the RWST from 3.1 to approximately 7.7 hours after initiation of the event.

All the cases were run for six seconds at full power to reach equilibrium throughout the system and then the breaks were opened and the reactor was scrammed. The results from the final case of Table 1 which included operator action are discussed in the following paragraphs in detail. The results for the cases involving the rupture of 1, 2.5, and 5 tubes are phenomenologically similar and are included in Appendices A, B, and C to this report. A summary of the assumptions and initial conditions for these scoping calculations are provided in Table 2.

Figures 2 through 6 present the calculation results of the main steam line rupture concurrent with five failed steam generator tubes for the operator action case. Figure 2 presents the RCS and failed secondary steam generator pressure responses. Because of the large steam line break size, the failed steam

generator depressurizes rapidly to near atmospheric conditions. As a consequence of the rapid cooldown of the failed steam generator, the RCS also experiences an initial rapid cooldown, which stabilizes due to the activation of the ECCS early in the event. The sudden decrease in RCS pressure at about 750 seconds in Figure 2 is due to the SIT discharge which condensed the steam and collapsed the voids which developed during the initial portion of the transient. The condensation caused the RCS to depressurize, increasing the SIT flow and further reducing the saturation temperature and hence RCS pressure. Continued ECC flow then pressurized the RCS to the condition where break flow equaled the ECC injection flow which occurred at about 750 seconds. At about 1000 seconds, operator action was initiated to throttle the ECCS, reducing RCS pressure during the latter portion of the event as shown in Figure 2. Note that without operator action to throttle ECC flow, the RCS pressure will remain at significantly higher pressures as shown in Figure C1 of Appendix C.

The ECC injection and rupture steam generator tube mass flow rates are given in Figure 3. The mass flow rate through the failed steam line is given in Figure 4. Using the ruptured tube break flow rate of about 105 lb/s from Figure 3 at 3600 seconds, the RWST is estimated to drain in about 7.7 hours. The ECC flow, shown in Figure 3, temporarily decreased at about 3300 seconds into the transient as a result of the emptying of the SITs. Although the ECC pumped injection flow is lower than the break flow at the end of the transient shown in Figure 3, pumped ECC flow would be increased at this time to maintain RCS subcooling and an RCS pressure of approximately 160 psia.

Figure 5 presents the primary and intact secondary temperature responses and shows that RCS temperature has stabilized after one hour into the event. The failed steam generator temperature transient is given in Figure 6.

It is important to note that there is a flow restrictor in each steam generator at the entrance of the steam line which is designed for a 2.75 psi pressure drop at a flow of 1051 lb/s. This restrictor had little or no impact on limiting the break flow through the broken steam line for the conditions calculated.

It should be recognized that other strategies or actions may be successful in further delaying exhaustion of the RWST or terminating the break flow through the failed steam generator tubes. It should also be emphasized that break flow and hence ECC flow can vary significantly depending on the operator throttling actions to achieve the degree of desired subcooling. As a consequence, the time to exhaust the RWST can also vary significantly. The significance of the calculations should not emphasize the exact times for exhausting the RWST, but that operator actions can extend the time to drain the RWST. Other strategies that may be considered could include:

1. Opening the PORVs early in the event to establish sufficient inventory in the sump to initiate ECC recirculation.

2. Activate Residual Heat Removal and attempt to establish mid-loop operation to terminate the loss of RCS liquid through the break in the steam generator tubes.

3. Replenish the RWST inventory with borated water at a rate greater that the ECC injection rate.

CONCLUSION

A double-ended steam line break outside of the containment concurrent with five failed steam generator tubes results in exhausting the RWST in about three hours without operator action. With operator action to throttle ECC flow, the exhaustion of the RWST is delayed until about eight hours after opening of the break. Because the break is located outside the containment, the eventual loss of the RWST inventory will lead to a core melt since there will be no coolant in the containment sump to initiate the ECC recirculation mode of cooling.

The importance of these results are that operator actions can successfully delay exhaustion of the RWST. However, to prevent a core melt additional accident management actions during the long term would be needed to terminate the break flow or identify alternate sources of ECC injection water.

Figure 1. RELAP5 NODALIZATION DIAGRAM FOR SEABROOK

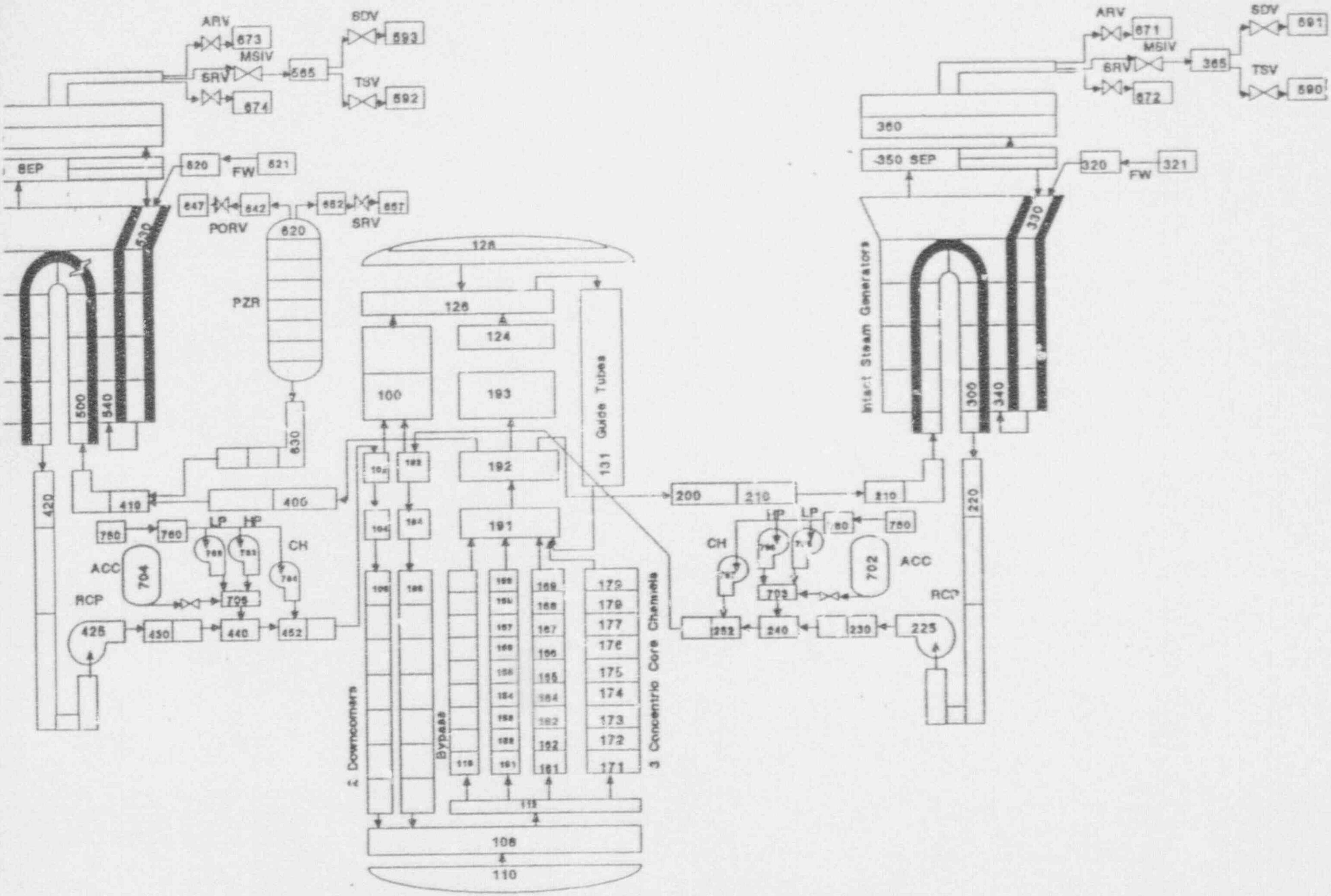


TABLE 1

TIME TO EXHAUST THE RWST FOR A STEAM LINE BREAK CONCURRENT WITH STEAM GENERATOR TUBE FAILURES

# D.E.G S.G. TUBES	TUBE BREAK AREA (ft^2)	M.S.L. BREAK AREA (ft^2)	OPERATOR ACTIONS	TUBE BREAK FLOW[1] (lb/s)	HOURS TO EMPTY RWST	FIGURES
1	0.004	4.9	None	83	8.5	Appendix A
2.5	0.010	4.9	None	155	4.1	Appendix B
5	0.020	4.9	None	200	3.1	Appendix C
5	0.020	4.9	Opened intact steam generator ADVs, throttled charging pumps, and terminated HPSI and LPSI after 18 minutes.	105	7.7	2 - 6

1 The steam generator tube break flow rate is based on the value at 3600 seconds.

TABLE 2

CALCULATION INITIAL CONDITIONS AND ASSUMPTIONS

1 Simultaneous break in main steam line and rupture in steam generator tubes.

2 Instantaneous scram of reactor coincident with break initiation.

3 Intact steam generators isolated.

4 All ECCS consisting of HPSI, LPSI, and [illegible]T, as well as charging pumps actuated.

5 Time to exhaust RWST based on break flows one hour after break.

6 No operator action (except for last case)

Figure 2. Primary and Broken Secondary Pressures, 5 DEG, Operator Action

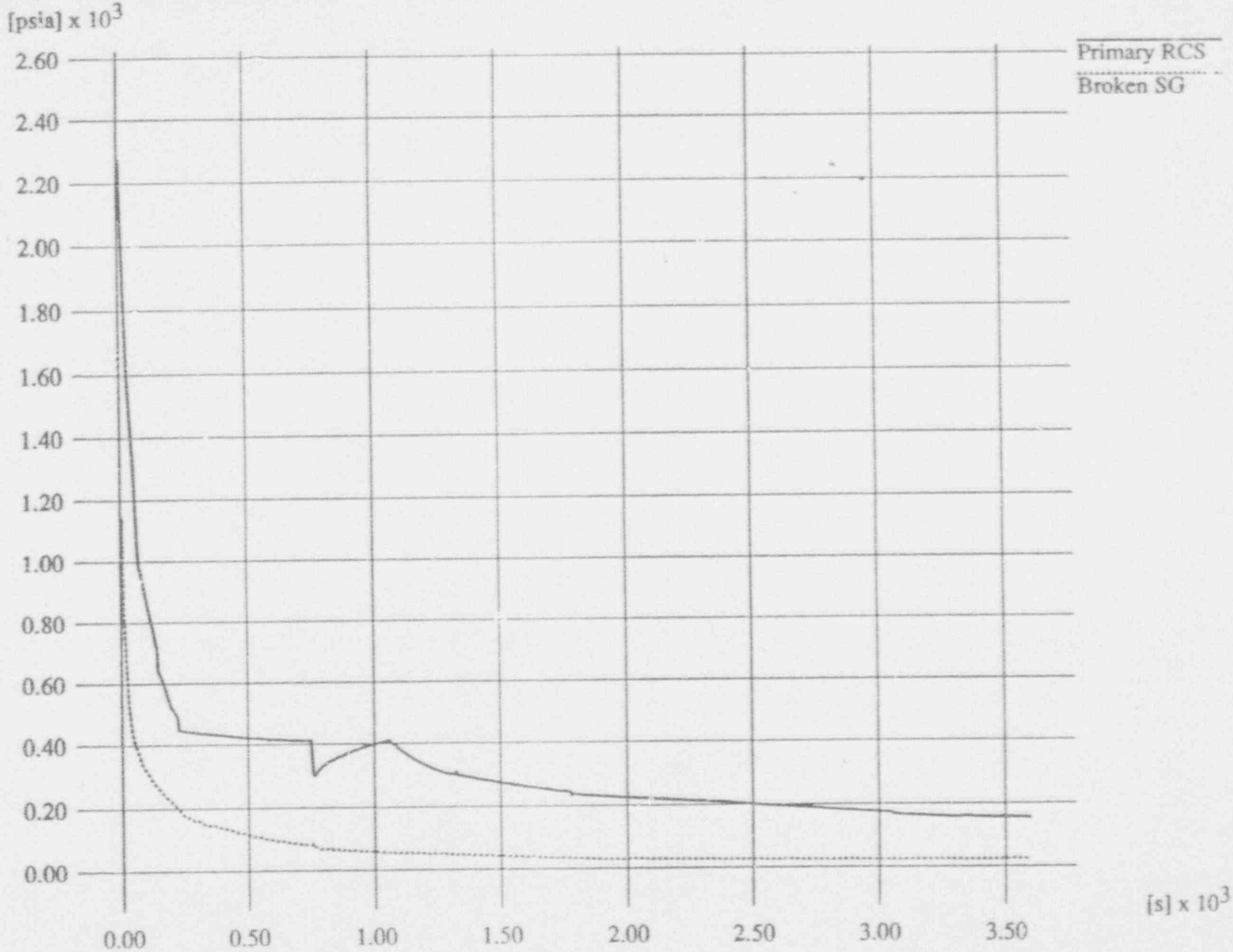


Figure 3. Steam Generator Break and ECCS Flows, 5 DEG, Operator Action

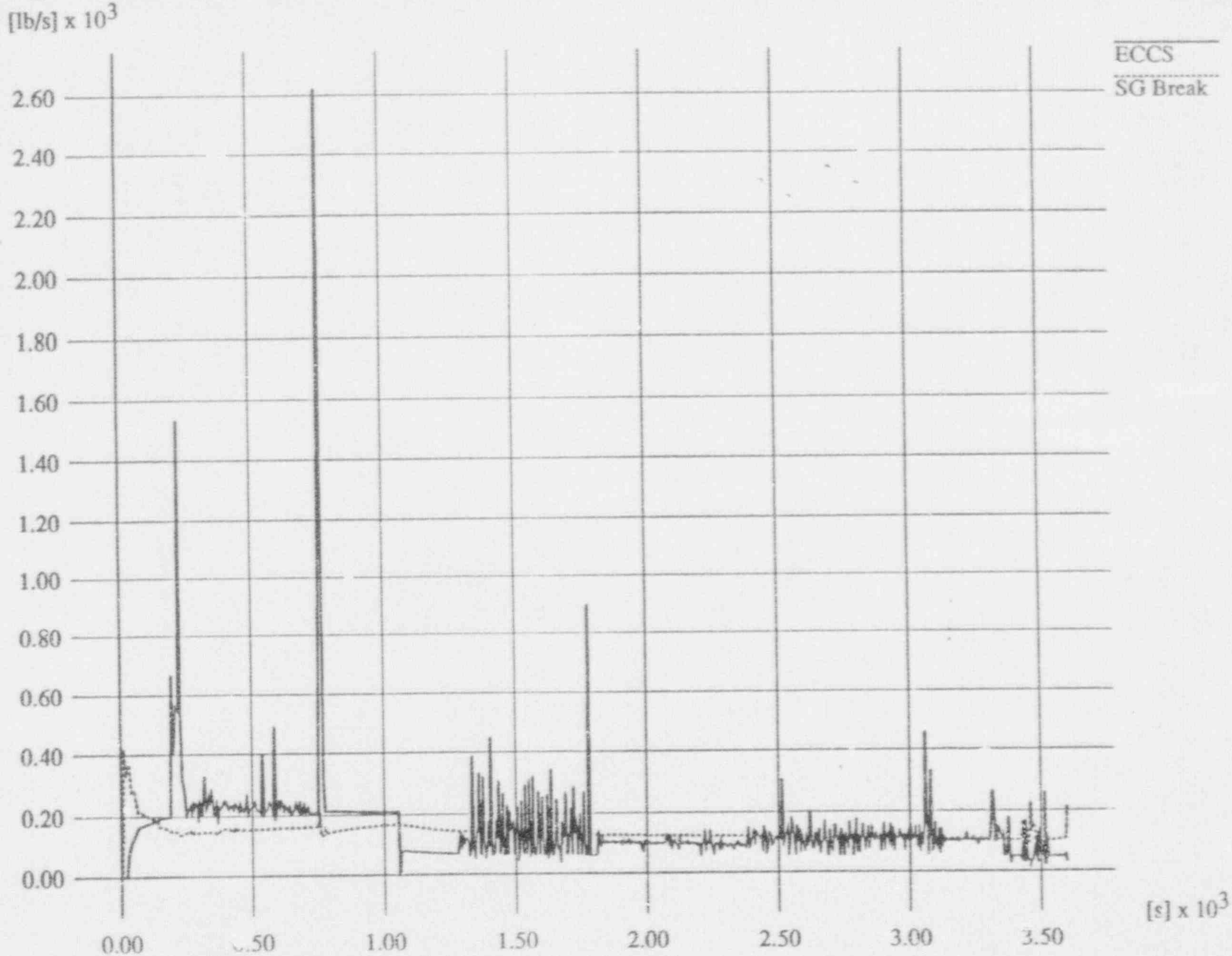


Figure 4. Main Steam Line Break Flow, 5 DEG, Operator Action

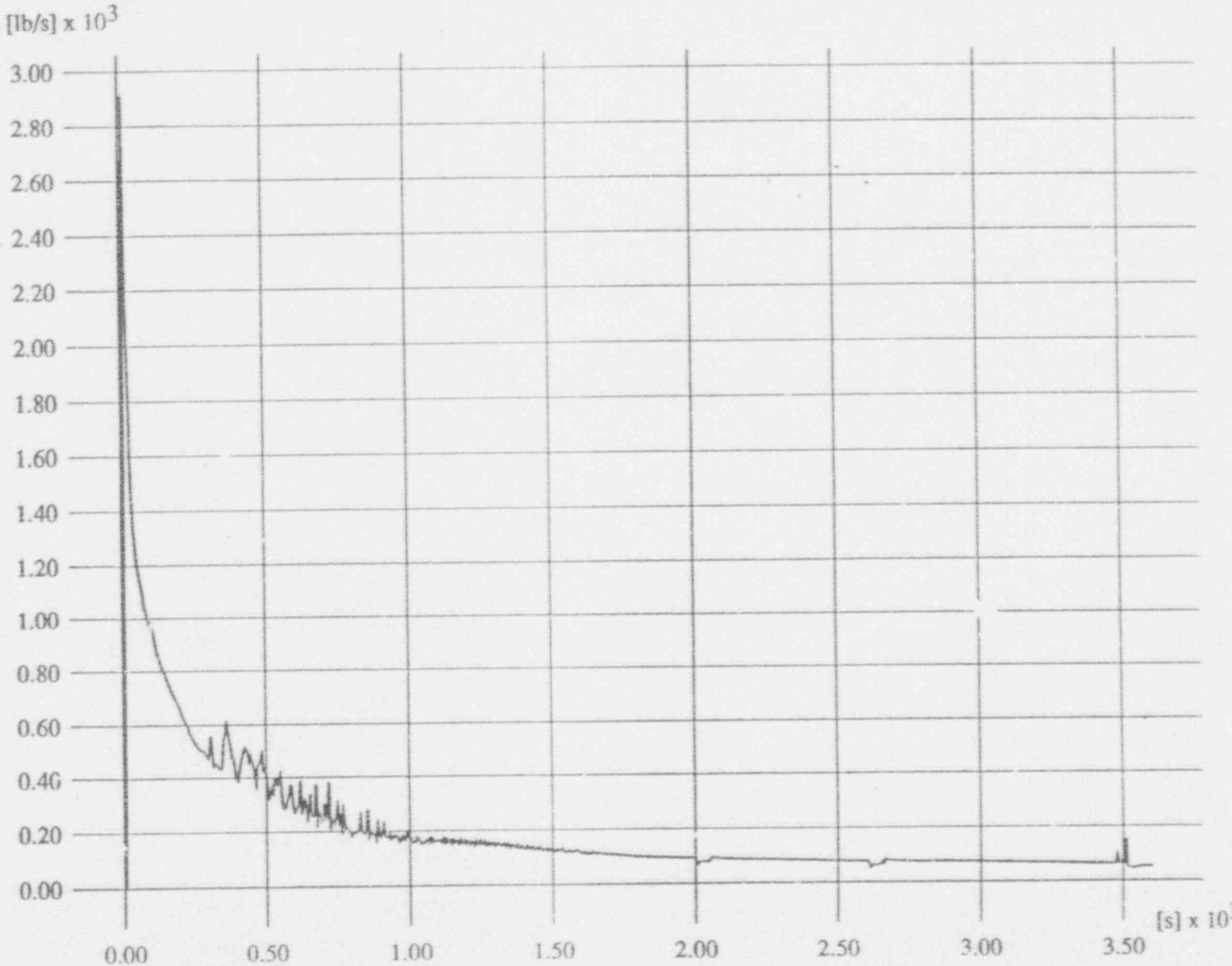


Figure 5. Primary and Intact Secondary Temperatures, 5 DEG, Operator Action

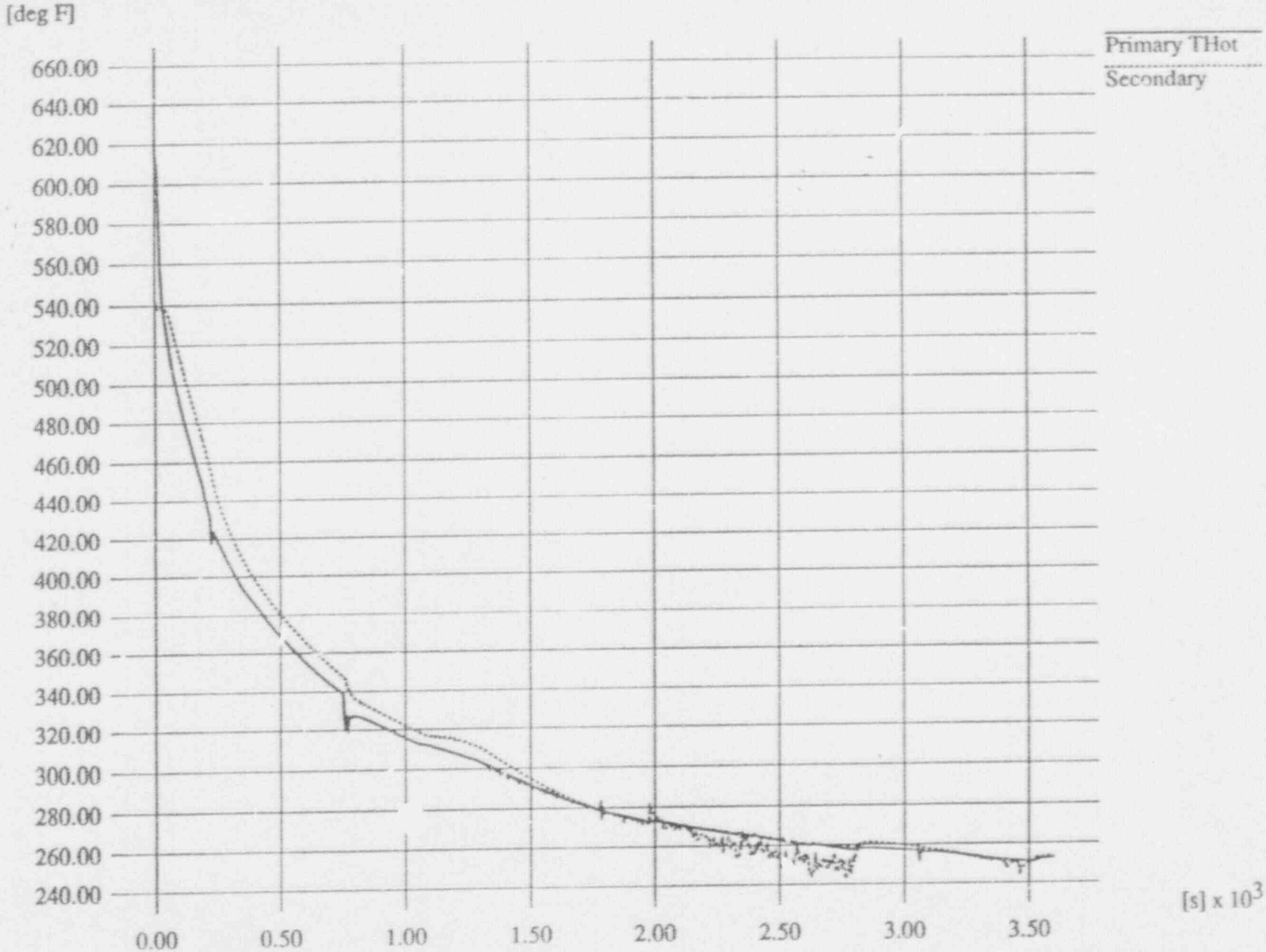
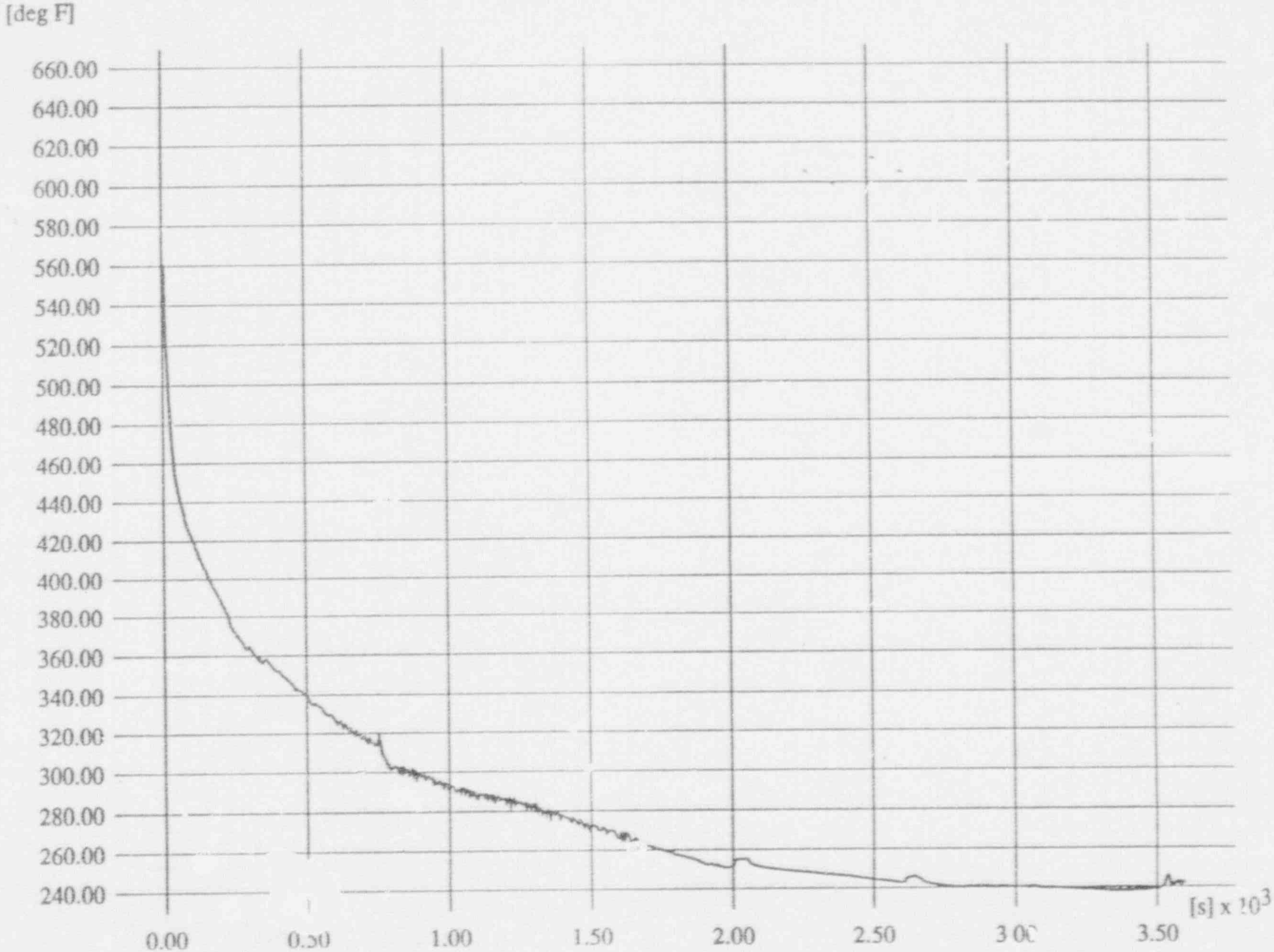


Figure 6. Broken Steam Generator Temperature, 5 DEG, Operator Action



APPENDIX A

1 Double Ended Guillotine Tube Break Calculation Results

Figure A1. Primary and Broken Secondary Pressures, 1 DEG Tube Break

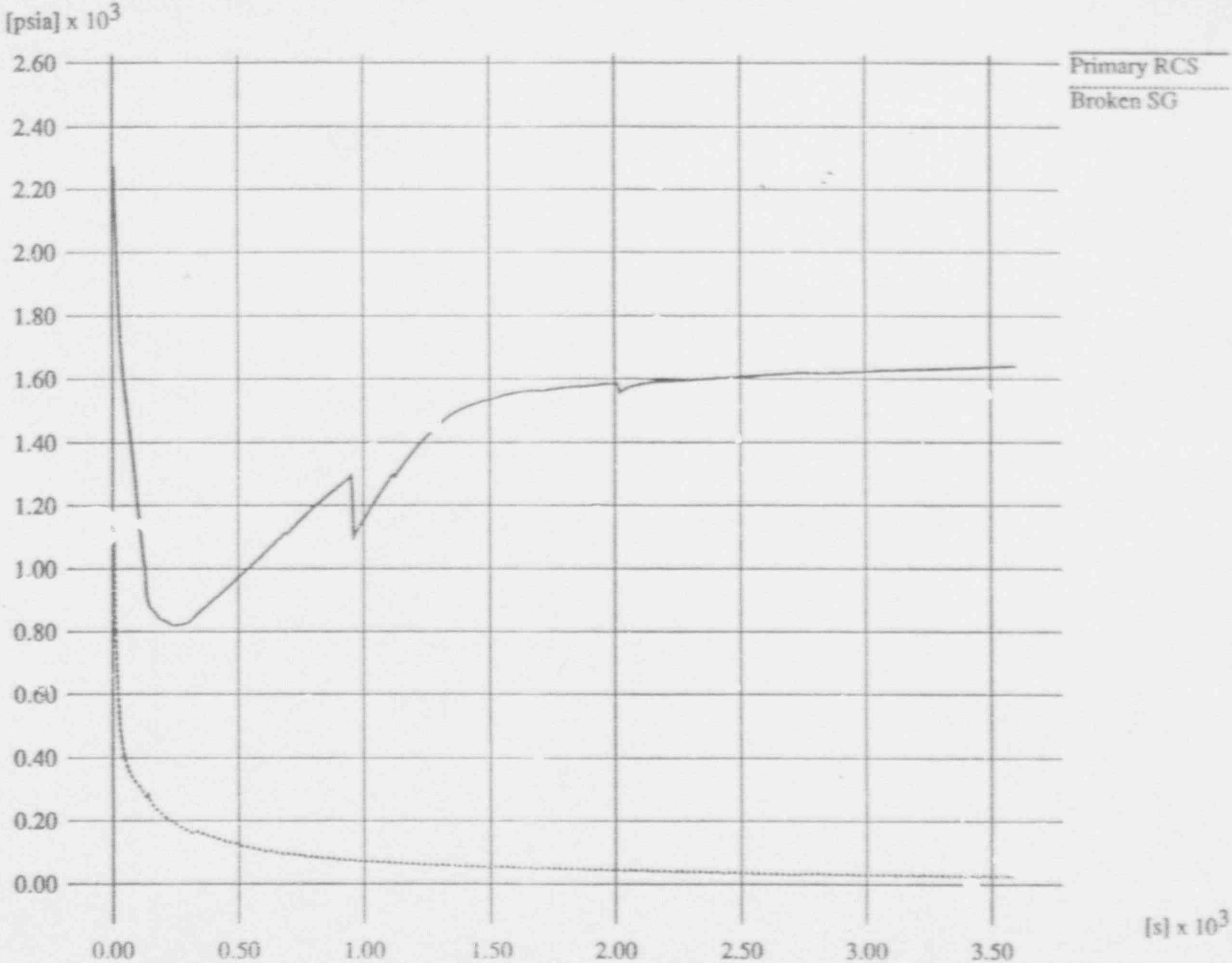


Figure A2. Steam Generator Break and ECCS Flows, 1 DEG Tube Break

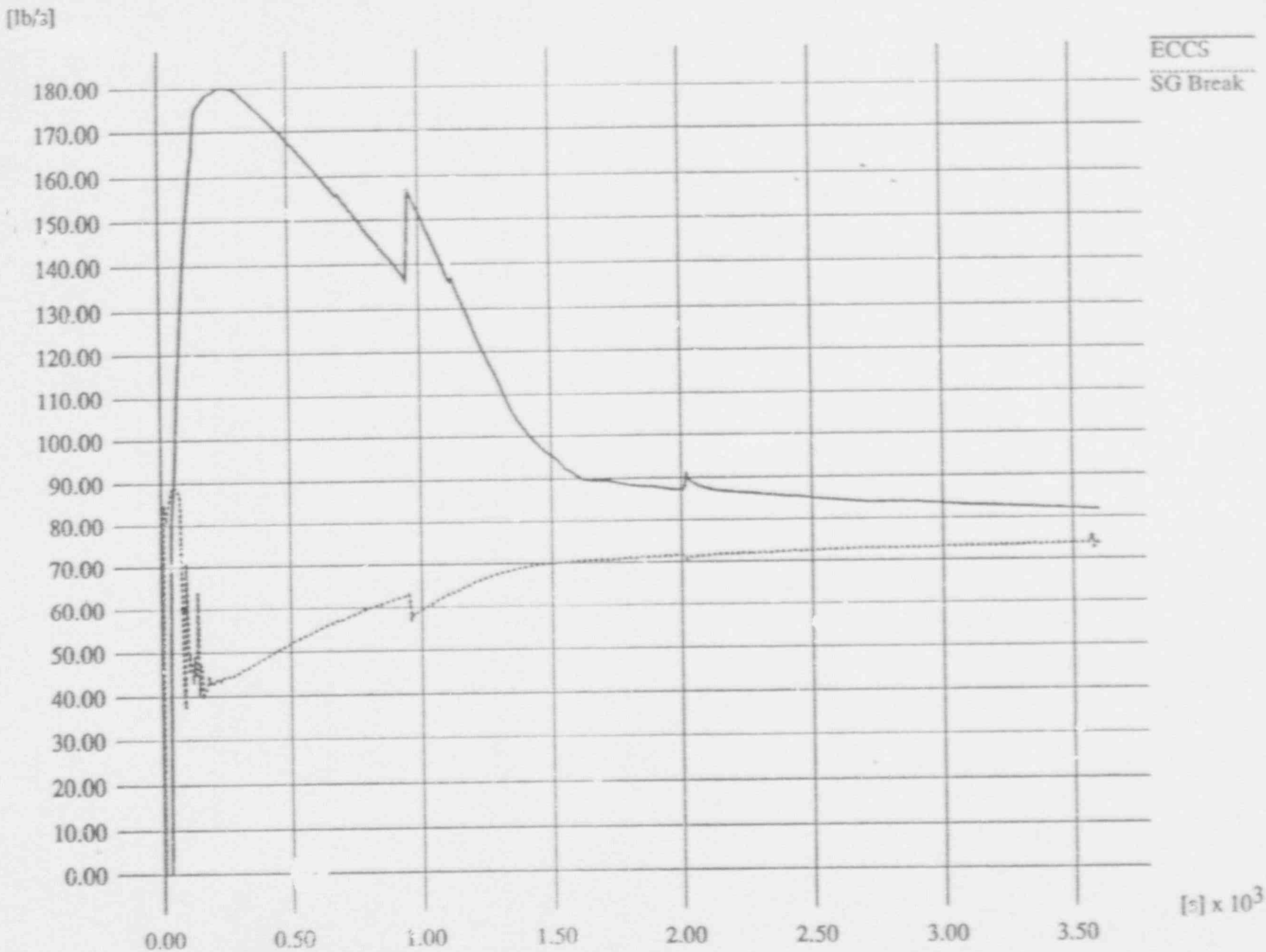


Figure A3. Main Steam Line Break Flow, 1 DEG Tube Break

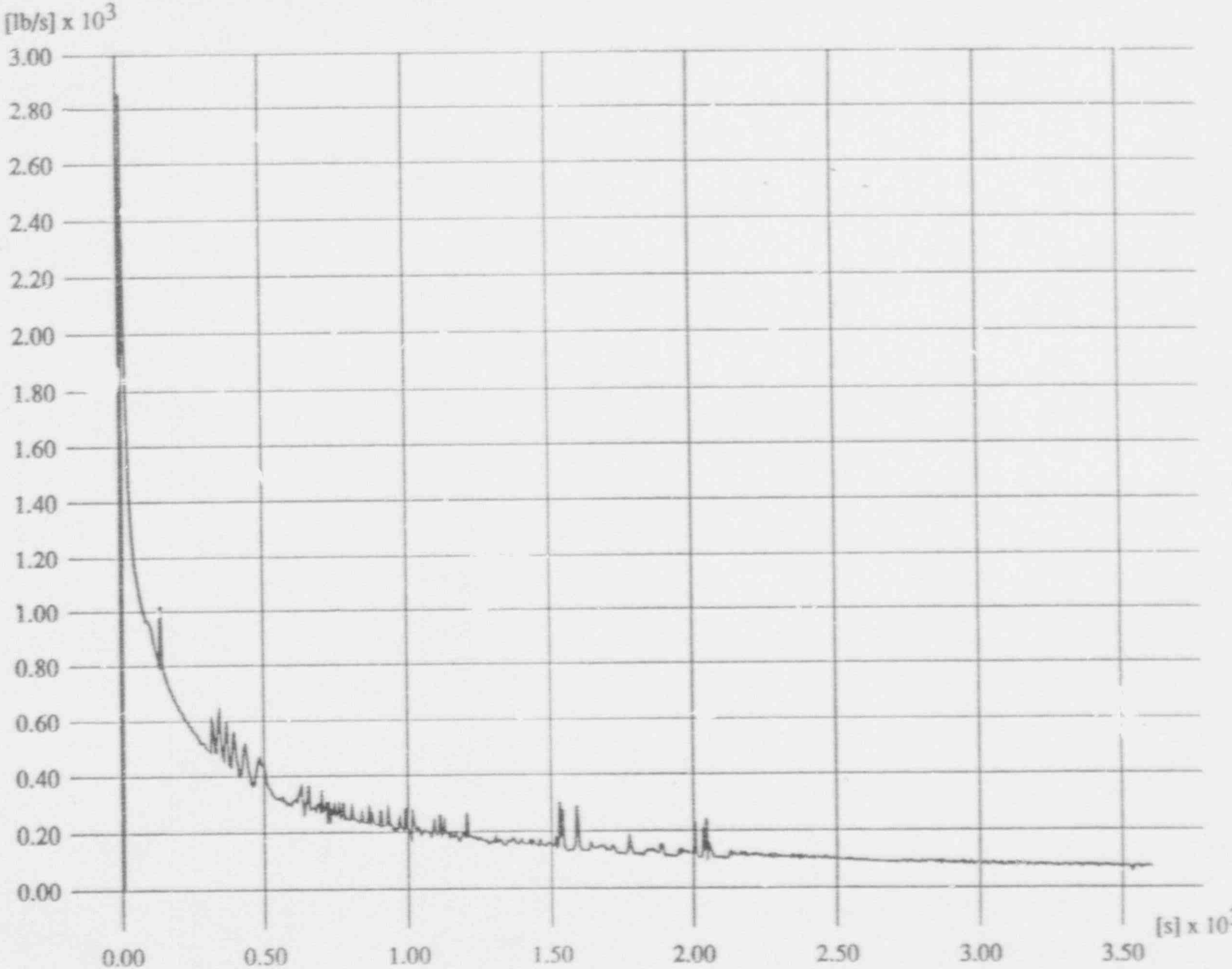


Figure A4. Primary and Intact Secondary Temperatures, 1 DEG Tube Break

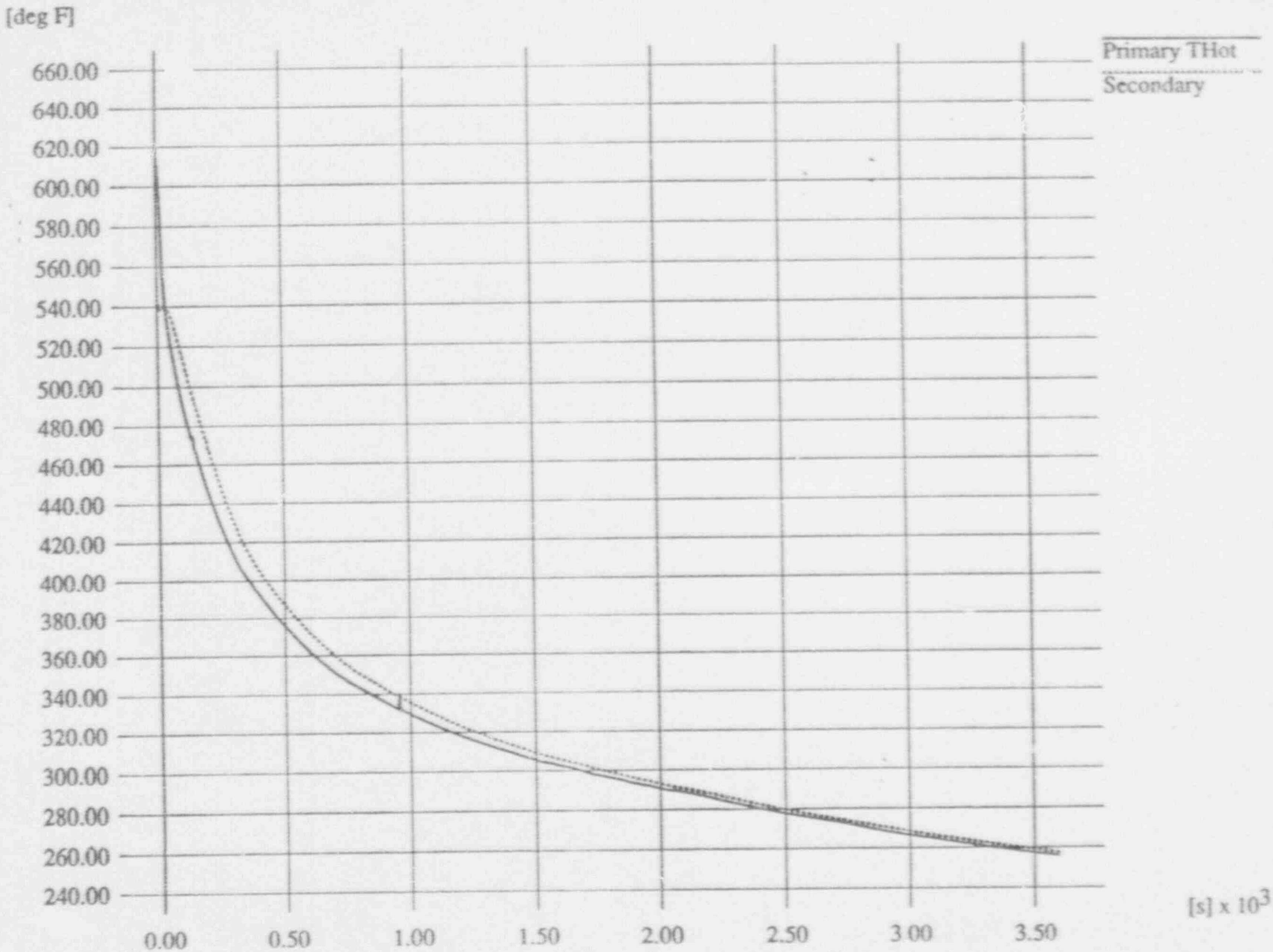
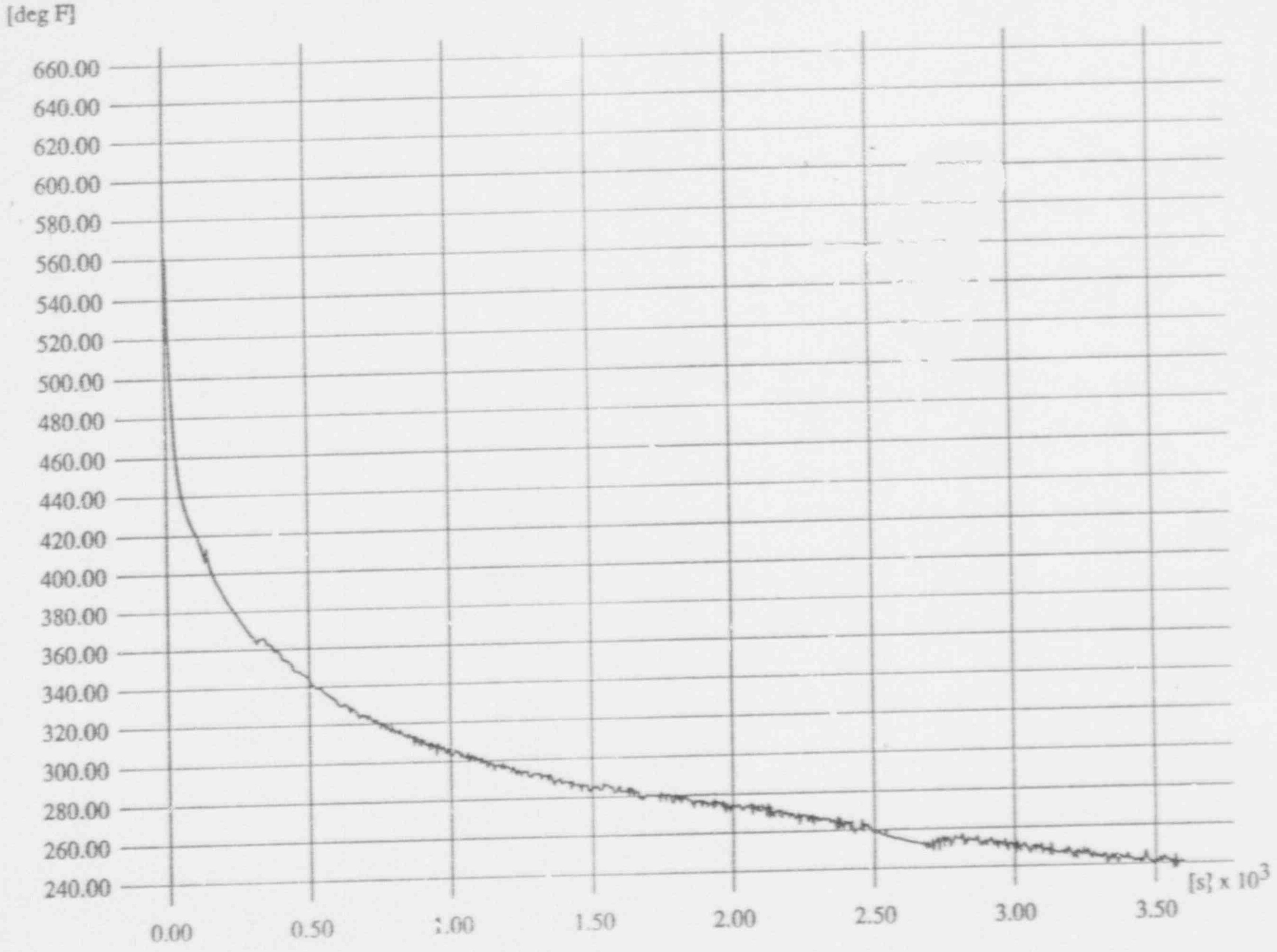


Figure A5. Broken Steam Generator Temperature, 1 DEG Tube Break



APPENDIX B

2.5 Double Ended Guillotine Tube Breaks Calculation Results

Figure B1. Primary and Broken Secondary Pressures, 2.5 DEG Tube Breaks

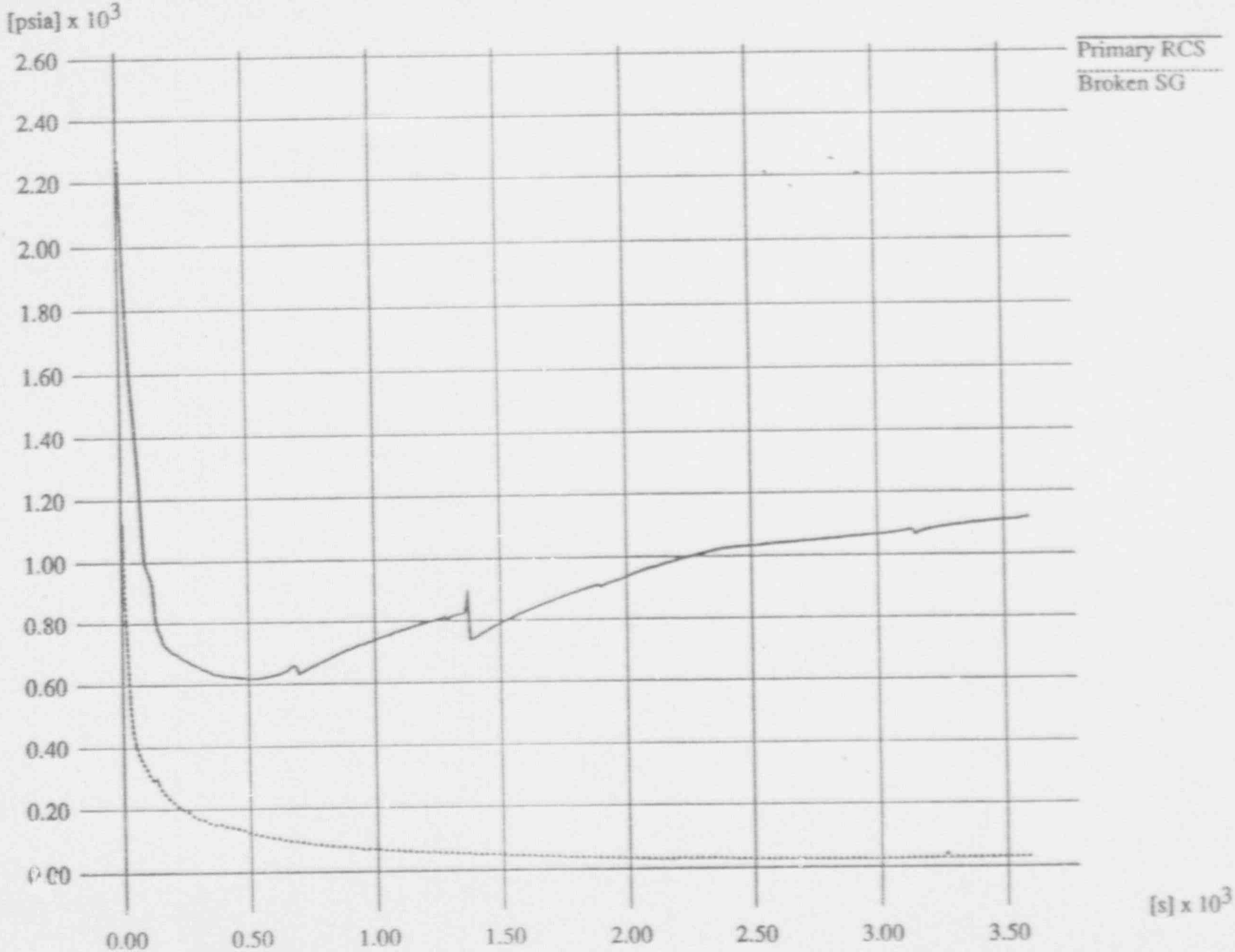


Figure B2. Steam Generator Break and ECCS Flows, 2.5 DEG Tube Breaks

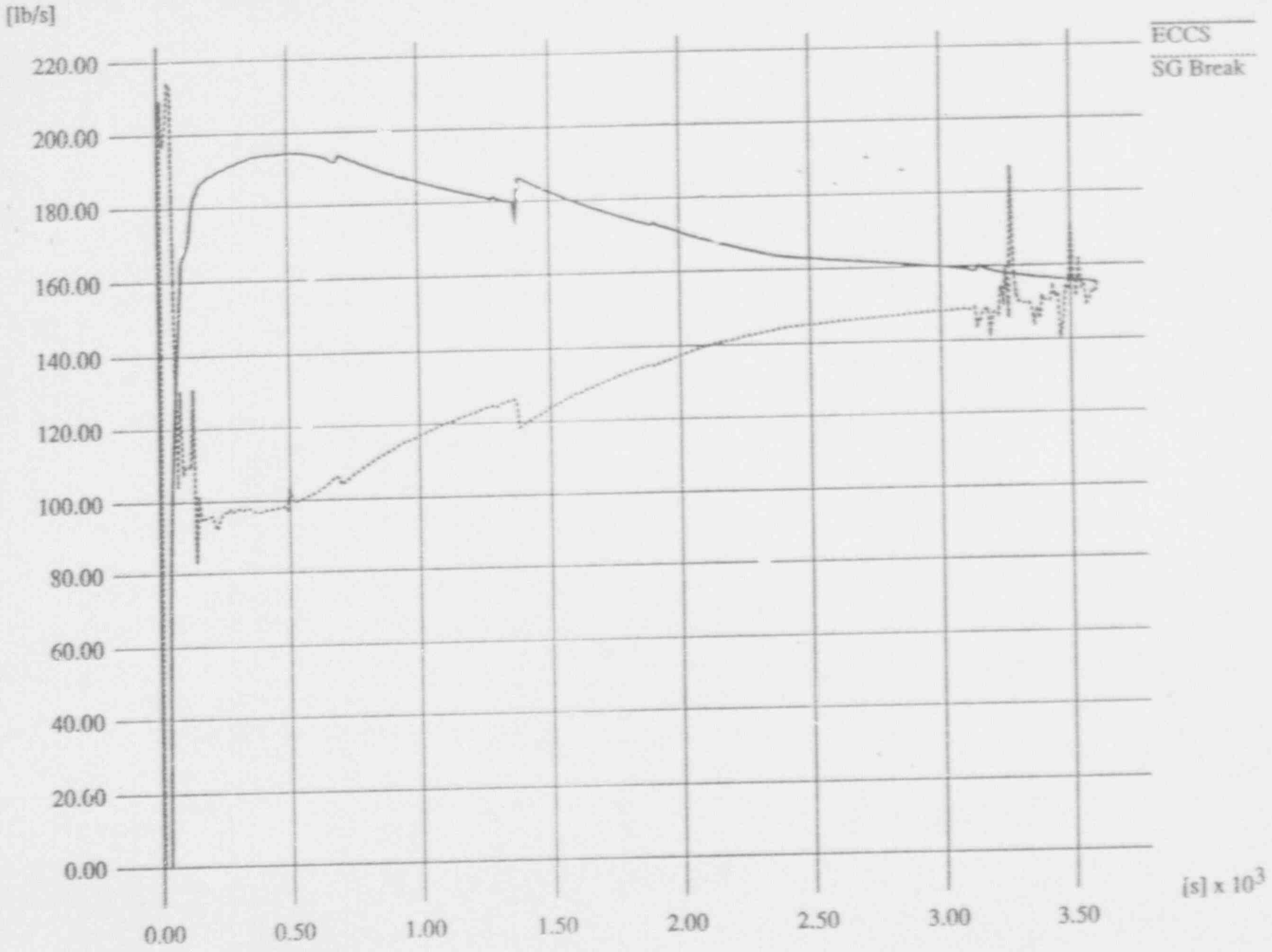


Figure B3. Main Steam Line Break Flow, 2.5 DEG Tube Breaks

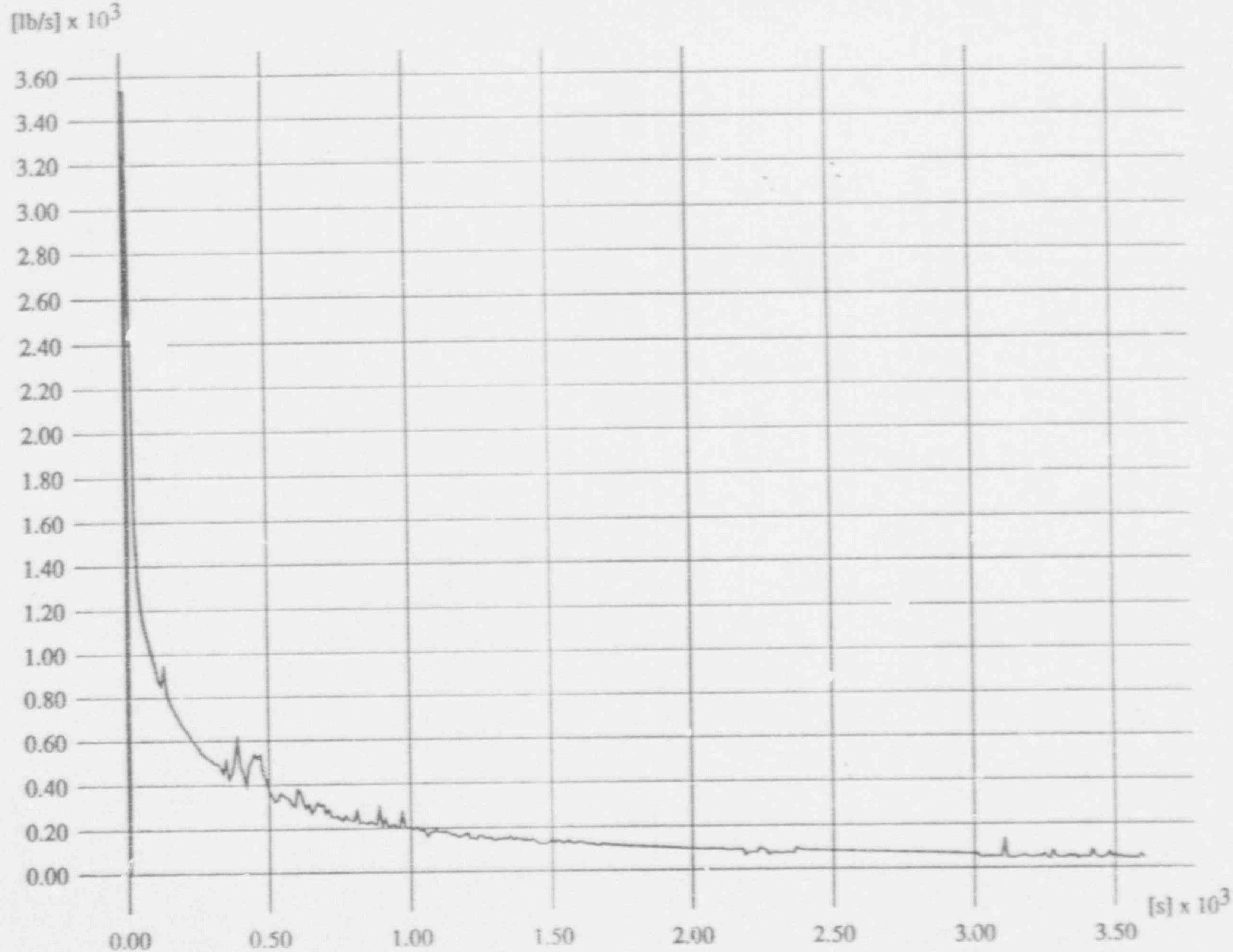


Figure B4. Primary and Intact Secondary Temperatures, 2.5 DEG Tube Breaks

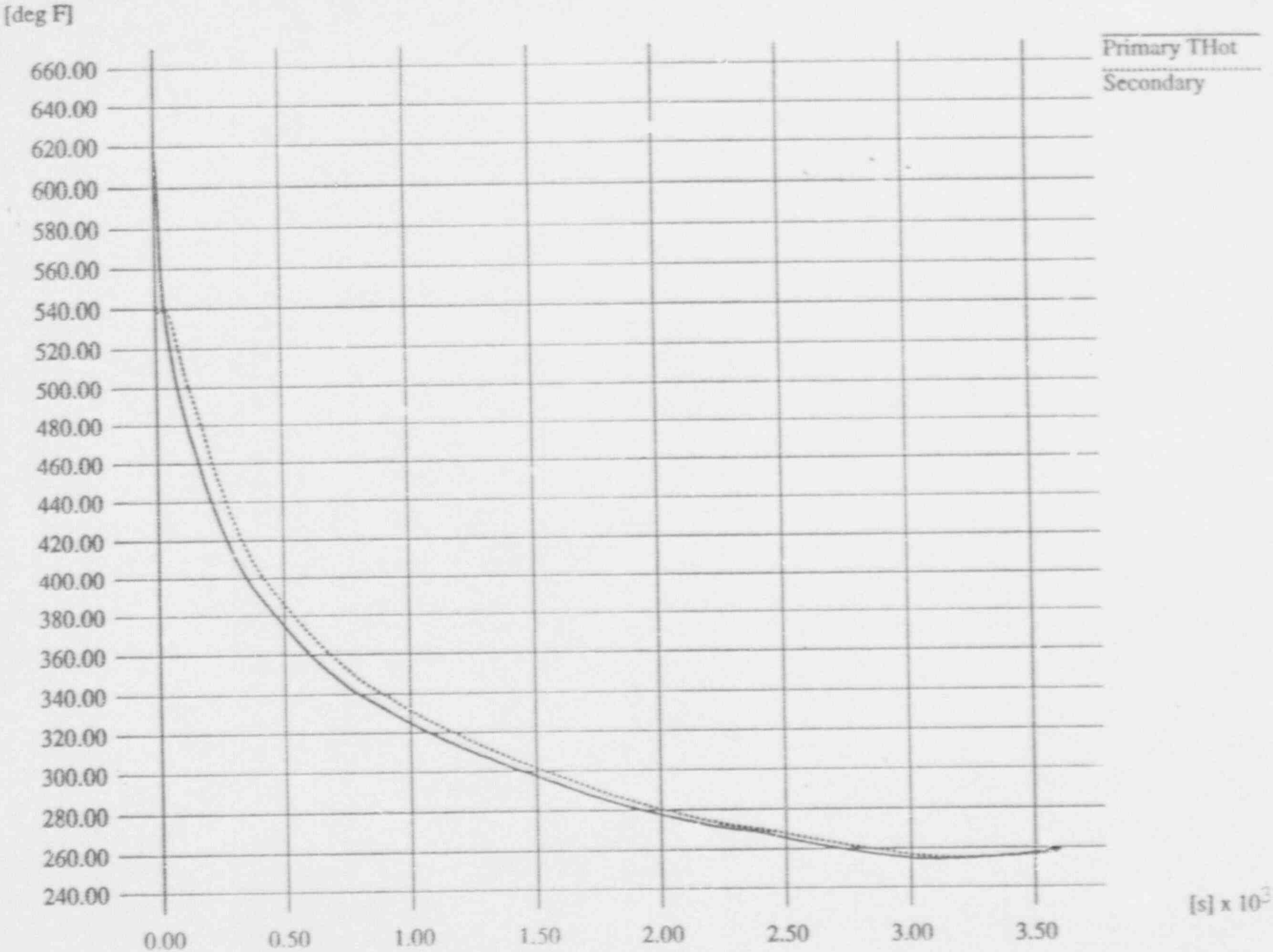
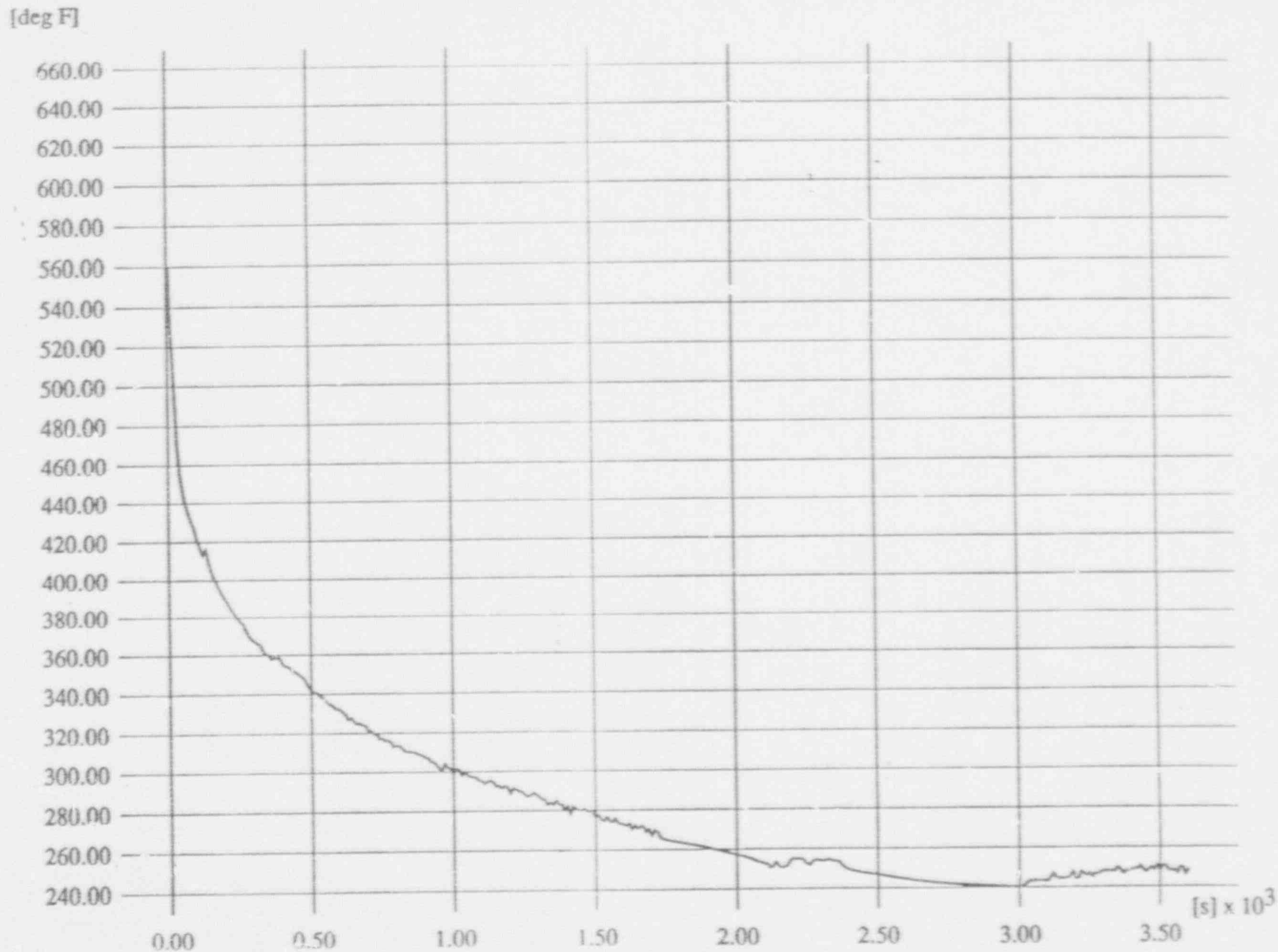


Figure B5. Broken Steam Generator Temperature, 2.5 DEG Tube Breaks



APPENDIX C

5 Double Ended Guillotine Tube Breaks Calculation Results

Figure C1. Primary and Broken Secondary Pressures, 5 DEG Tube Breaks

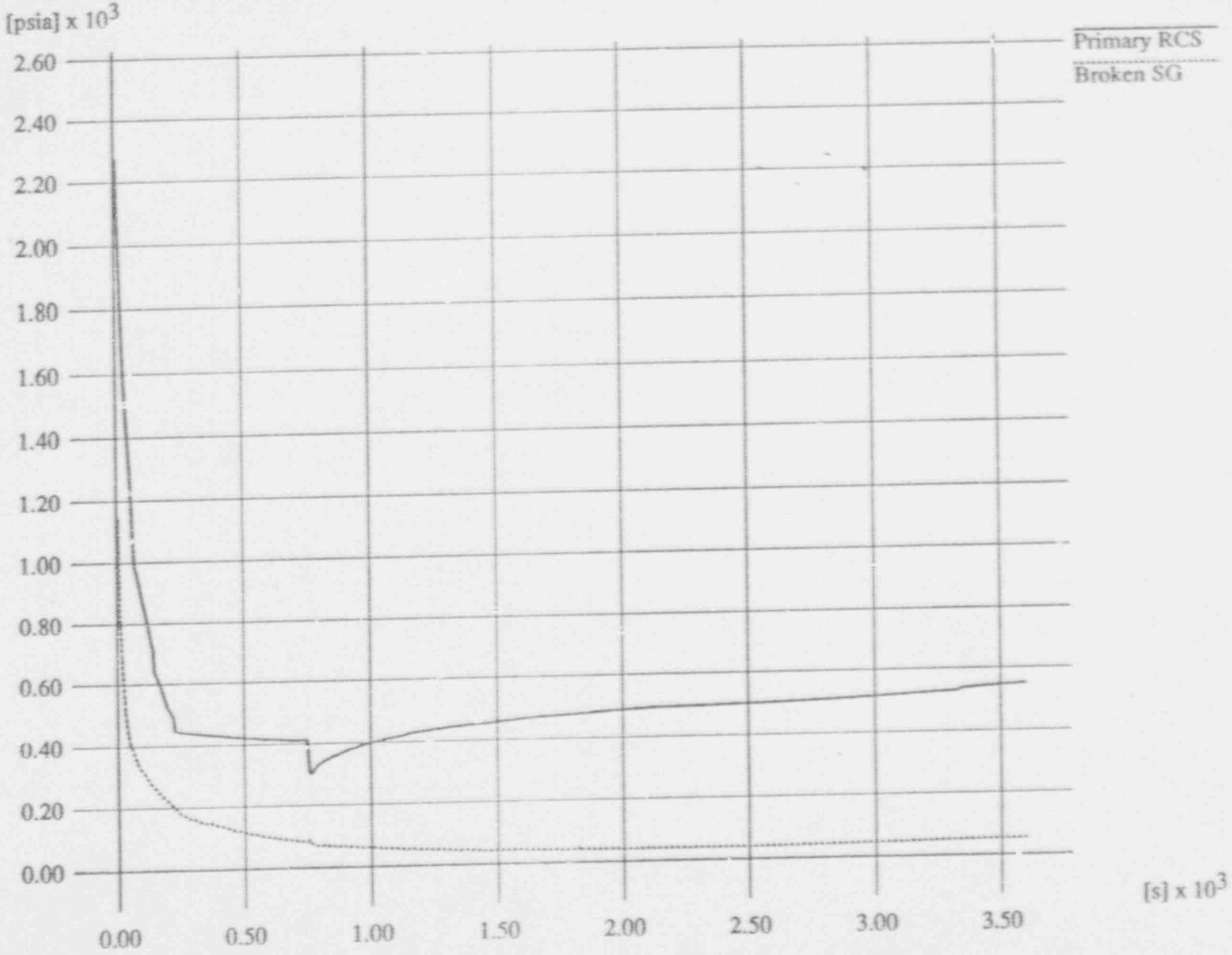


Figure C2. Steam Generator Break and ECCS Flows, 5 DEG Tube Breaks

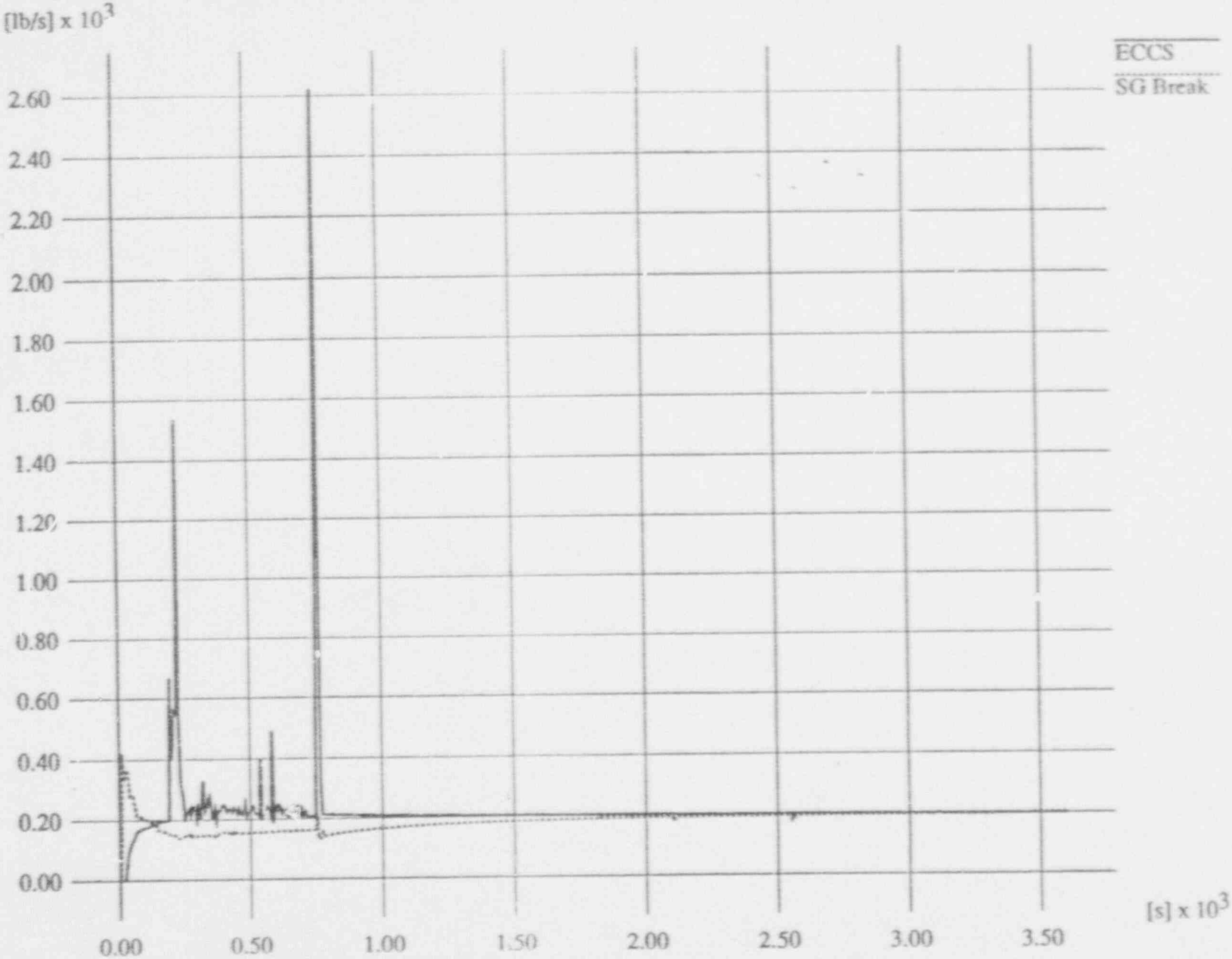


Figure C3. Main Steam Line Break Flow, 5 DEG Tube Breaks

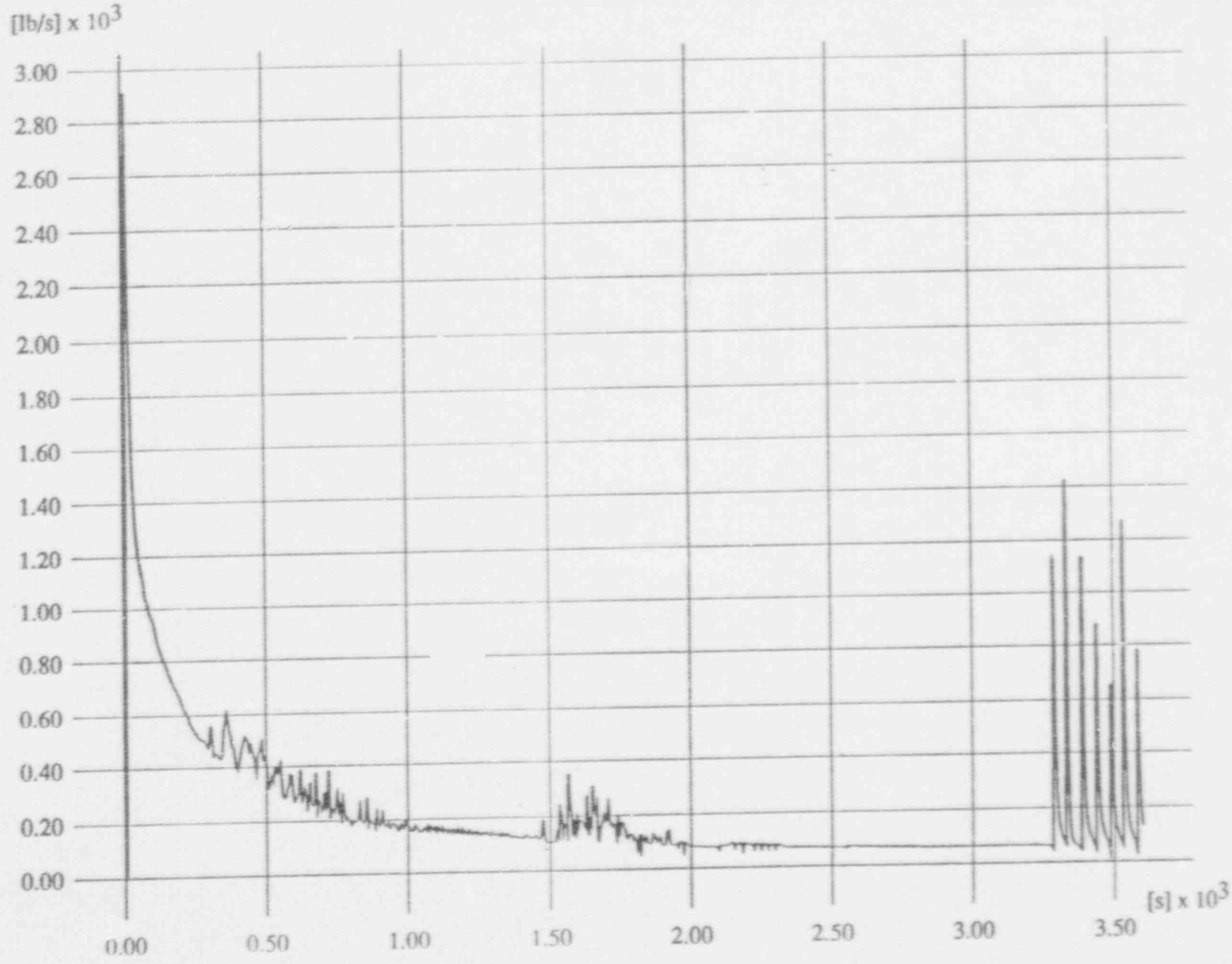


Figure C4. Primary and Intact Secondary Temperatures, 5 DEG Tube Breaks

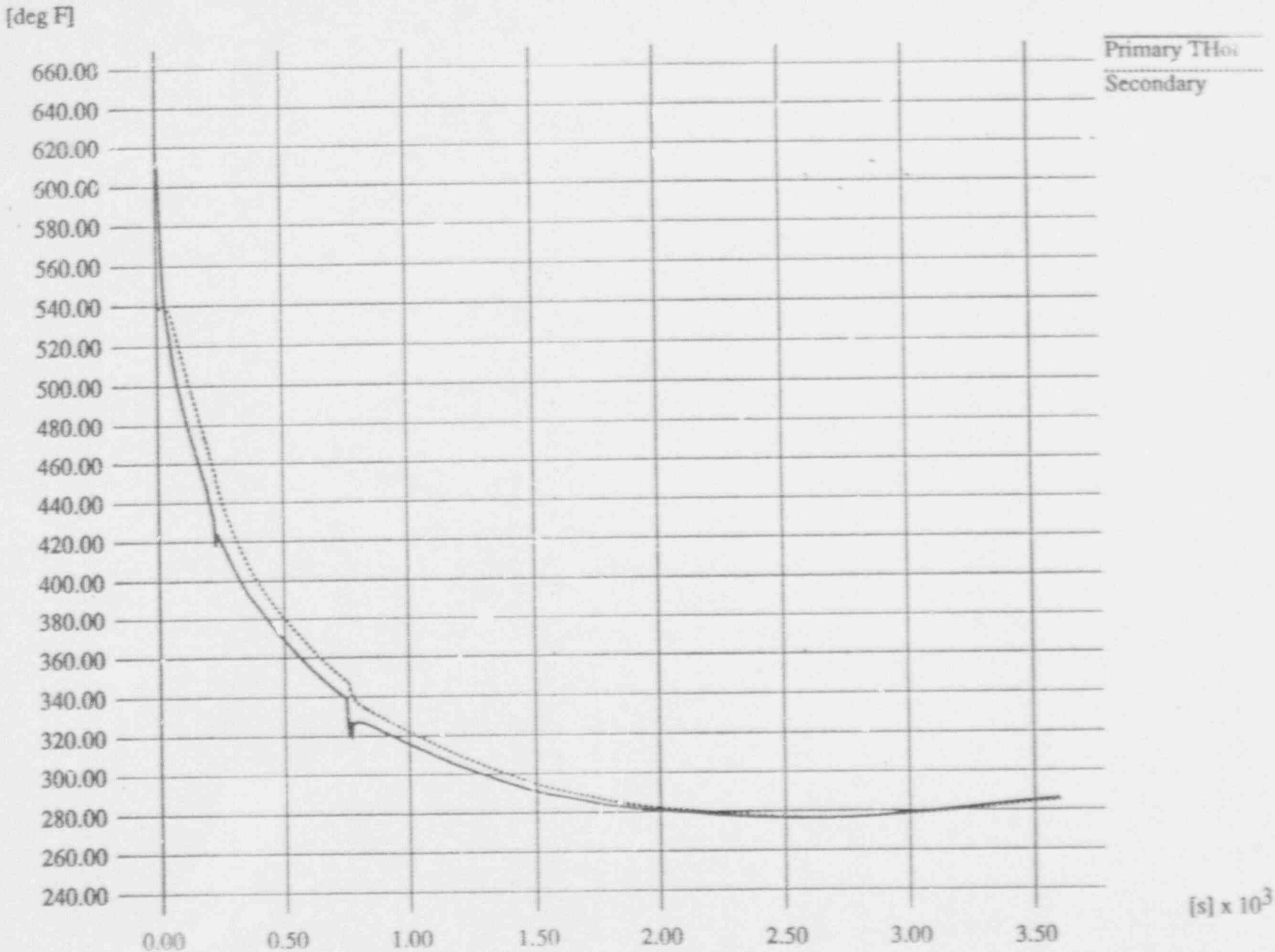
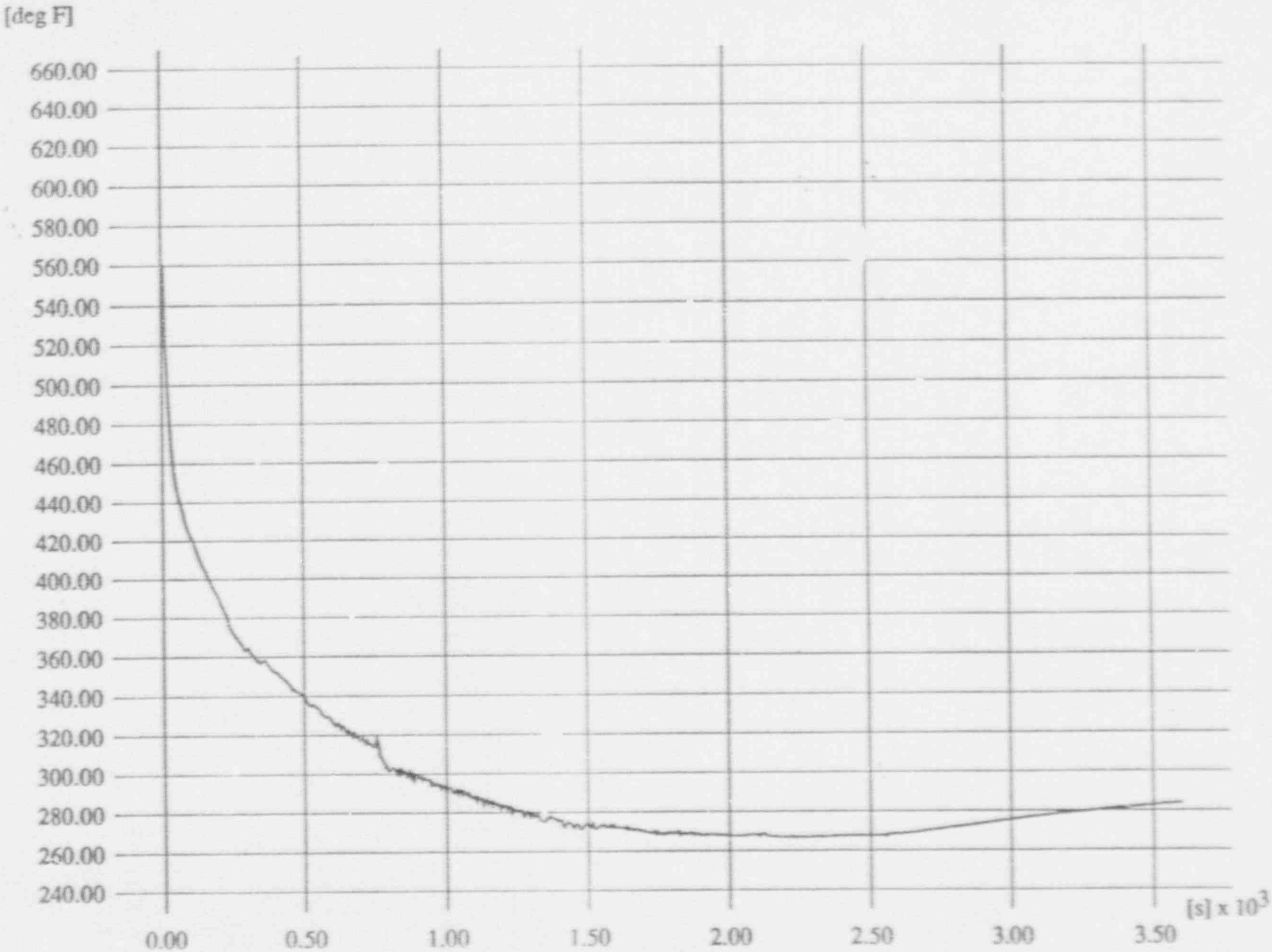


Figure C5. Broken Steam Generator Temperature, 5 DEG Tube Breaks



Attachment 2

Notes on Critical Flow Rate Estimation

The Darcy equation is applicable to incompressible steady-state flow through a constant diameter straight pipe where the pressure difference is given by:

$$\Delta P = f \frac{L}{D} \frac{\rho V^2}{2 g_c} \qquad (1)$$

Rearranging and expressing the flow as a a mass flux:

$$G^2 = \frac{2 g_c \Delta P}{\frac{fL}{D} v} \qquad (2)$$

If the flow through is desired through a length of pipe with a flow loss coefficient K, the above equation becomes:

$$G = \left[2 \frac{g_c}{v_o} \left[P_u - c P_{sat}(T_o) \right] \right]^{\frac{1}{2}} \qquad (3)$$

The Zaloudek correlation for subcooled critical flow is given by

$$G = c \left[\frac{2 g_c}{v_f} (P_u - P_{sat}) \right]^{\frac{1}{2}} \qquad (4)$$

for the range 400< P_u < 1800 psia and where

c = discharge coefficient

P_u = upstream pressure

P_{sat} = saturation pressure

v_f = specific volume of saturated liquid

If the Zaloudek correlation is modified to predict a frictionless Moody flow at saturation, thus:

$$G=\left[\frac{2g_c}{v_o}\left[P_u-cP_{sat}(T_o)\right]\right]^{\frac{1}{2}} \qquad (5)$$

where c is a coefficient that matches the Zaloudek flow rate with frictionless Moody critical flow at saturation.

If the upstream pressure of Eq.) equals the downstream pressure of Eq. (2), and the mass velocities are the equal, Eqs. (2) and (3) can be combined to yield:

$$G=\left[\frac{2g_c\left[P_o-0.85P_{sat}(T_o)\right]144}{v_o(K+1)}\right]^{\frac{1}{2}} \qquad (6)$$

where the pressure is in psia and c = 0.85.

P_o = system pressure, psia

P_{sat} = saturation pressure of subcooled liquid at temp. T_o °F, psia

v = specific volume, ft^3/lb

g_c = gravitational constant, ft/sec/sec

K = flow loss coefficient, dimensionaless

L = flow length, ft

D = hydraulic diameter, ft

f = friction factor

G = mass flux, $lbs/sec\text{-}ft^2$

ΔP = pressure difference

Pressure losses due to area changes and bends etc. can be accounted for through changes to K, the flow loss coefficient. The upstream pressure of the Zaloudek correlation (P_u) equals the downstream pressure of the Darcy equation (P_d) so that the flow rates predicted by each formulation are equal. The Zaloudek estimated

flow equals the frictionaless Moody flow at saturated conditions.

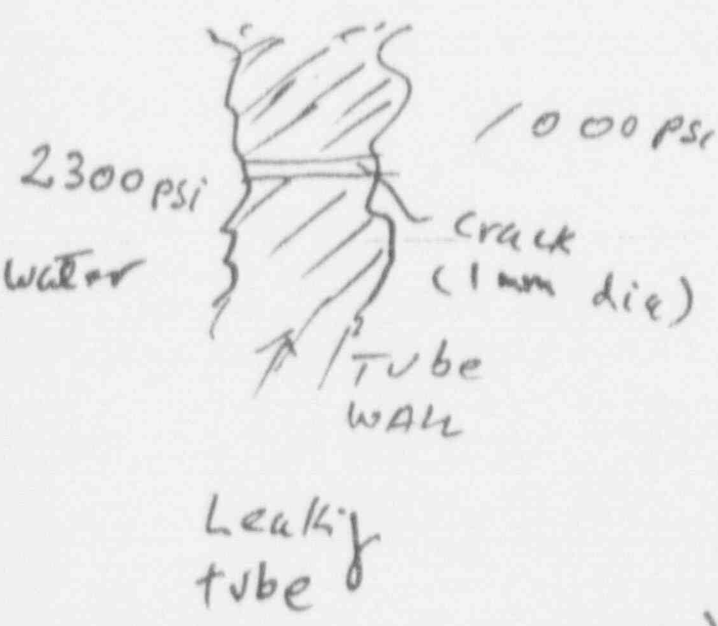
Eq. (6) is applicable to subcooled and saturated fluid discharge. For the critical flow of superheated steam, Murdock and Bowman is used where:

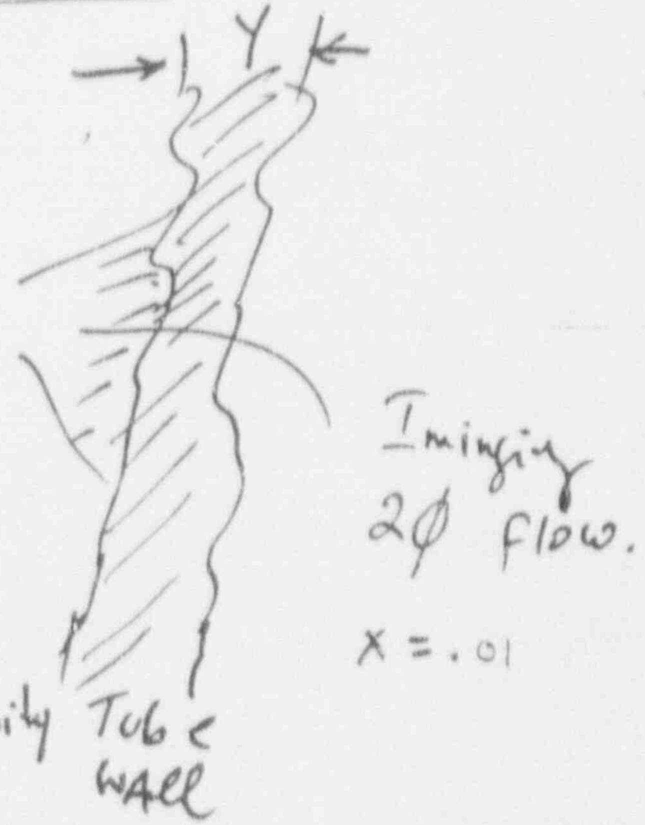
$$G=44.5\left[\frac{P}{v}\right]^{\frac{1}{2}} \qquad (7)$$

ATTACHMENT 3 -

ESTIMATE OF DAMAGE TO TUBES IN THE VICINITY OF LEAKAGE**

EROSION RATE





1. Flow velocity through crack

$$u = \sqrt{\frac{(64)(.36) \times 1300}{45} \times 144} \approx 300 \frac{ft}{sec.}$$

2. EROSION RATE

$$\log(R_e S_e) = 4.26 \log u - 14.8$$

$u \sim 100$ m/sec , $d = 1$

$$R_e S_e = 10^{-6.34}$$

$$R_e = \frac{10^{-6.34}}{S_e} = 10^{-6.34}$$

$$R_e = \frac{\text{Volume OF MAT'L LOSS}}{\text{Unit of Exposed Area}} \cdot$$

$$\frac{\text{UNIT OF Exposed AREA}}{\text{VOLUME OF } H_2O \text{ INPINGEMENT}}$$

$$= \frac{\text{Exposed Area} \cdot Y}{\text{Exposed Area} \cdot \text{Velocity} \cdot \text{time}}$$

where Y = depth of penetration
X = fraction of liquid in jet

$$R_e = \frac{Y}{X \; ? \; t} = 10^{-6.34}$$

$$\frac{y}{x\,t} = 10^{-6.34} \cdot 100 \frac{m}{sec} \times 1000 \frac{mm}{m} =$$

$$= .05 \text{ mm/sec}$$

$y = .04$ in ~ 1 mm.

$x = .01$

$$t = \frac{y}{(.05)\,x} = \frac{1}{(.05)(.01)} \approx 10^{4} \text{ sec.}$$

<u>TIME SCALE OF JET EROSION</u>

<u>IS ON THE ORDER OF</u>

<u>hours.</u>

** The above calculations have been made several years ago the Reference for the erosion rates is not readily available.

RelAP DATA

K = 0.320 BTU/HR-FT-F

GCRIT = 20836.05 LBM/S-FT2

EADY ... 2250 580

Initial

LIQUID STATE PROPERTIES

P	=	2250.000	PSIA	T	=	580.0000	F
RHO	=	44.78113	LBM/FT3	H	=	585.7833	BTU/LBM
S	=	0.7806864	BTU/LBM-R	U	=	576.4855	BTU/LBM
X	=	0.0000000E-01		ALPHA	=	0.0000000E-01	

HEAT CAPACITY

CP	=	1.335268	BTU/LBM-R	CV	=	0.7248101	BTU/LBM-R
CP/CV	=	1.842232					

VISCOSITY
MU = 1.812E-06 LBF-SEC/FT2
THERMAL CONDUCTIVITY
K = 0.320 BTU/HR-FT-F

GCRIT = 20979.43 LBM/S-FT2

EADY ...

$V = G_{CRIT} / RHO$

velocity $= \frac{2.1 \times 10^4}{44} \approx 500$ ft/sec.

Relap Data

```
K      =   0.395     BTU/HR-FT-F

GCRIT  =  13301.66 LBM/S-FT2

EADY ... 500 300
         P   T
```

LATER.

```
LIQUID STATE PROPERTIES
P       =   500.0000       PSIA          T      =   300.0000        F
RHO     =   57.40928       LBM/FT3       H      =   270.4979        BTU/LBM
S       =   0.4363126      BTU/LBM-R     U      =   268.8862        BTU/LBM
X       =   0.0000000E-01                ALPHA  =   0.0000000E-01

HEAT CAPACITY
CP      =   1.026471       BTU/LBM-R     CV     =   0.8490872       BTU/LBM-R
CP/CV   =   1.208911

VISCOSITY
MU      =   3.847E-06 LBF-SEC/FT2
THERMAL CONDUCTIVITY
K       =   0.396     BTU/HR-FT-F

GCRIT  =  15072.92 LBM/S-FT2

EADY ...
```

Flow Vel =

$$\frac{15 \times 10^3}{57} = 300 \ \frac{ft}{sec.}$$

ATTACHMENT 4

AN INDEPENDENT STATISTICAL ANALYSIS OF Westinghouse SPECIMENS WITH ODSCC PREPARED IN MODEL BOILERS

January 29, 1992

TO: Warren Minners

THRU: Jim Glynn

FROM: Les Lancaster

SUBJECT: Confidence Lines

For the Bobbin/LeakRate data I ran a simple regression taken from a computer package called STATGRAPHICS[R]. I borrowed the package from Dick Robinson and quickly learned how to use it and quickly ran the regression on the data. On presenting the results to you a question emerged on the resulting confidence bounds which I shall attempt to answer in this note.

STATGRAPHICS[R] gives two limits which they call confidence limits and prediction limits. It turns out that their 'confidence limits' is the confidence limits on the predicted mean and their 'prediction limits' is the confidence limits on the prediction of a single observation. The bounds closest to the fitted line is their 'confidence limits'. See attached three pages taken from NUREG/CR-4604.

Using this information I can answer your original question, which prompted this exercise with the following table (Remember, your original question was: At a specified confidence, how big can the Bobbin be to expect a zero LeakRa

	Using Confidence Limits	Using Prediction Limits
50% Level	6.5	11.7
95% Level	9.1	27.2

From the attached plots, printed from the STATGRAPHICS[R] run, note that your commented observation or question on the number of points lying outside of the bounds would hold for the 'prediction limits' if the fit had been better.

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