ENCLOSURE 2

TENNESSEE VALLEY AUTHORITY

BROWNS FERRY NUCLEAR PLANT UNITS 1-3

RHR PUMP PROTECTION AGAINST OPERATION IN EXCESS OF DESIGN RUNOUT

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1.0 INTRODUCTION

The Browns Ferry Nuclear Plant Emergency Core Cooling System (ECCS) design and performance for units 1 and 2 have been the subject of a recent review. This review has led to a proposed change in the system, as reported in reference 1, which provides a significant reduction in the peak cladding temperature for the 7X7 fuel following a postulated recirculation line break. This reduction in peak cladding temperature has been accomplished by elimination of the Low Pressure Coolant Injection (LPCI) System recirculation loop selection and keeping the residual heat removal (RHR) crosstie valve closed.

The operating modes of the LPCI pumps are changed by the LPCI modification such that two pumps discharge to each injection header thereby changing the discharge flow characteristics from that previously established. Additional flow resistance must be added on the discharge side of each pump to ensure satisfaction of net positive suction head (NPSH) requirements at the design runout of each pump that is delivering flow to the postulated recirculation line break. The original LPCI design was evaluated on the same basis and found in need of additional flow resistance.

Major areas of discussion in this report include the RHR pump and system performance with and without the added flow resistance for the three Browns Ferry units. Also considered is the effect of the added flow resistance on the RHR pump test return line flow and flow induced vibration.

2.0 BACKGROUND

During a single failure analysis of proposed modifications to the LPCI mode of RHR System operation for units 1 and 2 at Browns Ferry, a new potential failure was identified which was common to both the original design and the proposed modification. The identified failure occurring after a loss-of-coolant accident (LOCA) could result in short-term RHR pump operation in excess of design runout. This was considered an unacceptable challenge to pump availability since two RHR pumps are required for long-term containment cooling. This potential deficiency was reported to the Nuclear Regulatory Commission (reference 2). The General Electric Company also informed its customers of the problem (reference 3). The details of the failure and the potential effects on emergency core cooling and containment cooling are discussed below.

2.1 Emergency Core Cooling

The original LPCI mode of the RHR system at Browns Ferry was the standard BWR/4 configuration, using four pumps and loop-selection logic. For this design the LPCI injection valves are closed in normal operation and the RHR cross-tie valve is open. On receipt of an accident initiation signal following a recirculation line break in one recirculation loop, the loop selection logic uses a network of pressure transducers to determine which recirculation loop is unbroken. The LPCI injection valve in that loop is signaled to open, the recirculation pump discharge valve in that loop is signaled to close, and LPCI flow from all four pumps is directed to the unbroken loop. Failure of the injection valve to open would disable LPCI entirely. A single failure such as incorrect loop selection would result in flow from all four RHR pumps being lost to the broken loop.

The final ECCS acceptance criteria adopted by the AEC reduced operating flexibility and introduced possible power level restrictions for the standard BWR/4 design with 7X7 fuel. To offset the affect of the new criteria, a modification to the LPCI mode of RHR operation was developed which takes advantage of credit given for the flooding effect achieved through the availability of at least some of the RHR pumps under certain single-failure conditions. For the modified design, the LPCI injection valves and the RHR cross-tie valve are closed in normal operation. On receipt of an accident initiation signal following a recirculation line break in one recirculation loop, both LPCI injection valves are signaled to open, both recirculation pump discharge valves are signaled to close, and the LPCI flow from two RHR pumps is directed to the unbroken loop. The LPCI flow from the other two pumps is lost to the broken loop. A single failure such as a spurious accident signal from the opposite unit would result in LPCI flow from one RHR pump directed to the unbroken loop and one

RHR pump flow lost to the broken loop. Acceptable emergency core cooling under various single-failure conditions is assured by swapping RHR pump motor power supplies and making certain other electrical and mechanical hardware and wiring changes as outlined in reference 1.

The limiting single failure for the modified design is that failure which results in the longest reflood time and consequently the highest peak cladding temperature (PCT). Sensitivity studies have been performed, and reported in reference 1, which demonstrate that a typical limiting failure for a recirculation pump suction line break in the modified system is the failure of the LPCI injection valve in the unbroken loop to open.

For a recirculation pump discharge line break, the complement of ECCS equipment available after single failure is identical to that of the unmodified system following an injection valve failure. The blowdown transient, however, is much less severe for a break in this location because the frictional losses in the suction piping, the eye of the pump, and the pump casing, combine to reduce the effective size of the break. The blowdown is so much less severe that in fact the calculated peak cladding temperature is lower than for the suction side break. The suction line break remains the design basis accident for the modified system, but with a lower calculated peak cladding temperature than for the original LPCI design.

2.2 Containment Cooling

The RHR system operating in the LPCI mode, as discussed in section 2.1, performs a short-term, post-LOCA emergency core cooling function. The RHR system provides a long-term containment cooling function when operating in the containment spray or suppression pool cooling modes. For adequate containment cooling a minimum of two RHR pumps and associated heat exchangers, and two RHR Service Water pumps and associated valving on service water headers which supply the heat exchangers must remain available in the long term.

The availability of an adequate number of RHR pumps for long-term containment cooling was investigated and reported in reference 1. In the LPCI mode of the RHR system in a standard BWR/4 configuration, a single failure could result in all four RHR pumps discharging to a broken recirculation loop. For the modified design, two RHR pumps are assured of discharging to a broken loop without a single failure, and one RHR pump discharging to the break is possible with a single failure. For such cases, it is necessary to assure that the pumps required for long-term containment cooling remain available after operating for a short time at high flow rates with limited net positive suction head.

The flow characteristics of the RHR pumps discharging into a broken recirculation loop will be different from that established for an unbroken loop. The difference results from the loss of jet pump flow resistance (over 50 percent of the total LPCI system flow resistance) when the recirculation loop breaks. Additional flow resistance is required in the LPCI system to limit RHR pump flow to an acceptable value. The effect of any added flow resistance on long-term containment cooling capability must be considered.

Single failures which might influence long-term containment cooling were considered in reference 1. An adequate number of RHR pumps, heat exchangers, and service water pumps were assured for all postulated single failures provided the RHR pumps are protected against excess flow effects.

3.0 RHR PUMP PROTECTION

The protection of RHR pumps against excessive flow experienced when delivering to a broken recirculation loop requires consideration of the minimum flow requirements for adequate ECCS response and containment cooling, and the maximum flows which are commensurate with the estimated available net positive suction head. Since the LPCI modification has been added to Browns Ferry units 1 and 2 but not unit 3, the required protection was evaluated on a unit basis.

The minimum flow requirements for adequate ECCS response were established by General Electric and are given in Table 1. The maximum allowable RHR pump flows were established by TVA on the basis of system flow resistance studies and the pump operating characteristics as determined from the manufacturer's certified pump performance data and verified by in-plant tests. The maximum flow limits were assured by the insertion of a flow limiting orifice plate downstream of each RHR pump as indicated in Table 2. The results are outlined below.

3.1 Pump and System Head and NPSH Curves

Figures 1 through 7 are included to show system head loss and available net positive suction head (NPSH) curves for one, two, three, and four pump operation, with and without a pump protecting orifice. Also shown is typical RHR pump total dynamic head (TDH) and required NPSH curves derived from certified performance curves supplied by the pump manufacturer.

System head loss curves are included for 20 psid and 0 psid (reactor to drywell differential pressure) to show the effect of small variations in pressure drop through the postulated break. RHR pump protection is based on the 0 psid curve. Also shown is the system head loss which will be experienced at 0 psid if the jet pump resistance is removed from the flow path. This will be the system head loss curve for a pump delivering flow to a broken recirculation loop.

Calculated system available NPSH curves are included for 130°F and 170°F suppression pool water temperatures at 0 psig suppression chamber (torus) pressure to show the effect of increasing water temperature during isolation or post-accident heatup. For all cases it is assumed that no credit for containment pressure above atmospheric can be taken when calculating the system available NPSH. Also shown is the benefit to be derived if credit could be taken for containment overpressure (5 psig shown) during short-term heatup.

Pump performance data is shown over the full range certified by the manufacturer. Data extrapolations are indicated to facilitate prediction of performance; however, sustained pump operation at flow rates exceeding the certified data range would have to be verified by additional testing.

In each case, the predicted system flow will be that shown where the pump TDH curve crosses the system head loss curve. The pump NPSH required will be that corresponding to the predicted system flow. Stable pump operation should be assumed if the pump NPSH required does not exceed the system NPSH available for the predicted system flow and torus temperature and pressure conditions.

In view of the importance of assuring adequate NPSH at design runout, tests were performed on an installed RHR pump to determine if additional margin was available in the certified NPSH curves supplied by the pump manufacturer. The Hydraulic Institute procedures for determination of limiting suction requirements prescribe a 3 percent reduction in head at a given flow as a usually accepted criteria for prescribing NPSH. Since pump protection and not loss of head is the principal concern during pump runout, tests were performed to determine the NPSH at which the onset of unacceptable pump vibration and audible cavitation could be detected. These were considered more important evidences of acceptable short-term operating limits.

The NPSH tests were performed at Browns Ferry on the 3A RHR pump while operating in the suppression pool cooling mode. Reduced suction pressures were achieved by throttling a gate valve in the pump suction line. The pump suction pressure was monitored by a Bourdon-type pressure transducer and the installed suction pressure gauge. Pump motor vibration was monitored by two accelerometers at the top of the motor (one in-line and one at right angles to the flow). The pump discharge pressure was monitored at the installed discharge pressure gauge at the local panel. The pressure transducer and the pump motor accelerometer outputs were recorded on high speed strip charts.

The pump NPSH tests were performed at 8,000 and 10,000 gpm. The pump suction throttling was terminated in both cases before the "breakout point" (sudden and severe loss of discharge head) of the pump was reached. The maximum throttling point was selected on the basis of severe audible cavitation but acceptable motor vibration for short-term pump operation. The results of these tests indicate that the certified pump NPSH required curves supplied by the pump manufacturer may be reduced by an additional nine feet of head without adverse effects on short-term pump operation. A reduction of pump discharge head of 10 to 12 percent at a given flow rate was observed but this does not concern the pump protection problem. The results of the tests are given in Table 3.

3.2 Units 1 and 2 Pump Protection

The modified LPCI system head loss and available NPSH curves are shown for one and two pump operation without RHR pump orifice protection in Figures 1 and 2. These curves indicate that when one RHR pump is delivering flow to the break as a design bases (after a single failure), the pump flow rate will try to exceed 15,000 gpm and require pump NPSH which is simply not available in the system. Continued availability of the pump is unlikely and the pressure boundary components and piping may be jeopardized. The same situation applies for two pump operation except that it does not require a single failure for the pump flow to try to exceed 15,000 gpm.

Since it is a design basis to have one or two pump flow to the postulated recirculation line break, it is necessary to add RHR pump protection in the form of a flow restricting orifice at the discharge of each RHR pump. The modified LPCI system head loss and available NPSH curves are shown for one and two pump operation with pump orifice protection in Figures 3 and 4.

With pump orifice protection, one RHR pump will not exceed 12,000 gpm when delivering flow to the break. The calculated system NPSH available exceeds the pump NPSH required until the torus water temperature reaches 152°F (about 100 seconds after the postulated break per reference 4). Above this temperature, credit must be taken for a portion of the proven margin on the pump NPSH required curve discussed in section 3.1. If operator action to align the pumps for containment cooling is assumed in 10 minutes, the torus temperature will be about 160°F and the NPSH deficiency will only be approximately 2 feet. This is well within the 9 foot margin determined by tests to be available.

When two RHR pumps are flowing to the break, each pump flow will not exceed 11,500 gpm. The calculated system NPSH available will exceed the pump NPSH required until the torus water temperature reaches nearly

170°F (over one hour after the postulated break per reference 4). Operator action to trip the pumps is anticipated earlier in the heatup.

3.3 Unit 3 Pump Protection

The system head loss and available NPSH curves for the original LPCI mode of RHR system operation are shown for four pump operation without RHR pump orifice protection in Figure 5. These curves indicate that when four RHR pumps are delivering flow to a recirculation line break (due to a single failure), each pump flow rate will try to exceed 14,000 gpm and require pump NPSH which is significantly greater than that available in the system. Continued availability of the pumps for long-term use is questionable and pressure boundary leakage may develop.

Since it is a design basis to accept a loop selection logic failure, it is necessary to add RHR pump protection in the form of a flow restricting orifice at the discharge of each RHR pump. Even if the loop selection logic error were excluded as a single failure by appropriate design, it would be necessary to consider the failure to close of the recirculation line discharge valve in the unbroken loop. This failure to close would provide a low resistance flow path to the broken loop about equivalent to a direct flow path to the break. The original LPCI head loss and available NPSH curves for four pump operation with pump orifice protection are shown in Figure 6.

With pump orifice protection, the flow from each of four RHR pumps will not exceed 12,300 gpm when delivering flow to the break. The calculated system NPSH available exceeds the pump NPSH required until the torus water temperature reaches 152°F (about 100 seconds after the postulated break per reference 4). Above this temperature, credit must be taken for a portion of the proven margin in the pump NPSH required curve as discussed in section 3.2.

3.4 Verification of Emergency Core Cooling Flows

The RHR pump protection orifice will restrict the ability of each RHR pump to deliver flow to the unbroken recirculation loop. The minimum total RHR pump flow requirements for adequate ECCS response are those given in Table 1. An inspection of Figures 3 and 4 indicate that Table 1 minimum flow objectives are exceeded on a calculational basis for units 1 and 2. A similar inspection of Figure 7 indicates that the objectives are also exceeded on a calculational basis for unit 3.

To back up the calculations, tests were performed by TVA to verify the RHR system capability to meet the minimum pump flow requirements indicated in Table 1. For those tests, the RHR system was aligned in the LPCI mode with the RHR pumps taking suction from the suppression chamber and discharging through their respective pump protection orifice plates directly to the reactor vessel. The tests were performed on unit 3 but with the unit 1 and 2 pump protection orifice plates installed where applicable. The results of these tests are given in Table 4. All flow requirements stated in Table 1 were exceeded with adequate margin. The corresponding small increase in NPSH required to accommodate a larger than predicted flow to a broken loop was well within the margin in NPSH demonstrated for the pumps in section 3.1. The test results compared favorably with the calculations.

The RHR pump NPSH available was also measured during the test to verify the NPSH calculational methods used as a basis for the system NPSH available curves shown in Figures 1 through 7. The results are given in Table 5. The suppression pool temperature during testing was 90°F. The test results verify that the calculational methods yield conservative results.

Periodic surveillance tests are proposed to reverify pump performance. This will be achieved by establishing equivalent pump flows and discharge pressures in the RHR test return line. Proposed RHR pump flow and discharge pressure acceptance criteria are given in Table 6.

4.0 RHR PUMP TEST RETURN LINE FLOW AND FLOW INDUCED VIBRATION

The long-term containment cooling function of the RHR system, as discussed in section 2.2, requires that the flow of two RHR pumps pass through their associated RHR heat exchangers and through a single RHR test return line to the suppression pool to provide the required cooling. Both test return lines are not available for flow return because of certain postulated single failures.

The large flow in one 18-inch test return line has introduced troublesome flow-induced vibrations downstream of the 12-inch globe valve used to throttle the flow. The problem has been reported to the Nuclear Regulatory Commission (reference 5). The proposed solution has been to add a flow restricting orifice downstream of the 12-inch globe valve and thereby provide significant back pressure on the valve. Tests have verified that the back pressure effectively reduces downstream cavitation and its associated induced vibrations.

The addition of the RHR pump protection orifice has greatly reduced the allowable pressure drop for the cavitation suppressing orifice. As a result, this method of limiting flow induced vibration is no longer viable in all cases as discussed below. In addition, the RHR pump protection orifice is limiting the available flow in the test return line.

4.1 Flow and Vibration Tests

After installation of the RHR pump protection orifice and the RHR test return line orifice plates identified in Table 2, several tests were performed to determine their effect on test return line flow and flow induced vibration downstream of the 12-inch globe valve. Typical results of the flow tests are included in Table 7. General Electric established a minimum flow requirement of 8,000 gpm for each of two RHR pumps and associated heat exchangers for long-term containment cooling on each Browns Ferry unit.

The readings given in Table 7 were taken from a flow meter in the test return line. On all units, the test return line flow meter consistently reads somewhat lower than the flow meter in the combined pump discharge line. The lower reading is thought to be due to the close proximity of the flow element to the upstream branch connection to a Tee.

Southwest Research Institute (SwRI), under contract to TVA, investigated the flow induced vibration effects. SwRI has not completed its report on the tests, but preliminary results and recommendations are included below.

4.2 Units 1 and 2 Flow and Vibration Verification

The results included in Table 7 for units 1 and 2 are typical of those observed during testing. They meet the minimum flow requirements established by General Electric for two RHR pump operation but with little or no margin.

Preliminary results on the vibration measurements performed by SwRI indicate that cavitation and vibration levels have been reduced very little from those observed earlier without the pump or test return line orifice plates (original design). The very large hole required in the test return line orifice plate because of the addition of the RHR pump protection orifice has rendered it relatively ineffective in reducing cavitation. The SwRI recommendation is to replace the 12-inch globe valve with a drag-type valve (or equivalent) of appropriate size.

4.3 Unit 3 Flow and Vibration Verification

The results indicated in Table 7 for unit 3 are typical of those observed during testing. They exceed the minimum flow requirements established by General Electric for two RHR pump operation but with limited margin.

Preliminary results on the vibration measurements performed by SwRI indicate that cavitation and vibration levels have been reduced significantly from those observed earlier without the pump or test return line orifice plates (original design). However, the relatively large hole required in the test return line orifice plate, because of the addition of the RHR pump protection orifice, has rendered it somewhat ineffective in reducing cavitation to very low levels. SwRI is also recommending the replacement of the 12-inch globe valve with a drag-type valve (or equivalent) of appropriate size on unit 3.

4.4 Proposed Corrective Measures

TVA is taking steps to replace the 12-inch globe valve in the test return line with a larger globe valve and orifice plate combination or with a drag-type valve (or equivalent) on all Browns Ferry units. This commitment is intended to provide increased margins in the test return line flow and reduce the flow induced vibrations downstream of the valve to low values. After installation of the new valves, flow and vibration measurements will be taken to verify the final configuration.

Prior to replacement of the valves, the test return lines on units 1 and 2 will not be operated at high flows (≥ 12,000 gpm) unless required for special testing or emergency operation. This restriction has been recommended by SwRI and should minimize flow-induced vibration and associated fatigue. In addition, the test return line orifice plates will be removed from units 1 and 2 because of their ineffectiveness. A sparger will be installed on each test return line discharge to disperse the flow. Whenever feasible, both test return lines will be used to avoid prolonged high flow operation. The test return lines on unit 3 will be equipped with orifice plates and spargers. The effect of spargers on test return line flow and vibration was gound during testing to be inconsequential. They are being added to minimize suppression chamber flow induced vibration. There will be no operating restrictions on unit 3.

5.0 SUMMARY AND CONCLUSIONS

The application of the LPCI system modification to Browns Ferry units 1 and 2 with 7X7 fuel adds to the overall capability of the plant to continue operation in a manner that ensures the health and safety of the public while providing benefit in the production of electrical energy.

Adequate RHR pump protection against operation in excess of design runout has been provided and demonstrated for the modified units 1 and 2. RHR test return line flow is within NSSS vendor requirements but flow induced vibration still exceeds long-term objectives. Replacement valving will be provided which will add substantial margin to the flow and reduce the vibration to lower levels.

RHR pump protection has been added to Browns Ferry unit 3 to assure protection against RHR pump operation in excess of design runout. RHR test return line flow on unit 3 has been verified to be within NSSS vendor requirements and flow induced vibration is relatively low. However, replacement valving will also be provided on unit 3 to enhance the flow margin and reduce vibration further.

6.0 REFERENCES

1. "Browns Ferry Nuclear Plant Units 1 and 2 Emergency Core Cooling Systems Low Pressure Coolant Injection Modifications for Performance Improvement," Revision 1, February 1976 (Transmitted by letter from J. E. Gilleland, TVA, to B. C. Rusche, NRC, dated February 12, 1976).

2. "Browns Ferry Nuclear Plant Unit 3 Potential for RHR Pump Operation in Excess of Design Runout," DDR 224 Interim Report (Enclosure to letter from J. E. Gilleland, TVA, to D. F. Knuth, NRC, dated March 4, 1976).

3. "Long-Term Containment Cooling Requirements for BWR/3 and BWR/4 Plants," General Electric Plant Services Information Letter SIL No. 151, dated February 18, 1976.

4. Figure 14.6-12, "Torus Water Temperature After LOCA," Browns Ferry Nuclear Plant Final Safety Analysis Report.

5. "Browns Ferry Nuclear Plant Units 2 and 3 Potential for Failure of the Weld Between the Yoke and Motor Mounting Plate for Flow Control Valves (FCV's) 74-58 and 74-72," DDN 191 Eighth Interim Report (Enclosure to letter from J. E. Gilleland, TVA, to J. G. Davis, NRC, dated March 30, 1976).

TABLE 1

MINIMUM TOTAL RHR PUMP FLOW
REQUIREMENTS FOR ADEQUATE ECCS RESPONSE
(At 0 psid Reactor to Drywell)

	BFNP Units 1 and 2 (gpm)	BFNP Unit 3 (gpm)
One RHR Pump) One RHR Loop) One LPCI Path)	10,800	
Two RHR Pumps) One RHR Loop) One LPCI Path)	20,000	
Three RHR Pumps) Two RHR Loops) One LPCI Path)		28,200

TABLE 2

RHR PUMP PROTECTION AND TEST RETURN LINE
SQUARE-EDGE ORIFICE PLATE HOLE SIZES

	BFNP Units 1 and 2 (in.)	BFNP Unit 3 (in.)
RHR Pump Protection Orifice	6.8	7.9
RHR Test Return Line Orifice	11.3	9.6

TABLE 3

RHR PUMP NPSH REQUIRED

Flow Rate (gpm)	Certified by Mfr. (ft)	Measured by TVA (ft)
8,000	25.0*	14.2
10,000	25.5	16.4
12,000	34.5	25.0*

*By extrapolation.

TABLE 4

TOTAL RHR PUMP FLOW
TEST RESULTS IN LPCI MODE
(With Pump Protection Orifice Plates Installed)

	BFNP Units 1 and 2* (gpm)	BFNP Unit 3 (gpm)
One RHR Pump) One RHR Loop) One LPCI Path)	11,100	
Two RHR Pumps) One RHR Loop) One LPCI Path)	20,900	
Three RHR Pumps) Two RHR Loops) One LPCI Path)		30,500

*Test performed on unit 3 using units 1 and 2 orifice plates.

TABLE 5

RHR PUMP NPSH AVAILABLE
TEST RESULTS IN LPCI MODE
(At 90°F)

	BFNP Units 1 & 2*		BFNP Unit 3	
	Calc. (ft.)	Meas. (ft.)	Calc. (ft.)	Meas. (ft.)
One RHR Pump) One RHR Loop) One LPCI Path)	42.0	45.2		
Two RHR Pump) One RHR Loop) One LPCI Path)	41.5	44.2		
Three RHR Pumps) Two RHR Loops) One LPCI Path)			41.8	44.1

*Test performed on unit 3 using units 1 and 2 orifice plates.

TABLE 6

PERIODIC RHR PUMP SURVEILLANCE
FLOW AND DISCHARGE PRESSURE ACCEPTANCE CRITERIA

	BFNP Units 1 and 2		BFNP Unit 3	
	(gpm)*	(psig)**	(gpm)*	(psig)**
One RHR Pump) One RHR Loop) One Test Return Line)	≥9,000	≥125		
Two RHR Pumps) One RHR Loop) One Test Return Line)	≥15,000	≥200		
Three RHR Pumps) Two RHR Loops) Two Test Return Lines) (equal flow split)			≥28,200	≥160

*Combined pump flow.
**Pump discharge pressure.

TABLE 7

TYPICAL RHR TEST RETURN LINE FLOW
(With Pump Protection and Test Return Line Orifice Plates Installed)

	BFNP Units 1 and 2 (gpm)	BFNP Unit 3 (gpm)
One RHR Pump One RHR Loop One Test Return Line	10,500	11,500
Two RHR Pumps One RHR Loop One Test Return Line	16,000	16,500

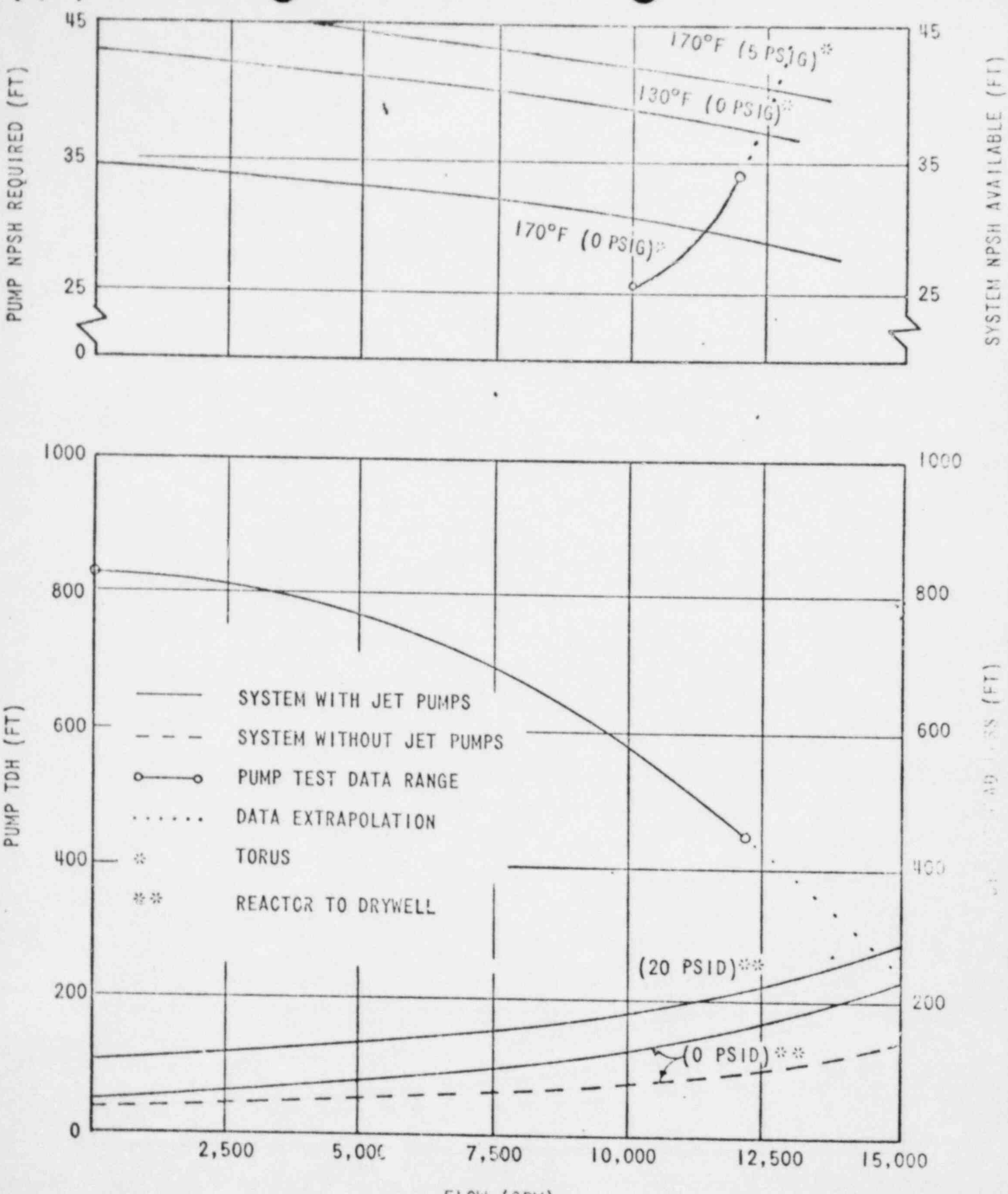

FIGURE 1 MODIFIED LPCI SYSTEM--ONE PUMP RUNNING WITHOUT PUMP ORIFICE

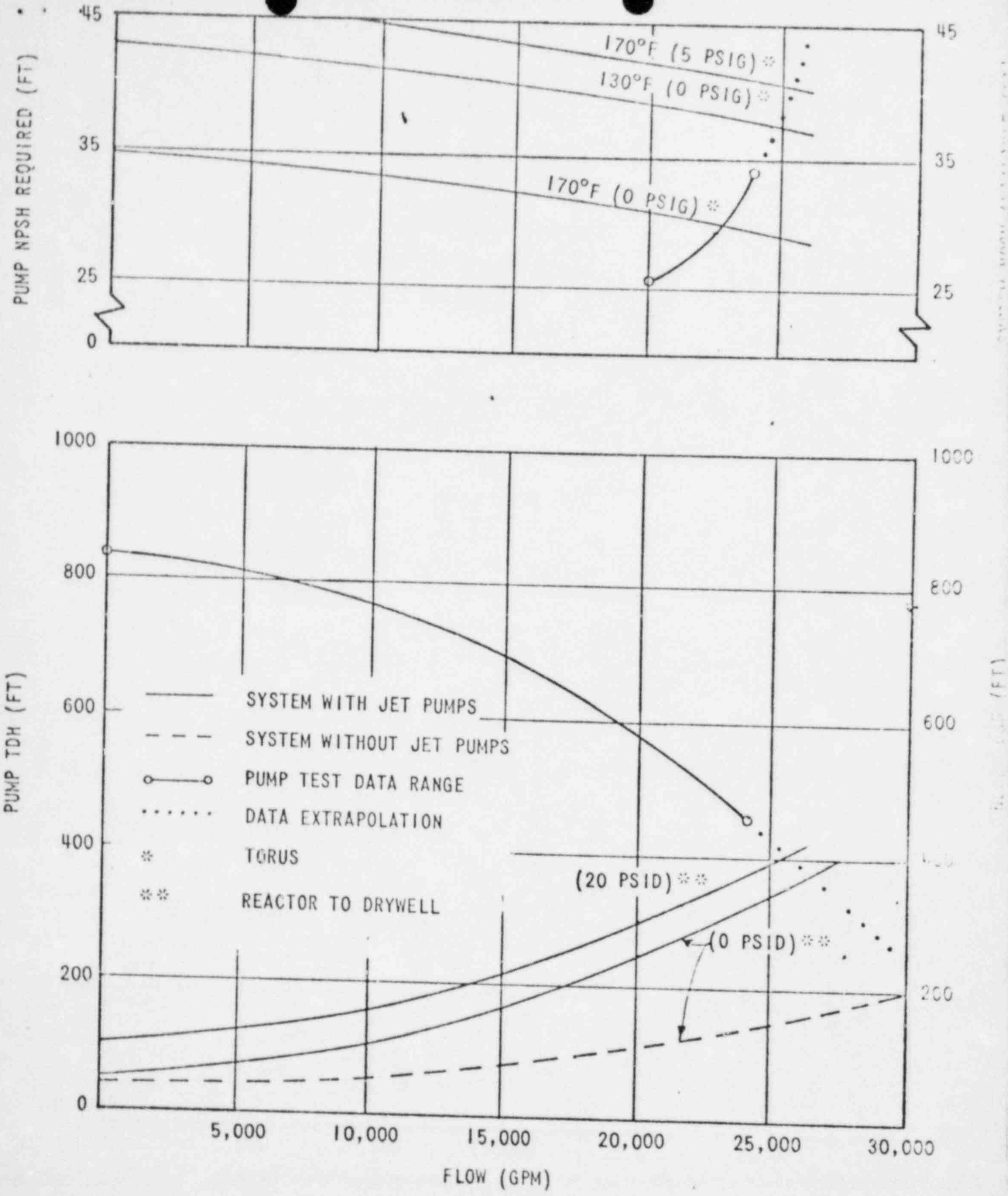

FIGURE 2 MODIFIED LPCI SYSTEM--TWO PUMPS RUNNING EACH WITHOUT PUMP ORIFICE

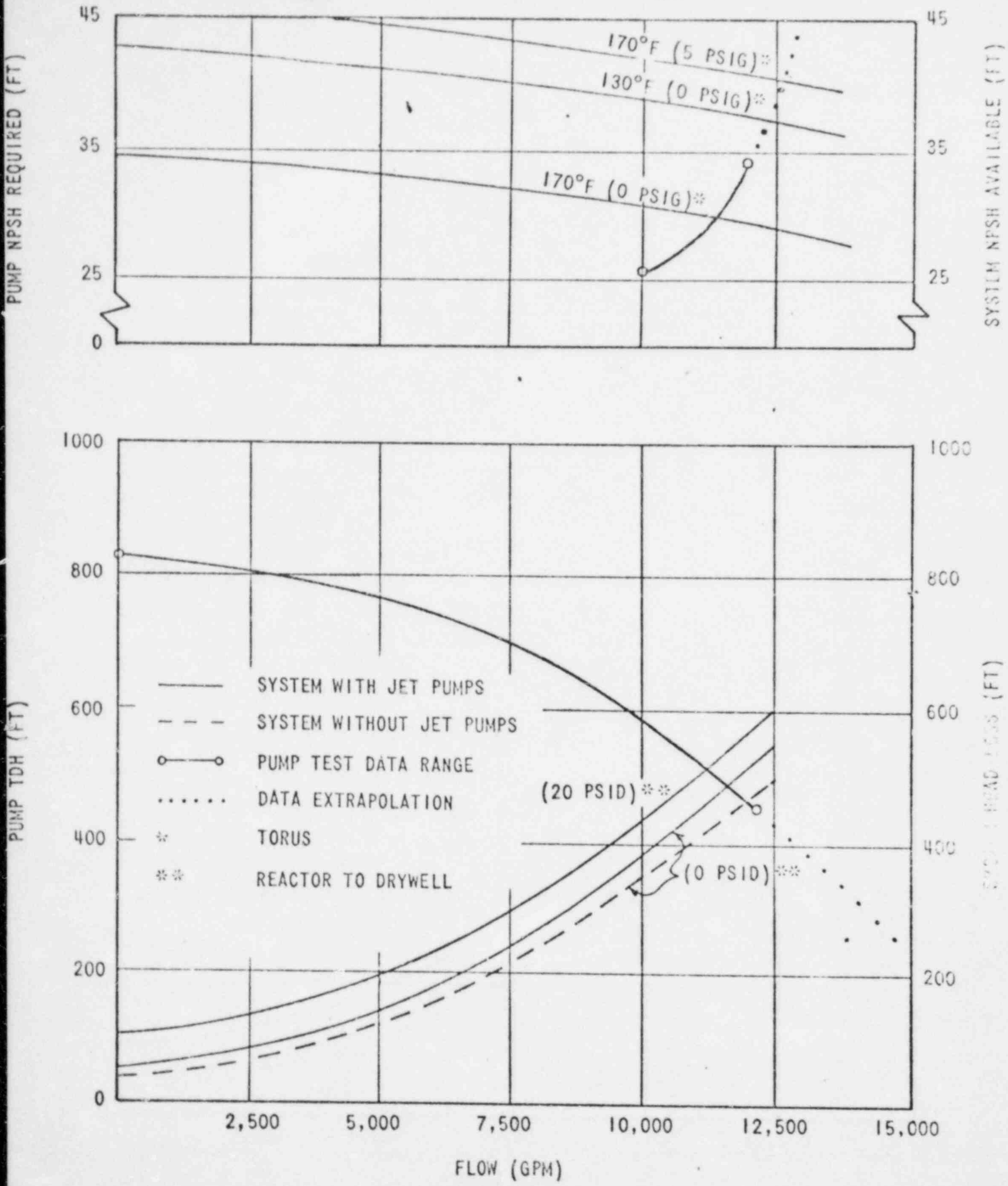

FIGURE 3 MODIFIED LPCI SYSTEM--ONE PUMP RUNNING WITH PUMP ORIFICE

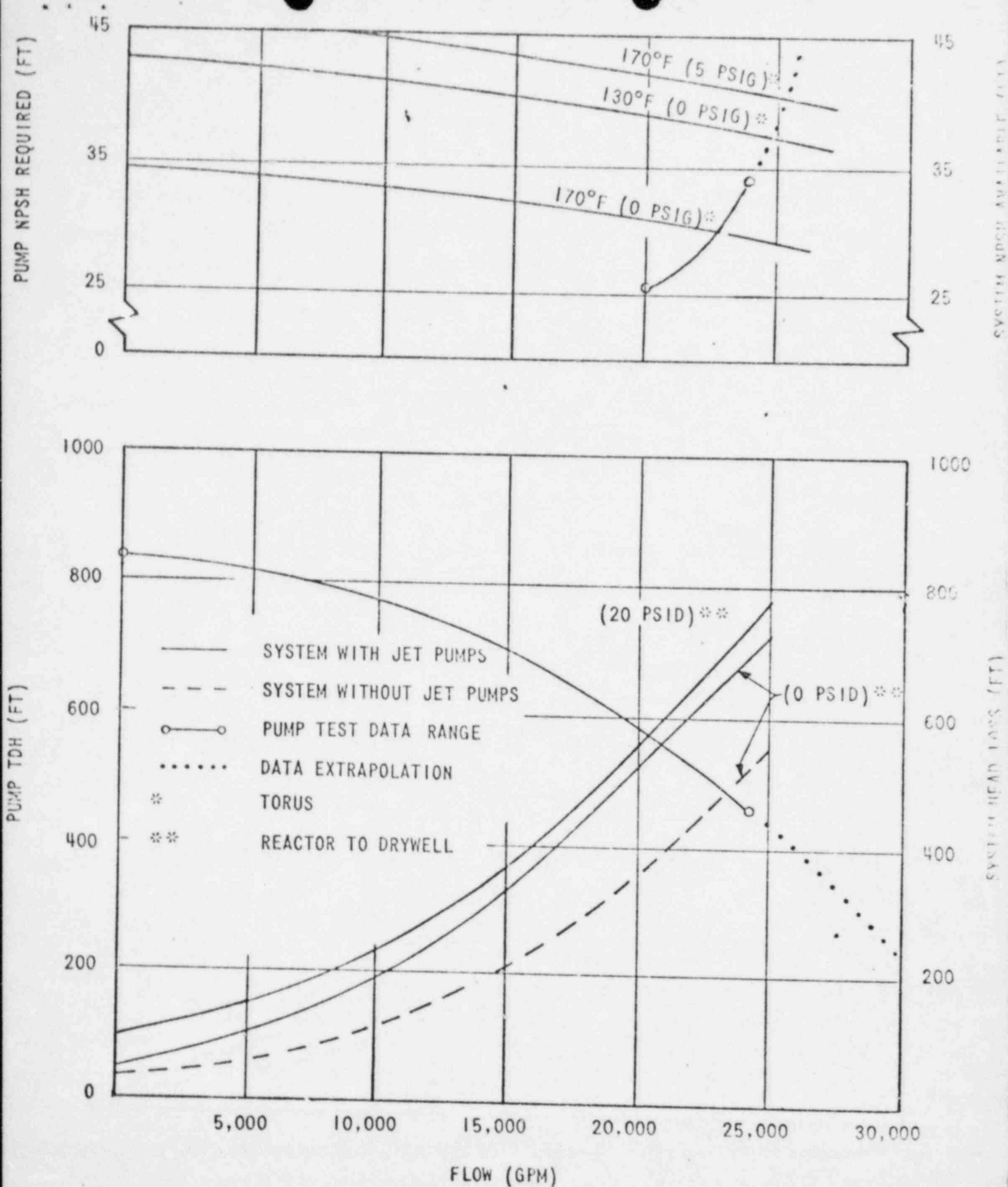

FIGURE 4 MODIFIED LPCI SYSTEM--TWO PUMPS RUNNING EACH WITH PUMP ORIFICE

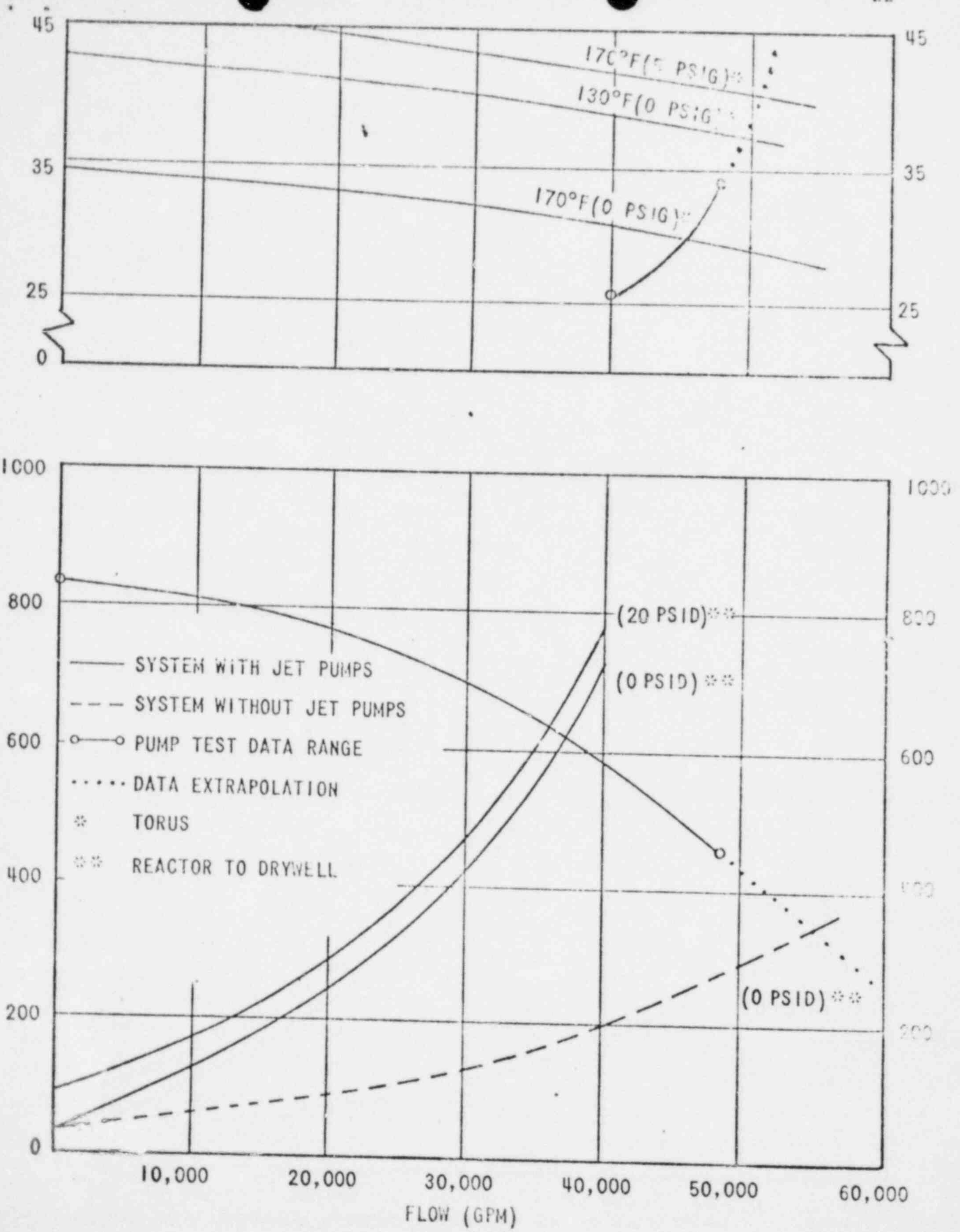

FIGURE 5 ORIGINAL LPCI SYSTEM-- FOUR PUMPS RUNNING EACH WITHOUT PUMP ORIFICE

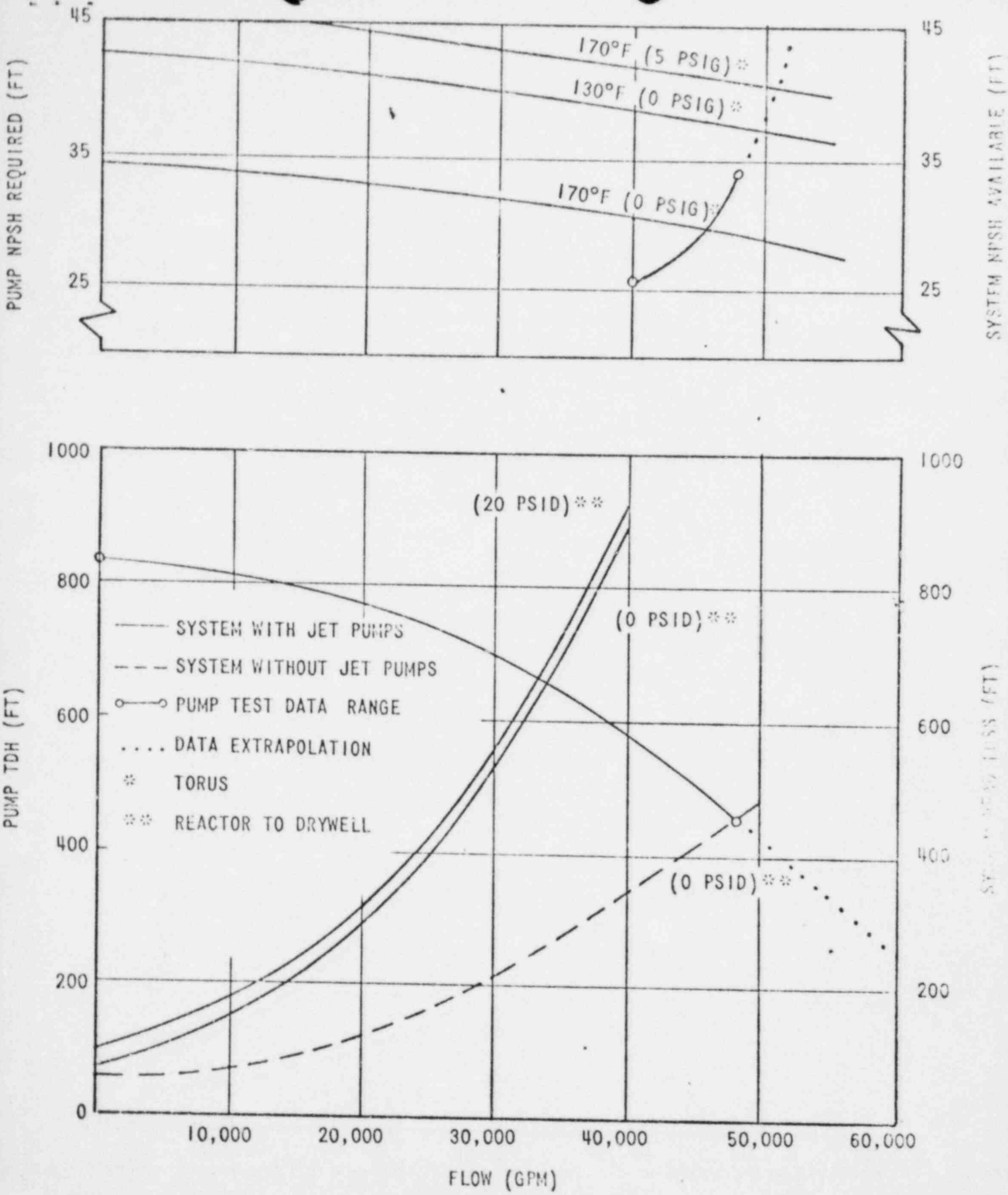

FIGURE 6 ORIGINAL LPCI SYSTEM--FOUR PUMPS RUNNING EACH WITH PUMP ORIFICE

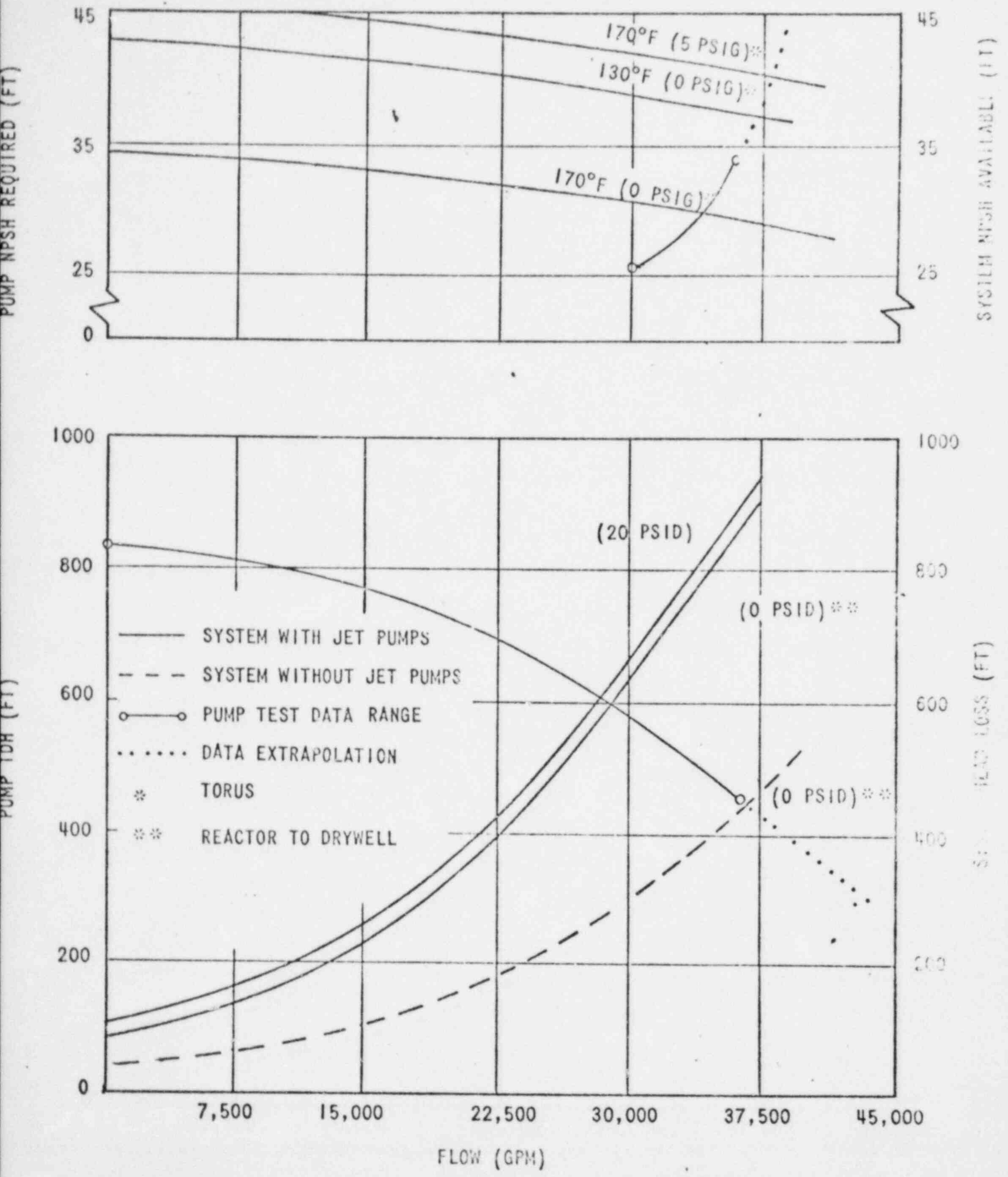

FIGURE 7 ORIGINAL LPCI SYSTEM--THREE PUMPS RUNNING EACH WITH PUMP ORIFICE

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