THERMALHYDRAULIC TRANSIENT ANALYSES of the SGECS INITIAL INJECTION PERIOD

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ABSTRACT

Following a secondary side accident event at Darlington NGS, initiation of the SGECS (Steam Generator Emergency Cooling System) will be into steam-filled piping, resulting in a condensation-induced waterhammer transient within the piping network. The TUF (Two Unequal Fluids) computer code, suitable for modelling thermalhydraulic transients with interaction between the liquid and steam phases, was employed to quantify the waterhammer pressure transient within the piping network, enabling piping stress analyses to be performed to verify the structural integrity of the system during the initial injection period. Results of the thermalhydraulic analyses indicate that the piping network undergoes a significant waterhammer transient.

1.0 INTRODUCTION

While performing operating limits analyses for the SGECS, a potential for waterhammer was identified during the system's initial injection period. Therefore, an indepth review of SGECS operation was undertaken, to establish whether the conditions under which the system is required to operate could lead to significant waterhammer.

Results of this review indicated that a significant portion of the SGECS piping network flowpath would be steam-filled when SGECS is initiated in an accident event. Thus the potential for steam condensation-induced waterhammer exists in the Darlington NGS A SGECS, and a thermalhydraulic analysis of the SGECS initial injection period was undertaken.

2.0 SGECS PIPING NETWORK

The SGECS is designed to supply inventory makeup to the SGs following a loss of heat sink event (eg., a loss of feedwater, or steam line break event). A schematic of the piping network flowpath is illustrated in Figure 1. (Note that this figure illustrates the SGECS network to SGs (Steam Generators) 1 and 3. Another, essentially identical, SGECS network supplies makeup to SGs 2 and 4. The analyses discussed in this paper is for injection from the SGECS network to SGs 1 and 3).

SGECS inventory at about 35°C is stored in a water tank about 13m above the SG injection nozzle, and is pressurized to about 800 kPa(g) via an air tank and compressed instrument air. Following an accident event that initiates SGECS, and once the SGs have depressurized to about 800 kPa(g), the SGECS injection valves open, and the pressurized inventory is injected into the SGs, via, essentially, the gravity head provided by the piping layout.

The piping network illustrated in Figure 1 is also used by three other systems to inject inventory into the SGs; namely the second stage reheater drains system, which is in service during normal power operation, and the Inter-unit Feedwater Tie (IUFWT) and the Emergency Service Water (ESW) systems, which like SGECS, are intended for use following loss of heat sink events. Therefore, when SGECS injection is initiated, these three systems (ie., IUFWT, ESW, and reheater drains) piping connection within this piping network become dead ends to SGECS, and thus potential sites for waterhammer transients.

During normal operation, the second stage reheater drains system returns hot condensate to the SGs at about 235°C. Thus, following a loss of heat sink event that initiates SGECS injection, the SGs must be depressurized below 1 MPa before injection begins. Because of the intimate connection between the SGs/reheater drains/SGECS piping, depressurization of the SGs also depressurizes the reheater drains piping, causing the reheater drains condensate to flash, yielding steam-filled conditions at about 800 kPa(g) and 180°C in the piping network upon SGECS injection. Thus the piping dead ends identified above can be steam-filled when SGECS injection begins.

Under these operating conditions, injection of relatively cold SGECS inventory (35°C) into steam-filled (180°C) piping will result in condensation of the steam phase in the piping network. And condensation of the steam phase will cause depressurization within the piping network, resulting in an increase in the SGECS injection flow rates (from gravity feed flow rates to gravity plus pressure-driven injection flow rates). Therefore the dead end portions of the piping network become susceptible to waterhammer due to the sudden decceleration of the liquid inventory at the moment their refill is complete.

2.1 Modelling the SGECS Piping Network

A node/link hydraulic model of the SGECS piping network, developed for the TUF computer code (Reference 1), is also illustrated in Figure 1, the nodes being aligned with their representative piping segment.

The pertinent requirement for modelling a fast transient such as waterhammer, is to ensure that the nodal volumes representing the piping network that will undergo the fast transient are all of the same relative size. This can be seen in the nodal volumes of the dead end portions of the piping network, as illustrated in Table 1. Optimization of the time-step control for a finite-element computer code then becomes relatively straight-forward, in that typical values for time-step control are effective in producing a representative solution.

3.0 TRANSIENT EVENT ANALYZED

The most limiting loss of heat sink event for SGECS, from a potential waterhammer transient event perspective, is one in which the SGs have sufficient interim inventory to remain pressurized during the initial SGECS injection transient. This scenario results in sufficient back pressure from the SGs to direct all the SGECS injection flow away from the SG itself and toward the piping dead end, thereby maximizing the flow rate into the dead end portion of the piping network.

Thus, the analytical results presented in this paper are for the scenario that results in all the initial SGECS injection flow being directed toward one SG, and thus its associated network dead end piping. The piping stress analyses performed on the thermalhydraulic transient for this case determined that the piping stress exceeded the ASME code allowable. Thus an interim solution, analyzed and shown to pass the ASME piping code requirements while still enabling the SGECS to meet its heat sink requirements, was put into place. This solution reduced the operating SGECS tank pressure and stroke-limited the injection valves, all in order to reduce the injection flow rate into the piping network. Results of this thermalhydraulic transient are not described here.

3.1 Analytical Assumptions

The pertinent assumptions employed in the analyses are summarized below:

· SGECS inventory at 35°C;

· both SGECS injection valves are assumed available, and have a stroke open time of 10 seconds.

· the SGECS tank pressure and the SG pressure remain constant during the short transient simulation;

· pressure difference between the SGECS tanks and the SGs is 200 kPa;

> This pressure difference yields the largest injection flow rate while still directing all flow to only one SG, and is therefore the limiting scenario for SGECS waterhammer.

· an operator-initiated controlled cooldown following the reactor trip results in the gradual depressurization of the SGs and reheat piping network, yielding conditions (steam and liquid phase interface) as summarized in Figure 2.

4.0 ANALYTICAL RESULTS

Results of the transient simulation of the initial SGECS injection period (ie., until the SGECS piping network is refilled and steady-state injection is reached) are illustrated in Figures 3 through 7.

Upon initiation of SGECS injection, flow through the SGECS injection valves increases from zero to a total of about 60 kg/s in about 3 to 4 seconds (Figure 3 - NOTE: the figure titles correspond to the piping sections as labelled in Figure 2). Once the injection flow reaches the split point to SGs 1 and 3 (point A in Figure 2), the elevation difference between NV38 and 39 yields a slightly larger driving force (via the static head) toward SG3 (the flowpath with the lower elevation NV39), resulting in all the injection flow being directed to SG3 (Figure 3).

The SGECS injection valves continue stroking to their full open position after the injection flow passes the SG1/3 split point in the piping network. As the injection flow proceeds toward SG3 (ie., between 5 and 10 s in the transient event), the SGECS injection valves have essentially reached their "full open" position; in addition, depressurization of the steam-filled portion of the network is compensated by steam flow from SG3 (Figure 4). Therefore, SGECS injection has reached a constant or "steady" flow rate.

As the injection flow reaches the split point between SG3 and the reheat/IUFWT dead ends, the steam flow from the SG "directs" the SGECS injection flow into the reheat/IUFWT dead ends. This "steady-state" injection flow into the steam-filled reheater drains dead end results in the waterhammer-induced pressure transients as illustrated in Figure 5.

Following refill of the SG3 portion of the network piping, injection flow into SG3 is reduced to that of a steady-state liquid-filled system (see Figure 3). Thus a pressure recovery at the SG1/3 split point occurs (point A in Figure 2), so that refill of the SG1 portion of the piping network begins.

As the refill transient proceeds toward SG1, depressurization of the steam-phase in this portion of the network, together with the increase in the static head as the piping is refilled, results in a gradual increase in flow being directed toward SG1 and its dead end piping (see Figure 3). Once the liquid front reaches the SG1/reheat dead end flow split (point C in Figure 2), the injection flow is directed, albeit in an oscillatory fashion, toward the reheat/IUFWT dead ends (Figure 6). However, as refill of the reheater drains dead end piping commences, the continued increase in the local injection flow, due partially to the addition of the static head/driving force of the reheater drains dead end piping, terminates the oscillatory portion of the injection flow (Figure 7). This 'steady-state' injection flow into the steam-filled reheater drains dead end piping (see Figure 6) results in the waterhammer-induced pressure transients as illustrated in Figure 8.

Once refill of the piping network is complete, the system operates in a steady-state condition with a total injection flow rate of about 52 kg/s.

5.0 SUMMARY

Injection of cold inventory into steam-filled, dead ended piping will introduce significant waterhammer transient loads within a piping network. The TUF computer code provides an analytical tool with which to analyze the thermalhydraulic transient effect of steam condensation-induced waterhammer.

6.0 REFERENCES

(1) LUXAT, J.C., et al, "TUF Engineer's Manual, An Advanced Thermal-hydraulic Code For Candu Reactors". Nuclear Safety Department, Ontario Hydro. Report No. 91001. January 1991.

TABLE 1
SUMMARY of PERTINENT NODAL DATA

Node No.	Node Volume ($m^3 \times 10^{-03}$)	Node Length (m)
SG3 Dead End Piping Nodalization:		
72	4.58	1.0
73	3.06	1.0
74	42.0	2.15
75	42.0	2.15
76	31.4	1.87
77	31.4	1.87
78	31.4	1.87
SG1 Dead End Piping Nodalization:		
103	8.95	2.1
104	7.18	2.1
105	4.79	2.1
106	16.8	1.23
107	32.8	1.95
108	32.8	1.95
109	32.8	1.95

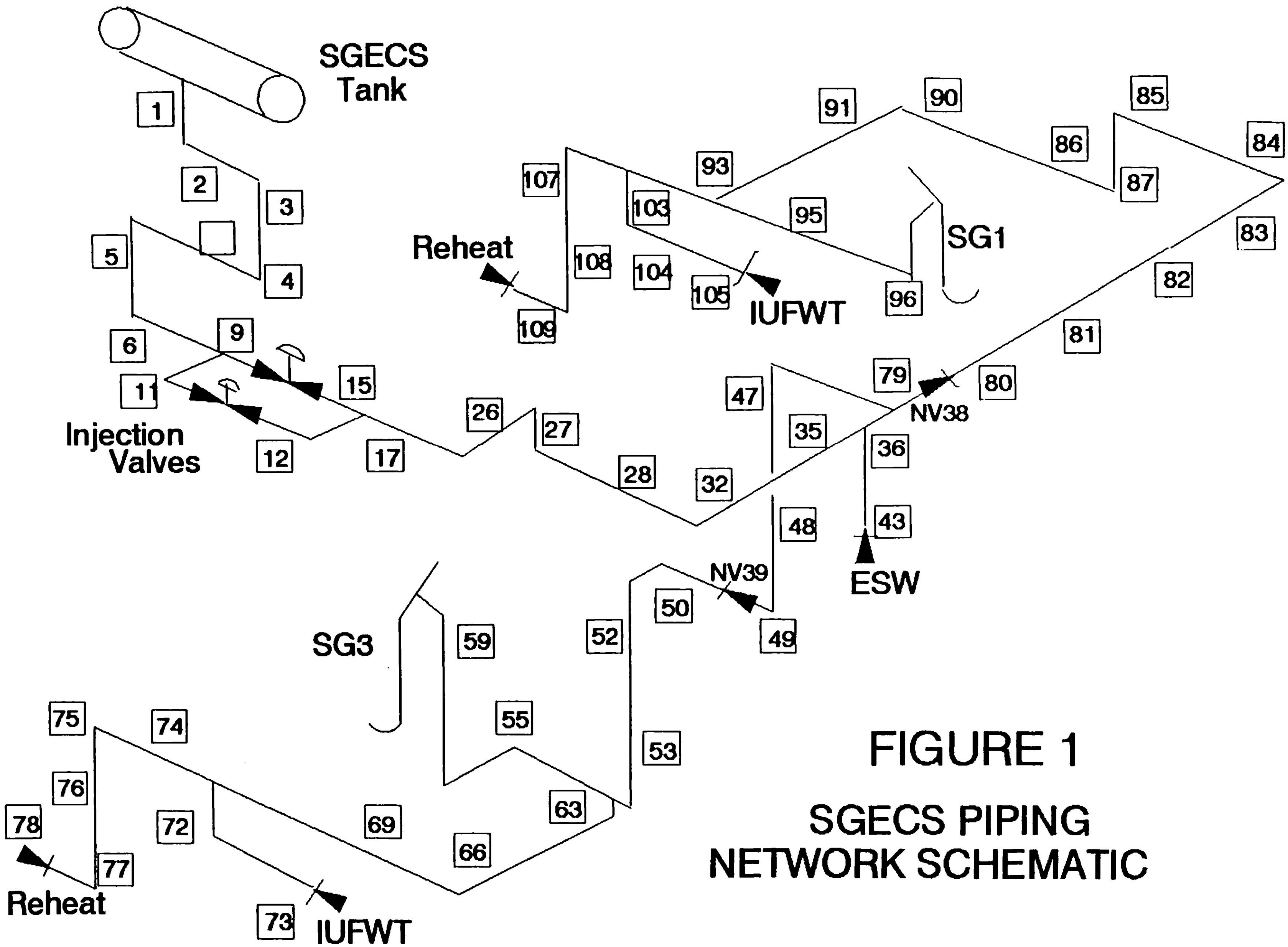

FIGURE 1

SGECS PIPING NETWORK SCHEMATIC

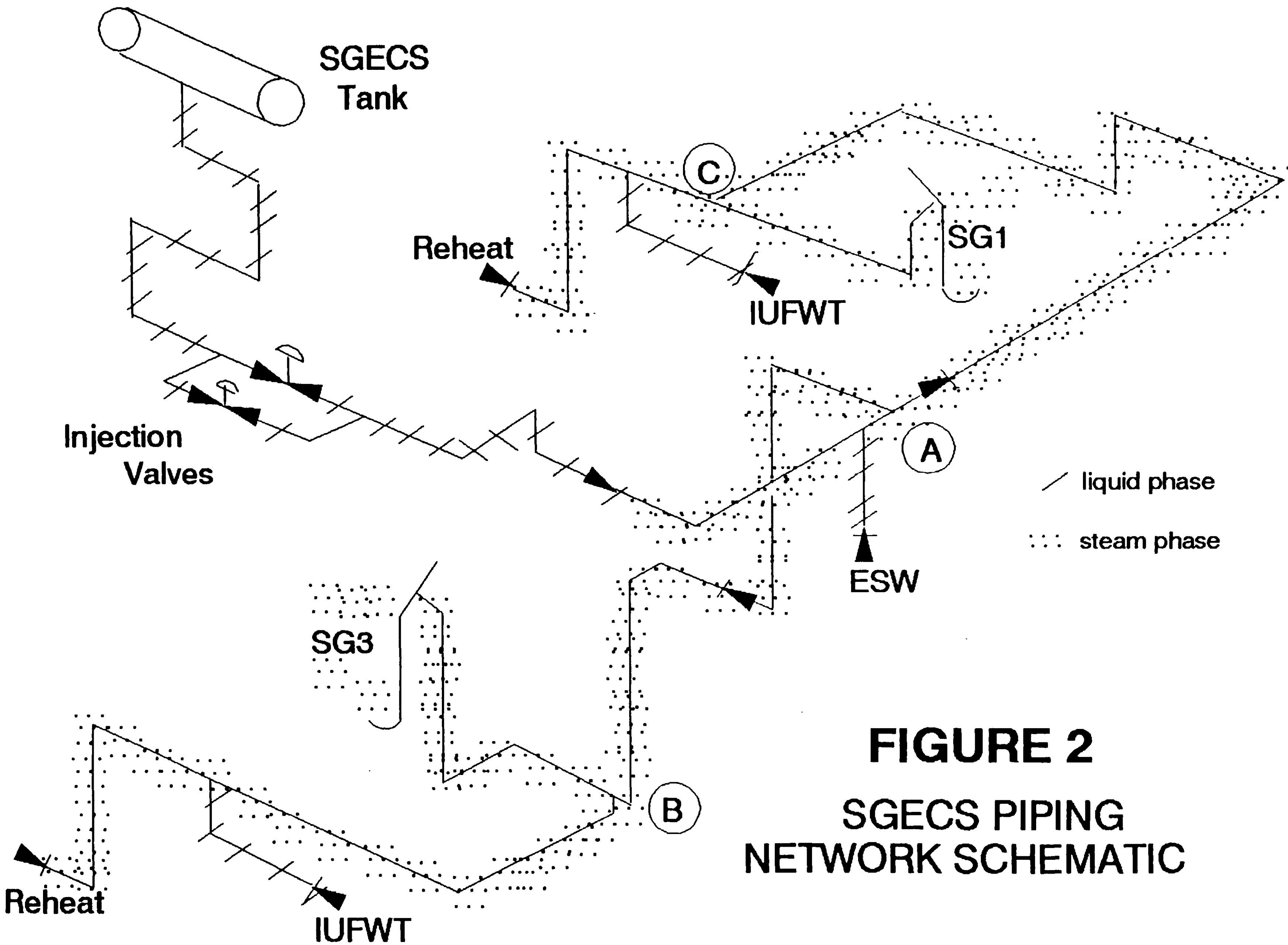

FIGURE 2

SGECS PIPING
NETWORK SCHEMATIC

FIGURE 3
SG1/SG3 INJECTION FLOW

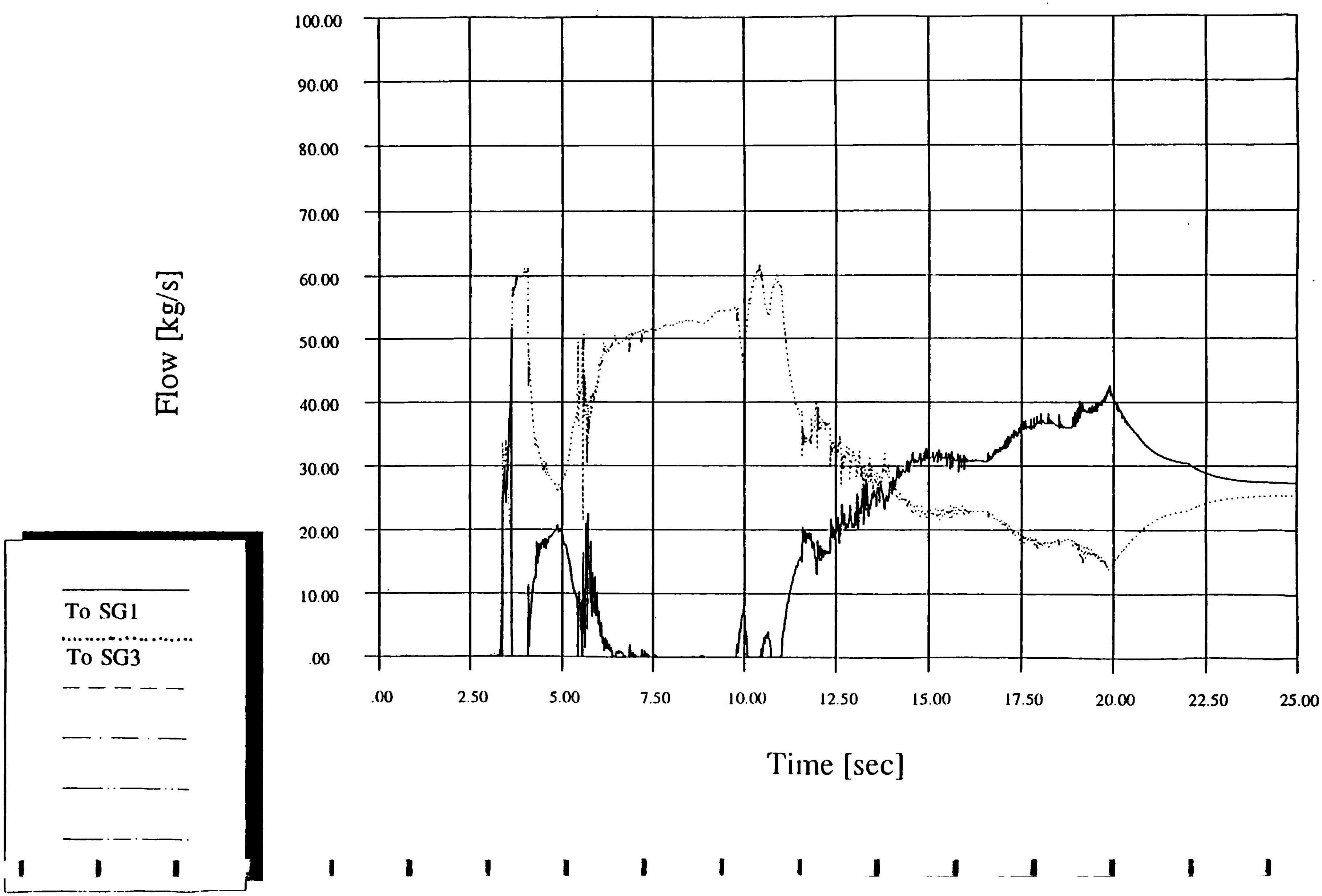

FIGURE 4
SG3-DEAD END FLOW SPLIT

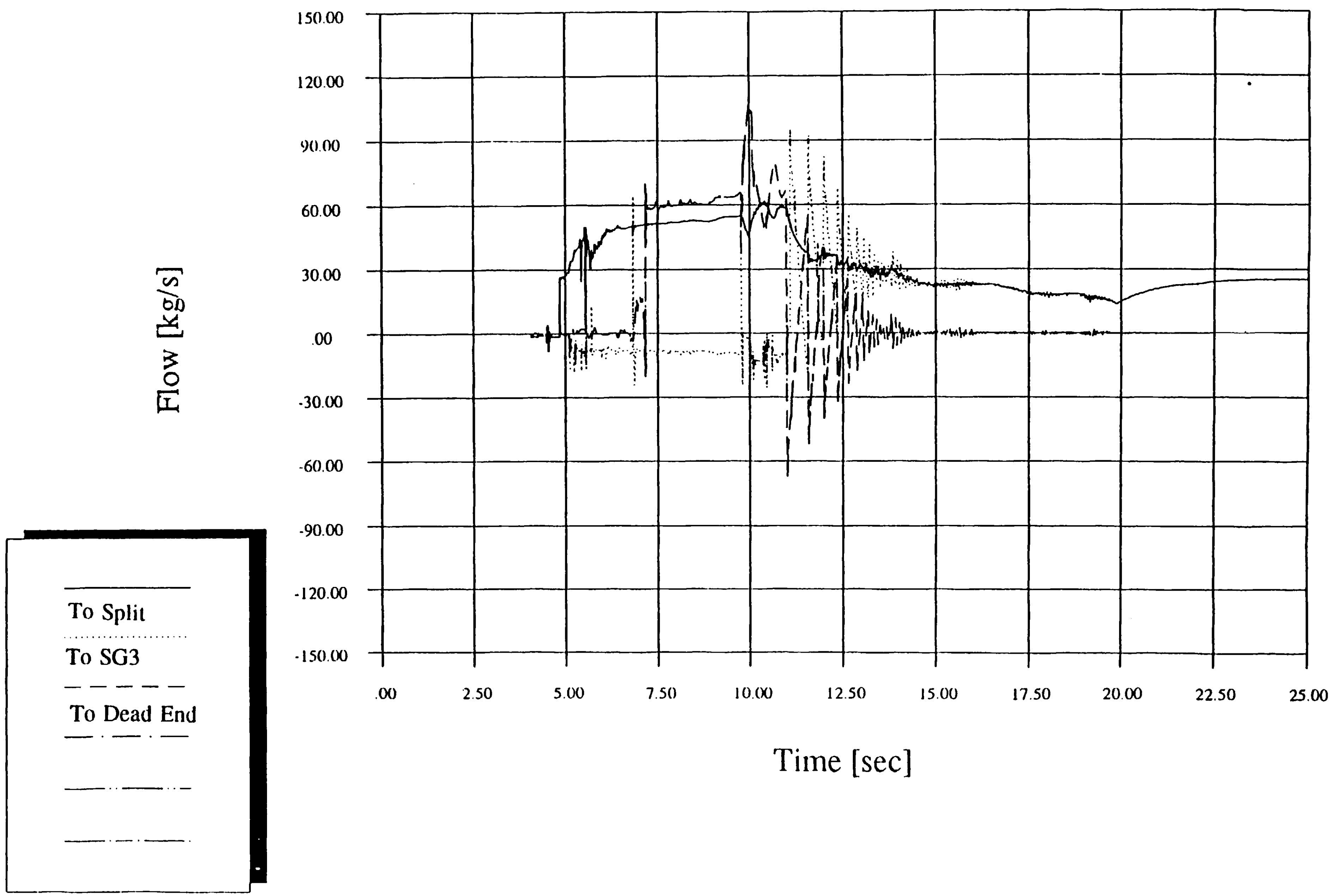

FIGURE 5
REHEAT DEAD END PRESSURE TRANSIENT (SG3)

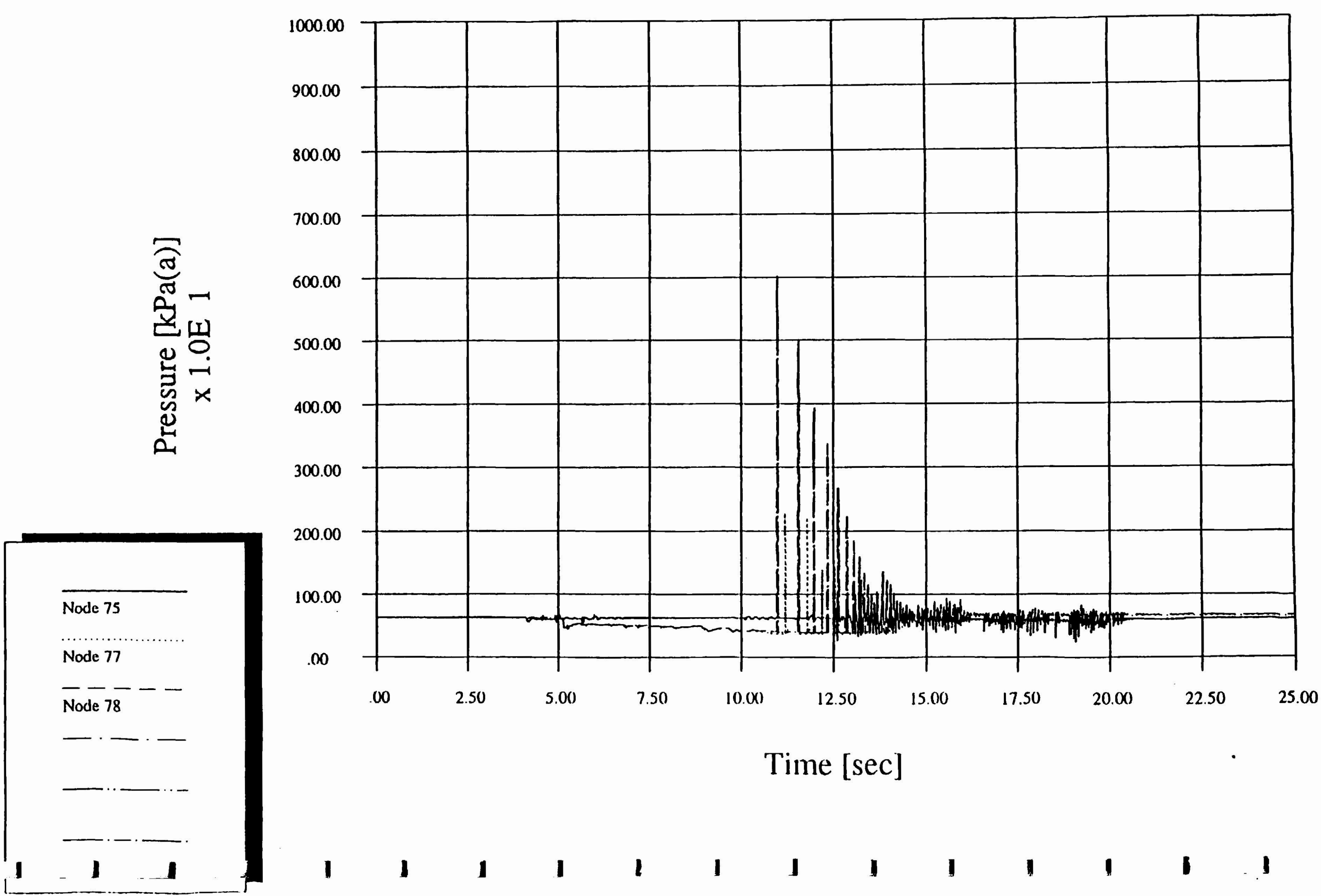

FIGURE 6
SG1-DEAD END FLOW SPLIT

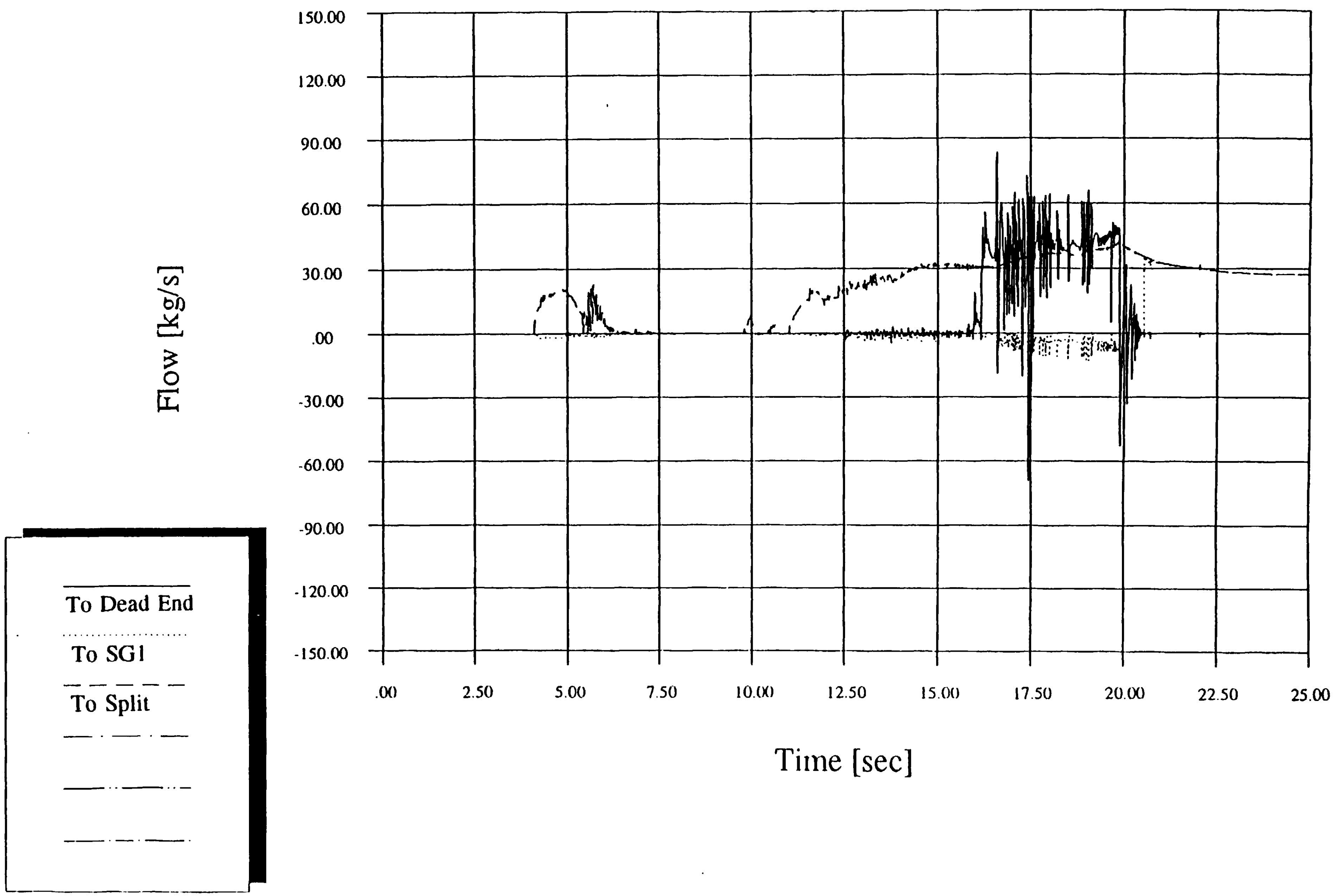

FIGURE 7
REHEAT/IUFWT DEAD END VOID TRANSIENT (SG1)

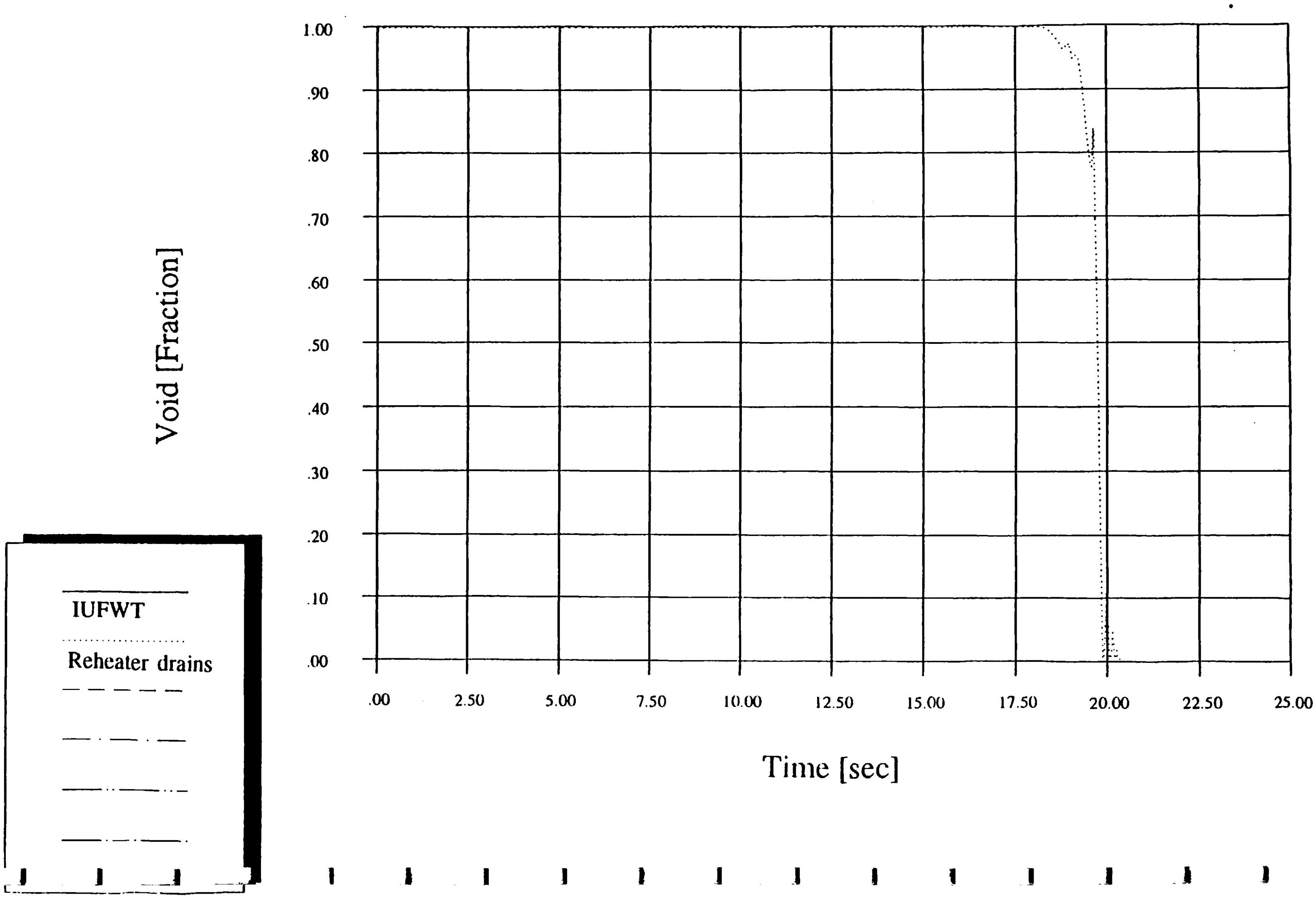

FIGURE 8
REHEAT DEAD END PRESSURE TRANSIENT (SG3)