14057-U(D)-1

SUPPRESSION POOL TEMPERATURE ANALYSIS

PREPARED FOR
WASHINGTON PUBLIC POWER SUPPLY SYSTEM

By
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SUMMARY

Calculations have been performed for six cases for WPPSS Nuclear Project No. 2 as required by Contract C-0699 using the CONTORT code.

The results for all of the requested cases are presented in the following table. The suppression pool temperature, reactor vessel pressure and coolant temperature transient response curves are shown in Figures 1 through 18.

Case No.	Accident	Single Failure	Peak Pool Temperature, °F
1a	Stuck open safety Relief Valve (SORV)	1 RHR system	190
1b	SORV	Spurious isolation	178
2a	Isolation/scram	1 RHR system	196
2b	Isolation/scram	SORV at scram	171
3b	Small break accident	Shutdown cooling	174
3c	Small break accident	Electrical division	198

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INTRODUCTION

The purpose of this analysis is to predict the transient temperature response of the WNP-2 suppression pool for six accident conditions selected by WPPSS.

CONCLUSIONS

1. The peak predicted bulk temperatures for four of the six cases investigated were equal to or less than the 190° guideline for maximum suppression pool bulk temperatures given by NUREG-0487. The other two cases (2A and 3C) fall within the limits of NUREG-0783. In applying the NUREG-0783 criteria, a maximum bulk temperature of 205°F (corresponding to a quencher submergence of 17 ft) is allowable.

2. The most important single failure is loss of one RHR system. The cases which yield the highest peak temperature all have one RHR system as the single failure.

ANALYSIS METHOD

The CONTORT code was used for the analysis in accordance with the assumptions contained herein, which were agreed upon in the September 25, 1981 coordination meeting held in Stone & Webster (SWEC) offices at the Denver Operations Center.

CONTORT is designed to analyze the reactor and containment system transient during normal and abnormal shutdown of the reactor system. The program uses a finite difference technique using input specified time steps to solve the transient equations. In each time step, the program determines the mass and energy flow across all control volumes and performs thermodynamic state calculations for the reactor vessel and suppression pool assuming saturated equilibrium conditions.

Major output from CONTORT is the suppression pool temperature and reactor vessel pressure response.

DISCUSSION

This analysis shows the strong dependence on RHR pool cooling. All of the cases in which only one RHR is available for pool cooling yield the highest pool temperatures.

Case 1a is strongly dependent on how long the main condenser is available as a heat sink.

For SORV cases, the pool was assumed to be heated from 90°F to 110°F before the operator manually scrams the reactor as required by the technical specifications. The initial pool temperature, therefore, was input as 110°F. The initial pool volume was adjusted for the mass of steam, transferred to the suppression pool through the stuck open relief valve, that is required to raise the pool temperature from 90°F to 110°F. Final pool mass and the time for the pool temperature to go from 90°F to 110°F were solved from two simultaneous equations. All of the computer runs start at t=0, the time of the scram.

This analysis was performed with the assumption that reactor water level is maintained by hot feedwater and CRD flow only. Feedwater is terminated and reactor core makeup is supplied by LPCI drawing suction from the suppression pool when either the enthalpy of the feedwater becomes less than the enthalpy of the pool, or the feedwater supply is exhausted, whichever comes first. All other ECCS systems were not utilized.

The effective flow area of 0.1185 ft^2 for SRV was determined in the following manner:

1. SRV flow at rated reactor vessel pressure (1020 psia) and 122.5 percent of rated ASME flow is calculated.

2. The maximum steam mass flux, lbm/ft^2 sec, (Moody) assuming saturated steam at rated reactor vessel pressure (1020 psia) is determined from Reference 4.

3. The effective flow area of the safety relief valve is calculated by dividing the SRV flow rate by the Moody mass flux.

An analysis was made by SWEC at the Cherry Hill, N. J. office to benchmark the CONTORT results to the G. E. Code HEX, and was reported to Pennsylvania Power & Light Company for Susquehanna Steam Electric Units 1 & 2 (Docket Nos. 50-387 and 50-388, respectively). The CONTORT results agree very well with the HEX results, with CONTORT predicting peak temperature about 2^{o}F lower than HEX.

ASSUMPTIONS

The following are assumptions which have been utilized in the analysis. These assumptions are in agreement with Reference 2.

I. Assumptions For All Cases

1. Reactor power at the time of the scram is 102 percent of rated core power.

2. Service water temperature is maximum and identical to value used in FSAR for containment analysis.

3. The initial supppression pool temperature is the maximum technical specification limit for power operation without pool cooling.

4. The initial suppression pool volume is the minimum technical specification limit for power operation.

5. The safety relief valve flow is assumed to be 122.5 percent of the ASME rated flow rate.

6. The RHR pool cooling mode is initiated 10 minutes after exceeding the technical specification limit for continuous power operation, TS1 (90^oF).

7. Main steam line isolation valve (MSIV) closure time is assumed to be 3 seconds following an 0.5 second delay.

8. The reactor cooldown rate for manual depressurization by safety relief valves (SRV) is $100^oF/hr$, and begins after the suppression pool temperature exceeds TS4 (120^oF), unless the depressurization rate for the event itself (e.g. SORV) exceeds the required rate at that time. To maintain the $100^oF/hr$ cooldown rate requires the actuation from one to seventeen SRV's, depending on reactor vessel pressure.

9. The mass of water contained inside the reactor vessel pedestal is neglected.

10. The energy absorbed by the containment heat sinks is neglected.

11. Reactor water level is maintained by feedwater and CRD flow. Feedwater flow is terminated when the enthalphy of the feedwater is less than or equal to the enthalpy of the suppression pool. The feedwater is then replaced by LPCI taking suction from the suppression pool.

12. The RHR pool cooling pumps have 100 percent of their horsepower rating added directly to the suppression pool.

13. The generic G. E. decay heat curve, which is combined with power coastdown, is used in the analysis.

II. Case-Specific Assumptions

a. Case 1a SORV at power

- One RHR heat exchanger is lost.
- Shutdown cooling is not available.
- The safety relief valve sticks open at a pool tempature of 90°F(TS1).
- Manual scram occurs at a pool tempature of 110°F (TS3); Time = 0 for the analysis.
- The turbine stop valves are closed 20 seconds after scram.
- MSIV's do not close.
- One RHR is in pool cooling mode 10 minutes after high pool temperature alarm (90°F).
- The bypass flow to the main condenser is re-established 20 minutes after SORV accident with full bypass (25% of rated steam flow) capability.
- The use of main condenser is terminated when steam jet air ejector (SJAE) design pressure is reached. Depressurization continued using SRV's for 100°F/hr manual depressurization.

b. Case 1b SORV at Power

- Two RHR heat exchangers are available for pool cooling.
- Shutdown cooling is not available.
- The SRV sticks open at a pool temperature of 90°F (TS1).
- The operator scrams reactor at a pool temperature of 110°F (TS3). Due to a spurious signal, main steam isolation valves closure is initiated, with 3.5 seconds closure time. Time = 0 for the analysis.
- Two RHR's are in the pool cooling mode 10 minutes after high pool temperature alarm (90°F).
- Manual depressurization is initiated at a cooldown rate of 100°F/hr when pool temperature is 120°F.

c. Case 2a Isolation/Scram

- One RHR heat exchanger is lost.
- Shutdown cooling is not available.

- Isolation/scram occurs at a pool temperature of 90°F. Time = 0 for the analysis.

- The non-mechanistic closure of the MSIV's is in 3.5 seconds.

- One RHR is in pool cooling mode 10 minutes after high pool temperature alarm (TS1=90°F).

- Manual depressurization is initiated at a cooldown rate of 100°F/hr when pool temperature is 120°F.

d. Case 2b Isolation/Scram

- Two RHR heat exchangers are available for pool cooling.

- Shutdown cooling is not available.

- Isolation/scram occurs at a pool temperature of 90°F. Time = 0 for the analysis.

- The non-mechanistic closure of the MSIV's is in 3.5 seconds.

- Safety relief valve sticks open at the time of the scram and cannot be closed.

- Two RHR heat exhangers are in the pool cooling mode 10 minutes after the pool high temperature alarm (90°F).

- Manual depressurization is initiated at a cooldown rate of 100°F/hr when pool temperature is 120°F, unless SORV gives a cooldown rate higher than 100°F/hr.

e. Case 3b Small Break Accident

- Two RHR heat exchangers are available for pool cooling.

- Shutdown cooling is not available.

- A small steamline rupture occurs at a pool temperature of 90°F. Time = 0 for analysis. Flow area from break = 0.01 ft^2.

- Scram at Time = 0 with non-mechanistic is 3.5 seconds MSIV closure time.

- Two RHR heat exchangers in the pool cooling mode 10 minutes after high pool temperature alarm (90°F).

- Manual depressurization is initiated at a cooldown rate of 100°F/hr when pool temperature is 120°F.

- Both RHR's switch to LPCI mode when the reactor vessel pressure equals the RHR pump shutoff head (333 psia), with a 10-minute delay for the operator to convert manually back to pool cooling.

f. Case 3c Small Break Accident

- One RHR heat exchanger is available for pool cooling.
- Shutdown cooling is not available.
- A small steamline rupture occurs at a pool temperature of 90°F (Time = 0) Flow area from break = 0.01 ft^2.
- The scram at Time = 0 on high drywell pressure.
- The isolation of MSIV's at Time = 0 with non-mechanistic 3.5 seconds closure time.
- One RHR heat exchanger is in the pool cooling mode 10 minutes after the high pool temperature alarm.
- Manual depressurization is initiated at a cooldown rate of 100°F/hr when pool temperature is 120°F.
- The RHR switches to LPCI mode when the reactor vessel pressure equals the RHR pump shutoff head (333 psia), with a 10-minute delay for the operator to convert manually back to pool cooling.

PERTINENT INPUT PARAMETERS

Initial reactor vessel pressure	1,020 psia
Initial reactor vessel liquid volume	13,189 ft^3
Total reactor vessel volume	23,625 ft^3
Initial pool temperature (Isolation/scram, SBA)	90°F
Initial pool temperature (SORV cases)	110°F
Initial pool volume (Isolation/scram, SBA)	127,007 ft^3
Initial pool volume (SORV cases)	129,774 ft^3
Feedwater flow rate	3,997 lbm/sec
CRD flow rate	16.8 lbm/sec
CRD enthalpy	68 Btu/lbm
Feedwater "on" volume	13,090 ft^3
Feedwater "off" volume	13,290 ft^3

Feedwater Inventory and Associated Enthalpy

Mass (lbm)	Enthalpy (pipe & fluid) (Btu/lbm)
134,226	386
187,826	326
370,952	208
200,000	152

LPCI rated flow	= 7,450 gpm
LPCI pump heat	= 566 Btu/sec
RHR heat exchanger K factor	= 289 Btu/sec°F
RHR pump heat per pump	= 566 Btu/sec
Minimum reactor vessel pressure required for discharging flow through SRV (SORV, Isolation/scram)	= 22.8 psia
Minimum reactor vessel pressure required for discharging flow through SRV (SBA cases)	= 20.7 psia
Safety relief valve effective flow area	= 0.1185 ft^2
Safety relief valve open to close band width	= 50 psi

Input for Automatic SRV's

No.	Open Pressure (psia)	Close Pressure (psia)
2	1,091	1,041
4	1,101	1,051
4	1,111	1,061
4	1,121	1,071
4	1,131	1,081

Reactor thermal power (102 percent of rated)	3,389 MW
Mass of reactor vessel and internals	2.89×10^6 lbm
Specific heat of reactor vessel & internals	0.12 Btu/lbm ^oF
Service water temperature	85^oF
Steam ejector design pressure (lower limit of RVP for discharge of steam to main condenser)	140 psia
RHR pump shutoff discharge pressure (LPCI injection valve pressure permissive to take RHR out of pool cooling)	333 psia

REFERENCES

1. Supply System Contract No. C-0699, Modification No. 1, Appendix A, "Statement of Work", Dated September 29, 1981.

2. "Assumptions for Use in Analyzing Mark II BWR Suppression Pool Temperature Response to Plant Transients Involving Safety/Relief Valve Discharge", Rev. 1, December 1980 (White Paper Rev. 1).

3. ASME Steam Tables, Second Edition, 1967.

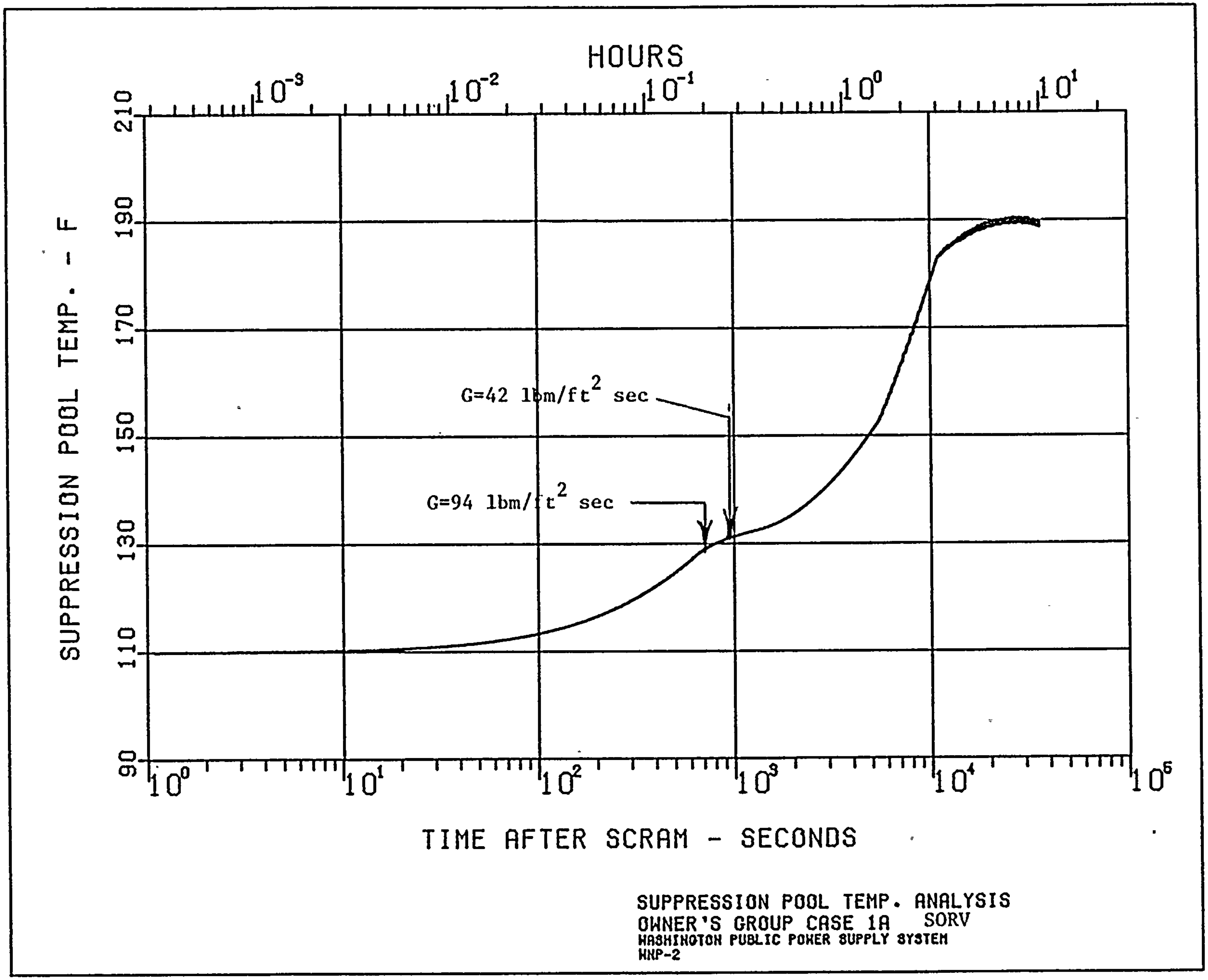
4. "Maximum Flow Rate of a Single Component, Two Phase Mixture", F. J. Moody, APED-4378, October 25, 1963.

5. Stone & Webster Computer Code CONTORT (containment and reactor vessel transient code), NU-163, Version 01, Level 00.

6. Pump Data Sheet Residual Heat Removal Pump, Ingersoll-Rand Order No. 006-36045, Pump Serial Number 0473-111/112/113.

7. Letter from L. E. Ostrom to J. W. Yetter, dated October 13, 1981, "Supply System Contract No. C-0699, Plant Specific Data".

8. "Suppression Pool Temperature Limits for BWR Containments" USNRC NUREG-0783 (Draft).



HOURS
SUPPRESSION POOL TEMP. - F
TIME AFTER SCRAM - SECONDS
G=42 lbm/ft2 sec
G=94 lbm/ft2 sec
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 1A SORV
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 1

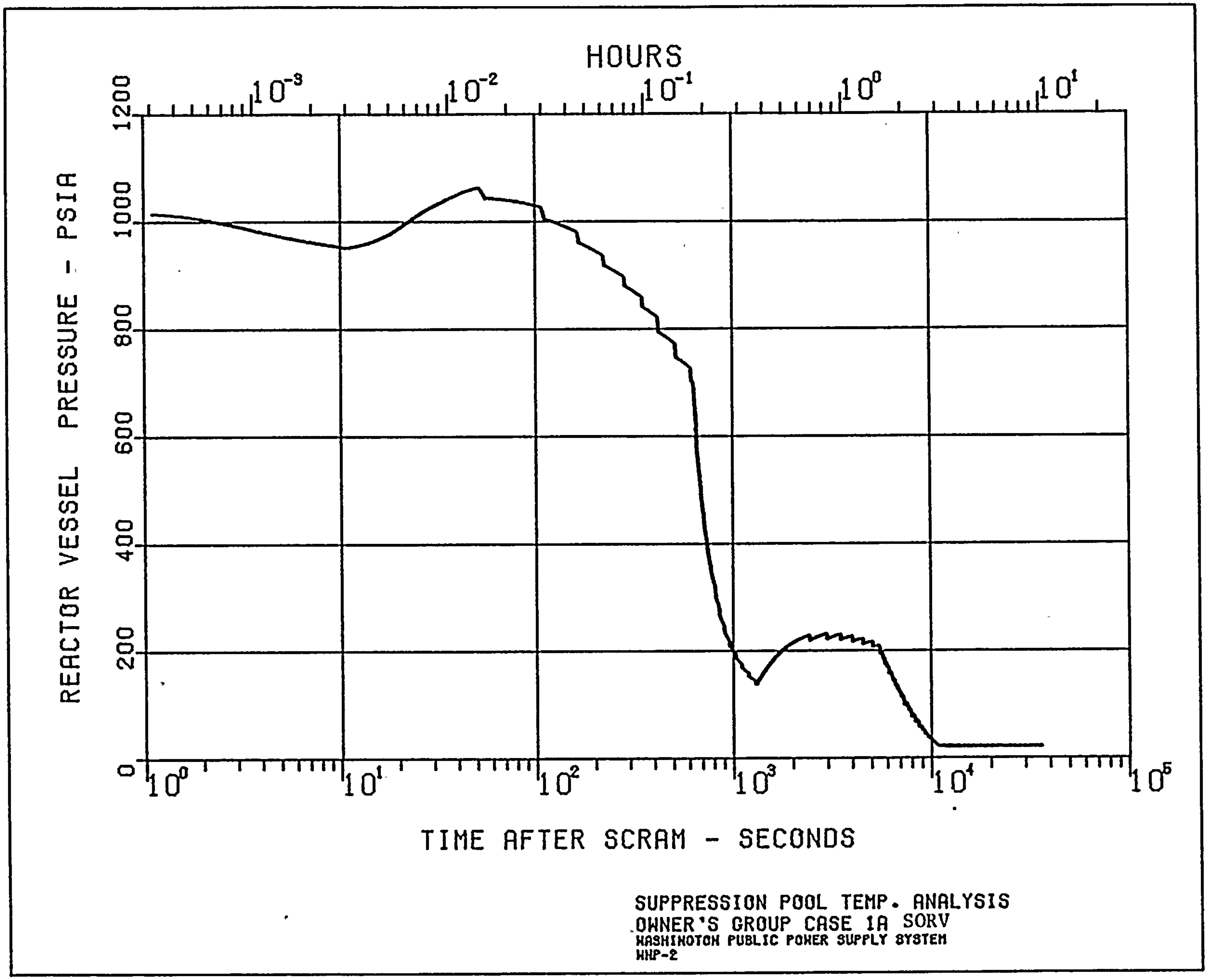
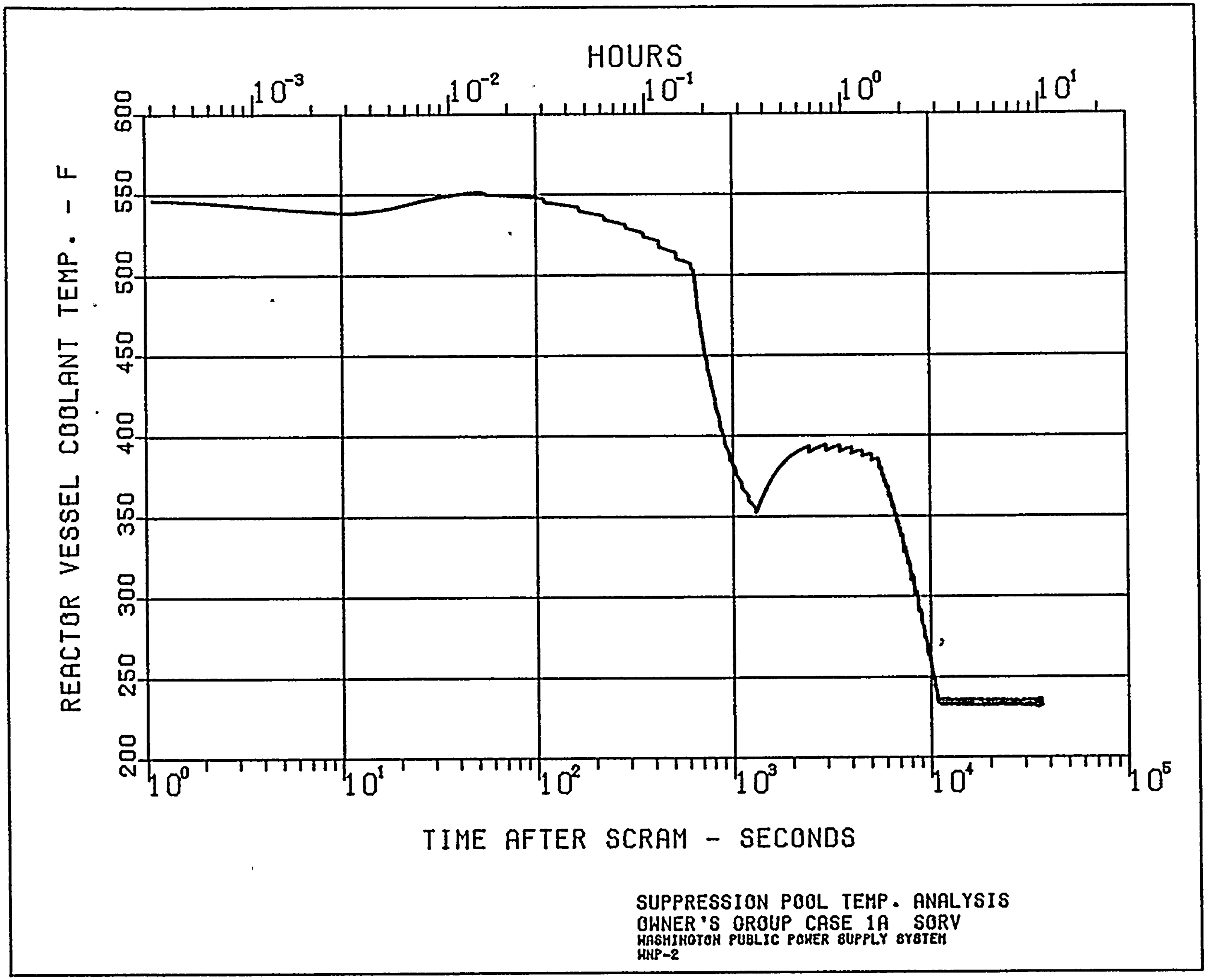

HOURS
10^-3
10^-2
10^-1
10^0
10^1
REACTOR VESSEL PRESSURE - PSIA
0
200
400
600
800
1000
1200
10^0
10^1
10^2
10^3
10^4
10^5
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 1A SORV
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 2


HOURS
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10^{-2}
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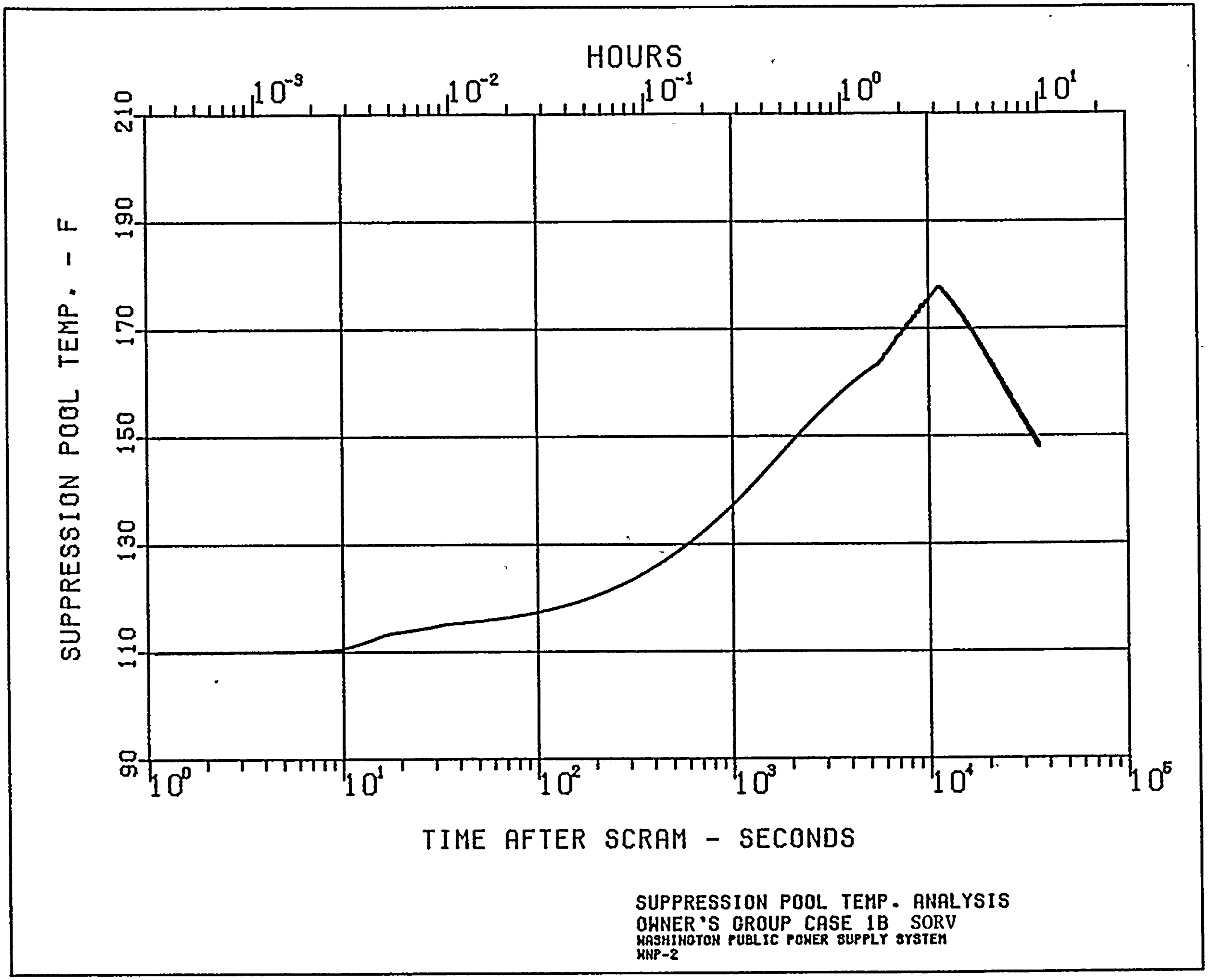
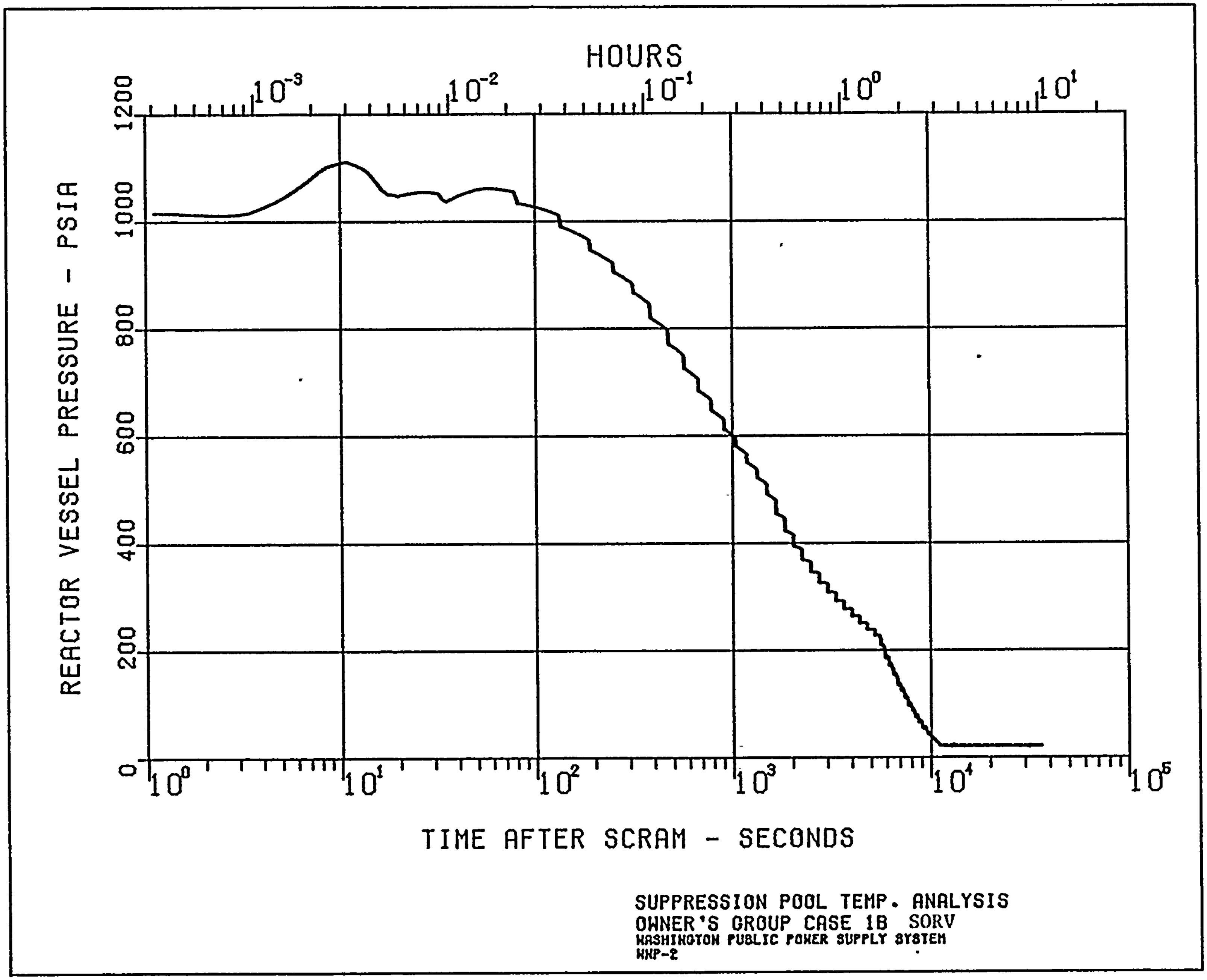
10^{1}
REACTOR VESSEL COOLANT TEMP. - F
600
550
500
450
400
350
300
250
200
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 1A SORV
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 3



HOURS
10^-3
10^-2
10^-1
10^0
10^1
210
190
170
150
130
110
90
SUPPRESSION POOL TEMP. - F
10^0
10^1
10^2
10^3
10^4
10^5
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 1B SORV
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 4


HOURS
10^-3
10^-2
10^-1
10^0
10^1
REACTOR VESSEL PRESSURE - PSIA
1200
1000
800
600
400
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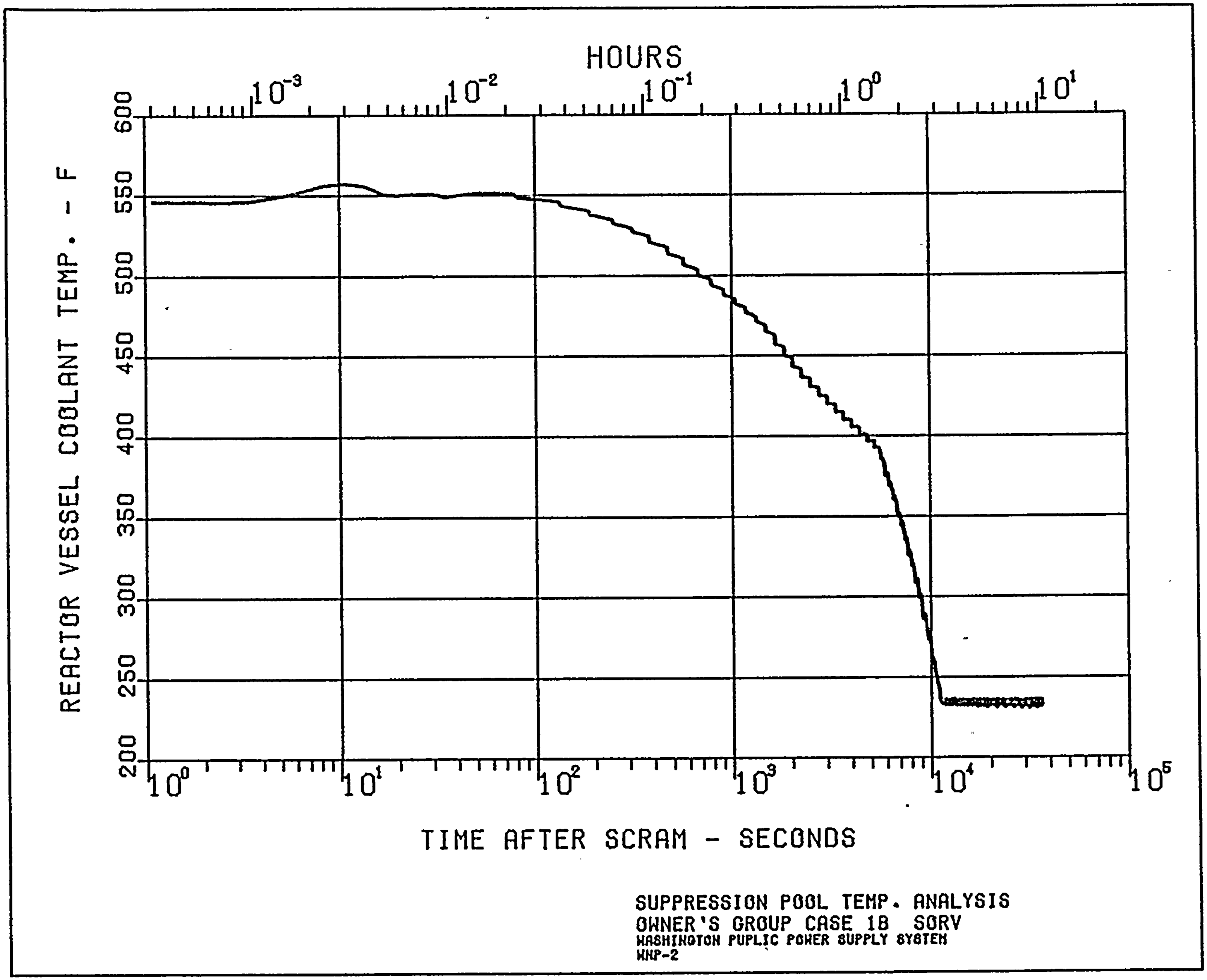
0
10^0
10^1
10^2
10^3
10^4
10^5
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 1B SORV
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 5


HOURS
10^-3
10^-2
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10^0
10^1
600
550
500
450
400
350
300
250
200
REACTOR VESSEL COOLANT TEMP. - F
10^0
10^1
10^2
10^3
10^4
10^5
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 1B SORV
WASHINGTON PUPLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 6

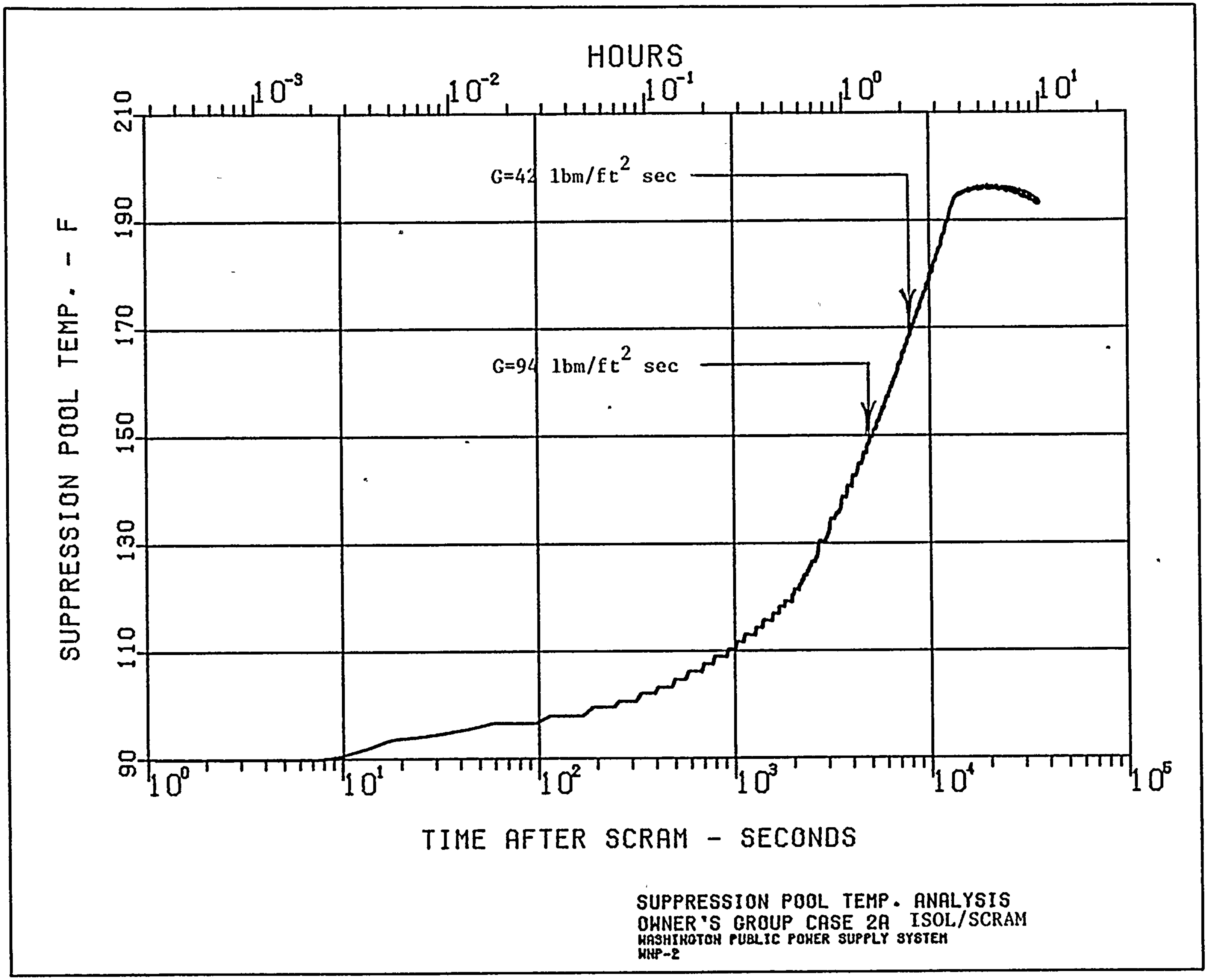
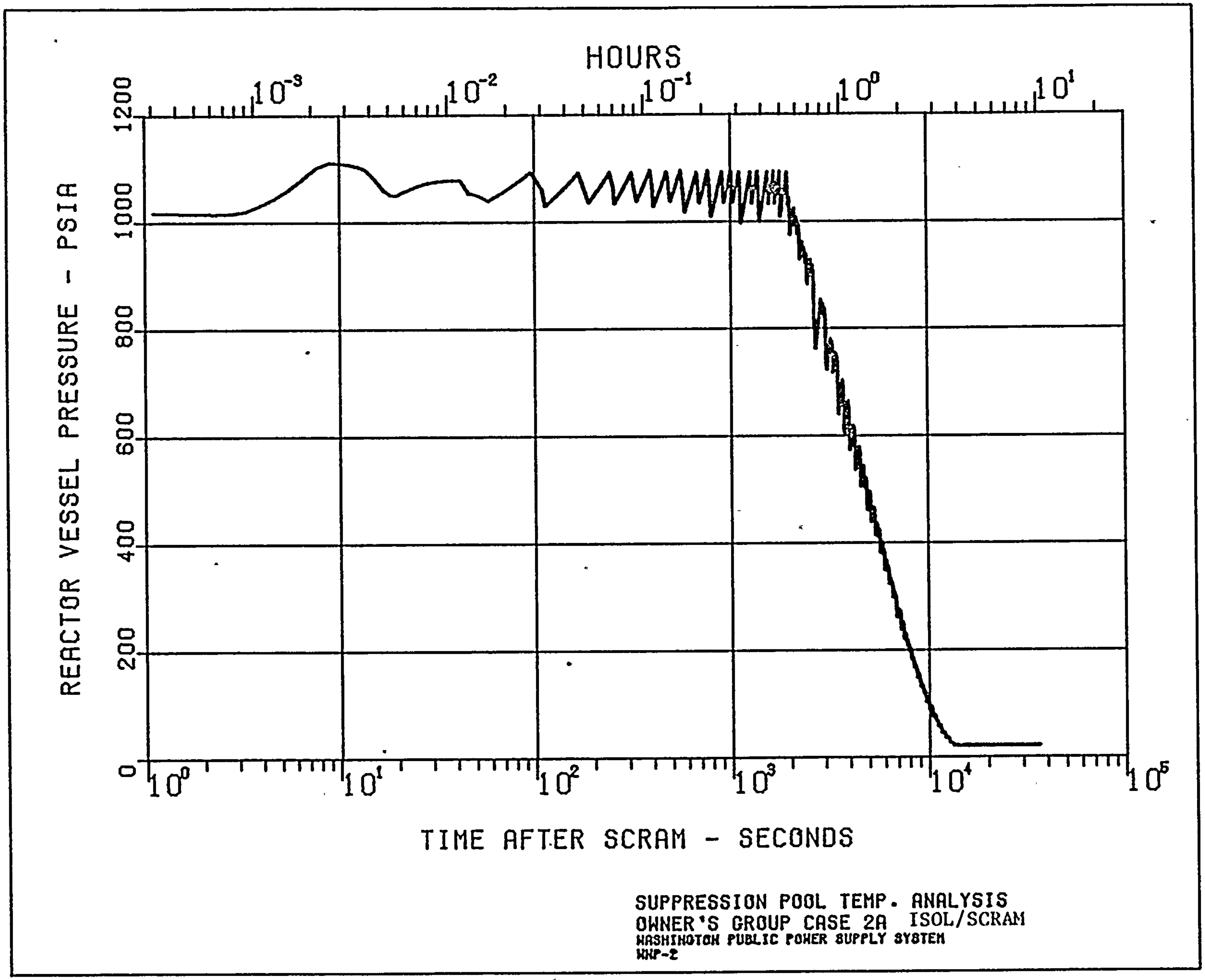

HOURS
10^-3
10^-2
10^-1
10^0
10^1
210
190
170
150
130
110
90
SUPPRESSION POOL TEMP. - F
G=42 lbm/ft^2 sec
G=94 lbm/ft^2 sec
10^0
10^1
10^2
10^3
10^4
10^5
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 2A ISOL/SCRAM
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 7


HOURS
10^-3
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REACTOR VESSEL PRESSURE - PSIA
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1200
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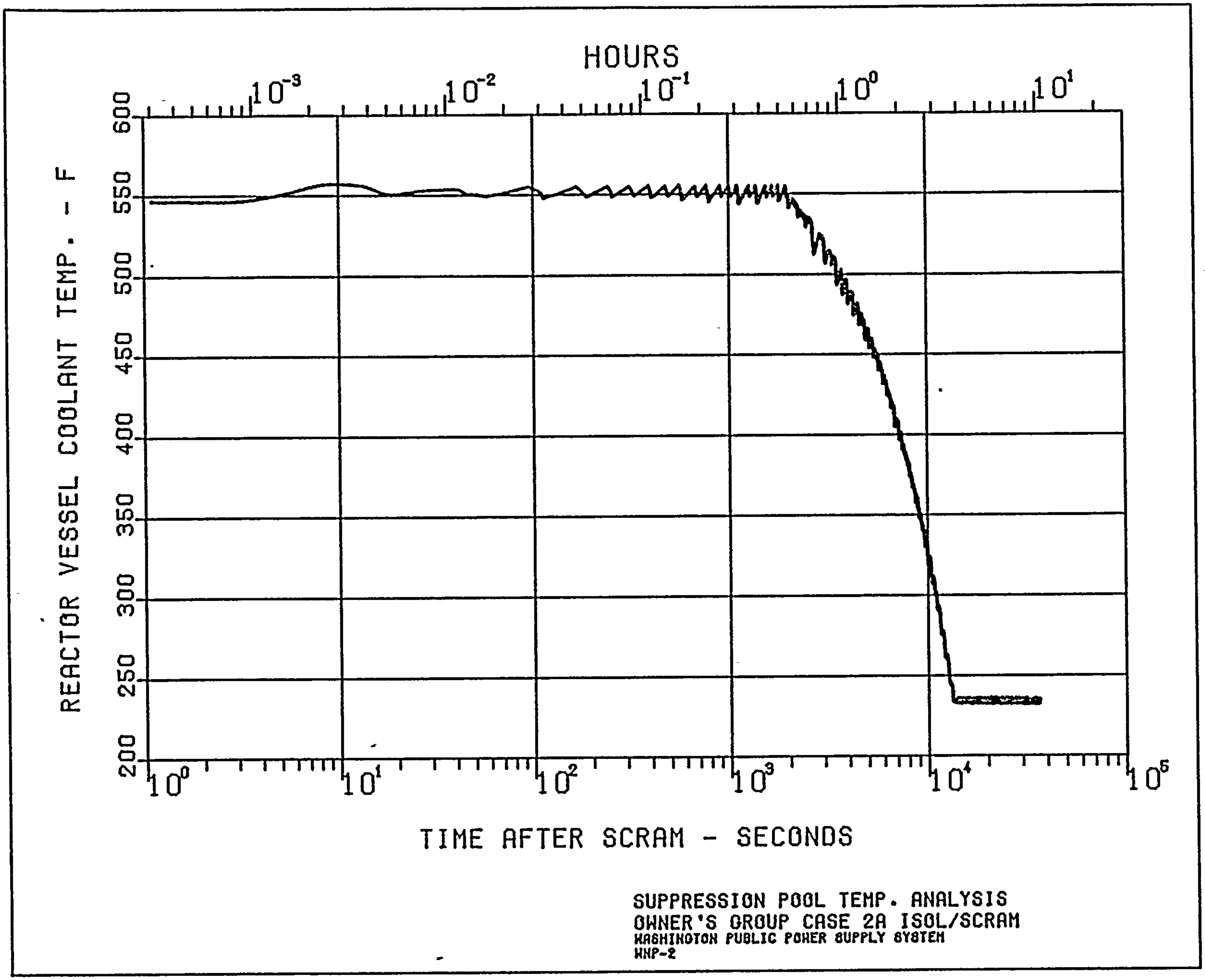
10^2
10^3
10^4
10^5
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 2A ISOL/SCRAM
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 8



HOURS
10^{-3}
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REACTOR VESSEL COOLANT TEMP. - F
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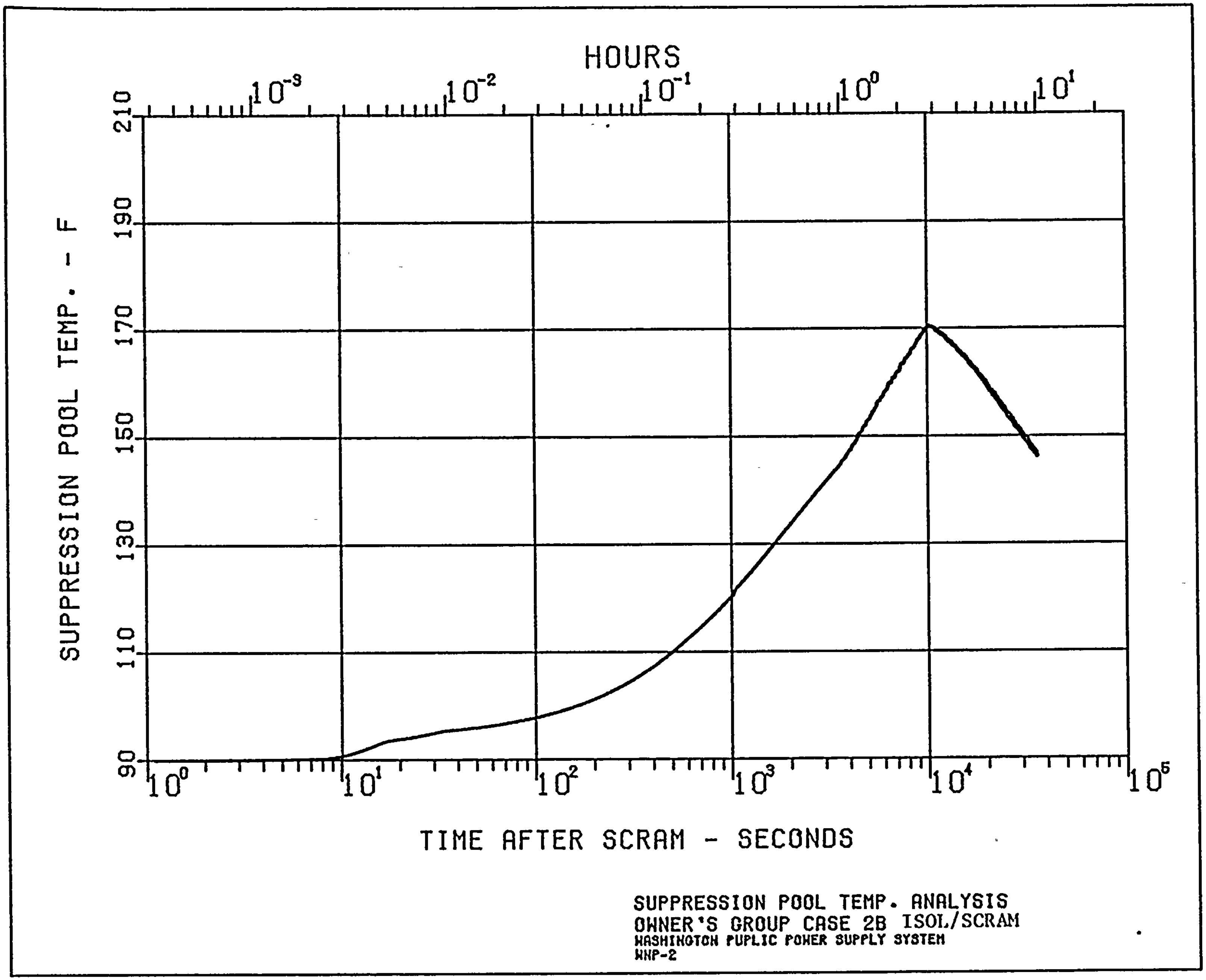
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 2A ISOL/SCRAM
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 9


HOURS
10^-3
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10^0
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SUPPRESSION POOL TEMP. - F
210
190
170
150
130
110
90
10^0
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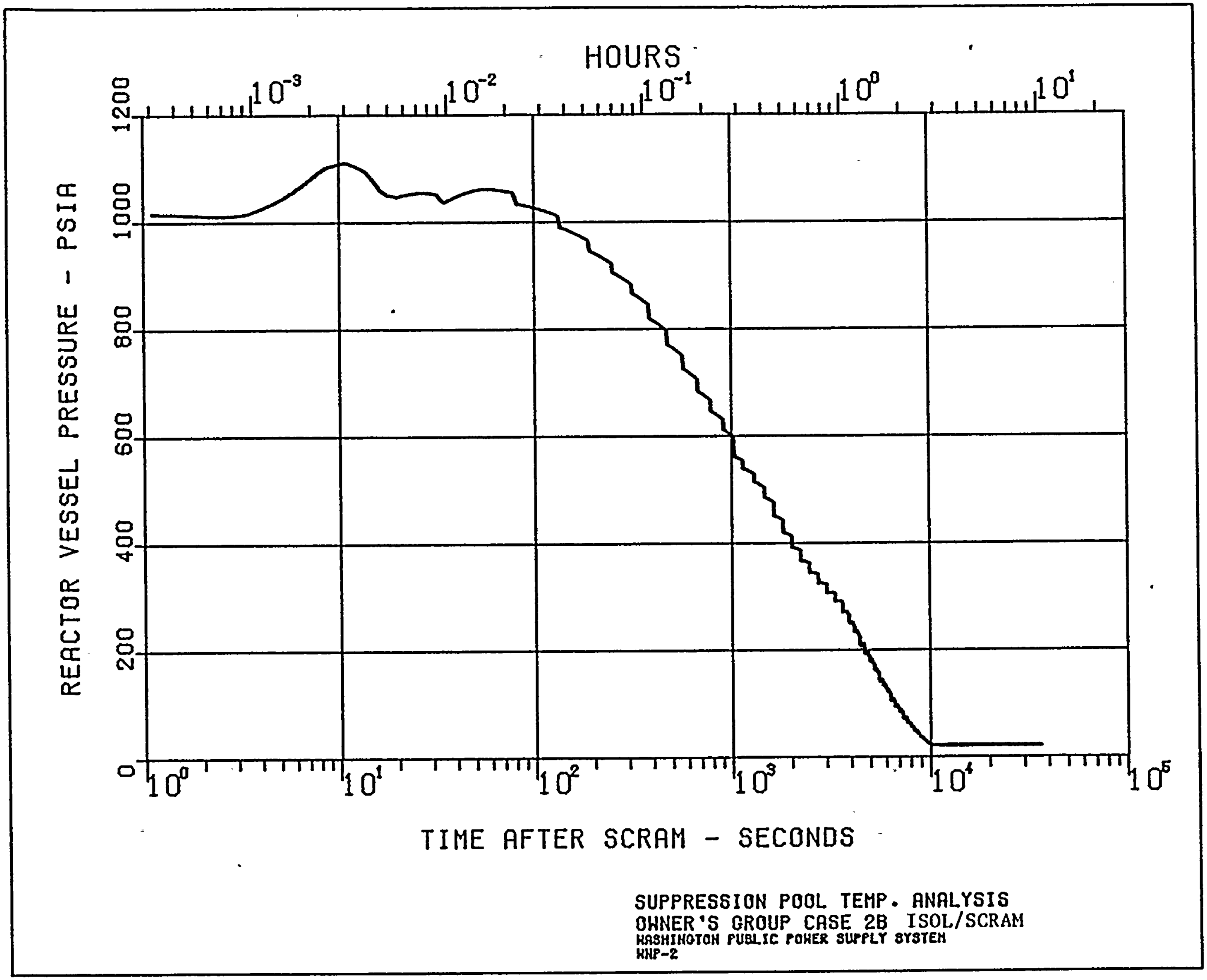
10^2
10^3
10^4
10^5
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 2B ISOL/SCRAM
WASHINGTON PUPLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 10


HOURS
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REACTOR VESSEL PRESSURE - PSIA
1200
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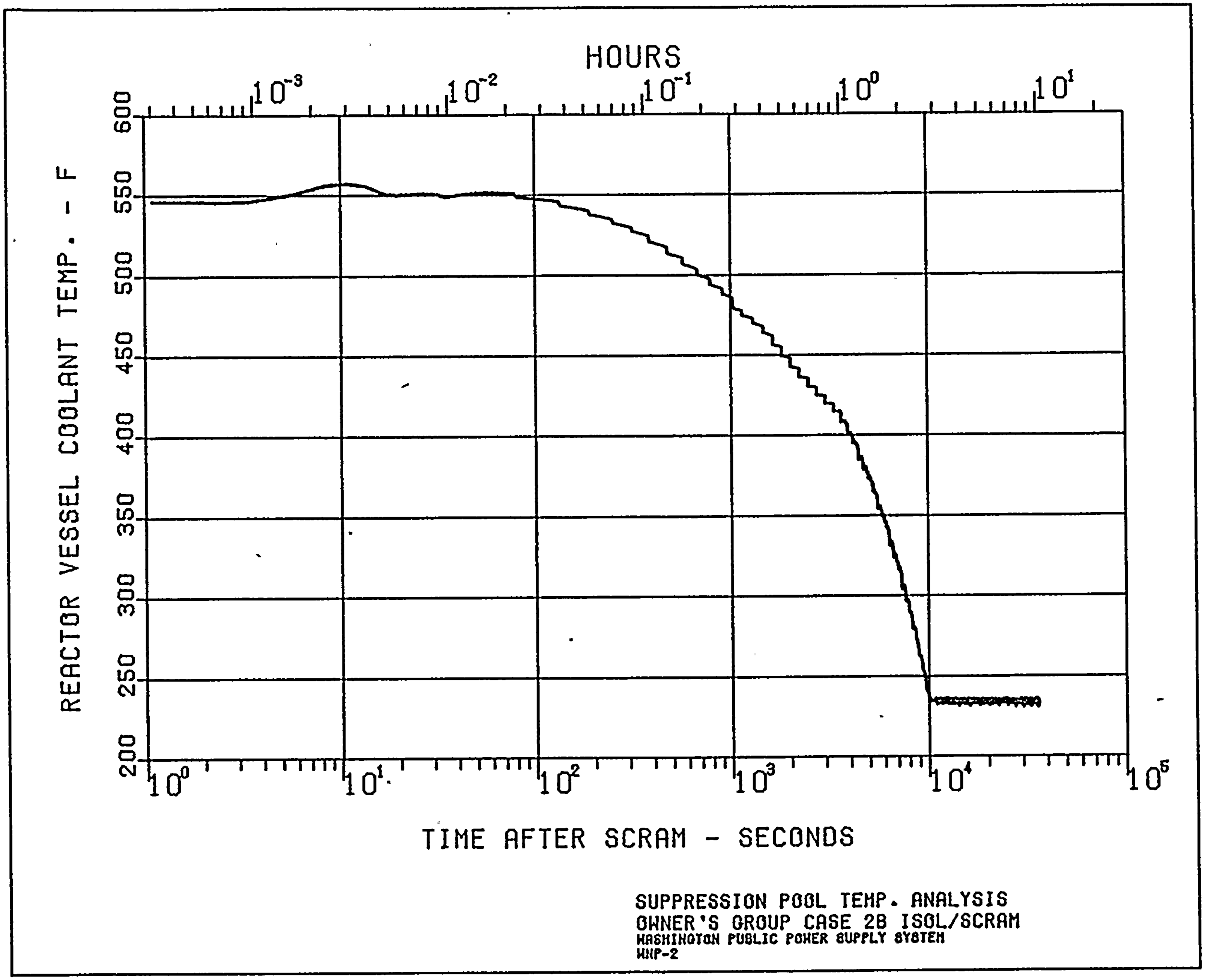
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 2B ISOL/SCRAM
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 11


HOURS
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REACTOR VESSEL COOLANT TEMP. - F
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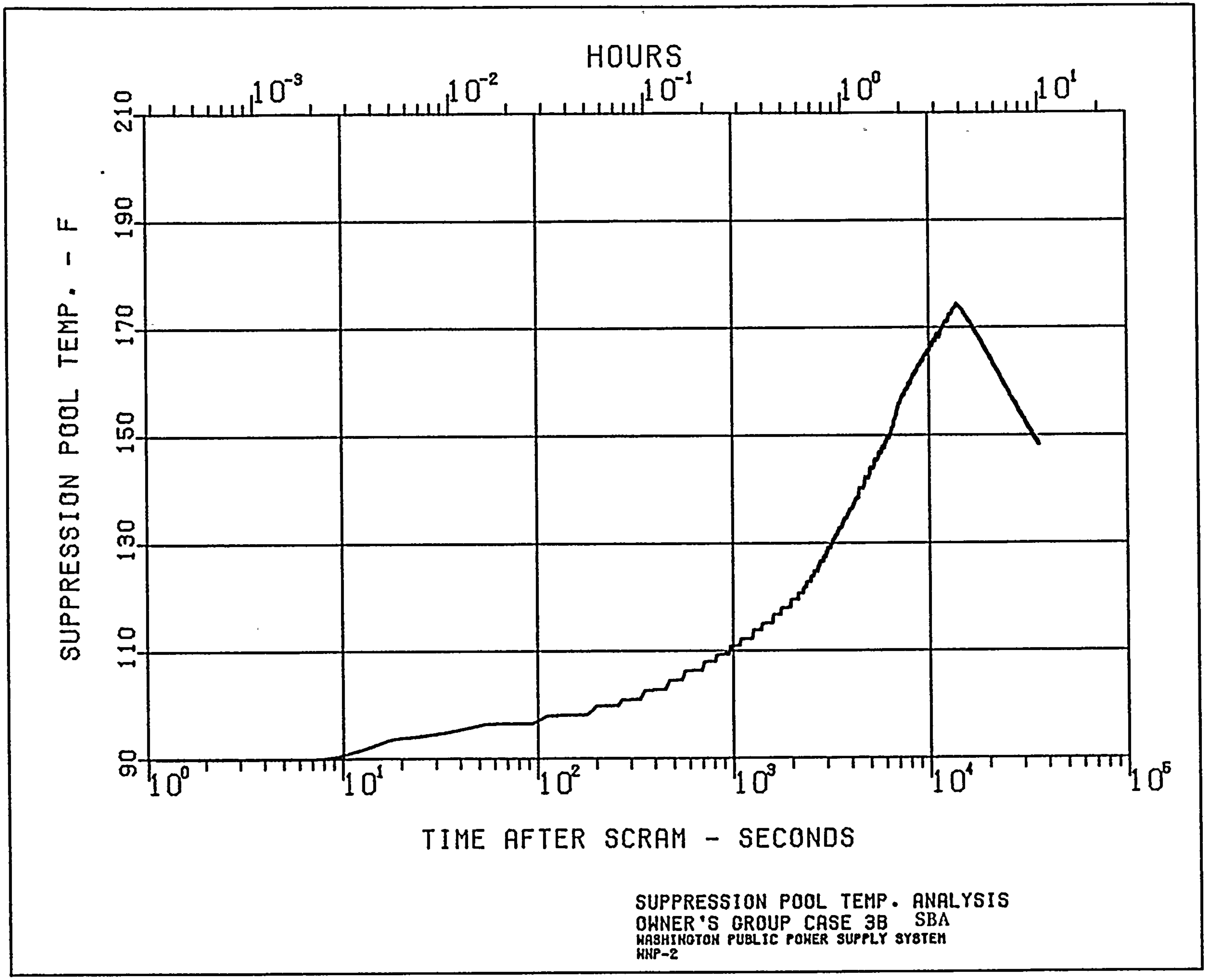
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 2B ISOL/SCRAM
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 12


HOURS
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SUPPRESSION POOL TEMP. - F
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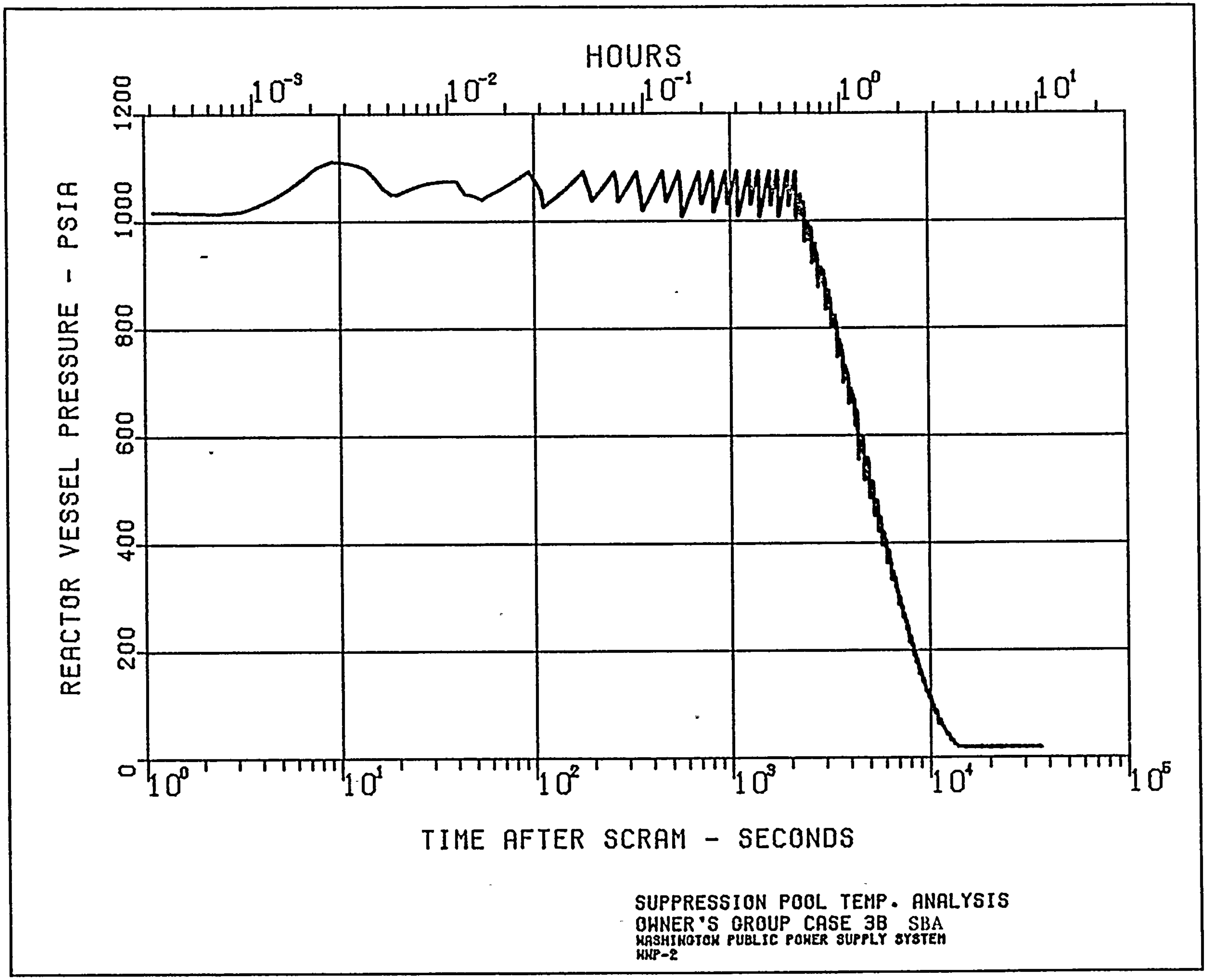
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 3B SBA
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 13


HOURS
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REACTOR VESSEL PRESSURE - PSIA
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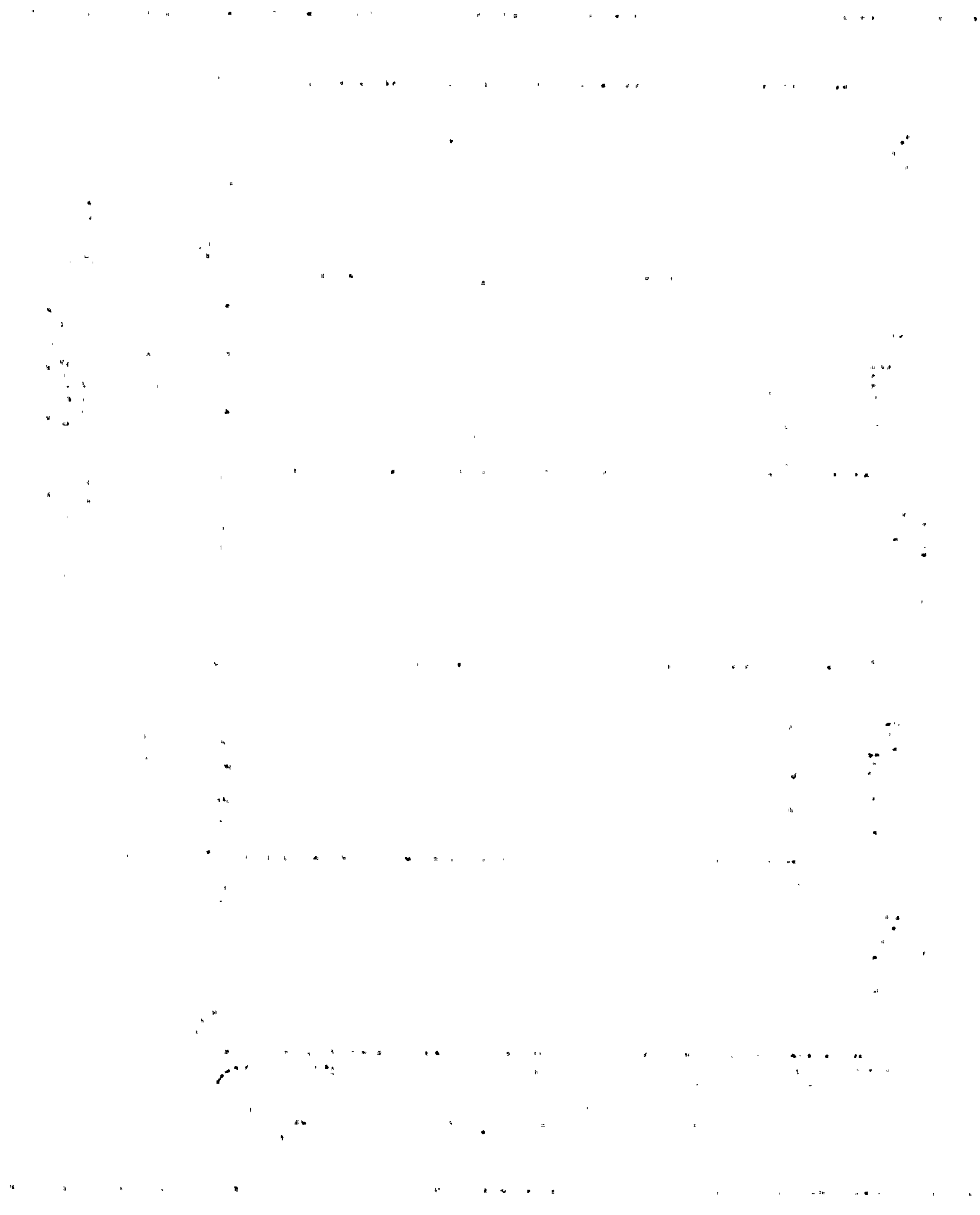
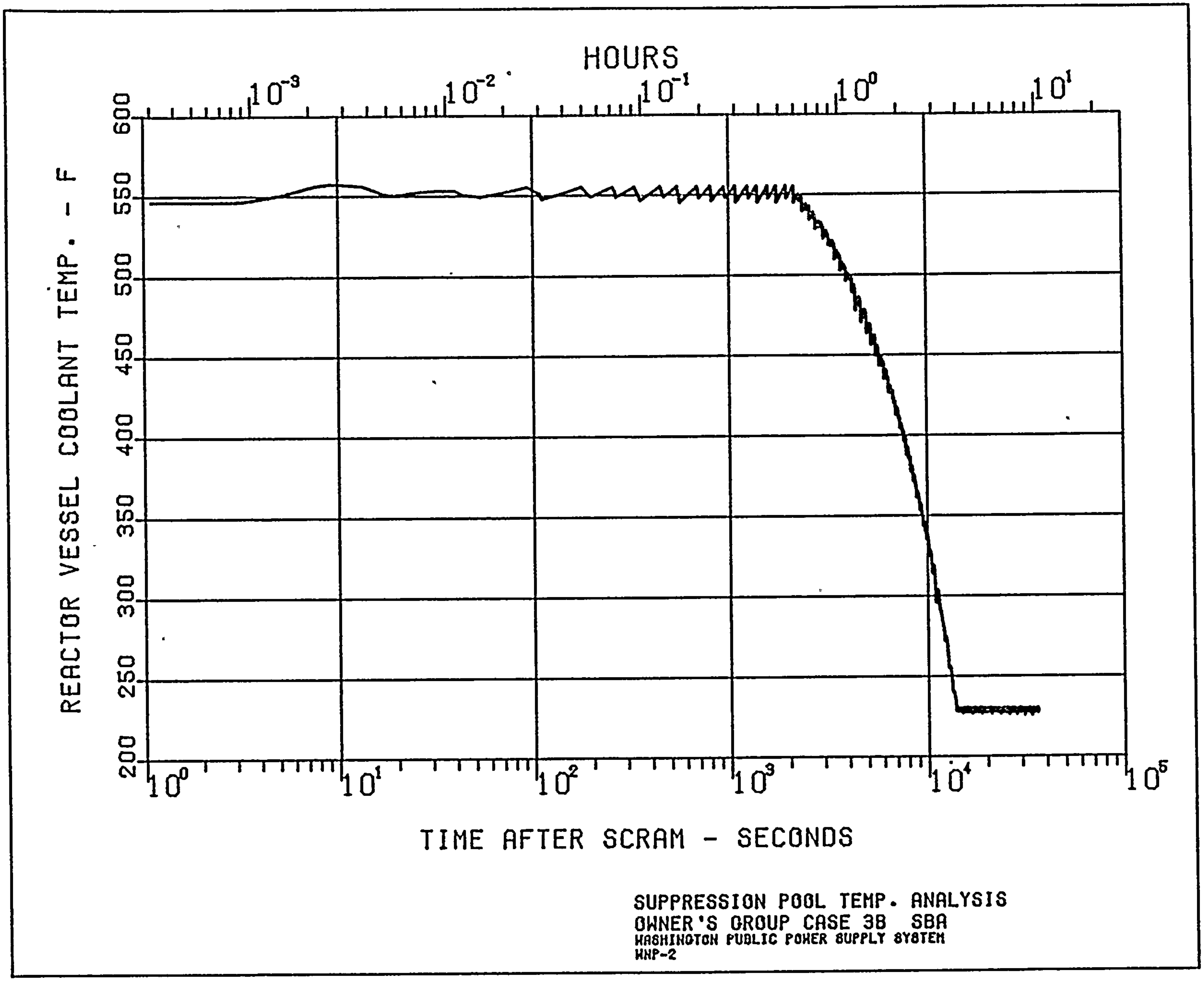
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 3B SBA
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 14




HOURS
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REACTOR VESSEL COOLANT TEMP. - F
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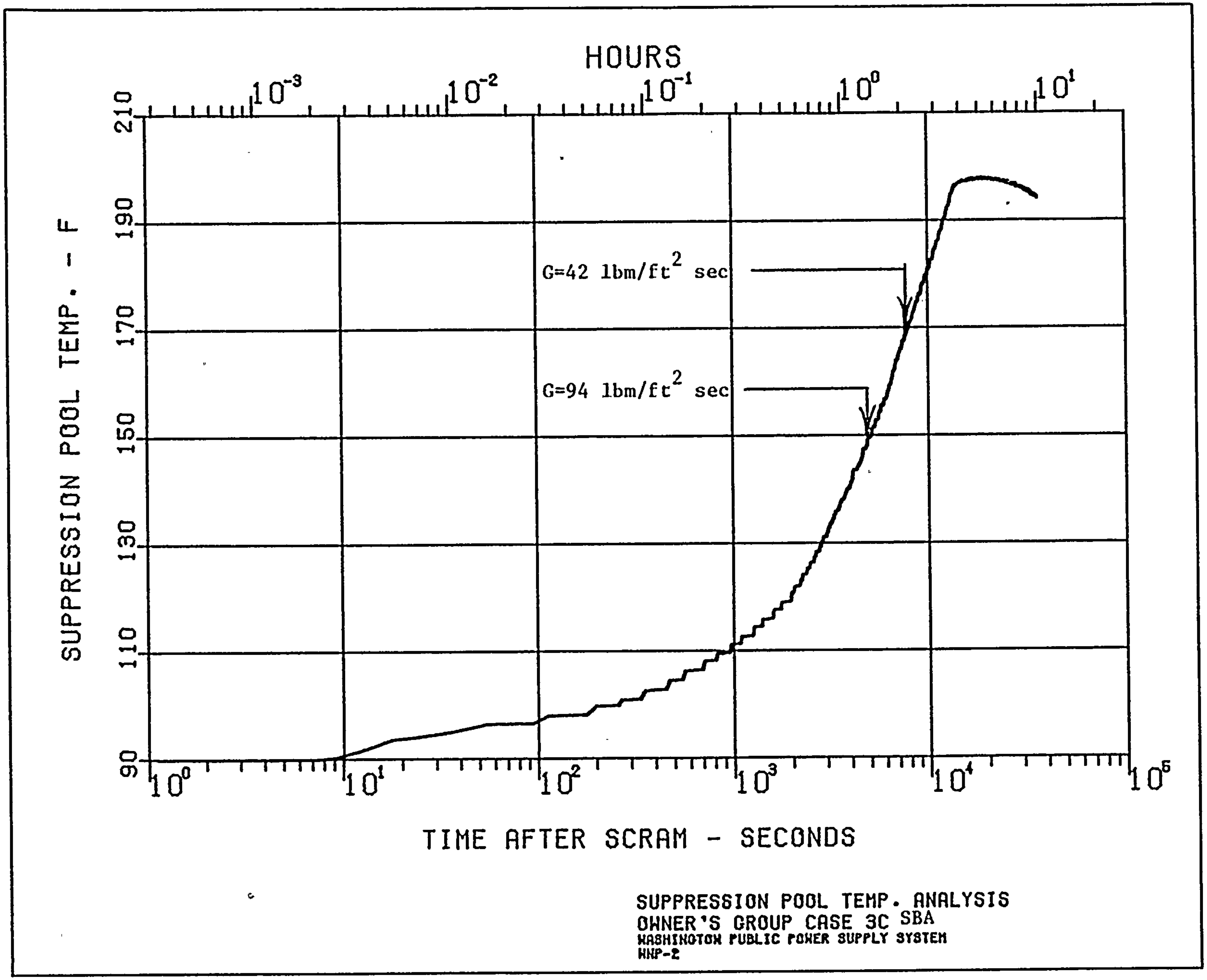
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 3B SBA
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 15


HOURS
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SUPPRESSION POOL TEMP. - F
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10^{2}
10^{3}
10^{4}
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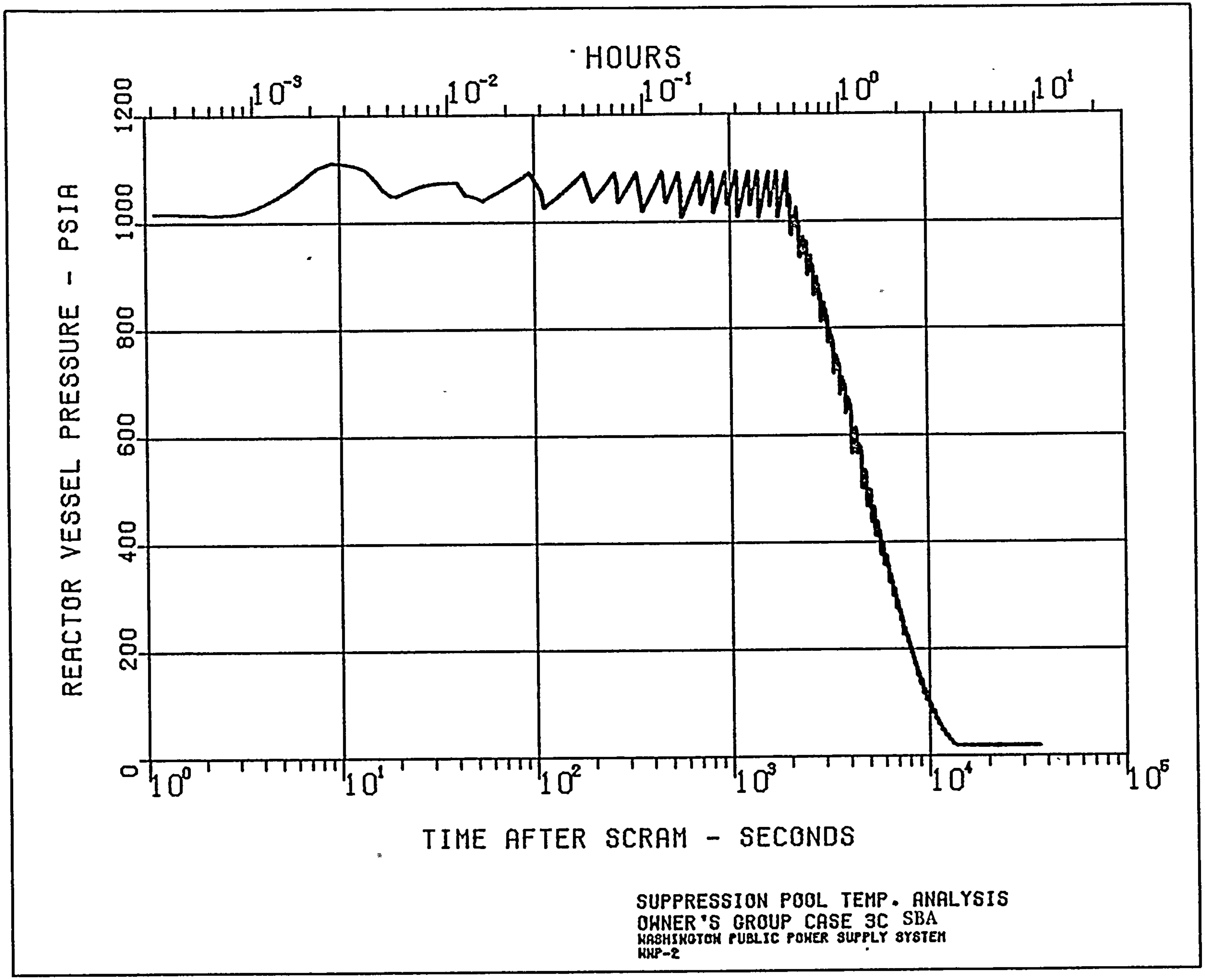
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 3C SBA
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 16


HOURS
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10^-1
10^0
10^1
REACTOR VESSEL PRESSURE - PSIA
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200
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10^0
10^1
10^2
10^3
10^4
10^5
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 3C SBA
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
WNP-2

Fig. 17

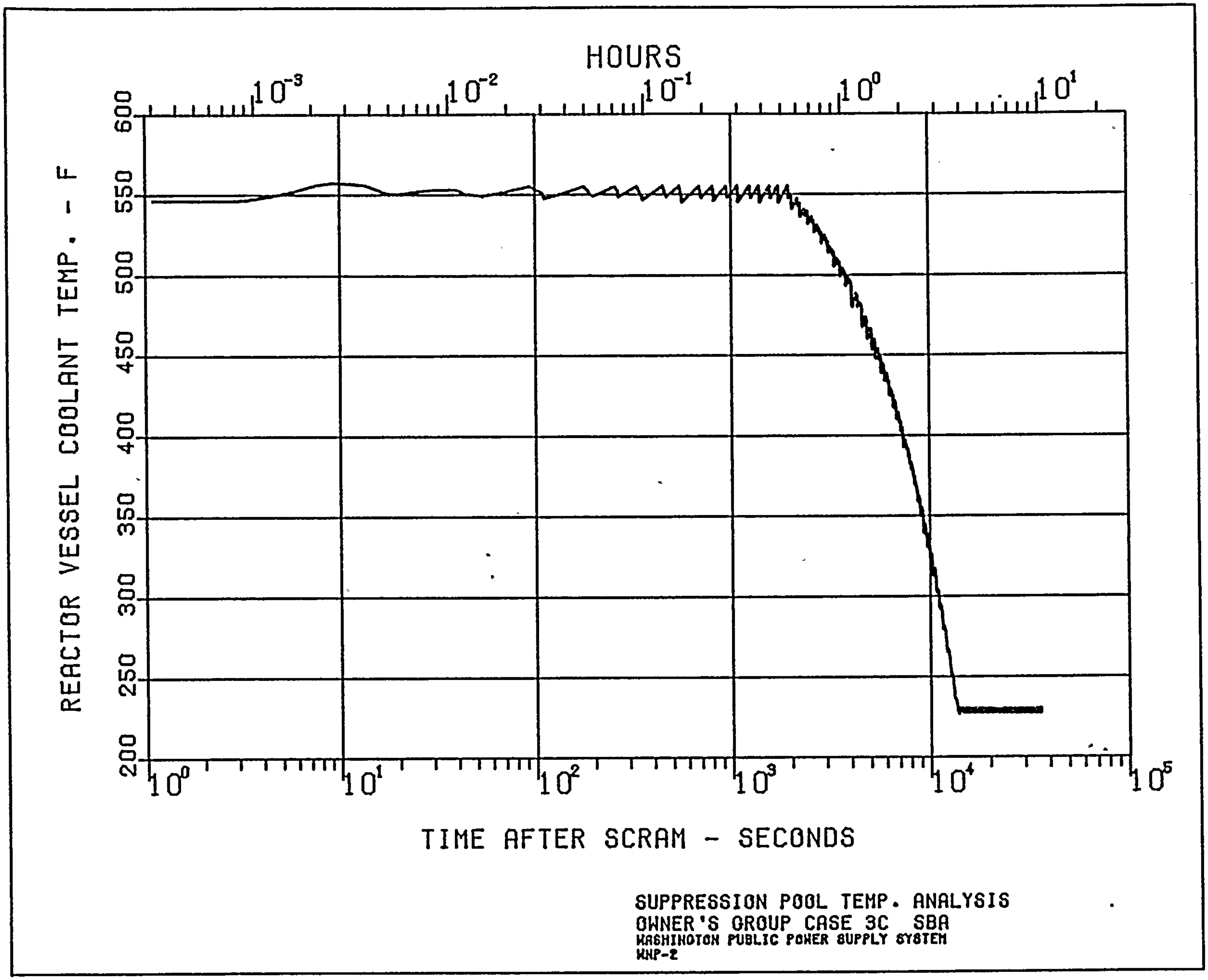
HOURS
10^-3
10^-2
10^-1
10^0
10^1
600
550
500
450
400
350
300
250
200
REACTOR VESSEL COOLANT TEMP. - F
10^0
10^1
10^2
10^3
10^4
10^5
TIME AFTER SCRAM - SECONDS
SUPPRESSION POOL TEMP. ANALYSIS
OWNER'S GROUP CASE 3C SBA
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
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Fig. 18