Lawrence Livermore National Laboratory

May 1?, 1981

Mr. Chang Li
Containment Systems Branch
Division of Operating Reactors
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Subject: FIN A0241 Containment Analysis Support for the Systematic Evaluation Program. Main Steam Line Break Analysis, MSLB, for Blowdown of One Steam Generator

References:
1. Palisades Plant--Automatic Initiation of Auxiliary Feedwater System at Palisades Plant, Docket 50-255 License DPR-20, January 21, 1980 letter from R. W. Huston of Consumers Power Co. to Dennis L. Zieman of NRR, NRC.
2. Palisades Plant--Proposed Technical Specifications Change Related to Containment Spray Initiation Time, Docket 50-255 License DPR-20, November 24, 1980 letter from D. P. Hoffman of Consumers Power Co. to D. Crutchfield of NRC.

Dear Mr. Li:

Attached is the MSLB analysis for the blowdown of one steam generator. This would be the wr st case analyzed provided a fix was imposed to prevent both steam generators from blowing down. In this case the single failure would be loss-of-offsite power with a diesel generator failure. The available containment heat removal system would then be reduced to two spray pumps and one air fan cooler. The mass and energy release data used in this analysis were taken from ref. 1. The assumptions that went into arriving at these mass and energy release rates were found to be conservative and in agreement with the SRP provided a failure of a MSIV is not considered. The assumptions used in the containment response calculation are based on the proposed technical specifications discussed in ref. 2

The results of our analysis show that the calculated peak pressure is 68.5 psia reached at 67 seconds. This 1.2 psi below design. The calculated peak temperature is 413°F reached at 37 seconds. Therefore, based on this analysis, a fix which would prevent the blowdown of both steam generators would limit the calculated peak pressure to 1.2 psia below design.

Yours truly,

David Vreeland
Principle Investigator

Attachment

cc: R. Bowman G. Cummings

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Enclosure 1

SEP Containment Analysis and Evaluation for the Palisades Nuclear Power Plant

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1.0 Introduction and Background

On January 1, 1980 the Office of Nuclear Reactor Regulation (NRR) initiated a two-year program with Lawrence Livermore National Laboratory (LLNL) titled Containment Analysis Support for the Systematic Evaluation Program (SEP). This program is directed toward resolution of SEP Safety Topic VI-2.D, Mass and Energy Release for Possible Pipe Break Inside Containment, and Safety Topic VI-3, Containment Pressure and Heat Removal Capability. The containment structure encloses the reactor system and is the final barrier against the release of radioactive fission products in the event of an accident. The containment structure must, therefore, be capable of withstanding, without loss of function, the pressure and temperature conditions resulting from postulated LOCA and steam line break accidents. Furthermore, equipment having a post-accident safety function must be environmentally qualified for the resulting adverse pressure and temperature conditions. To accomplish the objectives of this program, first, the existing docket information was reviewed and evaluated and then additional analyses were performed as required. The purpose of this report is to document original analyses performed by the LLNL on the containment functional design capability of the Palisades Nuclear Power Plant and evaluate existing analyses for conformance with current NRC criteria.

2.0 Containment Functional Design

Palisades is a Combustion Engineering PWR licensed to operate at 2200 MWt. The primary coolant system is a two loop system consisting of two steam generators with two cold leg loops per steam generator. The containment systems include the containment structure and associated systems. These systems include containment heat removal systems, containment isolation systems and a combustible gas control system.

The containment is a steel-lined, pre-stressed, post-tension concrete structure with a net free volume of 1,640,000 cubic feet. The containment structure houses the nuclear steam supply system, including the reactor, steam generators, reactor coolant pumps and pressurizer, as well as certain components of the engineered safety features systems. The containment is designed for an internal pressure of 55 psig and a temperature of 283°F.

2.1 Review of Palisades' Containment Design Analysis

There are two separate calculations which make up the containment design analysis. First is the mass and energy release analysis for postulated LOCA's. This consists of a blowdown, reflood and post-reflood phases. The results are mass and energy release rates into the containment. For PWR's there are two possible break types which must be analyzed, a primary system pipe break and a secondary system pipe break. A break on the primary side generally results in the most severe pressure response in the containment while a break on the secondary side results in the most severe temperature conditions in the containment. The second calculation which is performed in the containment design analysis is the containment response calculation. This results in the containment temperature and pressure response to the mass and energy release from the postulated breaks.

The acceptance criteria used to evaluate Palisades' Containment Design Analysis was based on the Standard Review Plan (SRP). In order for the containment design analysis to be found acceptable both the mass and energy release and containment response calculation must meet the acceptance criteria specified in the SRP.

2.2 Primary System Pipe Break

The SRP specifies several acceptance criteria applied to the mass and energy release analysis for primary system pipe breaks. Among these are break location. In ~~the case of Ginna~~ THE Palisades FSAR the most severe mass and energy release rate calculated for containment design was done assuming a double-ended cold leg discharge break with no accounting for the reflood phase or energy in the secondary system. Since this does not meet the acceptance criteria specified in the SRP or previously accepted methods by the NRC staff, this analysis is unsuitable for containment design calculation. Since the mass and energy release rate analysis is found unacceptable, so is the containment response calculation based on the mass and energy release rates.

2.3 Secondary System Pipe Break

The most recent secondary system pipe break analysis that was reviewed was submitted by Consumers Power Co. to the U.S. NRC on January 21, 1980.[1] In this analysis a main steam line break (MSLB) analysis was performed. In this analysis the blowdown of one steam generator with feedwater isolation and loss-of-offsite power was considered. However, the analysis did not address the possibility of a single failure of one of the main steam isolation valves which could lead to the blowdown of both steam generators. Therefore, the analysis was considered incomplete and unacceptable. A more thorough discussion of the MSLB analysis is given in Section 4.0, Secondary System Pipe Breaks.

2.4 Reanalysis of Palisades' Containment Design

As mentioned earlier in Section 2.1, Review of Palisades' Containment Analysis, there are two separate calculations which make up the containment design analysis, the mass and energy release rate and the containment

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1 Palisades Plant - Autmoatic Initiation of Auxiliary Ferdwater Ssytem at Palisades Plant, Docket 50-255 - License DPR-20, January 21, 1980 letter from Roger W. Huston of Consumers Power Co. to Dennis L. Ziemann of NRR, NRC.

response. The mass and energy release rate calculation can be the result of either a primary or secondary pipe break. The primary pipe break generally results in the limiting condition for calculating the peak pressure inside the containment. The secondary pipe break analysis generally is the most limiting case for temperature conditions inside the containment. Both of these analyses were performed and are discussed below.

3.0 Primary System Pipe Break

For a primary system pipe break there are three phases in calculating mass and energy release rates. These are the blowdown, reflood, and post-reflood phases. In each of these phases the calculation was done in accordance with ~~the SRP~~ Section 6.2-1.3 of the Standard Review Plan ~~where possible~~ under the cons~~traint~~ limitations of the computer codes used. In general, the analysis was done in a manner that conservatively establishes the containment design pressure; i.e., maximizes the post-accident containment pressure. The worst break location was determined to be at the cold-leg pump suction side because of the consideration of energy input during the reflood phase and the flow resistance.

[illegible] Palisades Nuclear Power Plant.

3.1 Initial and Boundary Conditions

The initial and boundary conditions for this analysis were defined to satisfy the requirements of the Standard Review Plan. The single failure assumption for these analyses was a loss of one diesel generator. The initial power was specified to be 102% of safeguards design rating or 2690.76 MWt. A steady-state mass and energy distribution was provided in the primary and secondary coolant systems consistent with the conservative core power. The break flows were calculated using a discharge coefficient of 1.0, with the Henry-Fauske correlation for subcooled and the Moody correlation for saturated fluid. The safety injection flows were minimum, corresponding to the diesel generator failure. The mass and energy release analysis was performed with RELAP4 MOD6. Steam quenching by the safety injection water occurred due to the homogeneous equilibrium (HEM) assumptions of the RELAP4 MOD6 code. All of the safety injection water temperatures were defined to be 90°F.

Scram was assumed to occur with a low pressurizer pressure of 1750 psia. A 1.0-second delay time was used in the model for conservatism; however, the moderator reactivity feedback caused core shutdown before the control rods were effective. The main coolant pump power was tripped off at the time of the break. Steam generator isolation was initiated one second after the break and the valves were assumed to completely close in five seconds. A 15-psia constant containment backpressure was assumed to maximize mass and energy release throughout the blowdown. The end of blowdown was defined as the time the primary system pressure reached the containment design pressure of 55 psig.

The RELAP4 input deck was obtained from NRC and was carefully reviewed for code options, initial and boundary conditions. The plant physical description was generally assumed to be correct. Additional information required for the analysis was obtained from the Palisades FSAR, and telephone conversations with C. Tinkler of NRC and D. Vandewalle of Consumers Power Company. A thorough discussion of the model can be found in the Methodology Report for the Palisades Nuclear Power Plant.

3.2 Blowdown Phase

The blowdown analysis results are summarized in Table 3.1 and Figures 3.1 through 3.4. Table 3.1 itemizes the energy sources for the duration of the blowdown which ended at 20.4 seconds after the break. The total energy released during blowdown was approximately 253.4 million Btu. Figures 3.1 through 3.4 provide break flow and enthalpy out the break.

The accumulator flows start after 16 seconds and do not reach maximum flow rates by the end-of-blowdown. The pumps coast down at different rates. The pump nearest the break reaches zero rpm before two seconds because of reverse flow through the pump. The pumps were not allowed to reverse, providing a conservatively high resistance which allows more flow through the steam generator side of the break. The other pump in the broken loop coasts down to zero rpm at about 11 seconds. The pumps in the unbroken loop continues to have a positive rotation throughout the blowdown, although it decreases to 500 rpm in about 10 seconds. Although the scram occurred at about eight seconds, moderator reactivity feedback had already reduced the power to less than 7-1/2% of the initial power.

The mass and energy release rates and energy sources were qualitatively compared to the CESSAR results for a double-ended suction leg slot break with the same area. The similarity of the results suggests the RELAP4 calculated blowdown results are reasonable.

3.3 Reflood Phase

The reflood analysis for the double-ended pump-suction break was assumed to immediately follow the LOCA blowdown analysis. The analysis was performed using RELAP4 MOD7. Within the limitations of RELAP4 MOD7, the analysis was performed in accordance with the requirements of Section 6.2.1.3 of the Standard Review Plan (SRP).

Initial conditions for the start of the reflood analysis were based on the end-of-blowdown (EOB) results. EOB was defined to occur when the primary system pressure fell below the Palisades containment design pressure of 55 psig which occurred at 20.4 seconds after the start of blowdown. At that time, the core power level had dropped to 159.41 MWt or approximately 6% of the initial power. The accumulator flows had been initiated on low cold leg pressure trips of 262.5 psia which occurred at about 16 seconds into the blowdown and had reached a total of 5900 lbm/sec at the start of reflood. The reactor coolant pumps had coasted down and the rotors were locked.

For the reflood analysis, the primary system was initialized at the containment design pressure, 69.7 psia. The primary system junction flows

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were zero except for the accumulator and lower plenum inlet and outlet junctions. Heat conductor temperature and primary system state conditions were established based on the EOB conditions. Core power continued to decrease according to the ANS decay heat curve.

A natural circulation heat transfer model was used in the steam generator secondary to maximize the energy transfer rates to the break. The primary coolant pump rotors were assumed locked to conservatively provide resistance to flow. A closed valve was modeled in the intact cold leg of the broken loop to conservatively increase the flow through the steam generator.

For numerical stability of the RELAP4 computer code, the Emergency Core Cooling System (ECCS) flow was modeled as being injected directly into the downcomer at a temperature of 300°F.

Plant specific information was predominantly derived from a RELAP4 Reflood input listing for the Palisades power plant which was obtained from the Nuclear Regulator Commission (NRC), and from ~~the~~ Palisades Final Safety analysis Report (FSAR).

Several sensitivity calculations were performed to evaluate various input model and code options. The results of the sensitivity studies are documented in the methodology report. The Palisades reflood transient results are presented in Table 3.2 and Figures 3.5 through 3.8. Table 3.2 is a summary of the energy balance at the beginning and end of reflood. Figures 3.5 through 3.8 provide break flow and enthalpy out the break.

The accumulator flow is initiated at 5900 lbm/sec and quickly rises to 6400 lbm/sec. The flow remains constant until 40 seconds, and then is ramped down to 0 lbm/sec at 50 seconds when the accumulator is empty. The HPI flow comes on at 0.6 seconds and remains at about 650 gal/min for the duration of the transient. The LPI flow comes on at 7.6 seconds and varies in magnitude between 400 and 600 lbm/sec for the duration of the transient, depending on the primary system pressure.

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The primary system pressure starts at 69.7 psia, increases to 160 psia at 20 seconds, and then slowly decreases to 100 psia. The pressure increase can be attributed to steam binding in the primary system. As the ECCS water enters the core, it boils away faster than the generated steam can escape through the break. After 20 seconds, the core is quenched and the steam generation rate reaches a new pseudo-steady-state with the break flow.

Normally, the end of reflood is defined as the time when the core recovers to within two feet from the top of the core. In the case of Palisades, the maximum mixture level is less than seven feet at 50+ seconds into the transient which is still four feet below the top of the 11-foot core. However, the core-stored energy was essentially removed at 30 seconds into the transient.

The reflood calculation was extended to 100 seconds to determine when and if the steam generator side break flow would begin a rapid decay expected after the accumulators emptied at 50 seconds. Since the rapid flow decay did not occur, the reflood calculation was continued beyond the time when the containment calculation predicts the peak pressure and temperature at 84 seconds after break or 64 seconds after start of reflood. Because the safety injection water was assumed to be at 300°F, the extended duration of the reflood analysis is considered to provide a conservatively high energy transfer rate to the secondary.

3.4 Post-Reflood and Containment Response Calculation

The containment model used was based on a CONTEMPT deck received from the NRC. The mass and energy flows to the containment were replaced and the remaining data carefully checked against the FSAR and other sources. The analysis was performed using CONTEMPT-LT/028.

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The heat structures used are listed in Table 3.3. All the structures are represented in rectangular geometry. The thermal conductivity and the volumetric heat capacity were checked for the four materials used: steel, concrete, insulation, and air (gap). The heat capacity was found to be about two orders of magnitude low for insulation and was changed. Tagami/Uchida boundary conditions were used for all heat structure surfaces except the base slab, which was assumed to be covered with water. The Tagami peak time used was 20 seconds, 0.5 second before the end of blowdown.

The basic assumption was that off-site power was lost and that one diese generator failed to start. The cooler and spray pump start times are based on the generator loading sequence.

It was assumed that one fan cooler was operating and that it started at 23 seconds after the break. The heat removal rate was variable, ranging from 97.5 MBtu/hr at a containment temperature at 350°F to 3.0 MBtu/hr at 104°F. The one operating diesel generator was ~~also~~ assumed capable of powering two spray pumps. Both pumps together were capable of 1.34 Mlbm/hr (2700 gpm) with spray efficiency of 90%. The containment spray started at 84 seconds and used water from the Refueling Water Storage Tank until 30 minutes when the tank was empty, at which time the water source switched to the ~~drywell pool~~ containment sump. The heat removal rate for the shell and tube heat exchanger in the containment spray system is computed in CONTEMPT. The entered parameters were: the product of the heat exchange surface area and the overall heat transfer coefficient was 2.28 MBtu/hr/F; the coolant inlet temperature was 114°F; and the coolant flow rate was 2.0 Mlbm/hr.

General initial conditions are given in Table 3.~~8~~4. Initial conditions for the primary system refer to the end of blowdown. No water was introduced to the ~~drywell~~ containment as an initial step input. The evaporation-condensation model in the ~~drywell~~ containment was bypassed until the end of blowdown. The fraction of wall or

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cooling coil condensate transferred from the superheated ~~drywell~~ containment atmosphere to the pool was set at 0.92. The heat and mass transfer multipliers were set at 1.0, and the temperature flash option was used.

Two methods of treating the post-reflood period were used for this analysis and three different assumptions made about the mass and energy release during reflood, resulting in six cases. The blowdown mass and energy release was the same for all cases. Peak flow was about 77,000 lbm/sec at 525 Btu/lbm, and the blowdown ended at 20.4 seconds. The reflood data ~~, which~~ lasted 100 seconds ~~, therefore~~ which corresponded to 120.4 seconds after the break. The core was not covered, or even two-thirds covered at this time, but it was substantially cooled. Therefore, the end of the RELAP4 reflood run was defined to be the end of reflood ~~as~~ even though the accumulator flow had been ramped down to zero between 60 and 70 seconds after the break.

During the post-reflood period, decay heat, heat from the secondary system, and heat from the heat structures in the primary system are released to the containment. The decay heat is released over the duration of the run based upon the ANS standard decay heat curve plus 20% and an ultimate reactor power of 2638 MWt plus 2% for instrument error (excluding pump heat). The heat from the secondary system (61 MBtu) and the primary heat structures (53 MBtu) was all released by one hour after the break. A linear ramp to zero was used.

The amount of heat released to the containment by the secondary was determined by obtaining the stored energy in the water in steam generators and in the SG tubes at the end of the RELAP4 reflood calculation. Assuming that this was based on 32°F and that the entire steam generator would be at 212°F after one hour, the amount of heat available to be released was computed to be 61 MBtu. This is conservative because the containment pressure will not decrease to atmospheric pressure in one hour, and so the secondary

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system will be hotter than 212°F. For the primary heat structures, the energy stored in all of the heat structures used in the reflood model, except the core (fuel rods) and the steam generator tubes, was used in the model. It was conservatively assumed that all this metal would be at 212°F after one hour, with the difference (53 MBtu) being released to the containment.

During the post-reflood period, two different methods were used which differ only in the manner in which the energy from the secondary system and primary heat structures is released after reflood. In Method A, ~~the primary compartment in CONTEMPT is not active, and~~ the energy is released directly to the ~~drywell~~ containment without considering the primary coolant system. The amount of mass accompanying this energy release is required, and it is obtained by assuming that the heat is used in converting water at saturation to steam. A typical value for the heat of vaporization at the pressures experienced in the containment for the first hour is 925 Btu/lbm, and this has been used to calculate the mass release rate. This method is ~~extremely~~ conservative, since after some time the water in the primary system will cool to below the boiling point and most of the decay heat will go into heating the water to saturation and leaving very little to generate steam. ~~production.~~ The systems (HPIS and LPIS) that inject water into the primary are not modeled in Method A since the mass and energy flow from the primary is already calculated as described above.

In Method B, ~~the primary compartment is active in CONTEMPT, and~~ the decay heat and heat from the secondary system and from the primary heat structures is passed to the ~~primary~~ compartment through the reactor coolant system. The model in CONTEMPT then determines how much steam is produced, how much heat goes into increasing water temperature, and so on. This is much more realistic than Method A since it allows the steam production to decrease with time. It is still conservative since the heat input has been calculated to be conservatively high. In Method B, injection into the primary is explicitly modeled. The LPIS

(5000 gpm) and the HPIS (450 gpm) both take water from the refueling water storage tank until it empties at 30 minutes. After that, only the HPIS continues, taking water from the ~~drywell pool~~ containment sump. There is no heat exchanger on either of these systems. The ~~drywell pool~~ containment sump is gradually cooled, ~~however,~~ since the water that ~~is~~ recirculated through the containment spray system does pass through a heat exchanger.

Three assumptions were considered for the mass and energy release to the containment during reflood. In the first assumption, only the steam flow from the SG side of the break was used from the RELAP4 results. To be ~~especially~~ conservative, it was then assumed that all of this dry steam was superheated to 1300 Btu/lbm (about 500^{o}F), and the energy release rate was obtained by multiplying the steam flow rate by 1300 Btu/lbm. The actual effluent enthalpy is about 1200 Btu/lbm for the first 20 seconds of reflood and gradually decreases to about 600 Btu/lbm after that. Thus, assuming that only dry superheated steam is released is ~~extremely~~ conservative.

In the second assumption, the mass and energy flow rates from the SG side of the break were used, but the energy flow was augmented to account for superheating. At 70 psia, saturation is about 310^{o}F, and the specific enthalpy of steam is 1185 Btu/lbm. At this pressure, the specific enthalpy at 500^{o}F is only 1282 Btu/lbm. While the SG tubes are a little below 500^{o}F at the start of reflood, their temperature is on the order of 350^{o}F at the end of reflood. Therefore, adding 100 Btu/lbm for each pound of steam flow is ~~certainly~~ conservative. The steam flow rate used to calculate this added energy was the same as that used in the first assumption. The additional energy was about 8% of that computed by RELAP4 at the beginning of reflood and about 6% at the end of reflood.

In the third assumption, the mass and energy released from the SG side of the break by RELAP4 were used directly. The liquid phase falls to the pool as

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released. Naturally, this case results in lower peak temperatures and pressures than the superheated-steam-only case, but it is more realistic and it is conservative.

For all three assumptions, the release of water from the pump side of the break is ignored. This release is all liquid phase and goes directly to the containment sump. The amount of water in the sump has a negligible effect on the temperature and pressure history of the containment vapor region. The RELAP4 model had to use ECCS water at 300°F in order to avoid instabilities, whereas the ECCS water would actually be about 100°F. Since the water coming out the pump side of the break will have had no contact with the core and little with any of the metal enclosing the primary system, it should not be significantly warmer than when it left the accumulators. In view of the large difference between the actual and the model ECCS water temperatures, neglecting the liquid flow from the pump side of the break is probably more realistic than including it.

3.5 Containment Results

The results of the CONTEMPT runs are shown in figure 3.9 through 3.14. Figures 3.9 and 3.10 show the results for the case where only dry, superheated steam flow from the SG side of the break was considered, and the energy release rate during reflood was obtained by multiplying the steam flow rate by 1300 Btu/lbm (which is approximately the specific enthalpy at 500°F and 70 psia). Figure 3.9 shows the results for Method A and Figure 3.10 shows the results for Method B. The two cases are identical to 120.4 seconds since the difference is in how the mass and energy releases are handled after reflood. The figures show that the containment atmosphere reached almost 70 psia and 325°F at 84 seconds just before the containment spray began. Since only dry steam was released to the containment during reflood, the containment spray has an immediate and dramatic effect on the containment vapor region temperature and pressure. The peak pressure equals the containment design pressure of 69.7 psia, ~~and the peak temperature exceeds the design temperature of 280°F~~. In view of the ~~extremely~~ conservative assumption of releasing only dry, superheated steam during reflood, this is not considered significant. It is inconceivable that the superheated steam could flow from the steam generator to the break with the saturated water and not mix to form a homogeneous, two-phase flow.

Since the Method A assumptions are not suitable for a long-term model, the run shown in Figure 3.9 was terminated at two hours, while the Method B run in Figure 3.10 was continued to ten days. The results of the two methods are quite close at two hours. The dip in the atmosphere pressure and temperature at 30 minutes (1800 sec) in Method B is due to the shutdown of the LPIS at the time when the RWST runs dry. This does not show up in Method A since the primary system is not modeled. The change in ~~slope~~ at 30 minutes in the Method A result is due to the fact that the source of water for the containment spray changes from the RWST to the warmer ~~drywell pool~~. The vapor region temperature reaches 135°F at about 8.08 days (698,400 sec) in Method B (see Figure 3.10).

Figures 3.11 and 3.12 show the results for the release of a two-phase mixture with the energy flow augmented to account for superheating the steam fraction. Peak pressure is about two psi below the design pressure, and the peak temperature is ~~just~~ about ~~equal to the design temperature~~. Behavior after a few hundred seconds is nearly identical for all the A cases and all the B cases. This is to be expected since events are dominated by the absorptive capacity of the heat structures and the effect of the sprays. The atmospheric temperature reaches 135°F at about 8 days.

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In view of all the conservative assumptions made elsewhere, the results shown in Figures 3.11 and 3.12 are sufficiently conservative and meet the Standard Review Plan requirement for superheated steam. Since the effluent to the containment will certainly not be dry steam in view of the carryover rate fraction in the core, this assumption of wet steam with the steam fraction arbitrarily superheated appears to be the maximum which can be justified as realistic.

Figures 3.13 and 3.14 show the results when the RELAP4 calculated releases from the SG side of the break ~~were entered unchanged into CONTEMPT~~ *without adding any energy to account superheating stea[m]* for the *release during the* reflood period. Peak pressure was over 4 psi below the design pressure, and the peak *containment atmospheric* temperature was ~~more~~ *less* than ~~10°F below the design temperature.~~ *273°F.* The *containment* atmospheric temperature dropped to 135°F after about 8 days. So many conservatisms, including the use of 300°F ECCS water, were made in arriving at the releases to the ~~drywell~~ *containment* during reflood and post-reflood that these results are definitely conservative. *However* They do not meet the SRP mandate for superheated steam~~, however~~.

4.0 Secondary System Pipe Break

Analyses of the containment response to a secondary system pipe break were also made. For PWR's the most limiting break location is a main steam line break with pure steam blowdown. In the case of Palisades the results show that a single failure assumption which allows both steam generators to blowdown will produce peak pressures and temperaturs which exceed design values. The model and assumptions that were used in analyzing the main steam line break are given in the following discussion.

4.1 Assumptions

A main steam line break (MSLB) analysis was performed by Consumers Power Company.[1] Results given in this reference are used for comparison purposes. In particular, mass and energy release data for the full power MSLB case discussed in the Palisades FSAR is provided in Table 1 of reference 1.

The Palisades FSAR full power analysis assumed:

(1) A double-ended guillotine rupture of a main steam line inside the containment.

(2) A reduction in feedwater flow from full flow to zero over the 60 seconds immediately following scram at less than 2 seconds on high containment pressure.

(3) Both main steam isolation valves would close on low steam generator pressure (500 psia) causing the unruptured steam generator to isolate in eight seconds.

(4) Off-site power was available.

(5) Only two containment spray pumps were available; no air coolers were available.

(6) Pure steam blowdown (no moisture carryover).

(7) A highly conservative containment heat transfer model.

In addition to the results reported in reference 1, a number of analyses for Palisades containment response to the MSLB were made. The analyses employed RELAP4 to obtain mass and energy release rates and CONTEMPT-LT/028 to obtain containment response.

The RELAP4 mass and energy release rates were obtained using a simplified model based on one volume, one heat conductor, one break junction, and one

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1 Palisades Plant - Automatic Initiation of Auxiliary Feedwater System at Palisades Plant, Docket 50-255-License DPR-20, Janury 21, 1980 letter from Roger W. Huston of Consumers Power Co. to Dennis L. Ziemann of NRR, Nuclear Regulatory Commission.

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feedwater fill junction. Two break sizes and three feedwater flow assumptions were analyzed. The resulting break flow rates are summarized and compared to reference 1 results in Figures 4.1 and 4.2. For the RELAP4 analyses, the steam generators were assumed to be at 770 psia, with an average water enthalpy of 552.2 Btu/lbm and contain 128,456 lbm each. The primary system was assumed to be held constant during the blowdown with 513.83°F local temperature and a 952 Btu/hr/ft^2/°F heat transfer coefficient in the steam generator. Figures 4.1 and 4.2 show that the main effect of the feedwater is to prolong the time of blowdown period and increase the total mass and energy to the containment.

The containment responses for a number of MSLB cases have been compared. The results are given in the following discussion.

4.2 Containment Response Results

Case 1

The first case selected for analysis was intended to determine if the CONTEMPT-LT/028 model used would give results similar to those in reference 1 if similar assumptions were employed. Consequently, two CONTEMPT runs were made, using the reference 1 mass and energy release rates. These CONTEMPT runs assumed two spray pumps and one fan cooler were available and a TPEAK of eight seconds for the CONTEMPT Tagami/Uchida heat transfer correlation.

The one run assumed that off-site power was not available so the two spray pumps were started at 84 seconds. The other CONTEMPT run assumed off-site power was available so the spray pumps were started at 30 seconds.

The containment histories for the two Case 1 runs are compared to the reference 1 pressure history in Figure 4.3P. The comparison between the results with spray after 30 seconds and the reference 1 results is close, indicating an acceptable CONTEMPT model. The containment temperature histories for the ~~RELAP4 model~~ case 1 are shown in Figures 4.3T-A and 4.3T-B.

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Case 2

The purpose of the Case 2 analysis was to determine if the one volume RELAP4 model was adequate for obtaining mass and energy release rates to the containment. The blowdown mass and energy release rates for various feedwater and break area combinations have been noted in Figures 4.1 and 4.2 For Case 2 the ruptured steam generator blowdown was simulated by the 36-inch break (area = 6.12 ft^2) with main feedwater only. This feedwater flow was initially 1650 lb/sec and ramped down to zero flow at 60 seconds. The unruptured steam generator was assumed to isolate (MSIV closure, not failure) so the mass and energy release rates were obtained from refrence 1. The mass and energy release rates for the two steam generators were added for input to the CONTEMPT model.

The CONTEMPT assumptions for Case 2 were similar to the assumptions for the Case 1 run with spray after a 30 second delay. The containment pressure and temperature response from Case 2 is shown in Figures 4.4P and 4.4T, respectively. The peak pressure is about 65 psia, which is slightly less than for the comparable Case 1 run and the reference 1 value. Therefore, the one volume RELAP4 model was judged to be adequate for obtaining mass and energy release rates. It is noted that complete phase separation is modeled in the RELAP4 analyses so that pure steam blowdown occurs.

Case 3

Cases 1 and 2 established that the CONTEMPT and RELAP4 models were adequate for obtaining containment response to a MSLB. Cases 3 and 4 were designed to determine the response of the Palisades containment to the MSLB for blowdown of both steam generators, with off-site power available. Case 3 assumed that each steam generator would blow down through a 24-inch break (3.06 ft^2). Case 4 assumed that the ruptured steam generator would blow down through the 36-inch (6.12 ft^2) break and the unruptured steam generator would blow down through a 24-inch break.

The assumptions used for Case 3 include:

(1) If off-site power is available, the spray pumps will be activated at 30 seconds after high containment pressure (5 psig). High containment pressure occurs in about 1.7 seconds. A conservative value of 33 seconds was used in the analysis.

(2) Single failure is the Main Steam Isolation Valve (MSIV) failure causing both steam generators to blow down.

(3) Ruptured steam generator blows down through one-half the maximum areas, or 3.06 ft^2, as areas larger than this would not give a pure steam blowdown.

(4) Isolated steam generator blows down through one-half the steam-line area becuase of MSIV flow area restrictions, thus through 3.06 ft^2.

(5) All three spray pumps and all four fan-coolers will be available. The single failure is assumed in the MSIV.

(6) The CONTEMPT time TPEAK for the Tagami/Uchida heat transfer correlation was changed to 99 seconds to correspond with the end of blowdown.

(7) Main feedwater is available to each steam generator at 1650 lb/sec initially and ramps down to zero flow at 60 sec.

The resulting containment pressure and temperature history is shown in Figures 4.5P and 4.5T, respectively. The peak pressure is about 107 psia, which is substantially greater than the 55 psig design pressure.

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The results show that the worst single failure assumption is a MSIV failure which would allow both steam generators to blowdown. This is possible since the closure of Palisades MSIVs is only in the forward direction due to the nature of the MSIVs (check valves held open by air against the normal flow of steam). This makes it possible for a steam line break to give rise to the blowdown of its associated steam generator plus the blowdown of the second steam generator through the failed MSIV, connecting header, and reversed flow through the closed MSIV. This produces the maximum pressure and temperatures which are higher than design values.

Case 4

The assumptions used for Case 4 were identical to those used in Case 3 except that the ruptured steam generator was allowed to blowdown through the maximum area of 6.12 ft^2. The resulting containment pressure and temperature predictions are shown in Figures 4.6P and 4.6T, respectively. The peak pressure is about 106 psia.

Case 5

Cases 3 and 4 assumed that off-site power was available. Case 5 was run to investigate the containment response for the loss of off-site power assumption. Case 5 is similar to Cases 3 and 4 except for two assumptions. First, because off-site power is lost, the spray pumps are not available until 84 seconds. In addition, the loss of off-site power results in a complete and immediate loss of feedwater.

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Case 5 was based on each steam generator blowing down through a 24-inch diameter break. The pressure and temperature response is shown in Figures 4.7P and 4.7T, respectively. The peak pressure is about 98 psia and a peak containment atmospheric temperature of 465°F at 70 seconds.

Case 6

Analyses have also been performed assuming a fix which would prevent the blowdown of both steam generators. In this case the single failure assumption is loss-of-offsite power with a failure of one diesel generator. The mass and energy release data used in the analysis is for the full power MSLB with one steam generator blowdown. This is discussed by Consumer Power Company in ref. 1 and provided in Table 4.1. The assumptions made in the mass and energy release analysis are the following:

1. A double-ended guillotine rupture of a main steam line inside the containment.
2. A reduction in feedwater flow from full flow to zero over the 60 seconds immediately following scram at less than 2 seconds on high containment pressure.

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3. Both mainsteam isolation valves would close on low steam generator pressure (500 psia) causing the unrupture steam generator to isolate in eight seconds.

4. Off-site power was available to maximize the rate of energy transfer from the primary to secondary.

5. Pure steam blowdown (no moisture carryover).

For the containment response calculation the following assumptions were made:

1. Loss-of-offsite power and failure of one diesel generator.
2. 2 of 3 containment spray pumps available.
3. Containment spray initiation at 36.7 seconds (200 gpm) and full flow at 52.5 seconds (2680 gpm) (Reference 2).
4. 1 of 4 air coolers available at 23 seconds.
5. Tagami/Uchida heat transfer correlation with Tagami peak time at end of blowdown (68 seconds).

The results of this analysis are the pressure and temperature responses shown in Figures 4.8P and 4.8T. The calculated peak pressure is 68.5 psia reached at 67 seconds. This is 1.2 psi below design. The calculated peak temperature is 413°F reached at 37 seconds. Therefore, based on this analysis, a fix which would prevent the blowdown of both steam generators would limit the calculated peak pressure to 1.2 psia below design.

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2 Palisades Plant -- Proposed Technical Specifications change Related to Containment Spray Initiation Time, Docket 50-255 License DPR-20, November 24, 1980 letter from D. P. Hoffman of Consumers Power Co. to D. Crutchfield of NRC.

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Conclusion

Based on the results of Case 1 and 2, the CONTEMPT and RELAP4 models are adequate for obtaining containment response to a MSLB. The results of Cases 3, 4, and 5 showed that the blowdown of both steam generator will result in containment pressure ~~and temperatures which~~ exceed design values. This is regardless of whether off-site power is available. The results of Case 6 showed that a design change which would prevent the blowdown of both steam generators would keep the containment peak pressure within the design limit.

Table 3.1

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Palisades Double-Ended Suction Leg Break
Blowdown Energy Balance
(Million Btu)

	0 Seconds	Decrease	20.4 Seconds
Primary System Coolant Inventory	253.7	246.6	7.1
Steam Generator Coolant Inventory	140.0	2.0	138.0
Secondary Flow to Turbine(1)	--	-9.2	--
Accumulator System Inventory(2)	19.5	0.7	18.8
Core Stored Heat	18.9	4.6	14.3
Conductor Stored Heat(3)	111.0	3.7	107.3
Decay and Fission Heat	--	5.0	--
	543.1	253.4	285.5

Note:

(1) Flow continues until valuve is fully closed at six seconds after the break. Energy value is net loss for steam and feedwater flows.

(2) Accumulators and lines at 90°F.

(3) Conductors include all metal transferring heat to the primary coolant system except for the fuel rods.

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Table 3.2

Palisades Double-Ended Suction Leg Break
Reflood Energy Balance
(Million Btu)

	20 Seconds	Decrease	120 Seconds
Reactor Coolant System Inventory	22.4	-3.1	25.5
Safety Injection Tank Water(1)		77.6	--
Safety Injection Pump Flow(1)	--	13.5	--
Core Stored Heat(2)	16.2	11.0	5.2
Decay and Fission Heat	--	12.3	--
Primary Vessel Walls	59.3	3.3	56.0
Primary Vessel Internals	12.4	3.5	8.9
Primary Loop Metal	28.4	1.0	27.4
Steam Generator Inventory (I.L. 69.8 - 59.1 = 10.7)(3)	137.9	33.7	104.2
Steam Generator Tube Metal (I.L. 7.6 - 6.3 = 1.1)(3)	14.3	3.6	10.7
TOTALS	290.9	156.4	237.9

Approximate Break Flow Energy

S.G. Side	72 (10^6) Btu
Pump Side	81 (10^6) Btu
Total	153 (10^6) Btu

Reference Temperature is 32°F

Notes:

(1) The S.I. water temperature was 300°F to prevent numerical instabilties. Actual value should be 110°F.

(2) Based on ANS + 20% decay heat curve.

(3) Energy from intact loop steam generator.

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Table 3.3

Heat Structures in Palisades Containment Model

Structure	Area ft^2	Thickness ft
1. Tanks and piping (.453 inch)	19,332	.0378
2. Ducts (.10 inch)	20,072	.0083
3. Reactor crane (2.35 inch)	6,973	.1958
4. Internal concrete (33 inch)	9,401	2.75*
5. Gratings and trusses	20,996	.0144
6. Containment dome	7,270	3.0217
7. Containment dome base	11,000	7.75
8. Containment side wall	50,600	3.5217
9. Storage pool floor and shielded walls	4,456	4.35
10. Containment base slab	8,229	12.44
11. Biological shield wall	2,340	7.8672
12. Structural support steel	26,320	.45

* Deck received had 2.25, which was in error.

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Table 3.4

Palisades Containment - Initial Conditions

Outside air temperature	95°F
Outside air pressure	14.7 psia
Relative humidity of outside air	0.60
Volume of primary capable of holding liquid	3050.3 ft^3
Temperature of primary system vapor region	250°F
Temperature of primary system liquid region	250°F
Volume of ~~drywell~~ containment	1.6E6 ft^3
Volume of liquid pool ~~on drywell floor~~ in containment sump	10 ft^3
Temperature of ~~drywell~~ containment vapor region	120°F
Temperature of ~~drywell~~ containment liquid region	120°F
Pressure in ~~drywell~~ containment	14.7 psia
Relative humidity in ~~drywell~~ containment	1.0
Horizontal cross-sectional area of ~~drywell~~ containment	8,229 ft^2

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TABLE 4.1
Main Steam Line Break
Mass/Energy Release Data

Ruptured Steam Generator

Time (Sec)	Lbm/hr	Btu/Lbm
0.0	3.266E07	1200.7
0.1	3.266E07	1200.8
0.2	3.186E07	1201.2
0.3	3.106E07	1201.5
0.4	3.037E07	1202.0
0.5	2.957E07	1202.3
0.7	2.826E07	1202.8
1.0	2.637E07	1203.5
1.3	2.501E07	1204.0
1.5	2.409E07	1204.3
1.8	2.283E07	1204.5
2.0	2.215E07	1204.6
2.5	2.067E07	1204.8
3.0	1.942E07	1204.8
4.0	1.759E07	1204.5
5.0	1.621E07	1204.1
7.2	1.370E07	1203.2
8.0	1.336E07	1202.9
10.0	1.233E07	1202.3
15.0	1.062E07	1200.9
20.0	9.592E07	1199.9
30.0	8.221E06	1197.6
40.0	7.193E06	1196.0
45.0	6.852E06	1195.1
50.0	6.[illegible]66E06	1194.1
54.0	6.280E06	1193.5
60.0	5.938E06	1191.1
68.0	5.481E06	1191.1
68.0	0.0	

Isolated Steam Generator

Time (Sec)	Lbm/hr	Btu/Lbm
0.0	1.656E07	1200.4
0.1	1.656E07	1200.4
0.2	1.656E07	1200.6
0.6	1.587E07	1201.3
1.0	1.530E07	1201.8
1.3	1.496E07	1202.2
1.5	1.473E07	1202.5
2.0	1.416E07	1202.9
3.0	1.279E07	1203.6
3.5	1.233E07	1203.8
4.0	1.153E07	1204.0
5.0	9.930E06	1204.2
5.4	9.135E06	1204.2
6.0	7.650E06	1204.3
6.4	6.622E06	1204.2
6.8	5.709E06	1204.2
7.2	4.339E06	1204.1
7.8	1.484E06	1203.9
8.1	0.0	1203.8

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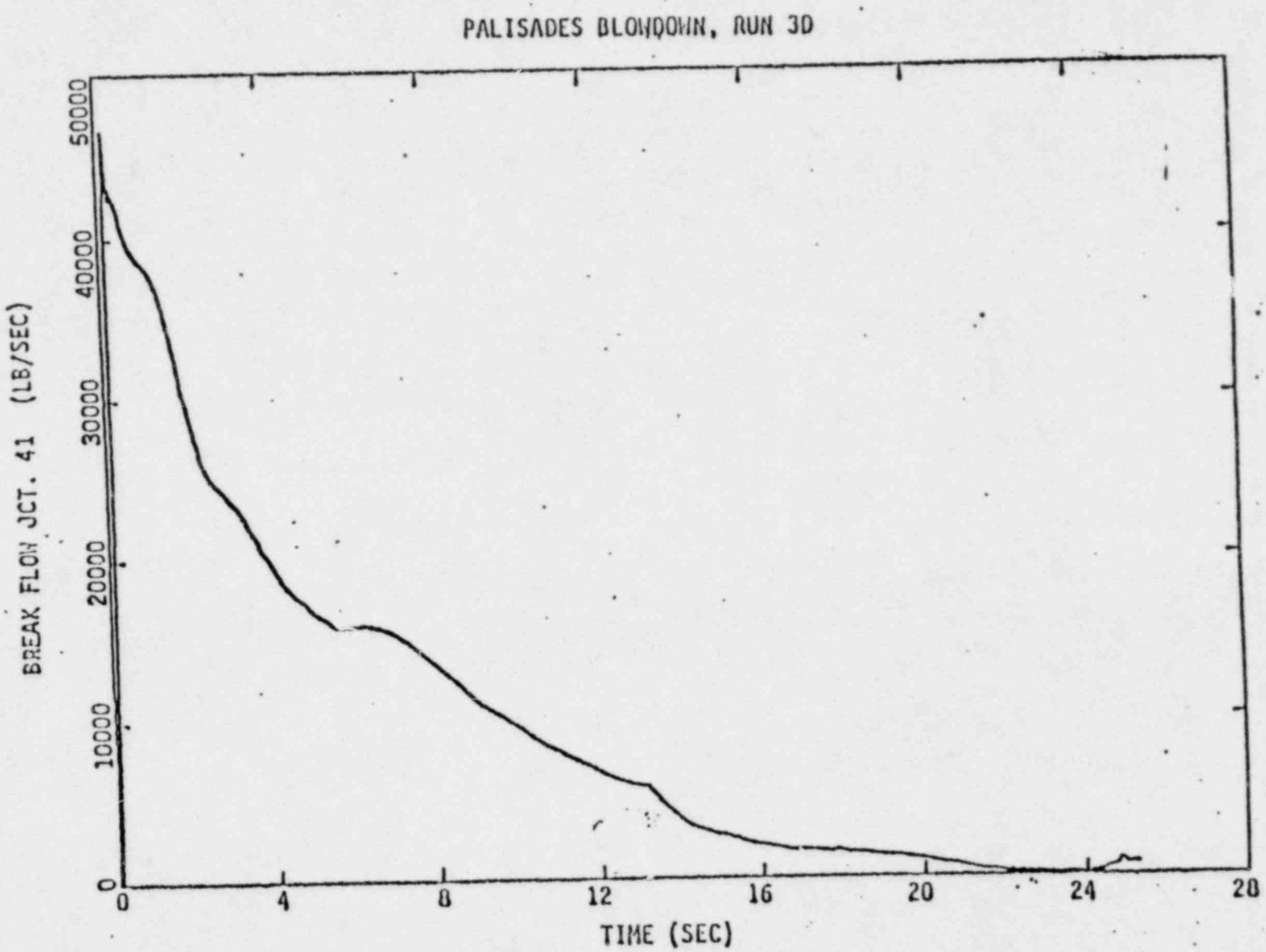
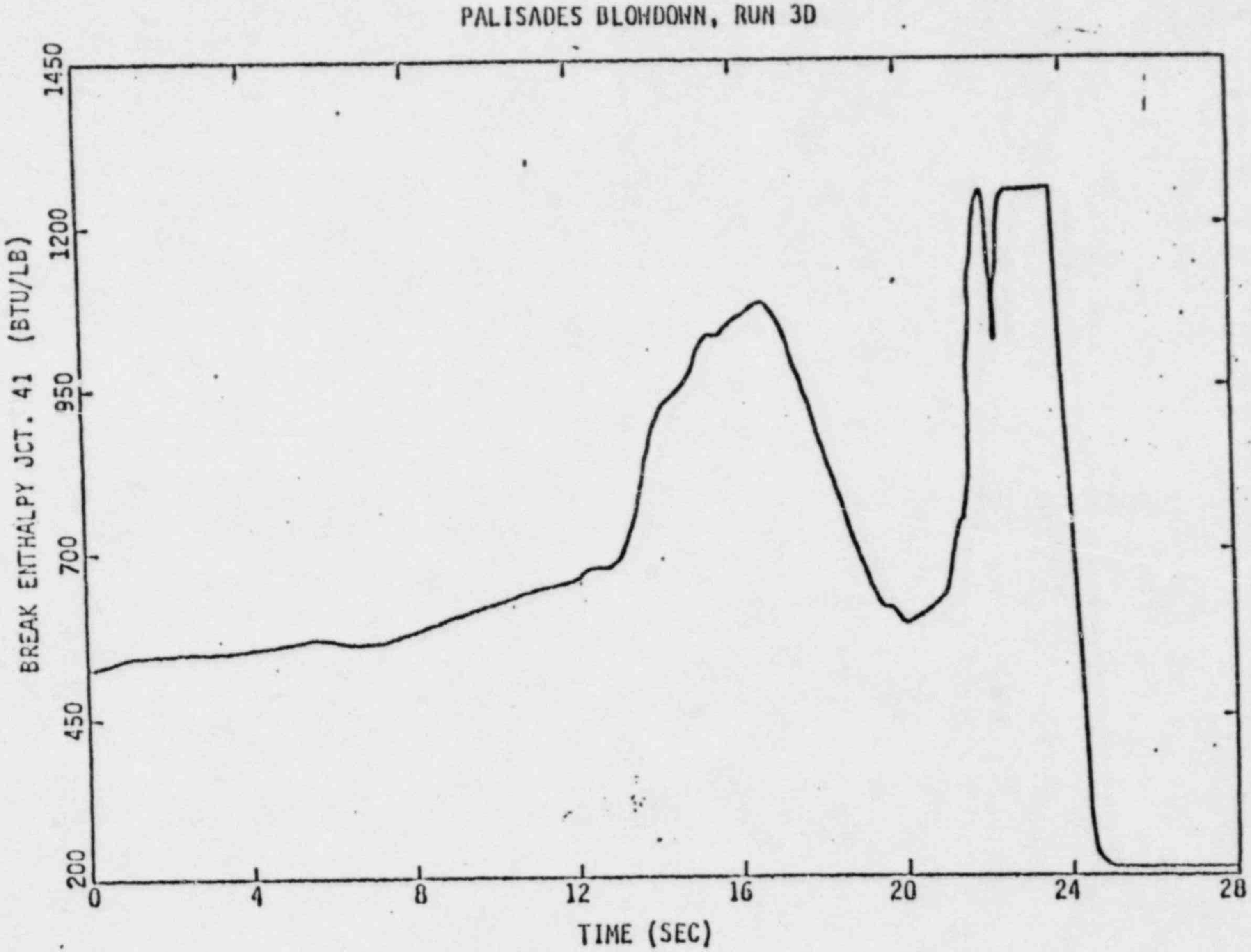


Figure 3.1 BREAK FLOW, STEAM GENERATOR, SIDE OF BREAK


PALISADES BLOWDOWN, RUN 3D
BREAK ENTHALPY JCT. 41 (BTU/LB)
1450
1200
950
700
450
200
0
4
8
12
16
20
24
28
TIME (SEC)

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PALISADES BLOWDOWN, RUN 3D

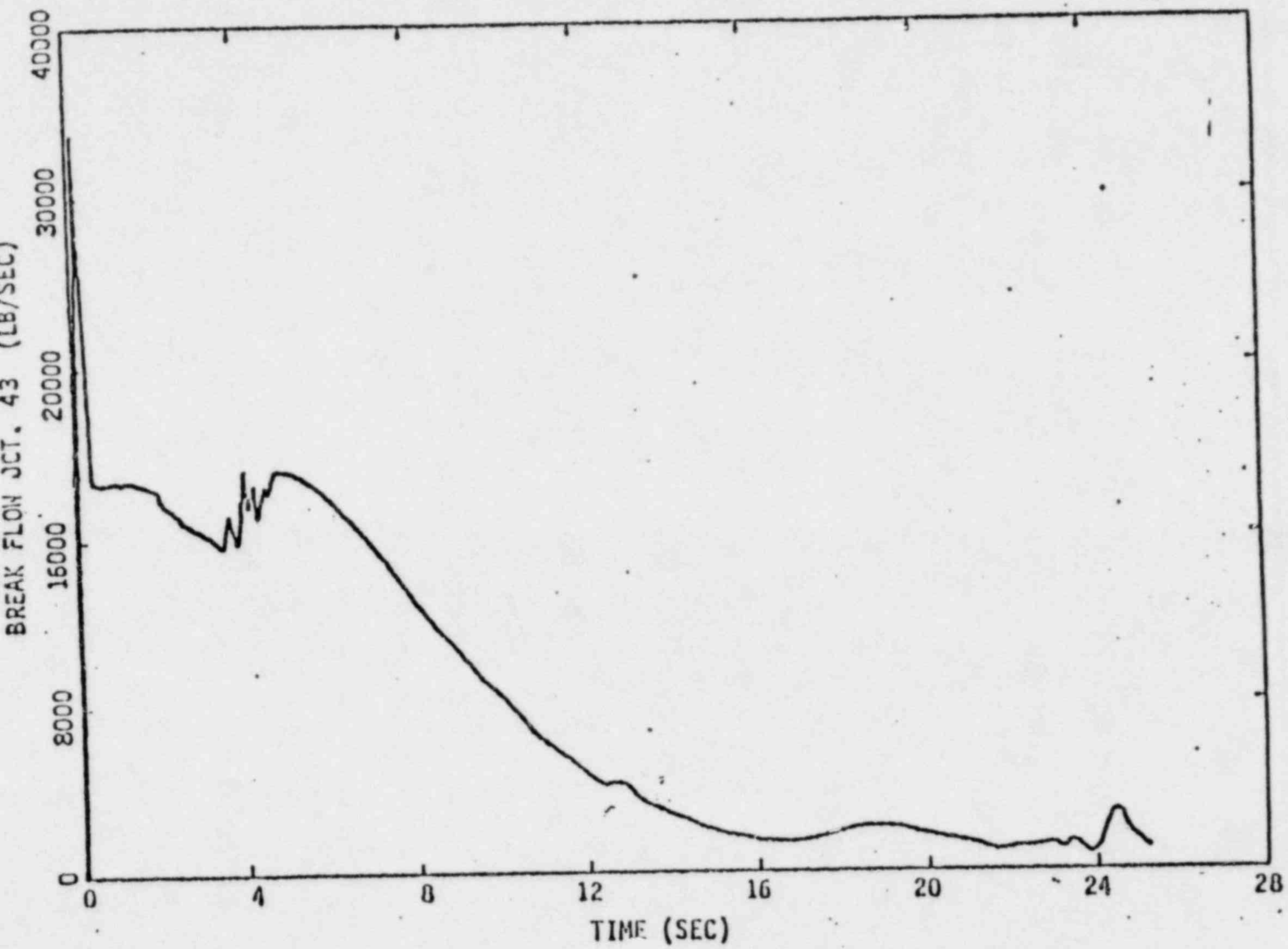

Figure 3.3½ BREAK FLOW, PUMP SIDE OF BREAK

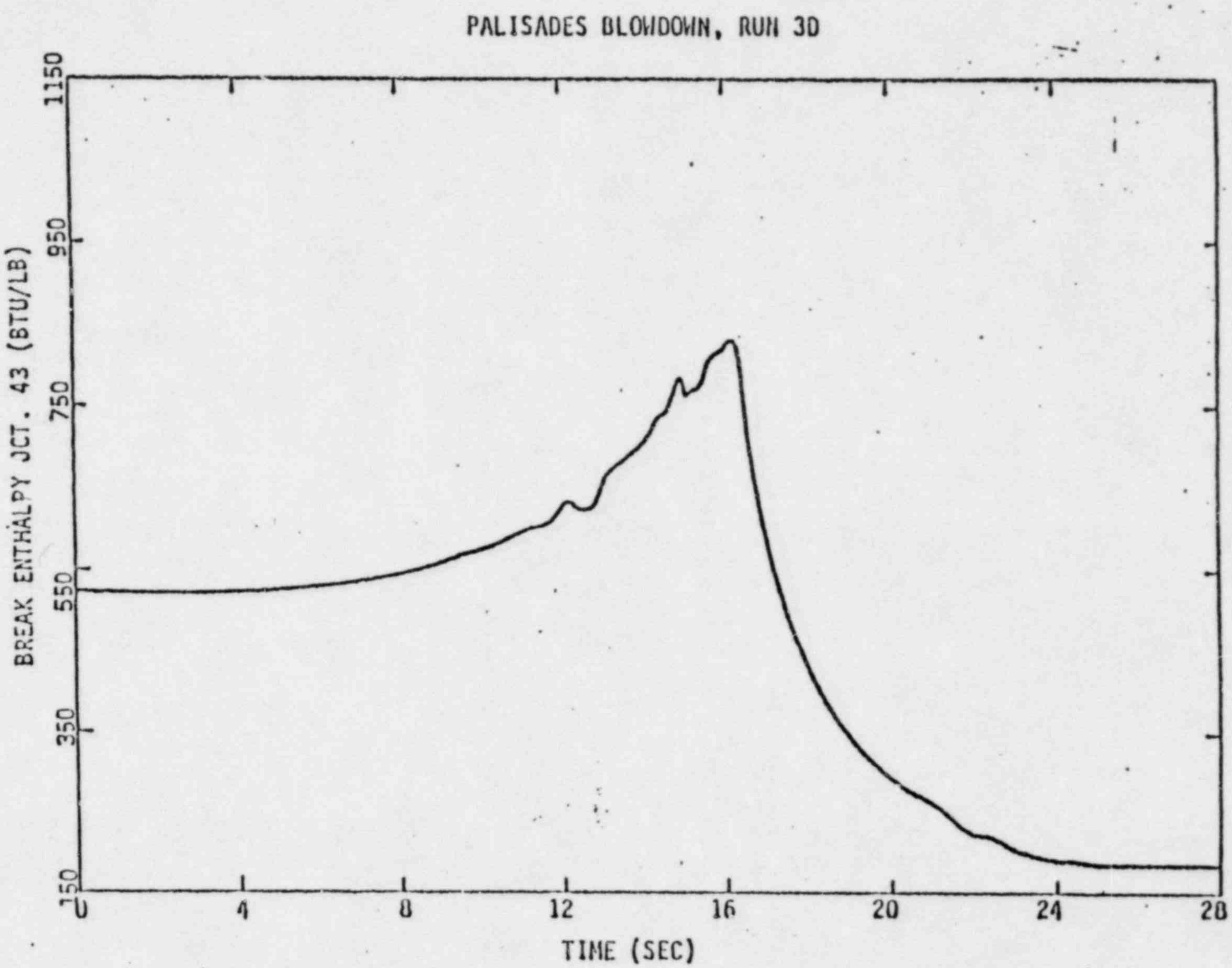

Figure 3.4 BREAK ENTHALPY, PUMP SIDE OF BREAK

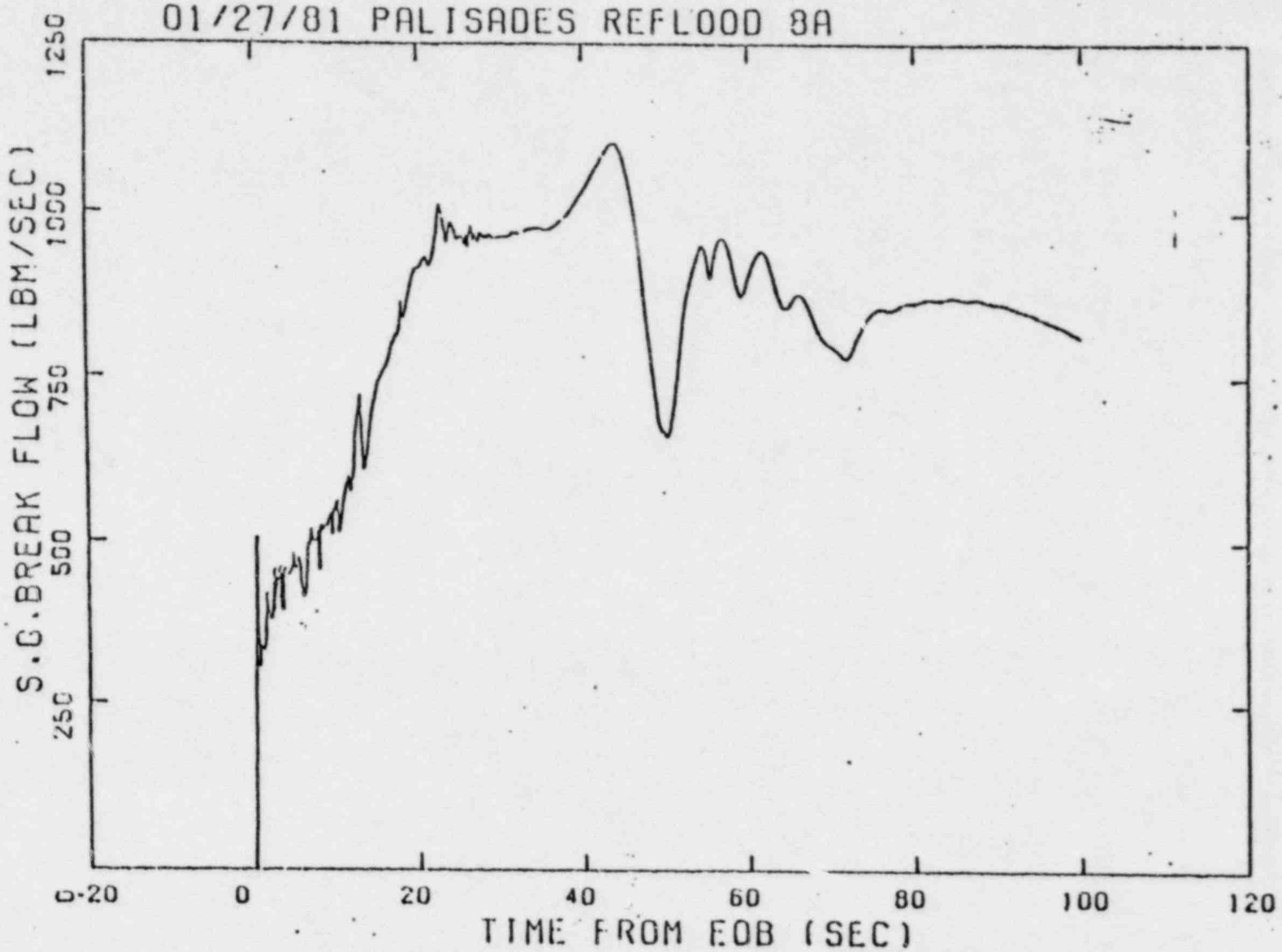

Figure 3.5 BREAK FLOW-STEAM GENERATOR SIDE

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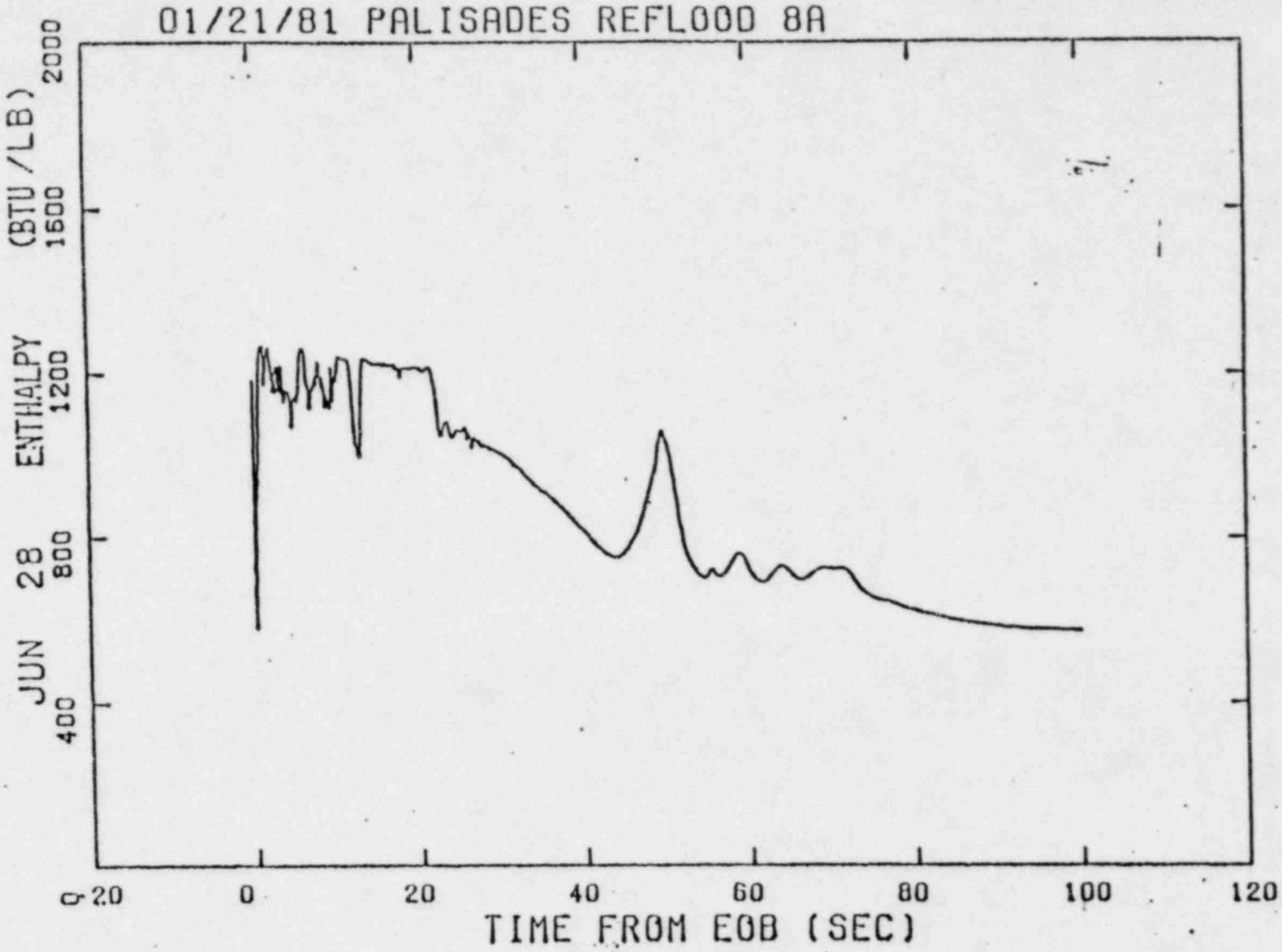

Figure 3.6 BREAK FLOW ENTHALPY-STEAM GENERATOR SIDE

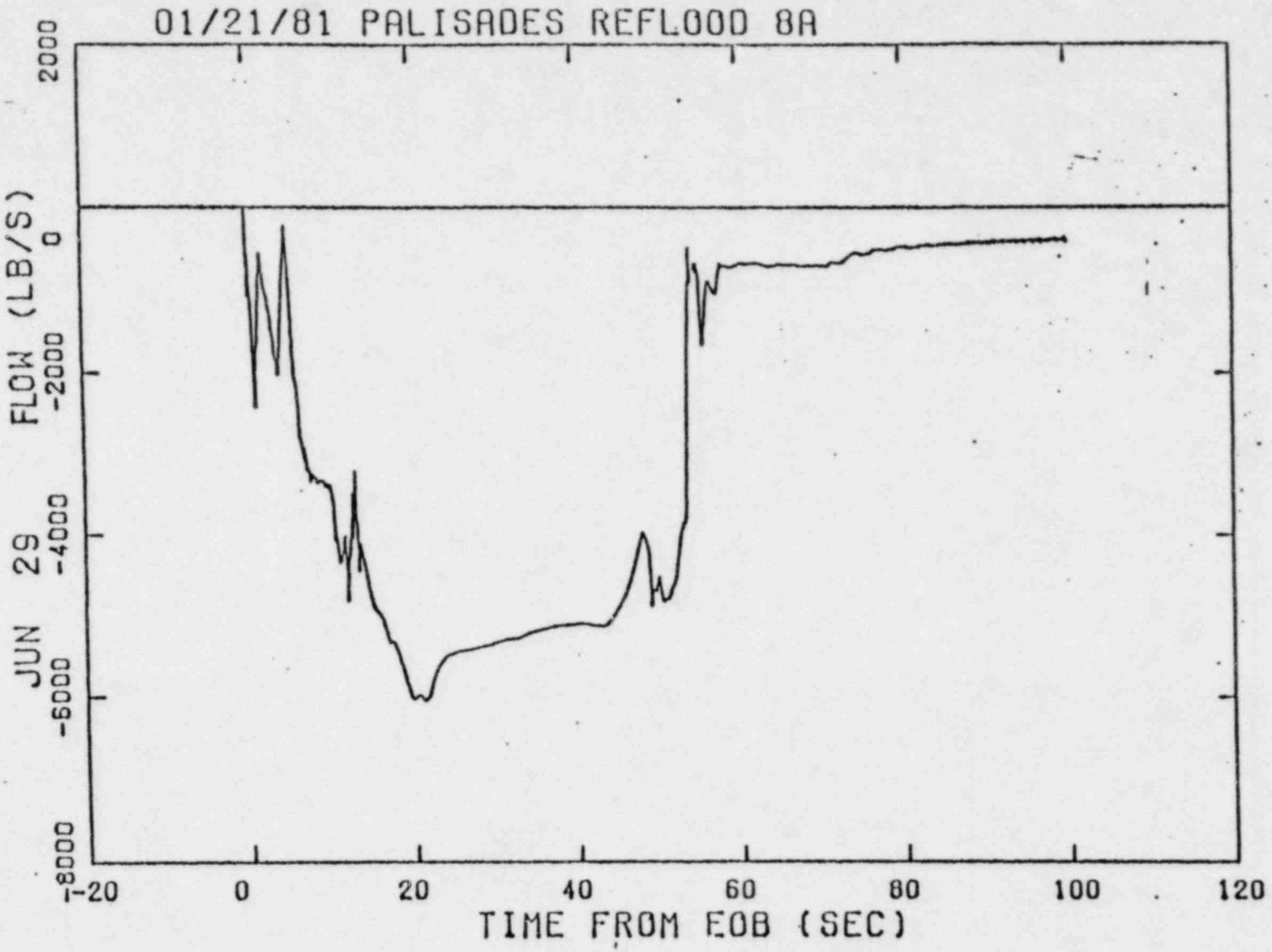

Figure 3.7 BREAK FLOW-PUMP SIDE

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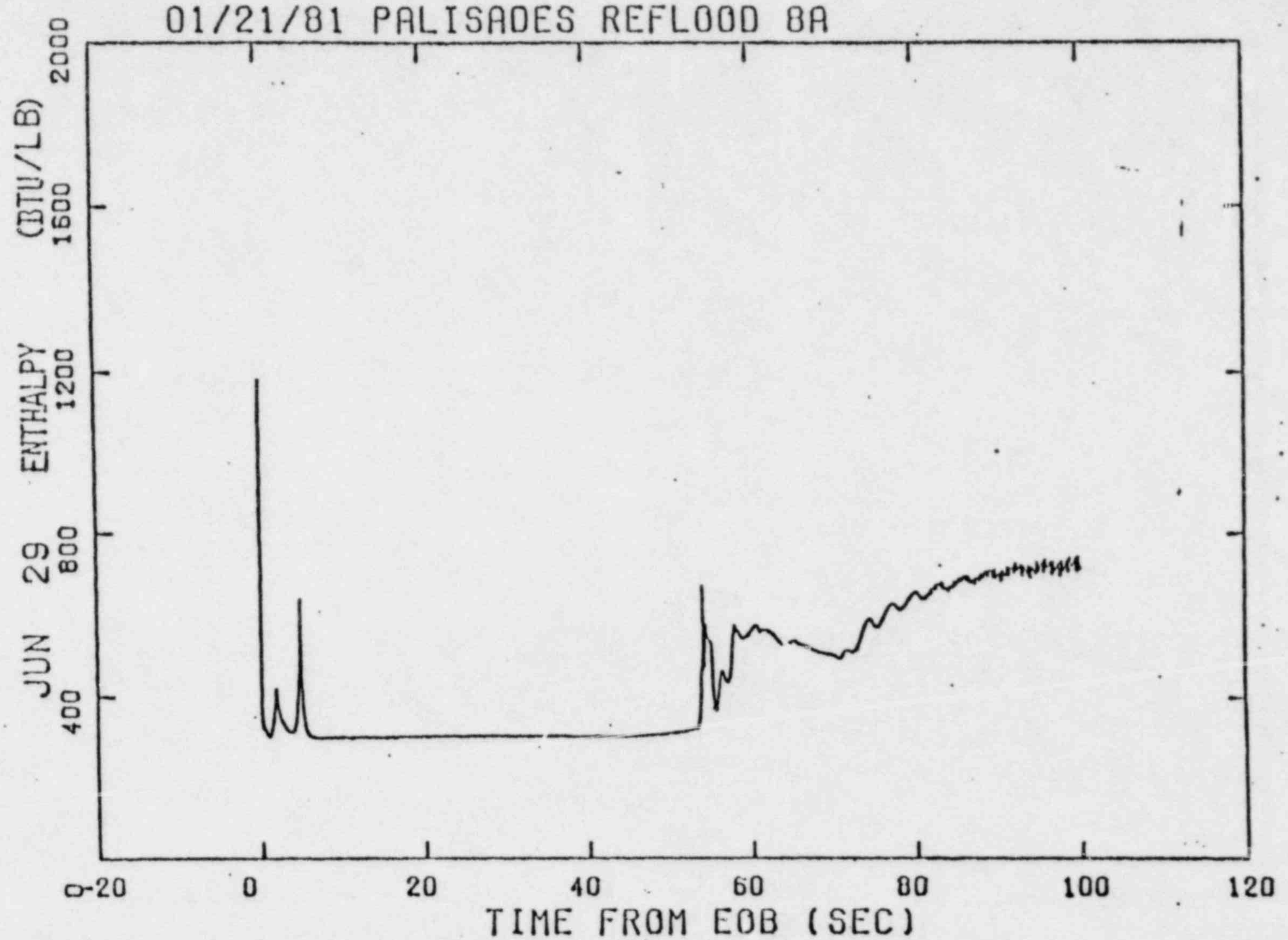

Figure 3.8 BREAK FLOW ENTHALPY-PUMP SIDE

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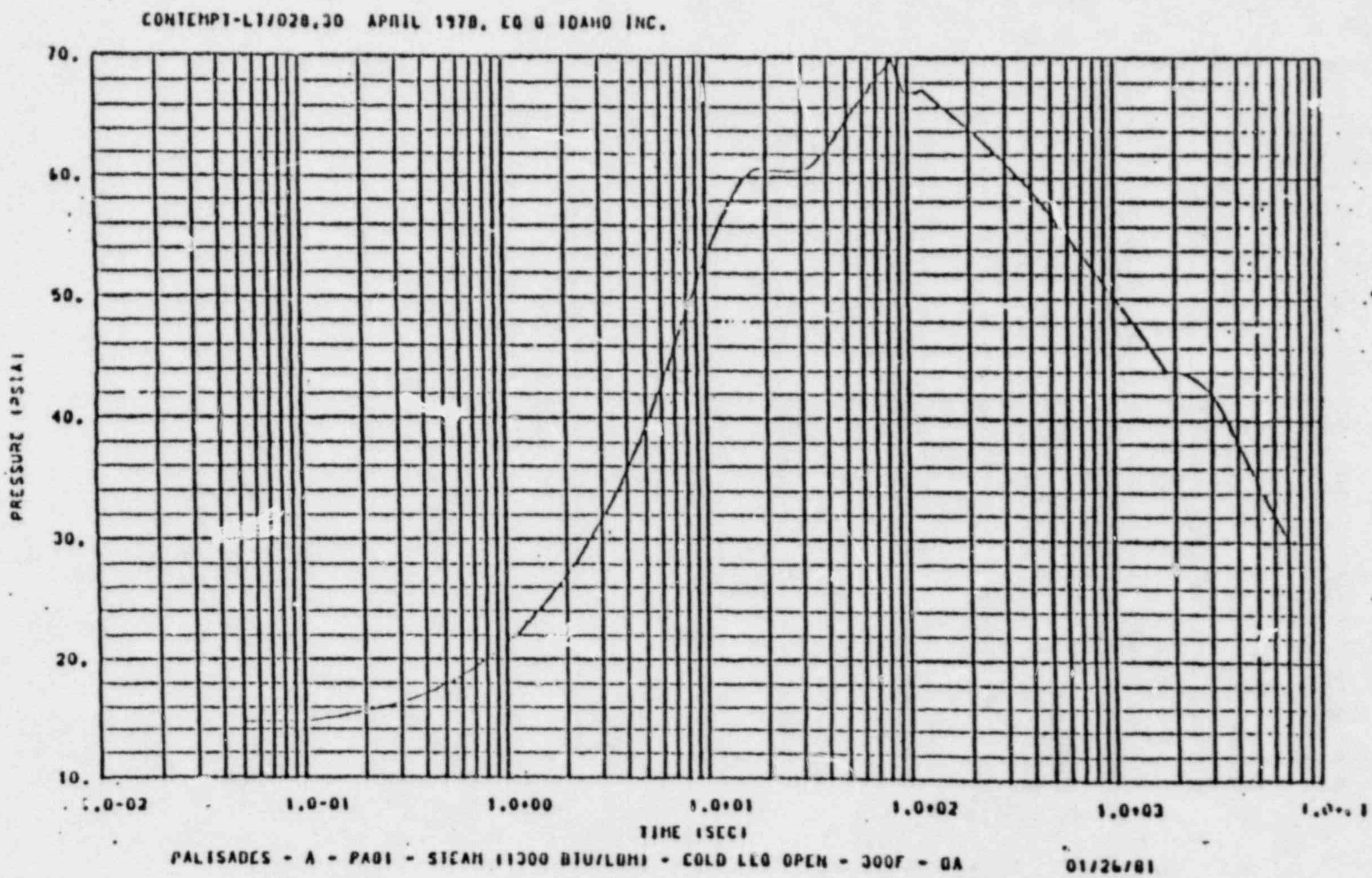

Figure 3-9P CONTAINMENT PRESSURE-SUPERHEATED STEAM ONLY (METHOD A)

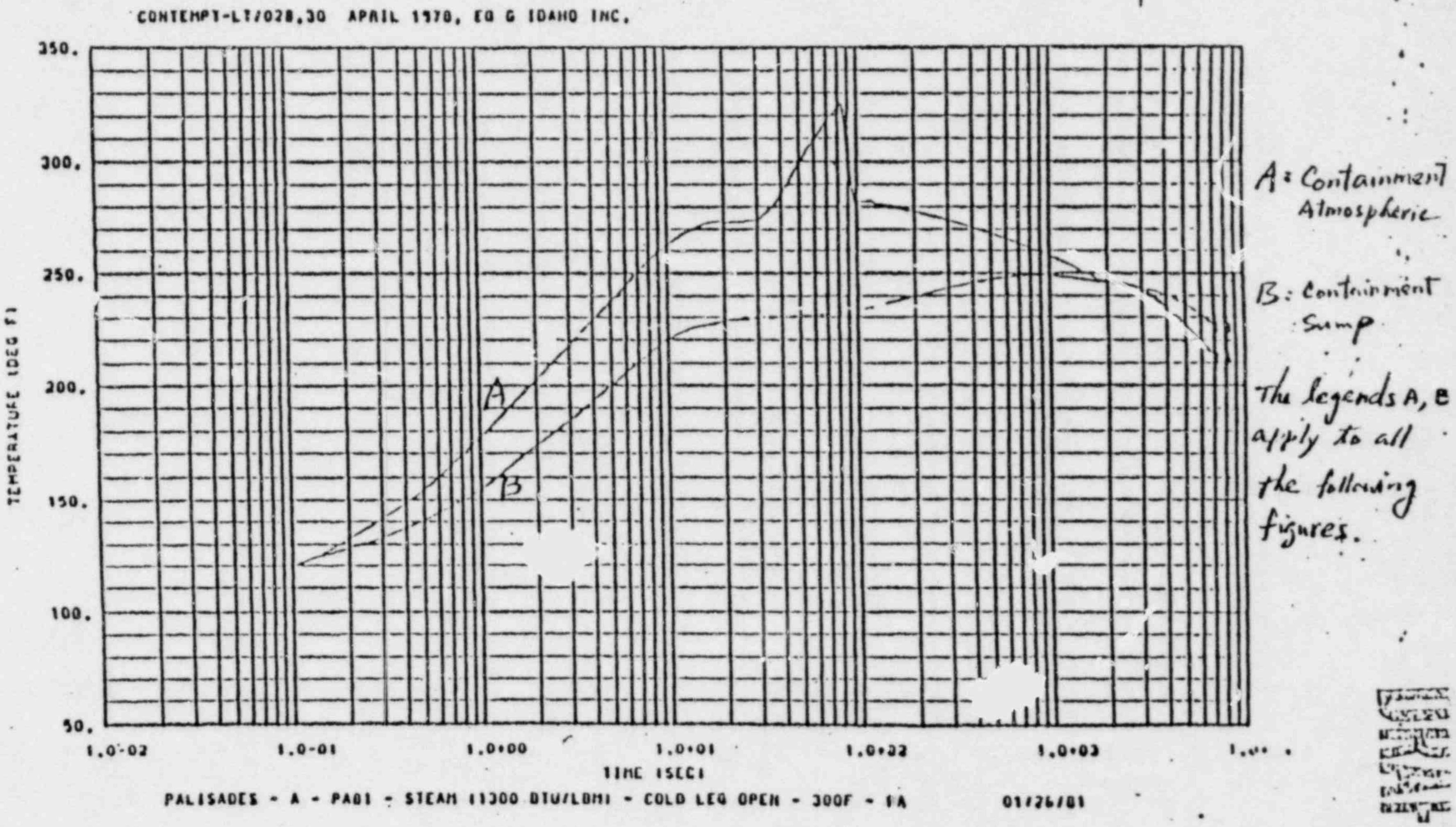

Figure 3.9T CONTAINMENT TEMPERATURE-SUPERHEATED STEAM ONLY (METHOD A)

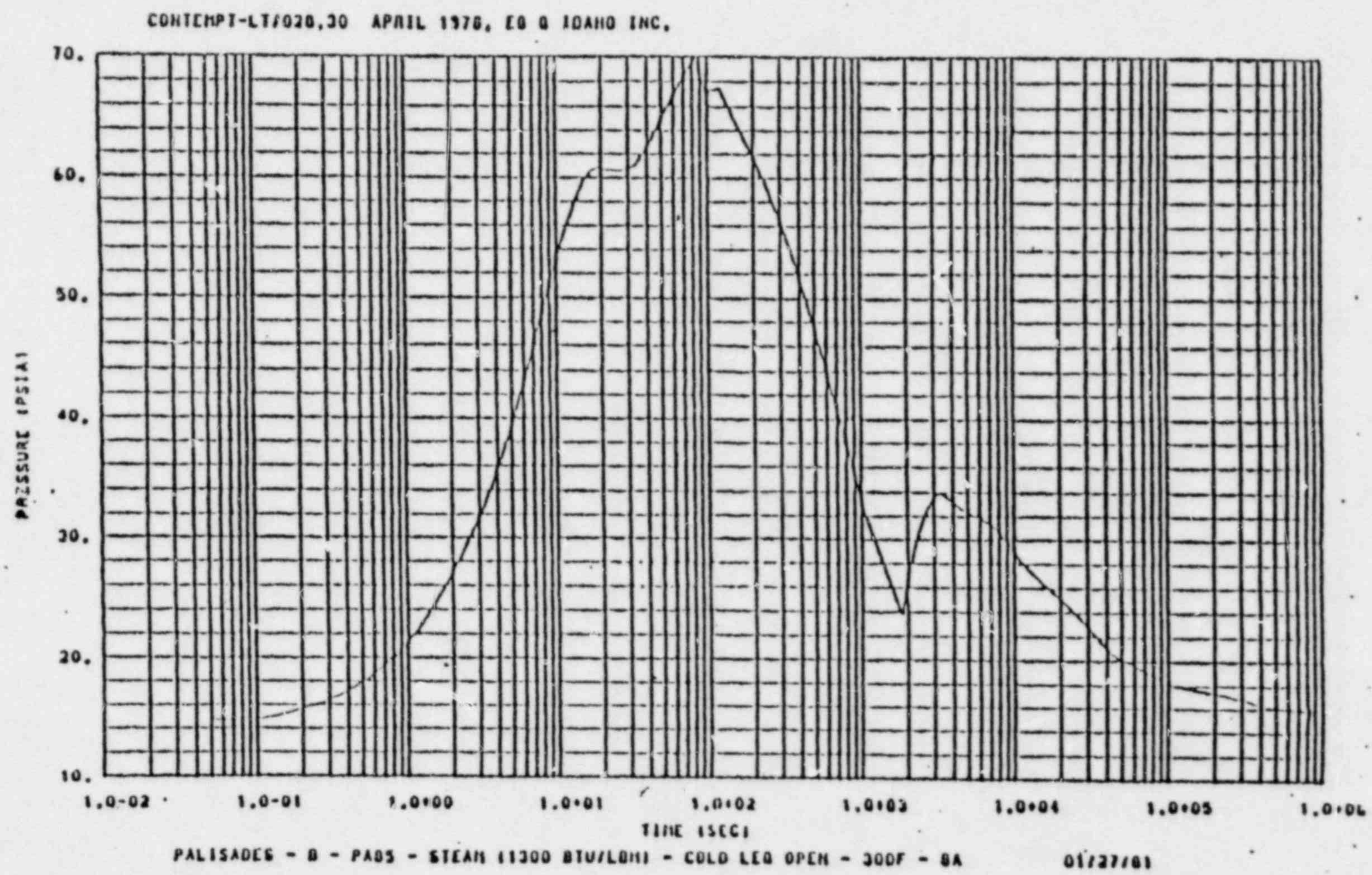

Figure 3.10P CONTAINMENT PRESSURE-SUPERHEATED STEAM ONLY (METHOD B)

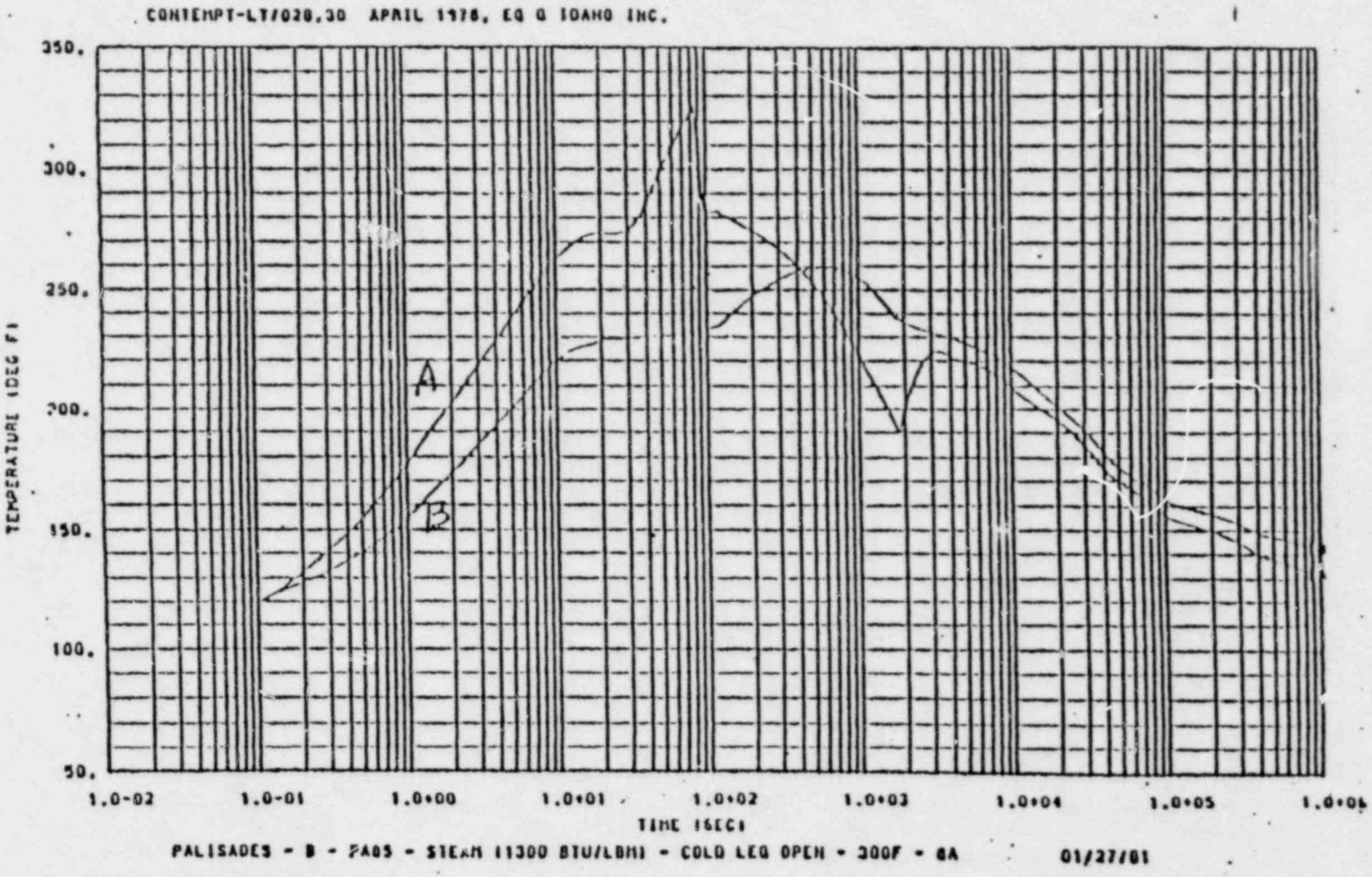

Figure 3.10T CONTAINMENT TEMPERATURE-SUPERHEATED STEAM ONLY (METHOD B)

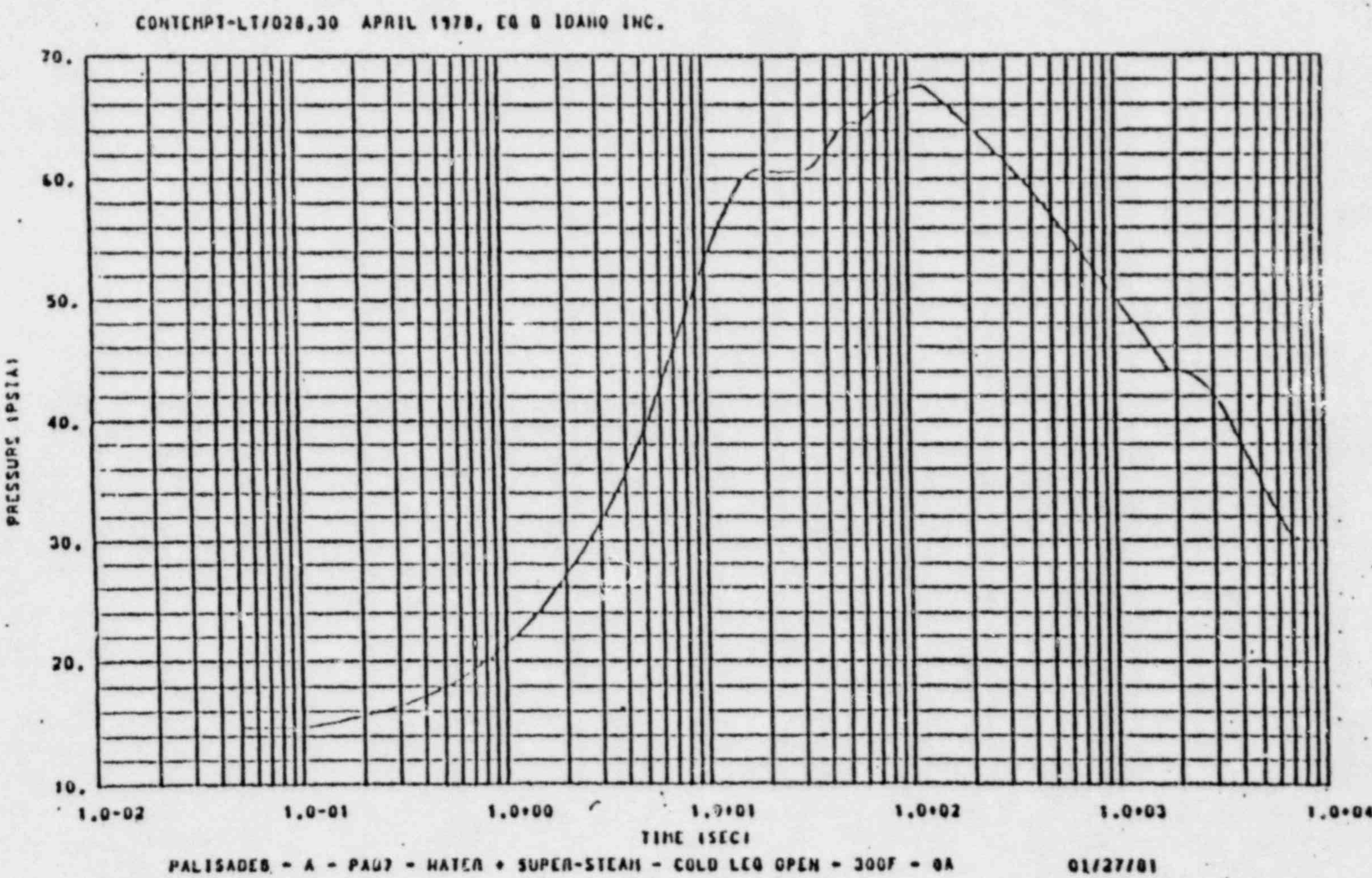

Figure 3.11P CONTAINMENT PRESSURE-WATER + SUPERHEATED STEAM (METHOD A)

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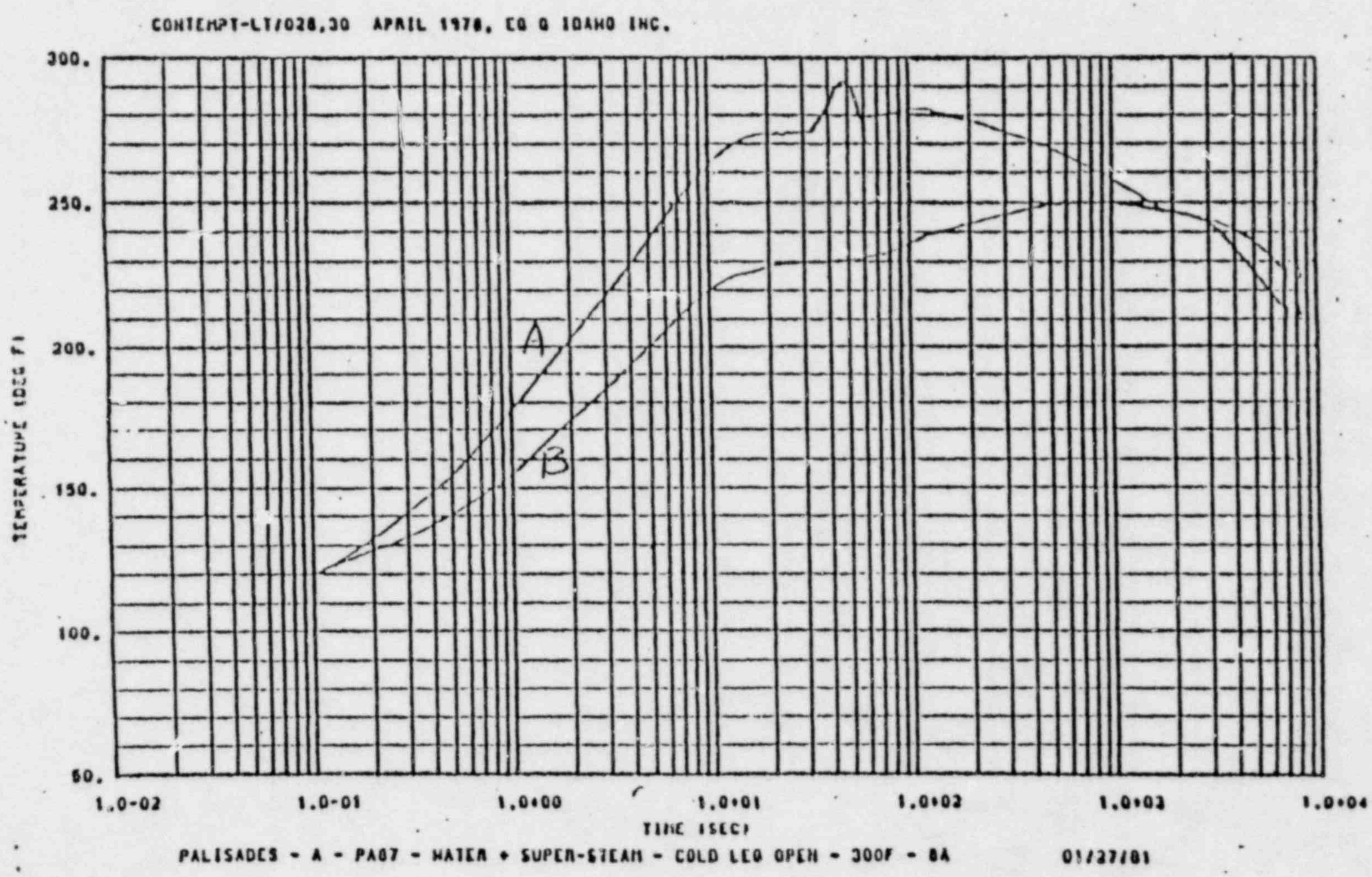
CONTEMPT-LT/028,30 APRIL 1978, EG G IDAHO INC.
300.
250.
200.
150.
100.
50.
TEMPERATURE (DEG F)
1.0-02
1.0-01
1.0+00
1.0+01
1.0+02
1.0+03
1.0+04
TIME (SEC)
A
B
PALISADES - A - PA07 - WATER + SUPER-STEAM - COLD LEG OPEN - 300F - 8A
01/27/81

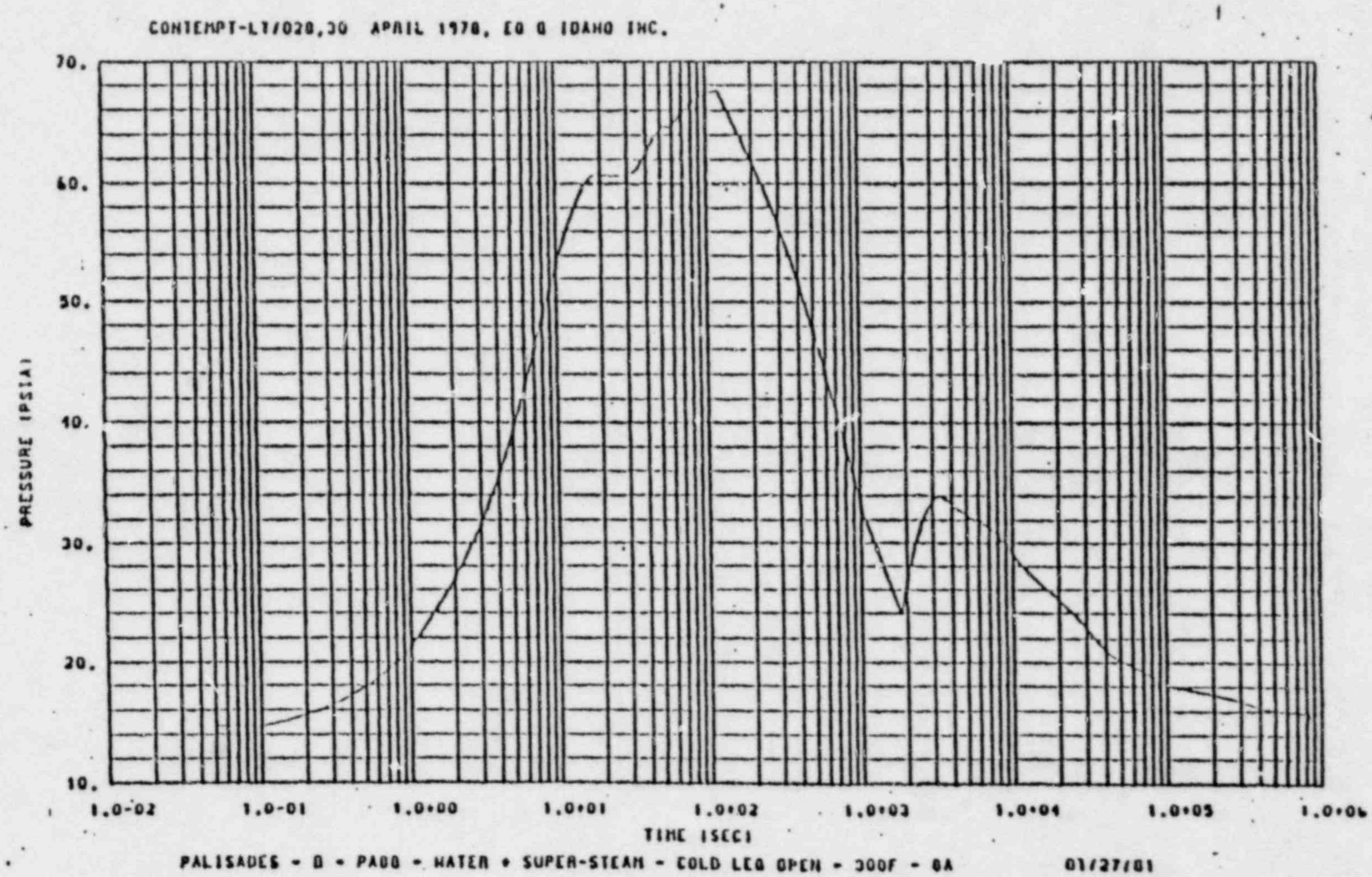

Figure 3.12P CONTAINMENT PRESSURE-WATER + SUPERHEATED STEAM (METHOD B)

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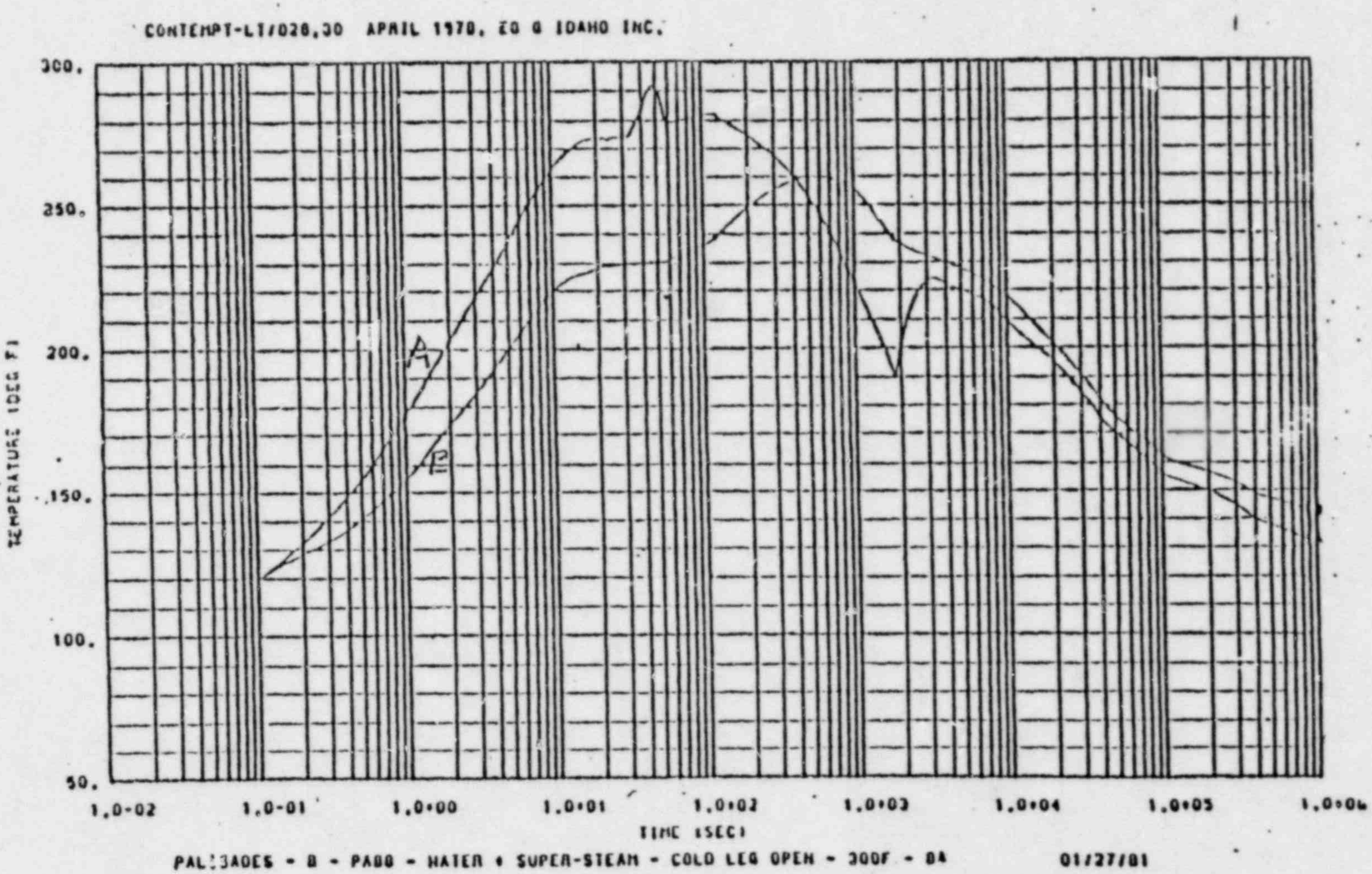

Figure 3.12T CONTAINMENT TEMPERATURE-WATER + SUPERHEATED STEAM (METHOD B)

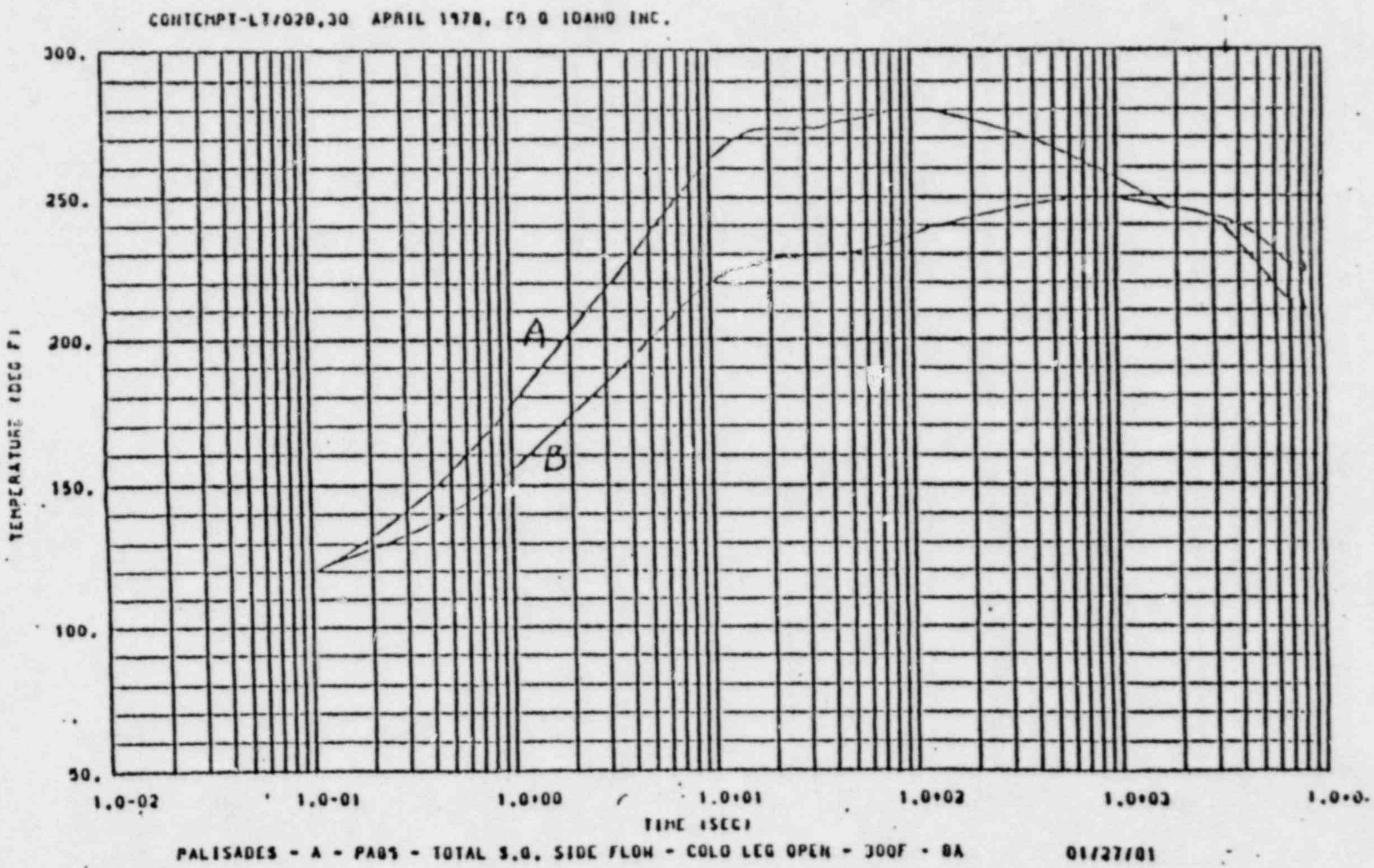

Figure 3.13T CONTAINMENT TEMPERATURE-WATER + SATURATED STEAM (METHOD A)

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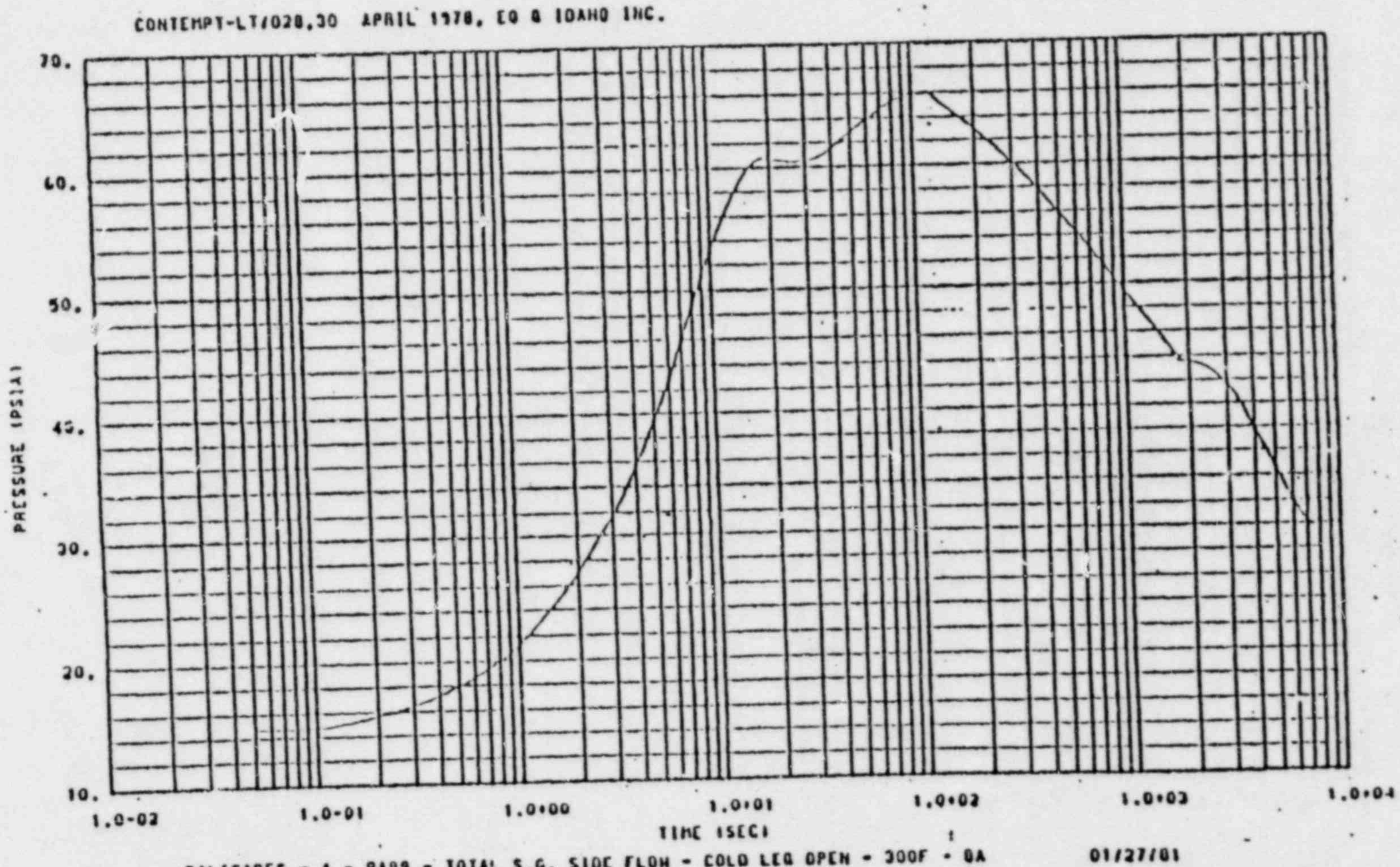
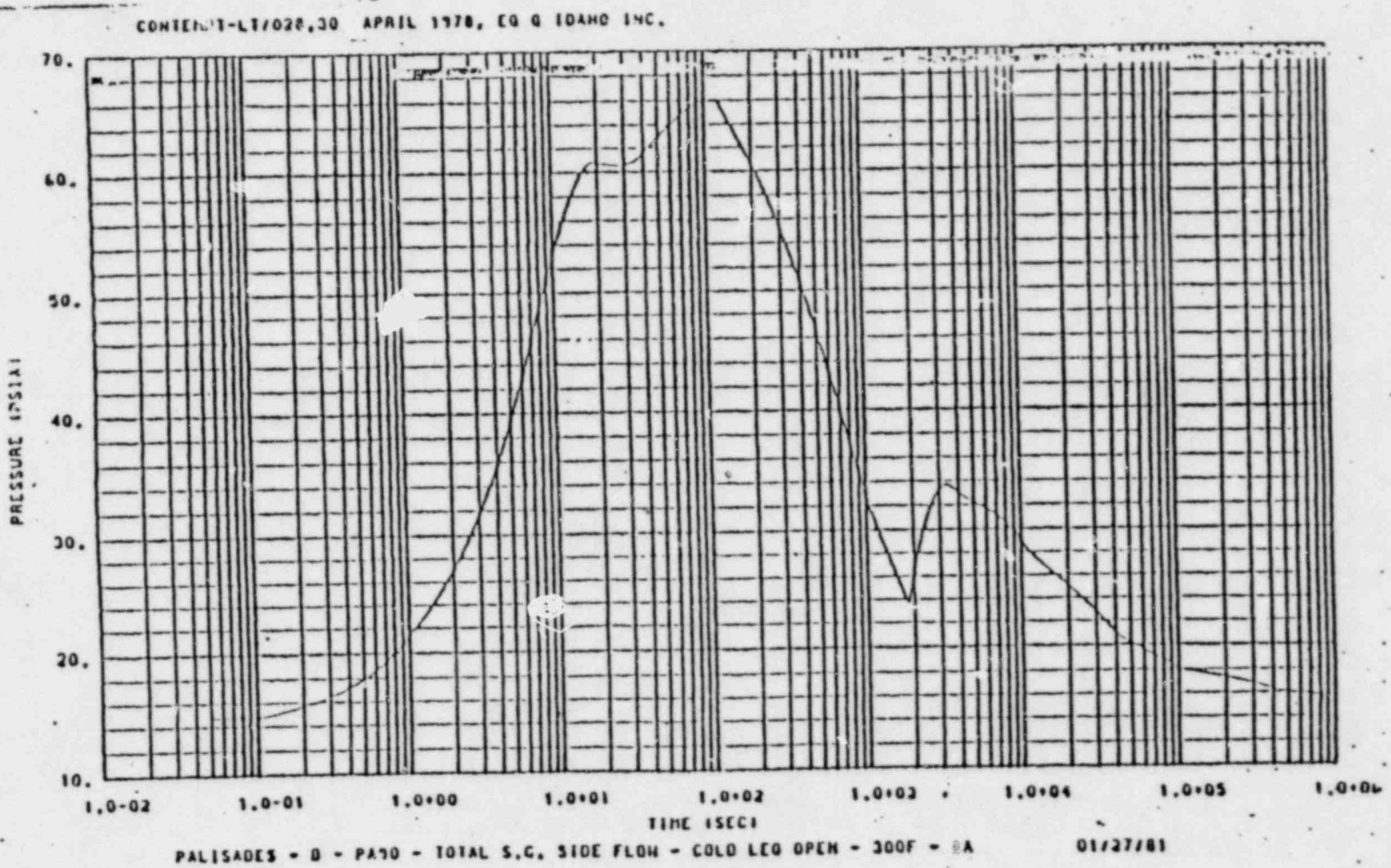


Figure 3.13P. CONTAINMENT PRESSURE-WATER + SATURATED STEAM (METHOD A)



SATURATED STEAM (METHOD B)

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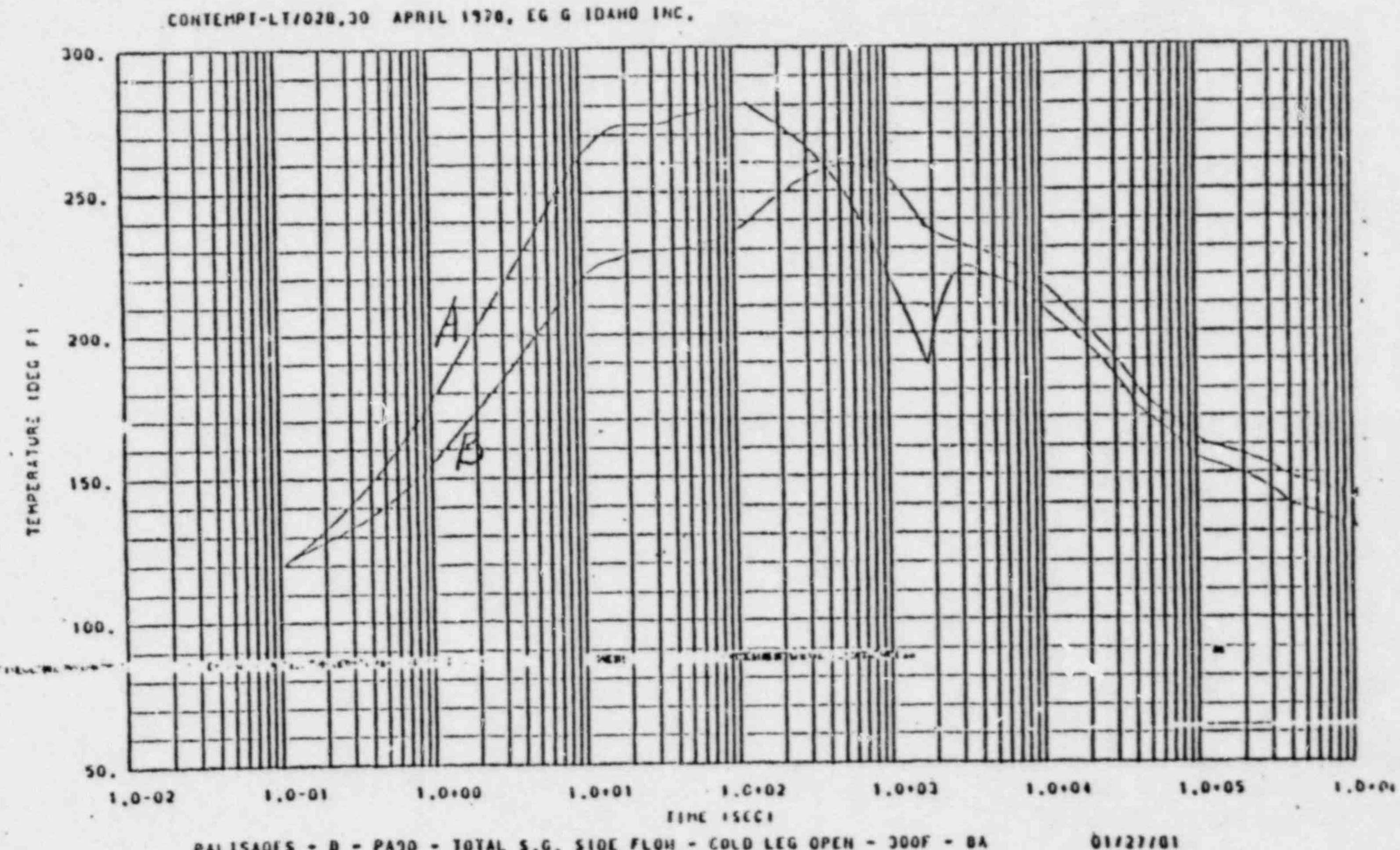
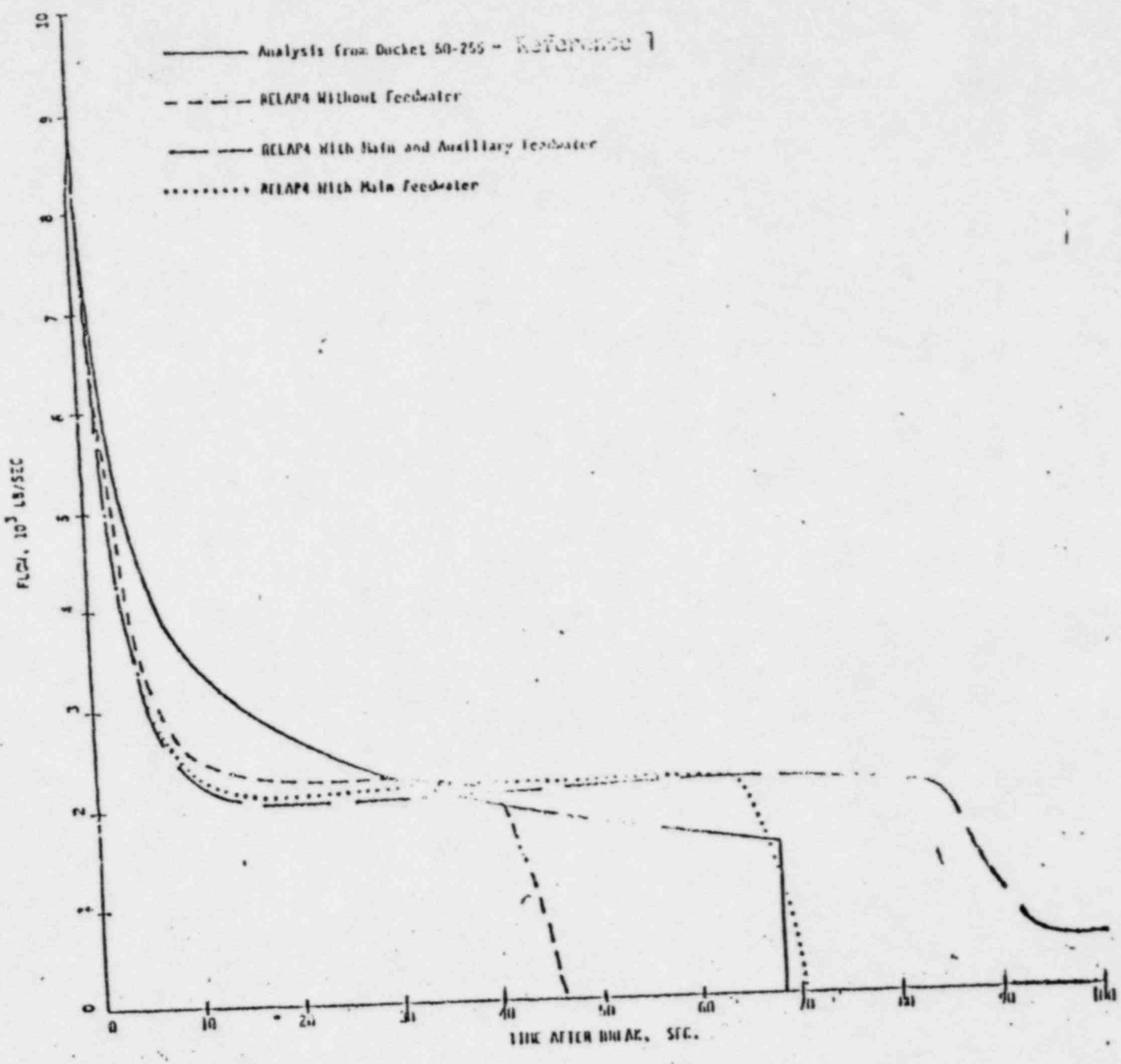


Figure 3.14T CONTAINMENT TEMPERATURE-WATER + SATURATED STEAM (METHOD B)


Analysis from Docket 50-255 - Reference 1
RELAP4 Without Feedwater
RELAP4 With Main and Auxiliary Feedwater
RELAP4 With Main Feedwater
FLOW, 10^3 LB/SEC
TIME AFTER BREAK, SEC.
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
60
70
80
90
100

... OF 30 INCHES

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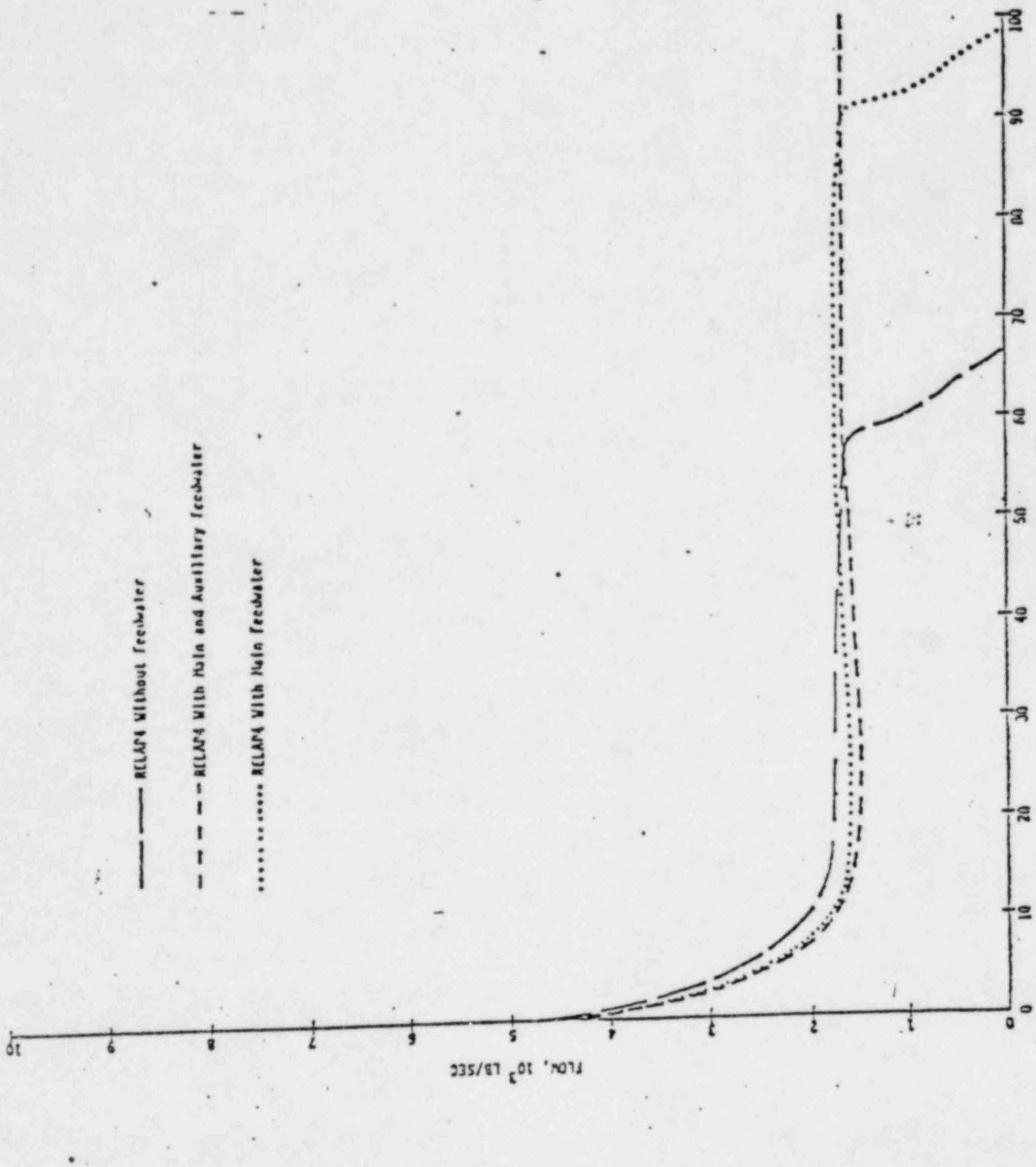

RELAP4 Without Feedwater
RELAP4 With Main and Auxiliary Feedwater
RELAP4 With Main Feedwater
FLOW, 10^3 LB/SEC
0
1
2
3
4
5
6
7
8
9
10
TIME AFTER BREAK, SEC.
0
10
20
30
40
50
60
70
80
90
100

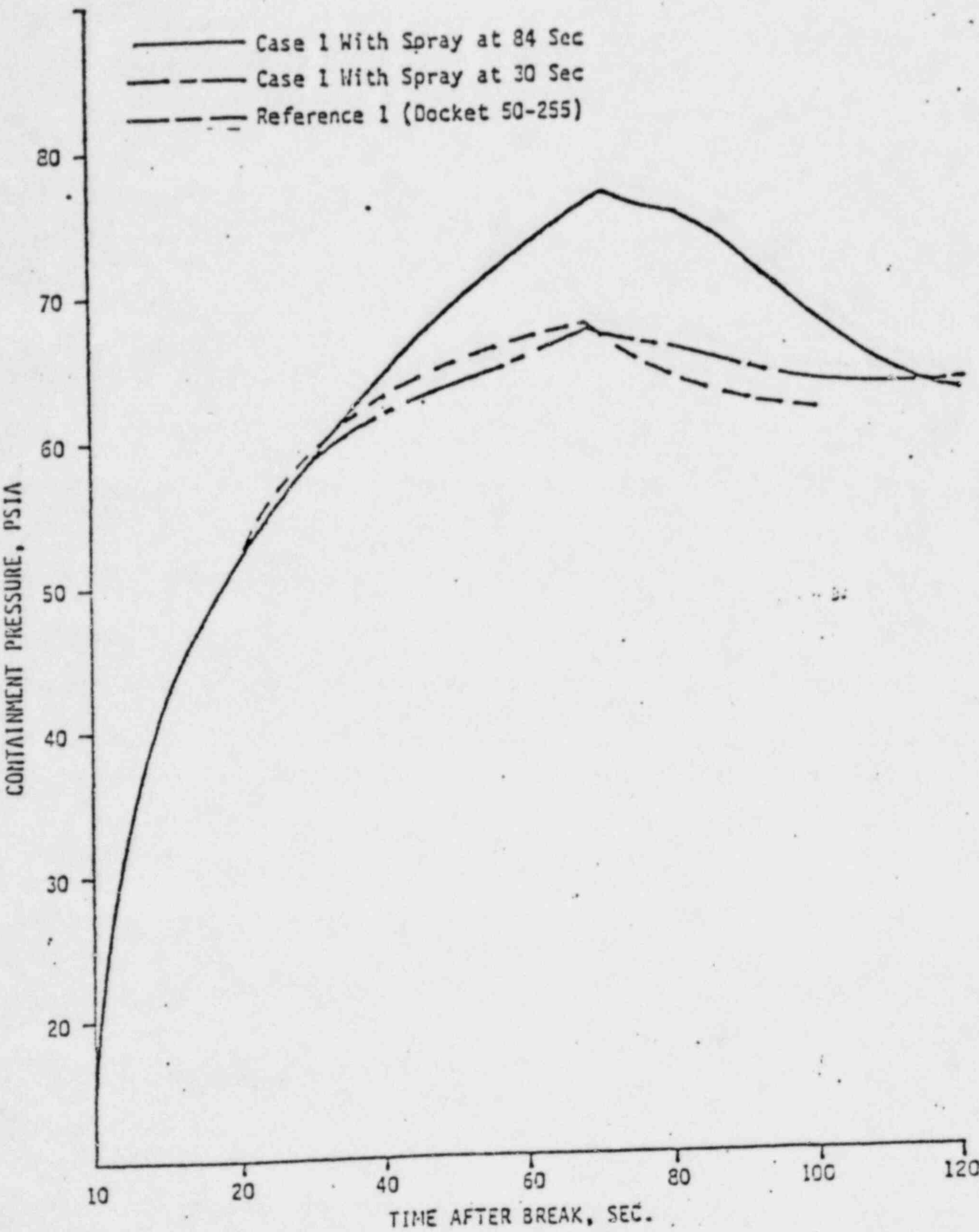

Figure 4.3P COMPARISON OF CASE 1 AND REFERENCE 1, CONTAINMENT PRESSURE

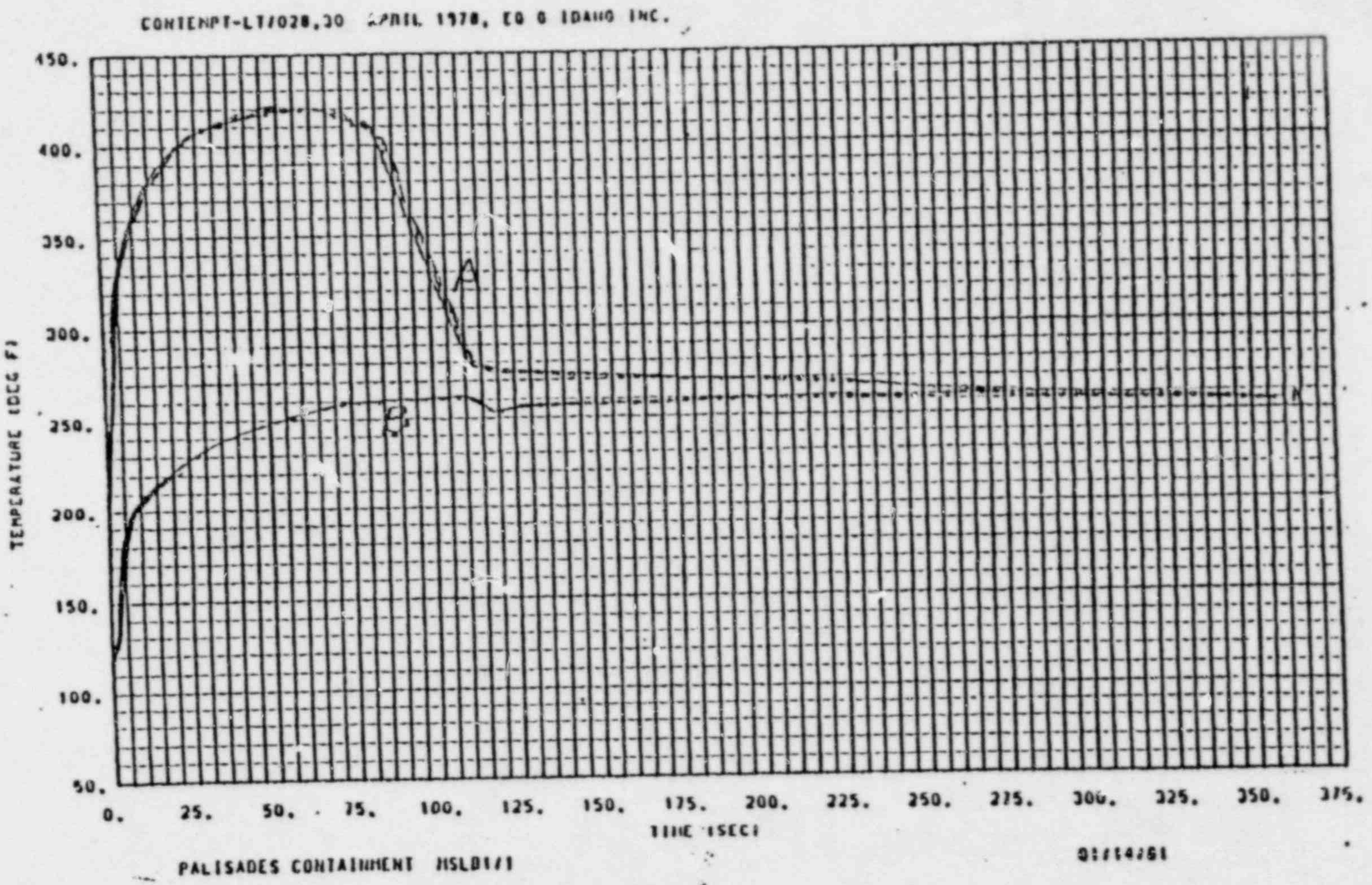

Figure 4.3T-A CONTAINMENT TEMPERATURES - ATMOSPHERE & POOL (Sump), CASE 1 WITH SPRAY AT 84 SEC.

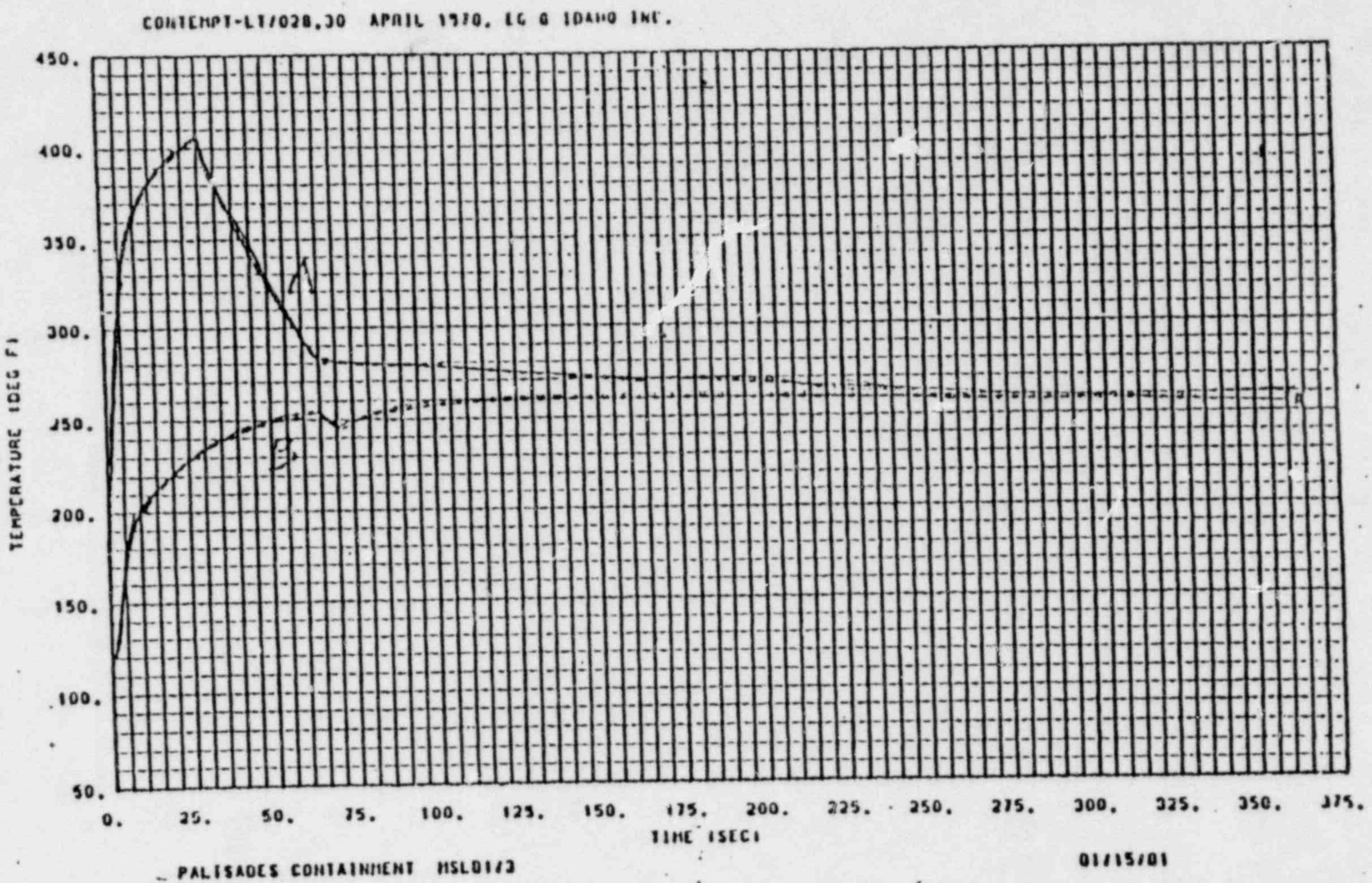

Figure 4.3T-B CONTAINMENT TEMPERATURES - ATMOSPHERE & ~~POOL~~ Sump, CASE 1 WITH SPRAY AT 30 SEC.

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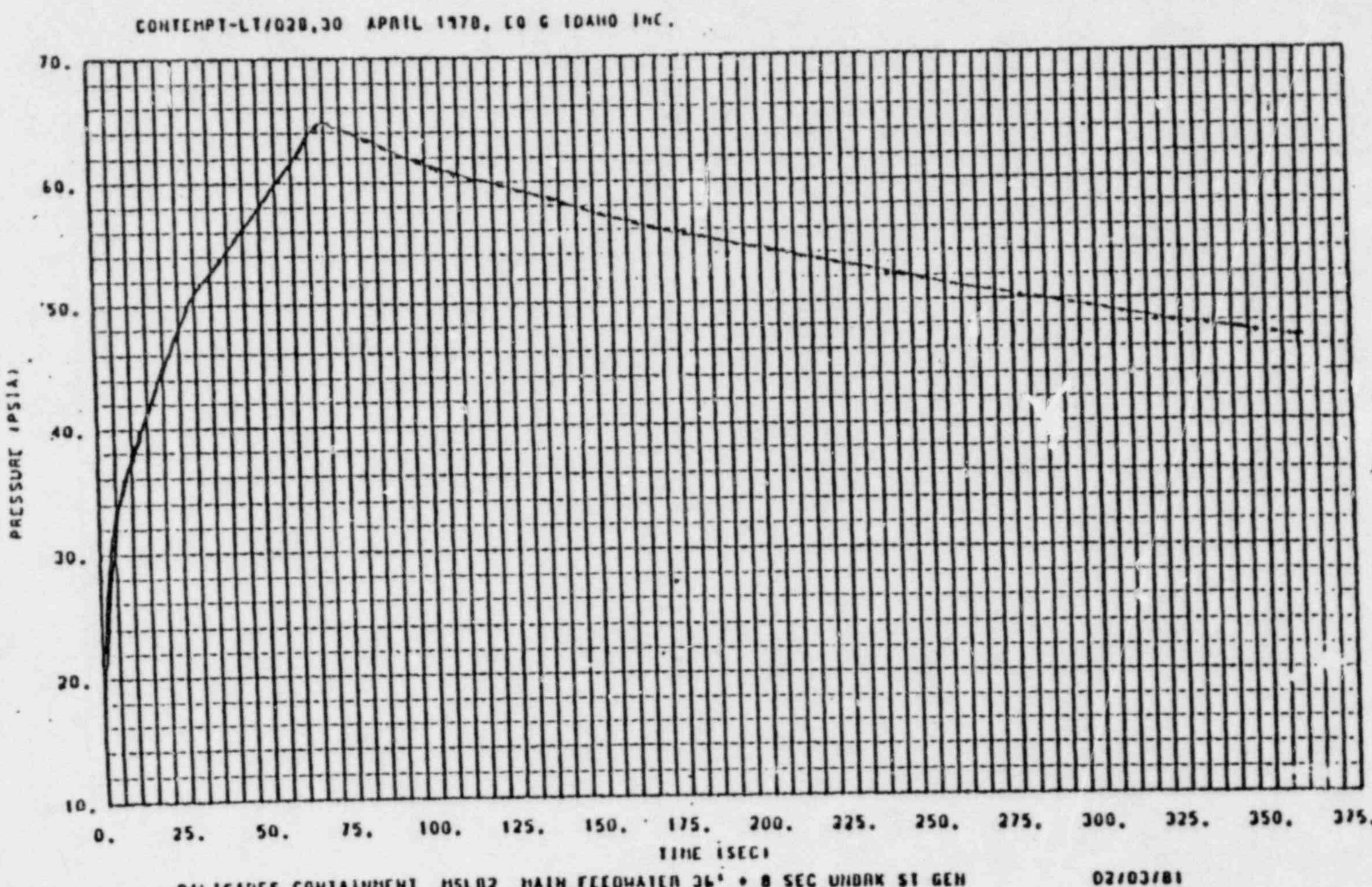

Figure 4.4P CONTAINMENT PRESSURE FOR CASE 2

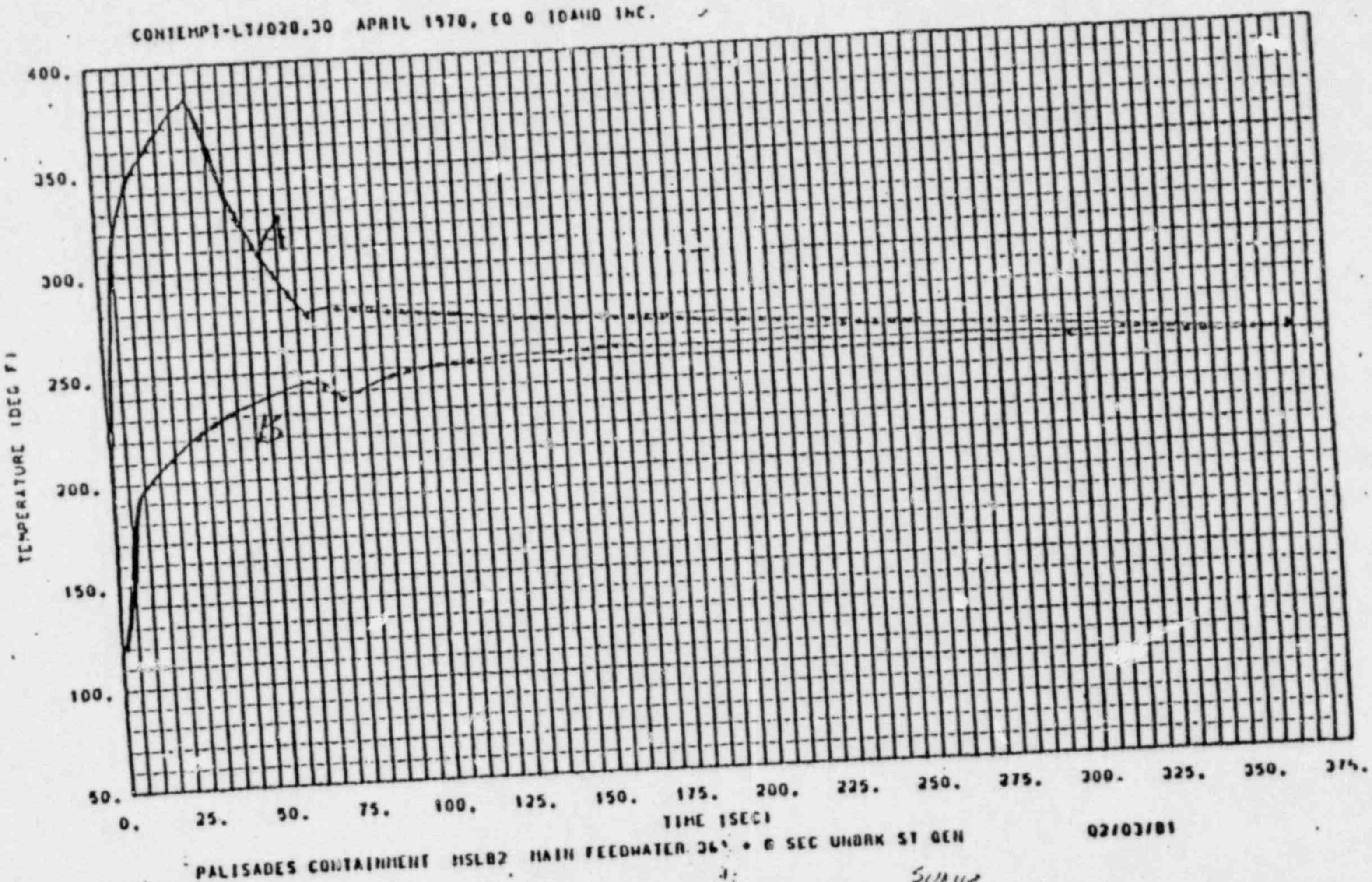

Figure 4.4T CONTAINMENT TEMPERATURE - ATMOSPHERE & ~~POOL~~ Sump, CASE 2

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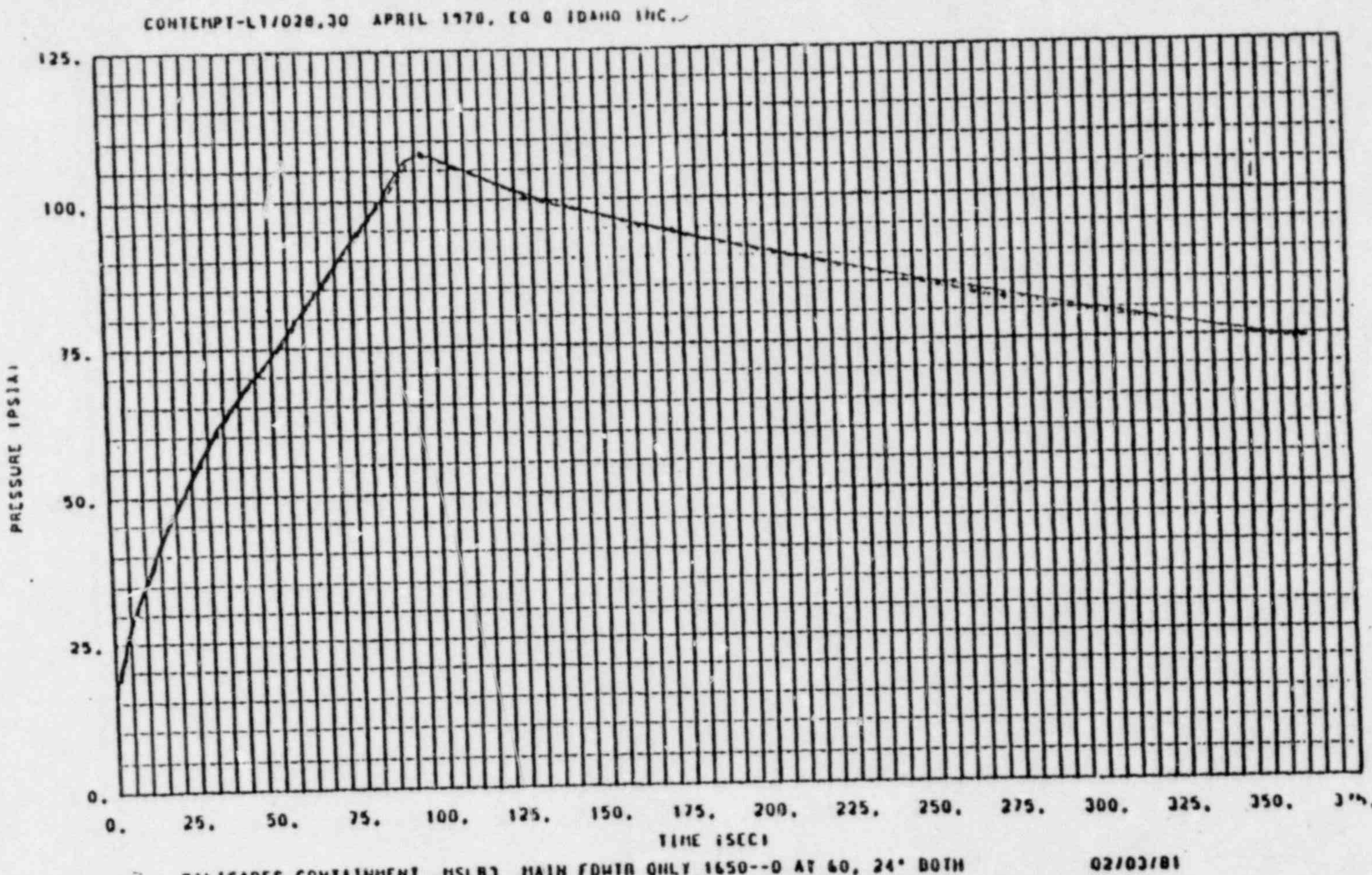

Figure 4.5P- CONTAINME T PRESSURE FOR CASE 3

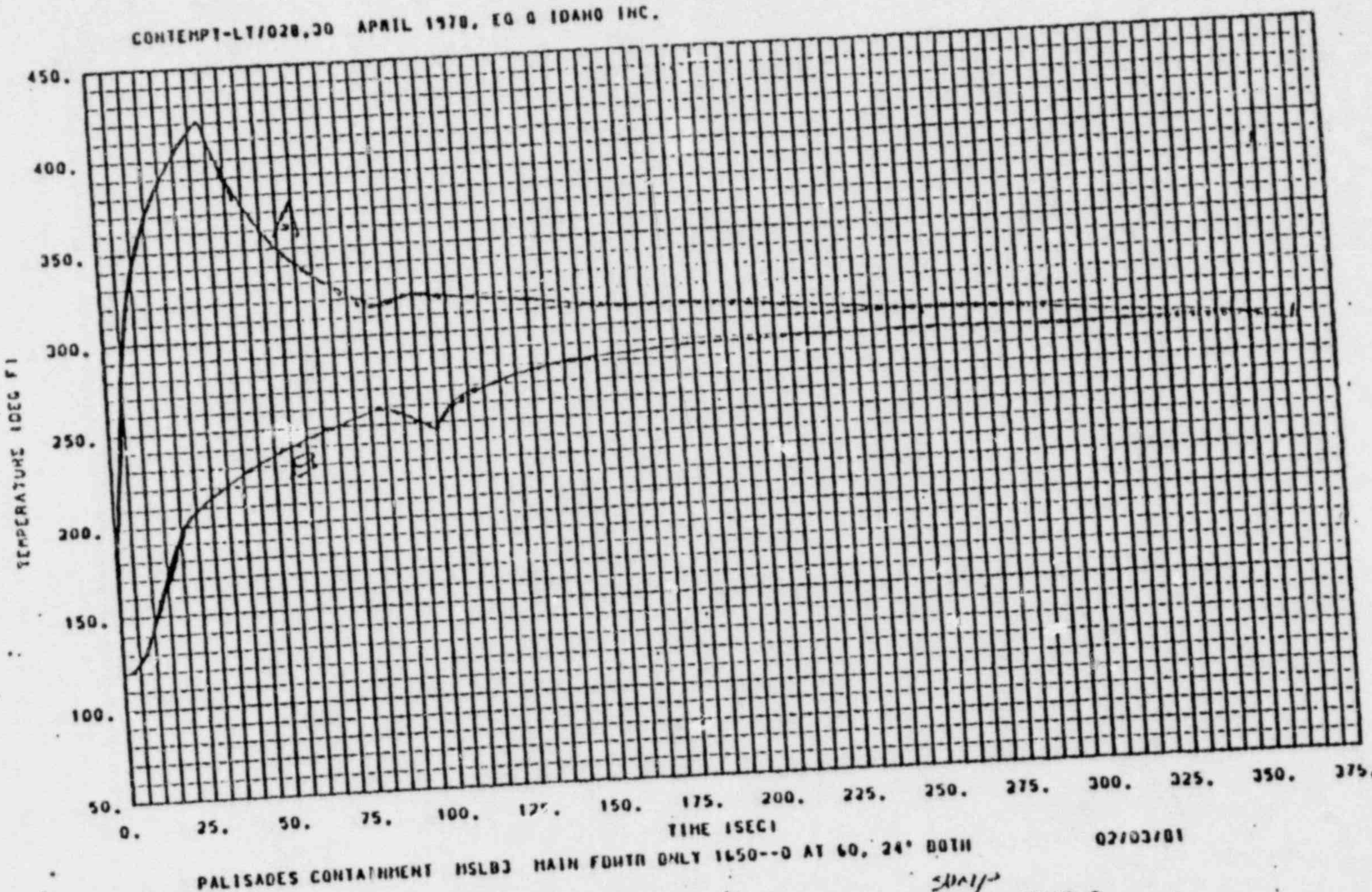

Figure 4.5T CONTAINMENT TEMPERATURES - ATMOSPHERE & POOL, CASE 3

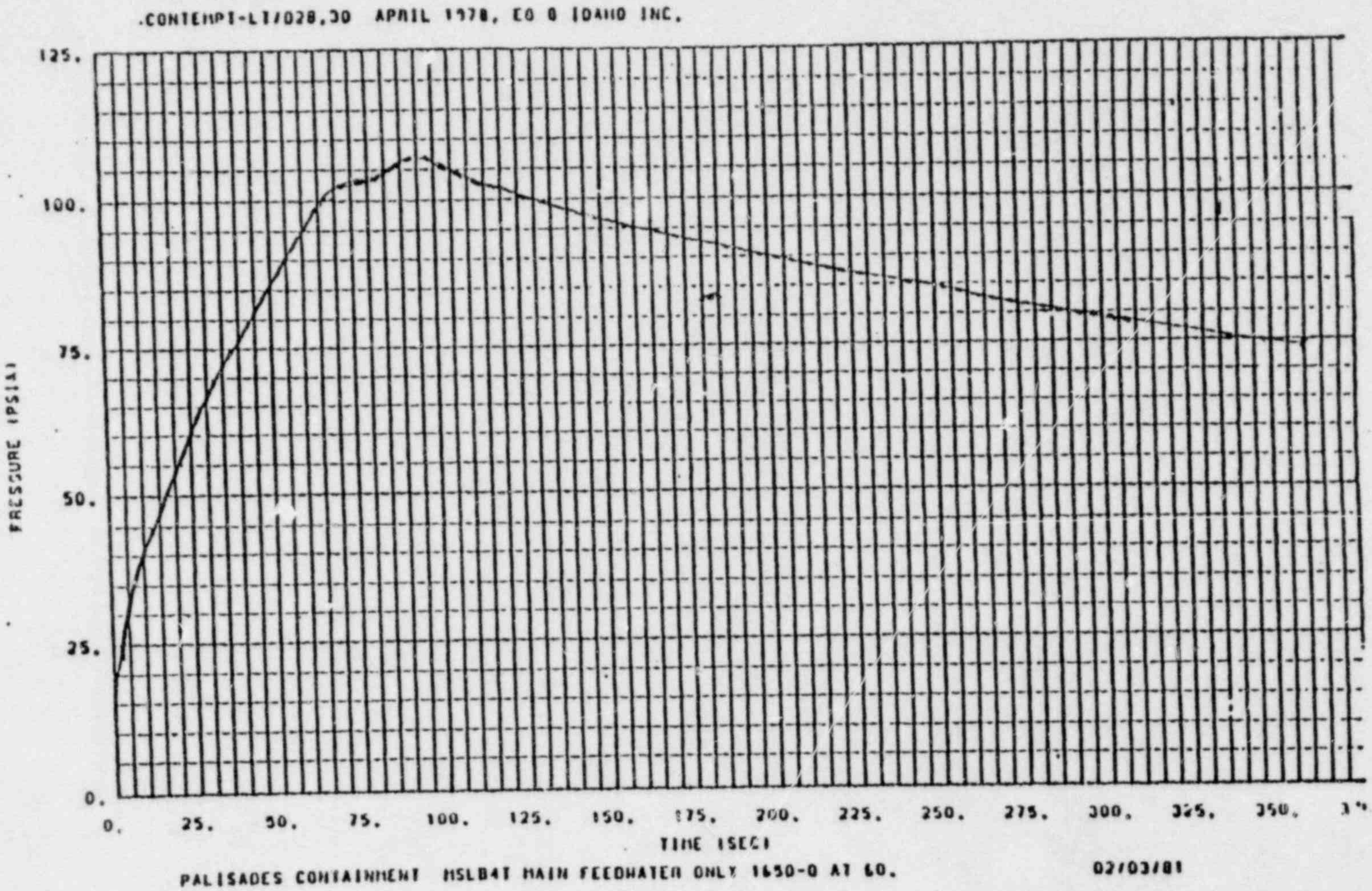

Figure 4.6P CONTAINMENT PRESSURE FOR CASE 4

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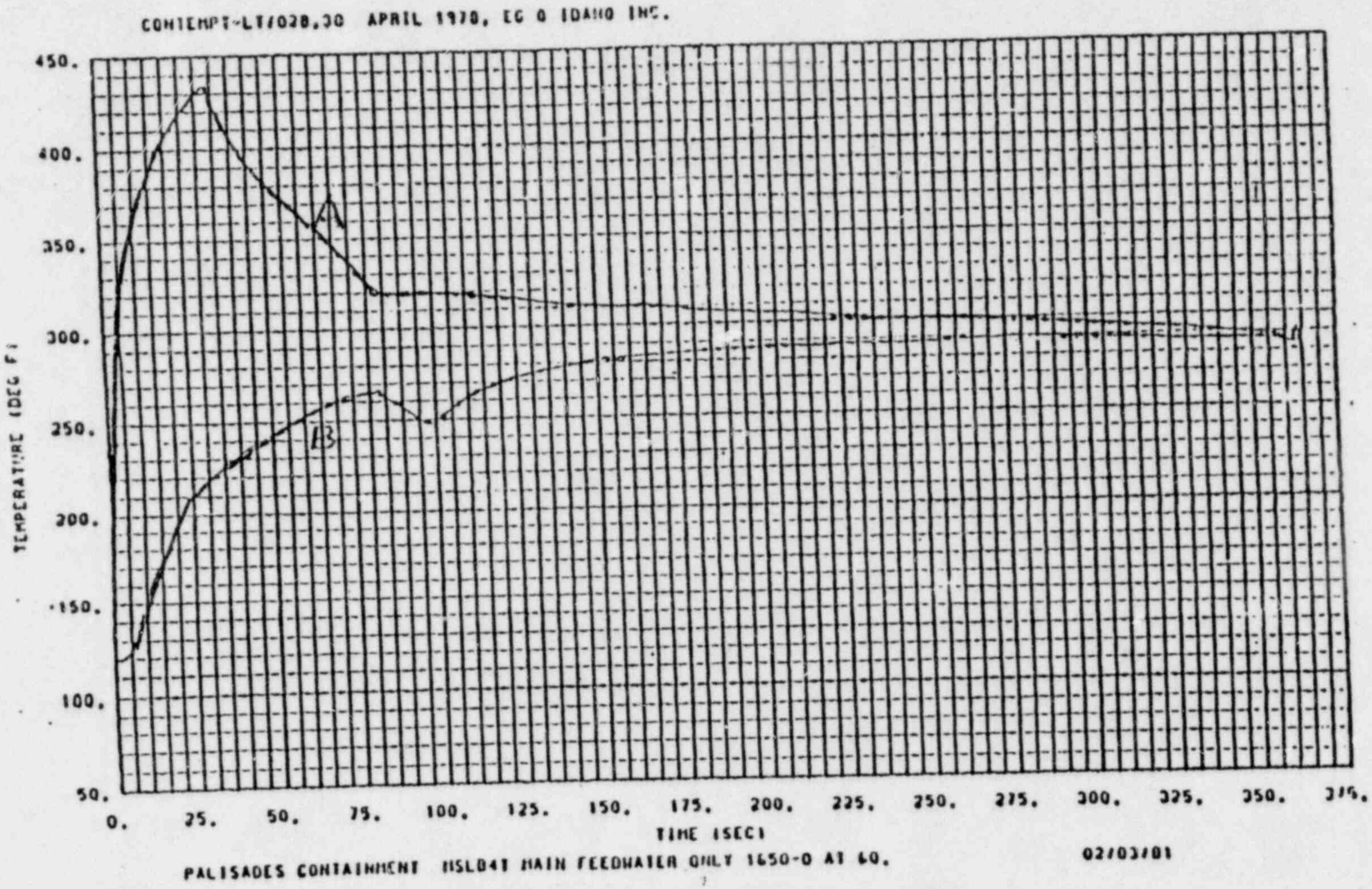

Figure 4.6T CONTAINMENT TEMPERATURES - ATMOSPHERE & SUMP POOL, CASE 4

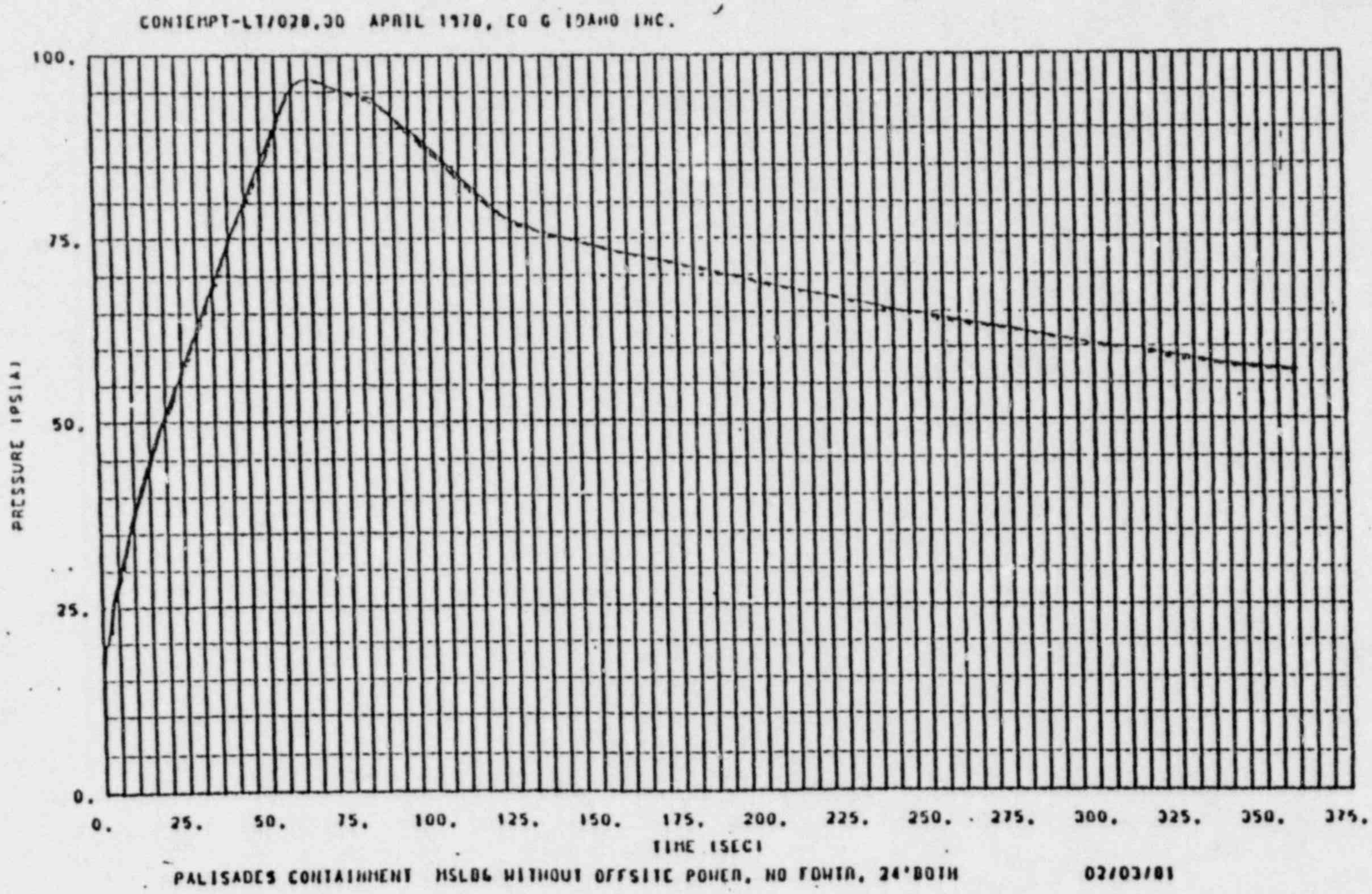

Figure 4.7P CONTAINMENT PRESSURE FOR CASE 5

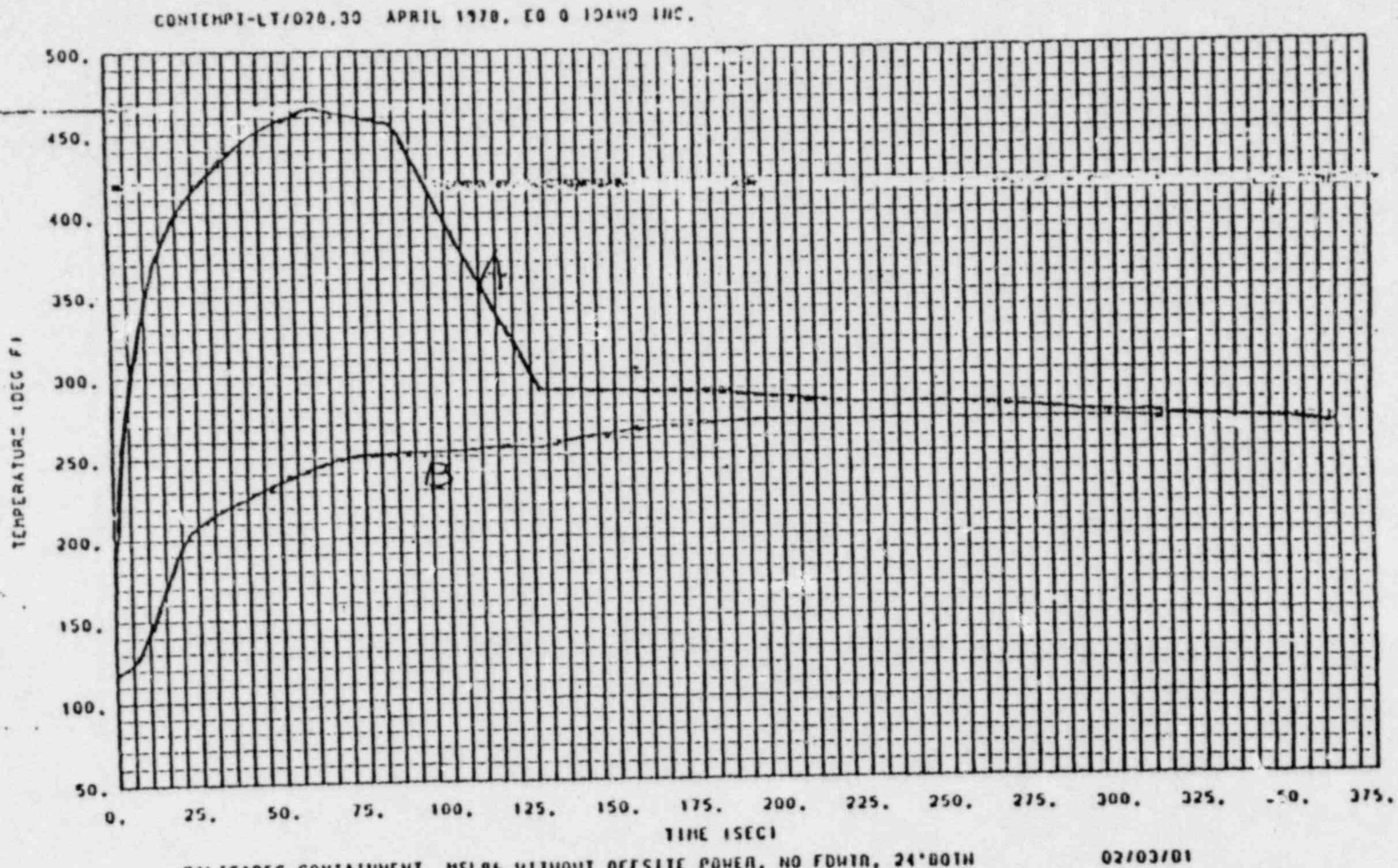

Figure 4.7T CONTAINMENT TEMPERATURE - ATMOSPHERE & POOL, CASE 5

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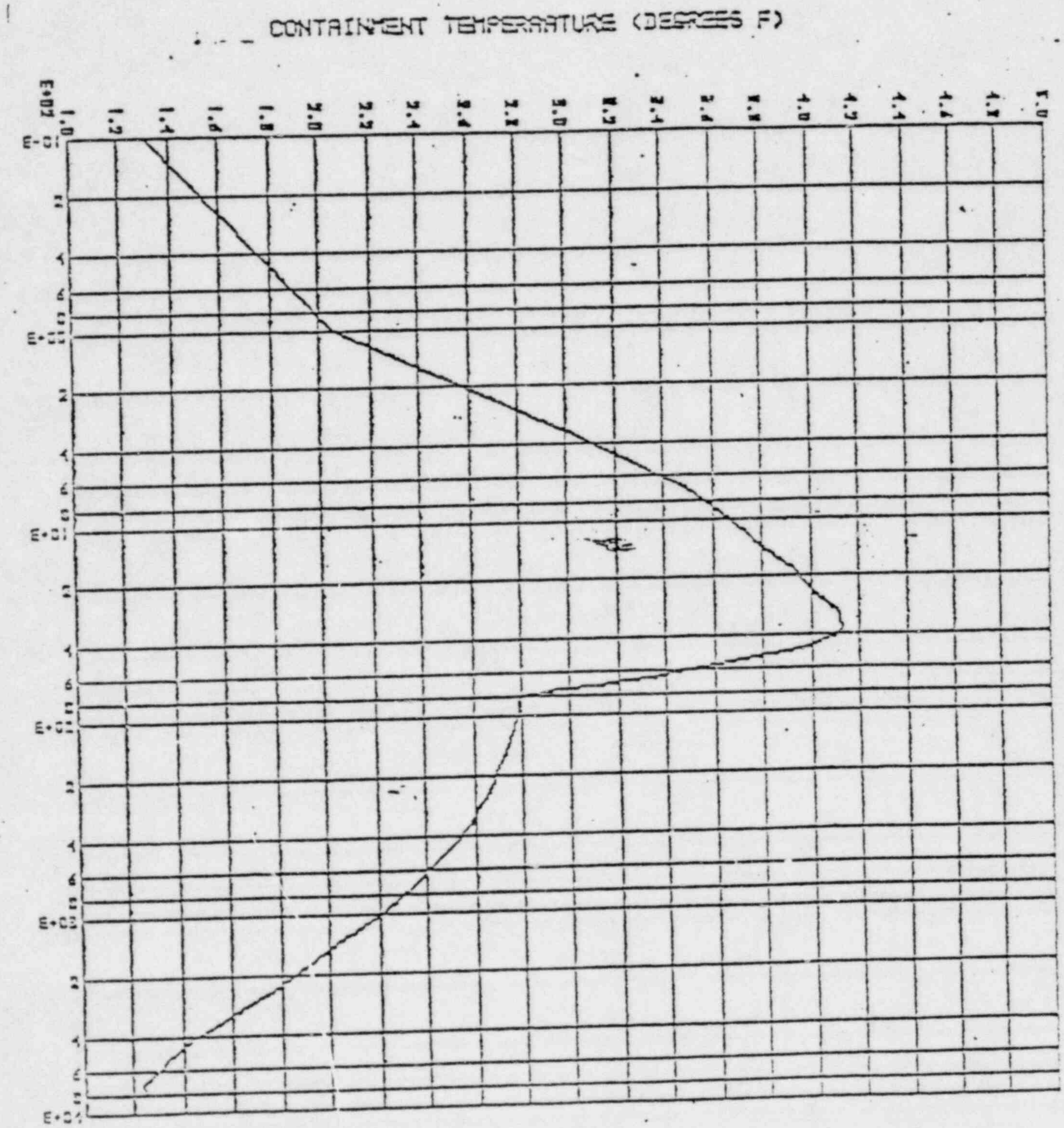
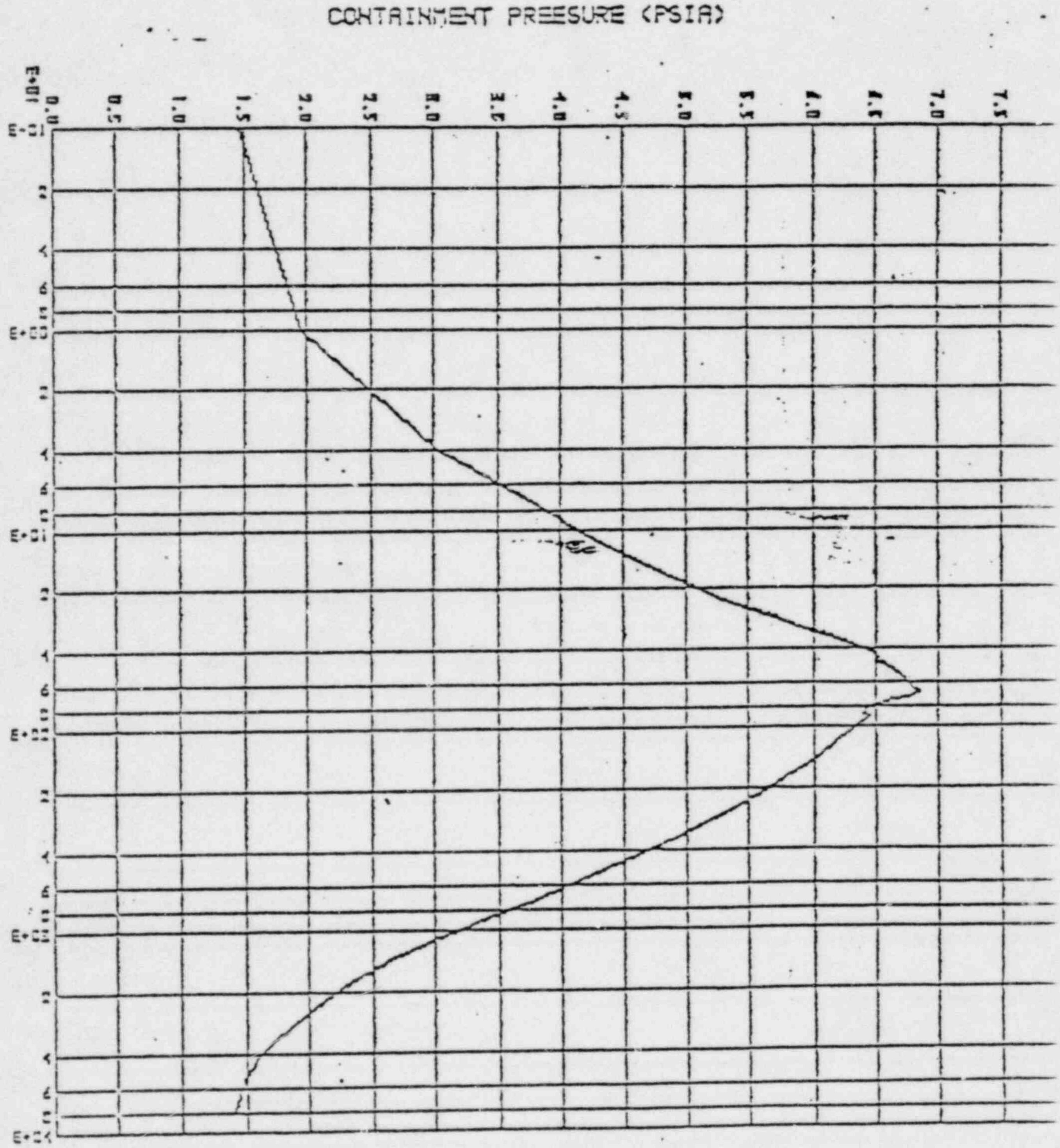


Figure 1 Containment ~~Pressure~~ Temperature Response for MSLB
4.8T

DRAFT



4.8 P

Figure 2 Containment ~~Temperature~~ Pressure response for MSLB