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International Agreement Report

Assessment of TRAC-PF1/MOD1 Against an Inadvertent Pressurizer Spray Total Opening Transient in José Cabrera Power Plant

Prepared by
R. Martinez Fanegas

TECNATOM, S.A.
km. 19 Crt. Nac. Madrid-Irun
San Sebastian De Los Reyes
28709-Madrid, Spain

Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

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Prepared as part of
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SYNOPSIS

The work to which this report refers falls within the framework of the ICAP/SPAIN Project, the objectives being those referred to in the ICAP Program itself, in particular, achievement of the capacity required to apply calculation tools supporting the quantitative analysis of transients and operation procedures, as well as joint participation in the international efforts aimed to validate and experience using appropriate calculation codes.

The work consists of reproducing an actual pressurizer spray valve opening transient (30 minutes) that occurred at the Jose Cabrera Nuclear Power Plant (Spain), by means of the TRAC-PF1/MOD1 code, and is thus part of an assessment type exercise.

Generally speaking, the match between the calculation results and plant data was good, and the Jose Cabrera NPP model for TRAC-PF1/MOD1 has shown itself to be adequate for simulation of prolonged plant transients, such as the case dealt with in this study.

TABLE OF CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

The work consists of using the TRAC-PF1/MOD1 code to reproduce an actual transient that occurred at Jose Cabrera NPP on 30th August, 1984, and is thus part of an assessment exercise within the framework of the ICAP Program.

The transient to be simulated consisted of the failure to close of the pressurizer spray valve (for approximately 30 minutes). This transient caused a gradual depressurization of the primary system, with energization of all pressurizer heaters and actuation of the reactor protection system. The reactor tripped on low pressure coincident with a safety injection signal, although this latter system did not in fact actuate.

Jose Cabrera NPP is a commercial Westinghouse PWR owned by UNION ELECTRICA-FENOSA, S.A (UEFSA). The plant went first critical in 1968, and was the first nuclear power plant to be coupled to the Spanish grid.

The plant has a single loop, which includes the primary system cold leg, reactor vessel, hot leg, pressurizer, steam generator tubes, crossover leg and main coolant pump.

The nominal power of the reactor is 510 MWt, electric output being 160 MWe.

The calculations were performed using the TRAC-PF1/MOD1 code, version 12.7, on the CRAY X-MP vectorial computer belonging to TECNATOM, S.A.

The model developed for TRAC-PF1/MOD1 is based on the one used for RELAP5/MOD2, developed by UEFSA. The model was completed through incorporation of the plant control systems.

Generally speaking, analysis of the results obtained with the TRAC-PF1/MOD1 model, and their comparison with plant data, shows a good match, taking into account the uncertainties inherent in any actual transient, in which a large number of actions are performed manually.

The importance of the pressurizer in this transient made it advisable to partially validate the sub-model with respect to tests carried out at the NEPTUNUS and M.I.T. experimental facilities.

From the run statistics it was found that the 3500 s transient made use of 36482 time steps requiring 5608 CPU-seconds on a CRAY X-MP computer. During the transient, the maximum time step was set to 0.1 s.

1. INTRODUCTION

The work to which this report refers falls within the framework of the ICAP/SPAIN Project, the objectives being those referred to in the ICAP Program itself specifically, achievement of the capacity required to apply calculation tools supporting the quantitative analysis of transients, operational procedures, etc ..., and joint participation in the international efforts aimed to validate and experience using appropriate calculation codes.

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The transient to be simulated consisted on the failure to close of the pressurizer spray valve (for approximately 30 minutes). This transient caused a gradual depressurization of the primary system, with energization of all pressurizer heaters and actuation of the reactor protection system. The reactor tripped on low pressure coincident with a safety injection signal, although this latter system did not in fact actuate.

The report includes the fundamental milestones attained during each of the different stages of the work.

- Identification of the main variables involved in the transient and its different stages.

- Construction of a reference plant (Jose Cabrera NPP) model for TRAC-PF1/MOD1, on the basis of a general purpose model already existing for the RELAP5/MOD2 code, developed by UNION ELECRICA-FENOSA (UEFSA).

- Incorporation of the plant systems required for a successful tracking of the transi , especially those related to the pressurizer pressure and level control systems.

- Steady state results and performance of the calculations relating to the transient, with different sensitivity studies concerning the environment conditions existing during the transient and the actuation of certain plant systems.

- Response [illegible] the pressurizer component model to characteristic transients, such as those performed at the NEPTUNUS experimental facility.

Calculations were carried out using version 12.7 of the TRAC-PF1/MOD1 code on the CRAY X-MP vectorial computer belonging to TECNATOM, S.A.

The transient will also be executed in the near future by UEFSA using the RELAP5/MOD2 code, and the results obtained from both codes will be subjected to comparative analysis.

2. DESCRIPTION OF THE PLANT AND TRANSIENT

2.1 Plant Description

The transient occurred at Jose Cabrera NPP (Figure 1), a commercial Westinghouse PWR owned by UNION ELECTRICA-FENOSA, S.A. The plant went first critical in 1968, and was the first nuclear power plant to be coupled to the Spanish grid.

The plant has a single loop, which includes the primary system cold leg, reactor vessel, hot leg, pressurizer, steam generator tubes, crossover leg and main coolant pump. The Chemical and Volumen Control System (CVCS) and Residual Heat Removal System (RHRS) are also connected to this coolant loop.

The nominal power of the reactor is 510 MWt, electrical output being 160 MWe. The reactor core has 69 fuel elements (14 x 14 array) with an active length of 2.40 meters. Fuel loaded into the core has an average degree of enrichment of 3.40% U-235.

The Emergency Core Cooling System (ECCS) connects directly to the reactor vessel downcomer, and includes an accumulator, two intermediate head safety injection pumps taking suction of borated water from the refuelling water storage tank (RWST) and two recirculation pumps and an ejector that take suction from the containment sump during the recirculation phase of a LOCA.

The secondary side includes the usual balance of plant (BOP) components: two 50% feedwater pumps, main steam line, safety and relief valves, main steam isolation valves, turbine trip valves, main steam control valves, turbine, condenser, heaters, etc.

Main feedwater flows directly to the upper part of the steam generator downcomer. Circulation ratio on the secondary side of the steam generator is 1.96 at rated power.

The auxiliar feedwater system includes a turbine-driven pump and two motor-driven pumps. The first of these injects into the upper part of the downcomer, requiring a permissive from the operator by opening of an isolation valve. The two motor-driven pumps inject into the lower part of the downcomer and require no operator intervention. There is also the possibility of an optional injection path to the upper part of the downcomer, requiring correct alignment of the system by the operator.

The reactor control system maintains the programmed rage primary coolant temperature by positioning the ntrol rods. Reactivity changes due to burnup of the fuel re compensated by the operator manually reducing primary system boron concentration.

Plant safety is guaranteed by the reactor protection system and the engineered safety features.

Primary pressure is controlled by means of the pressurizer spray and two types of pressurizer heaters: variable and back-up.

Pressurizer level is controlled by means of the CVCS makeup and letdown flows and the pressurizer heaters.

The turbine bypass shows the two classical aspects of this particular reactor type: average primary temperature control and secondary side steam pressure control. Level in the steam generator is controlled using the feedwater system.

2.2 Transient Description

The transient occurred at Jose Cabrera NPP on 30th August 1984, with the plant at 96% rated power, and consisted of the pressurizer spray control valve sticking open.

Table 1 shows the plant sequence of events. During the initial moments of the transient, the gradual depressurization of the primary system caused the pressurizer back-up heaters to energize, and the variable heaters to deliver maximum power.

Between one and two minutes into the event, two load reductions (totalling 20 MWe) were performed, in order to stop primary pressure dropping, and controlled manual operation of the second charging pump was also initiated, despite the fact that pressurizer level was not dropping because of cold water entering via the spray and steam condensing in the pressurizer.

Plant trip on low pressure occurred some 6.5 minutes into the event, followed a few seconds later by a safety injection signal.

Following reactor trip, switchover of the turbine bypass from the temperature mode to the pressure mode considerably reduced cooldown of the primary, slowing down depressurization and momentarily stabilizing pressure.

Shutdown of the main coolant pump (30 minutes into the transient) stopped primary depressurization interrupting the flow of water into the pressurizer via the spray system. Pressure recovery was initiated via natural circulation (approximately 30 minutes), and the plant was taken to a stable situation.

Primary pressure reached a minimum 100 Kg/cm^2 (98.1 x 10^5 Pa), and no safety injection was observed due to the pressure setpoint of the corresponding pumps being very close to the minimum pressure experienced.

Primary subcooling was tracked continuously throughout the transient, the minimum value reached being 28°C. Primary temperature was controlled via the bypass, initially in the temperature mode and subsequently in the pressure mode; this temperature was maintained at high values in order to reduce depressurization.

3. DESCRIPTION OF THE CODE INPUT MODEL

The work described herein was carried out using the TRAC-PF1/MOD1 code, version 12.7, on a CRAY X-MP computer, the operating system being UNICOS. The graphics results were obtained via a program developed by TECNATOM and adapted to TRAC for graphics applications.

As has been pointed out above, the model developed for TRAC-PF1/MOD1 is based on the model for RELAP5/MOD2 (Figure 2), developed by UEFSA. Adaptation of the plant model from the existing model was performed on the basis of the following significant aspects:

- Nodalization was adapted to the modelling requirements of the transient in question; consequently, certain components which did not actuate during the transient were eliminated, an example being the pressurizer safety and relief valves. Table 2 shows the list of previously existing general purpose model components or systems, not included in the model for simulation of the selected transient.

- A second aspect to be underlined is the incorporation into the TRAC-PF1 model of those control systems which were not simulated in the RELAP5/MOD2 nodalization, but which played an important role in the development of the transient. Table 3 lists the control systems incorporated in the model.

The nodalization used in TRAC-PF1 is shown in Figures 3 and 4, where the components referred to above have been eliminated.

In the reactor vessel, the downcomer is divided into two parts: upper and lower, both with their corresponding TEE components. The lower part (component 10) includes the path to the lower plenum in four cells or nodes; the upper part of the downcomer (component 40) is made up of a single cell. The lower plenum and vessel head (components 15 and 45 respectively) are each represented by a type of component existing in TRAC-PF1/MOD1 called PLENUM, which is used to model volumes affected by large losses of momentum. The upper plenum is modelled using the elements TEE 30, whose side tube includes core bypass flow, and 35 with the outlet nozzle.

The reactor core (20) has six active nodes (with heat transfer) and two unheated nodes at its upper and lower ends. For modelling of the core, the unidimensional component CORE was chosen. The bypass is represented by four cells (25).

The different coolant bypass flow paths in the reactor vessel, which are not valid for core heat removal, are represented in the model: core bypass, via component 25; flow in the upper head, via components 40, 45 and 35; and finally direct coolant flow from the inlet nozzle to the outlet nozzle, represented by junction 52 which branches off from the riser annulus.

The transient to be analyzed by means of this model does not show any physical phenomena making it necessary to model the vessel in three dimensions, a capacity that TRAC-PF1/MOD1 possesses through the so-called VESSEL component and which is characteristic of the TRAC range. Besides this, selection of a three-dimensional model for the vessel places heavy requirements on calculation as regards CPU time, and is consequently not in keeping with the scope of the model for the case in hand. A third reason is related to one of the purposes of the work: comparison of the results obtained with RELAP5/MOD2, this being better achieved via a unidimensional model applicable to both codes.

The hot leg of the primary system is modelled in four cells (components 55 and 60). From this last component (TEE) the surge line branches off to the pressurizer, which is in turn divided into three parts, in order to correctly model the location of the pressurizer spray and heaters. Component 81 includes the heaters, modelled as a direct supply of energy to the fluid regulated by the control system, and not as a distribution of power through the component wall. Components TEE 82 and 85 include respectively the continuous (steady state) and main (control system) sprays. The first of these is modelled by a FILL (600), while the pressure control spray system is represented by five cells (components 80 and 95), which incorporate the spray control valve (95).

The crossover leg (70), main coolant pump (75) and cold leg (78 and 80) comprise a total of twelve cells. Component 87 models net input (makeup-letdown) from the chemical and volume control system. Makeup to the primary is accomplished by means of a FILL (component 92), with flow regulated by the pressurizer level control system.

Component 65 represents the steam generator (component STGEN), which on its primary side includes the part corresponding to the "U" tubes, formed by a PIPE with twelve cells, two representative of the inlet and outlet chambers. The secondary side of the steam generator is made up of five sub-components included in the steam generator module (65). The area in which the secondary fluid comes into contact with the tubes (riser 1) includes five nodes that cover up to where the moisture separators (2) begin. As TRAC-PF1/MOD1, version 12.7, does not include any specific separator component, the effect of the ideal moisture separators is achieved by way of appropriate values in the loss coefficients.

The remaining parts of the steam generator secondary side include the following: moisture separator bypass (3), steam dome (8) and downcomer (5), giving a total fourteen nodes, with feedwater injection into the zone corresponding to the downcomer.

The secondary system at the outlet of the steam generator (main steam line) is divided into several parts: the steam flow path to the turbine (340, bounding condition), represented by nineteen nodes grouped into several components (100, 165, 170, 175, 180, 185 and 190), and including the main steam isolation and control valves (175 and 190) and the turbine trip valve (185).

Steam consumption to the auxiliary feedwater turbine-driven pump following trip of the motor-driven main feedwater pumps is represented by bounding condition 320, which is a FILL with flow depending on pressure.

The two fundamental aspects of the turbine bypass system, from the point of view of nodalization, are modelled: via the bypass to the condenser, including the condenser relief and isolation valves (components 225 and 235) and via the atmospheric steam dump valves (200 and 210), both legs ending in the volumes described by the appropriate bounding conditions.

The heat structures incorporated in the model are as follows: in the core, those corresponding to the fuel rods; in the steam generator, the primary side tube slabs, the partition plate between the primary coolant inlet and outlet chambers and the structure corresponding to the tubesheet; and in the pressurizer, in this case with an important influence on the transient, external losses from the pressurizer vessel and operation of the heaters.

As regards the core, the point kinetics model is used, in conjunction with fuel temperature, moderator temperature and density feedback. The different neutron parameters are those corresponding to cycle 12, the situation existing in the plant when the transient occurred (30th August, 1984).

In summary, the Jose Cabrera NPP TRAC-PF1/MOD1 model for the transient simulated, which is briefly described in this section, includes a total of 46 components with 150 cells or control volumes, 7 of which are time-dependent bounding conditions, 145 junctions and 34 heat slabs.

It may be estimated that adaptation of the model for RELAP5/MOD2 to TRAC-PF1/MOD1 would mean an effort of one man-month, on the basis of the set of characteristics referred to above.

The model has been completed by including the plant control systems listed in Table 3, along with the protection system and the setpoints of the different variables causing reactor trip, and an important number of control variables necessary for correct modelling of the control systems and safeguards actuations.

The complete control and protection systems include 180 control blocks and 65 trips.

Given the importance of adequately simulating the pressurizer for application to the transient chosen, separate nodalization of this component was validated with respect to characteristic transients, such as those simulated by means of the NEPTUNUS experimental facility, which represents a pressurizer at a scale of 1/40 with respect to commercial models, and of the smaller M.I.T. facility (Figures 25 and 26).

4. STEADY STATE RESULTS

Steady state results were obtained by separately considering the major components: core, vessel, steam generator and pressurizer, prior to considering the complete plant.

A sensitivity study was performed by adjusting the heated diameter corresponding to the heat structures located between the primary side "U" tubes and the secondary coolant (riser), in order to adjust secondary pressure. It is necessary to carry out this sensitivity study as, physically, the tube support plates and the "U" bend give rise to an important transverse flow on the secondary side, which considerably improves heat transfer. This fact is not normally taken into account in the correlations used for heat transfer. The value obtained for this heated diameter is approximately equivalent to the separation between tubes.

The actual geometric value of the hydraulic diameter in the riser is maintained for calculations unrelated to heat transfer.

The value of circulation ratio in the steam generator under nominal conditions, 1.96, was obtained by adjusting the coefficient of losses (K) in the downcomer-riser (junction 1 in component 65).

The study of steady state for the overall plant was accomplished in different stages: first, and with initial plant conditions determined on the basis of actual data, a calculation was made with the steady state search option. At 100 seconds a series of simple stabilizing systems were introduced. These are a simplification of the real plant control systems and allow a search to be made for the steady state with special attention paid to the controlled variables: pressurizer pressure and level, primary system average temperature and flow and steam generator level.

Checking of the steady state obtained using this method is accomplished by eliminating these simple control systems, the steady state thus being obtained once more. Using this last result, the different actual plant control systems are introduced and a null transient calculation is carried out as the definitive starting point for simulation of the transient.

Figure 5 shows a schematic representation of the different stages mentioned above, with the corresponding time values.

The reason for this last calculation being based on null transient conditions instead of a search for steady state is the result of the way this last option is treated by the code. For steady state, TRAC-PF1/MOD1 does not use the point kinetics model; consequently, it would not be possible to observe the effects on nuclear power of the reactivity associated with movement of the control rods.

The steady state results reflected in Table 4 agree with the input data obtained from the plant, at 97% rated thermal power.

Initially, the plant was adjusted to exactly match the 100% power condition; subsequently, the 97% power condition was obtained, using the stabilizing systems, with important savings in time and effort.

5. BOUNDARY CONDITIONS AND SENSITIVITY STUDIES

The boundary conditions for the transient, which were the subject of a special study, were as follows:

- Mass spray flow: Continuous spray serves to maintain thermal balance in the pressurizer under steady state conditions with respect to losses across the walls of the component and energy input from the heaters. Losses to outside the pressurizer were estimated at 15 Kw, and the continuous spray flow rate used was 0.023 Kg/s (steady state value), this falling to zero on pump trip. In the code model, continuous spray was represented by a FILL component (600) introducing the above-mentioned flow into the pressurizer (component TEE 82) via junction 600.

  Mass spray flow during the transient was represented by instantaneous opening of the corresponding valve (component 95), the cold leg intake nozzle (component TEE 80) being modelled in detail. Given the uncertainty existing with respect to the mass flow across the valve, an important point of reference for the transient was the time measured in the plant for reactor trip on low pressure (see plant table of events). In this respect, a parametric study was performed of the flow rate producing the above-mentioned effect, the value obtained being 2.92 Kg/s. This value was obtained by adjusting loss coefficients in the spray line, and mainly at the inlet to the pressurizer, where exact calculation of this coefficient is not a simple matter.

  The value obtained by this process (2.92 Kg/s) is significantly lower than that given in the reference documentation (4.81 Kg/s); in this respect, the efficiency of the spray system, related to the way in which the inflow of water is modelled by the code, is an important factor to be taken into account.

- Load reductions: Reduction of turbine power by 20 MWe determined the need for a sensitivity study of the degree of opening of the turbine control valve (component 190), in order to provide the steam flow corresponding to these load reductions. Figure 6 shows the results of the parametric study performed. Table 5 includes the overall result of valve actuation versus time.

- Charging pump actuation in manual: The results obtained from the plant show that one of the two charging pumps operated in the manual mode during two periods of the transient: at the beginning of the event, when an important drop in pressurizer pressure was first appreciated, and subsequently, in order to recover pressure by increasing level at the time of reactor trip. The operational profile for this pump in manual is shown in Table 6; the pump is considered in the model of the pressurizer level control system along with the pump in automatic mode (component FILL 92 regulated by control).

- Feedwater control: The model does not include the steam generator level control system, the evolution in time of this level throughout the transient being a bounding condition. The main reason for this is that following reactor trip, feedwater flow was controlled manually for the rest of the transient, this making system actuation difficult to model.

  The solution adopted in this respect consists of introducing a very simple control model making feedwater flow follow the evolution of level in the plant, which is taken as a reference.

Feedwater (300) is a a FILL component with input of a time table for all corresponding variables following reactor trip; consequently, the evolution of the inlet temperature, which changes substantially after reactor shutdown, is taken into consideration (Table 7).

- Turbine bypass in pressure mode: On reactor trip, the turbine bypass was switched from the temperature mode to the secondary pressure mode. However, the pressure setpoint was not maintained at a fixed value in the plant, but was controlled manually, being varied and adapted to the requirements of the evolution of the transient.

Modelling of this aspect of the calculation would have meant following the evolution of secondary pressure in the plant and taking it as a reference for operator variation of this setpoint. For the purposes of the work described in this report, preference was given to an approximate solution by means of which two pressure setpoint values were established, applicable to those stages of the transient in which highly detailed analysis of secondary plant pressure was advisable.

The two values selected were 59 Kg/cm^2 (57.9 x 10^5 Pa) for the first 55 seconds after reactor trip, and 64 Kg/cm^2 (62.8 x 10^5 Pa) from this time onwards.

This aspect explains clearly the differences observed in secondary pressure measurements during the final phase of the transient.

6. TRANSIENT ANALYSIS

The results of the transient are shown in Figures 7 to 23, six of which show the plant measurements for these fundamental variables. These plant results were chosen because of their importance to the transient and because of the ease with which the data are read. The variables for comparison are: primary pressure, average temperature and hot leg-cold leg differential temperature, pressurizer level and steam generator secondary side level.

The graphic results include an initial 100 seconds of null transient; in other words, the disturbance causing the transient (opening of the spray valve) begins 100 seconds into the results. Throughout the rest of this report the time scale will begin in all cases from onset of the transient, in order to clarify analysis of the event sequence.

Table 8 shows the sequence of the most important transient events for simulation with TRAC-PF1/MOD1.

During the initial phase of the transient, the continuous depressurization of the primary as a result of the flow of subcooled water (2.92 Kg/s) across the spray valve (Figure 7) caused the pressurizer heaters which remain inactive under steady state conditions (back-up heaters) to energize. Energy input by these heaters was maximum (300 Kw) during the calculation performed (Figure 8).

Between 60 and 90 seconds into the transient, two successive load reductions occurred, the aim being to stop depressurization of the primary system.

The characteristics of modelling of these load reductions have been described in a previous section, within the framework of the set of non-automatic actuations occurring during the transient and mainly defined as bounding conditions.

These load reductions can be seen in Figure 9, which shows the evolution in time of turbine power (steam mass flow).

Before the reactor trip, during the time period between 60 and 360 seconds into the event, the first manual start-up of the corresponding charging pump occurred (Figure 10), this action also having been described above. The effect of this was to maintain primary pressure at high values prior to reactor shutdown.

Reactor scram on low pressurizer pressure (123.97×10^5 Pa) occurred at 397.6 seconds (6.6 minutes), and caused a drastic reduction in reactor power (Figure 11) and in primary pressure (Figure 12).

Figure 13 shows the control rod insertion phase (%) before the reactor trip, due to the effects of the primary Tavg control system, which follows temperature variations during this phase of the transient. Consequently, the figure does not reflect the rod drop insertion at the time of reactor scram.

Figure 14 shows the evolution of the average temperature in the primary system.

At the time of reactor trip, secondary pressure increases (Figure 15), this increase being controlled by actuation of the two sub-systems of the turbine bypass: bypass to the condenser and atmospheric steam dump. Initially, and until such time as the average temperature in the primary decreases to below 548°K, actuation of the bypass system (degree of opening) is regulated by this variable, automatically switching to the pressure control mode and being regulated by pressure in the secondary.

Prior to switching to the pressure control mode, a safety injection signal was initiated on low primary pressure (117.11 x 10^5 Pa), and as a result of the decrease in Tavg following reactor trip, closure signals are initiated for the secondary relief valves (430 and 440 s).

The switching of the bypass to the pressure control mode (440 s) caused the cooldown rate of the primary to decrease, which also decreased depressurization, as can be seen clearly in Figure 12, primary pressure, which shows a slight recovery of pressure.

In the plant, actuation of the turbine bypass in the pressure control mode was manually regulated throughout the transient, secondary pressure being regulated and primary depressurization being controlled in order to avoid excessive cooldown.

Adjustment of the bypass system pressure setpoint was the operational mechanism by which system actuation was controlled. In the code model, two time periods have been simulated with their respective setpoints: 57.9 x 10^5 Pa up to 55 seconds after reactor trip and 62.8 x 10^5 Pa from then onwards.

This simulation differs from what actually occurred in the plant, and explains the difference that can be observed between the calculation and the plant data as regards the evolution with time of secondary pressure during the second half of the transient, in which the effects of the bypass in the pressure control mode can be clearly appreciated (Figure 15).

Figures 16 and 17 show the degree of opening of the bypass in the pressure mode and steam flow at the outlet of the steam generator, respectively.

On switching the turbine bypass system from one operational mode to another, there is a second manual start-up of the charging pump, and feedwater is also switched to manual control. The charging pump, which operated until 745 seconds into the event, provided maximum makeup flow (240 lpm, 0.004 m^3/s). The effect of this on pressurizer level was a drastic increase. In any case, there is some operational uncertainty as to the exact time the pump was actually in operation. The differences with respect to the results obtained using plant data (Figure 18) might be explained partly in terms of sensitivity to the volume of water injected. During the last phase of the calculation there are differences in pressurizer level, which may be attributed to greater inertia (in calculation) in actuation of the charging pump in automatic (limitation of integrators, time constants, etc.).

Feedwater flow in manual has been simulated in a simple manner. Given the difficulty to appreciate with any accuracy the actual variation of this parameter in the plant, the measured steam generator level has been taken as a reference, with feedwater flow present or absent depending on deviations in calculation (Figures 19 and 20).

The minimum recuperation of primary pressure (Figure 12) with the turbine bypass in pressure mode was not maintained, and this parameter decreased again to a calculated value of 96.1 x 10^5 Pa (1800 s, 30 min). At this moment, the main coolant pump was stopped, thus interrupting spray flow (Figure 7), and the system heated up once more (Figure 1[illegible]), primary pressure being rapidly recuperated.

The minimum pressure value reached in the plant was 98.0 x 10^5 Pa, the evolution with time of this variable agreeing closely with the results of the code, this match also being clear from the variation of primary Tavg throughout the transient.

Figure 21 represents the volumetric flow in the primary, with the sudden drop that occurs prior to establishment of natural circulation, an operational mode that implies a change in the temperature difference between the hot and cold legs (Δ T) as a result of natural convection flow being much smaller than under forced flow conditions (figure 22).

Figure 22 (Δ T) shows significant differences at the beginning of the transient, due to use of a much lower primary flow in calculation (thermal design) than actually existed at that time in the plant. During the natural circulation phase the match with plant data is good, although there is a time period in which the main coolant pump is shutdown and when a peak Δ T value is observed in the plant which was not identified in calculation. Operator intervention to manually control the turbine bypass in the pressure mode has an immediate effect on primary temperature. This can be the reason of this evolution, in conjunction with aspects related to the instrumentation. The natural circulation flow arrived at by the code shows a value similar to that obtained in the plant, the temperature gradient existing at that time closely agreeing (2400 to 3200 s).

Finally, Figure 23 shows the cold leg temperature, with the above-mentioned effect of the cooldown caused by the charging pumps and the variations caused by manual control of the turbine bypass and feedwater systems.

As regards the statistics relating to calculation, Figure 24 shows the total CPU time used. Evolution is highly uniform, with brief periods of higher consumption which mainly coincide with insertion of operational conditions during the actual transient.

The maximum time step used and maintained throughout the transient was 0.1 seconds, the overall ratio of CPU time to real time being 1.60. This means that transients of this type may be studied in a very short time period.

7. CONCLUSIONS

Analysis of the results obtained using the TRAC-PF1/MOD1 model and comparison of these results with plant data show a generally good match, as is shown by important variables such as primary pressure and average temperature. Extension of this comparison to include variables such as pressurizer level, differential temperature between the primary legs and secondary pressure has been equally positive, taking into account the uncertainties inherent in any actual transient in which a large number of actions are performed manually, with a varying time scale as regards duration of these actions and where the results obtained are lacking in detail and have an immediate influence on development of the transient. Generally speaking, the match has been good, and the Jose Cabrera model for TRAC-PF1/MOD1 has shown itself to be suitable for the simulation of long time plant transients, such as that considered in this study.

Also, adaptation to TRAC-PF1/MOD1 of the general purpose model already existing in relation to the plant for the RELAP5/MOD2 code has been an important experience and an extremely positive aspect as regards the efforts required and the short-term results.

The importance of the pressurizer to this transient made it advisable to partially validate the submodel with respect to tests carried out at the NEPTUNUS and M.I.T. experimental facilities.

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5. "TRAC-PF1/MOD1 Independent Assessment: NEPTUNUS Pressurizer Test Y05", A.C. Peterson. NUREG/CR-3919. December 1.984.

6. "An Experimental and Analytical Model of a PWR Pressurizer during Transients", Sang-Nyung Kim. MIT. February 1.984.

EVENT	TIME (MIN.)	CALCULATION (TRAC-PF1/MOD1)
Spray valve opening	0.0	0.0
Total power of pressurizer heaters	0.0 +	0.1
Controlled load decreasing (20 MW)	1.0 - 2.0	1.0-1.6
Charging pump starting (Manual)	1.0 - 2.0	1.0-6.0 (*)
Primary low pressure reactor trip	6.5	6.6
Steam dump from average temp. to sec. pressure mode and manual control	7.5	7.3
Main coolant pump tripped No spray mass flow Natural circulation	30.0	30.0
Primary pressure recovery (To about 130 kg/cm2)	60.0	60.0 (124.0 kg/cm^2)

(*) Actuacion interval

TABLE 1.- CHRONOLOGY OF EVENTS FOR PLANT TRANSIENTS

COMPONENT	RELAP5 MODEL
Accumulator and safety injection system.	Volumes 600 to 650, valves 610 and 630.
Pressurizer relief and safety valves.	Volumes 314 to 340, valves 316 to 338.
Secondary safety valves.	Volumes 542 to 563, valves 540 to 552.
Water supply and steam consumption of auxiliary feedwater turbine driven pump to S.G. after the reactor trip.	Volumes 448 and 462, junctions 449 and 461.
Emergency feedwater to S.G.	Volume 456, junction 457.

TABLE 2.- NOT INCLUDED COMPONENTS IN THE TRANSIENT

1.- RCS AVERAGE TEMPERATURE CONTROL SYSTEM

- Average temperature program versus turbine load (steam mass flow)
- Control rods motion
- Control bank reactivity

2.- PRESSURIZER PRESSURE CONTROL SYSTEM

- Spray and heaters (back-up and proportional ones)

3.- PRESSURIZER LEVEL CONTROL SYSTEM

- CVCS charging and letdown flow rates
- Heaters

TABLE 3.- CONTROL SYSTEMS INCORPORATED TO TRAC-PF1/MOD1 MODEL

4.- STEAM DUMP CONTROL SYSTEM

- Primary average temperature
- Steam pressure

5.- STEAM GENERATOR LEVEL CONTROL SYSTEM

- Manual control of feed water during almost all the transient (just after the reactor trip)

TABLE 3.- CONTROL SYSTEMS INCORPORATED TO TRAC-PF1/MOD1 MODEL (cont.)

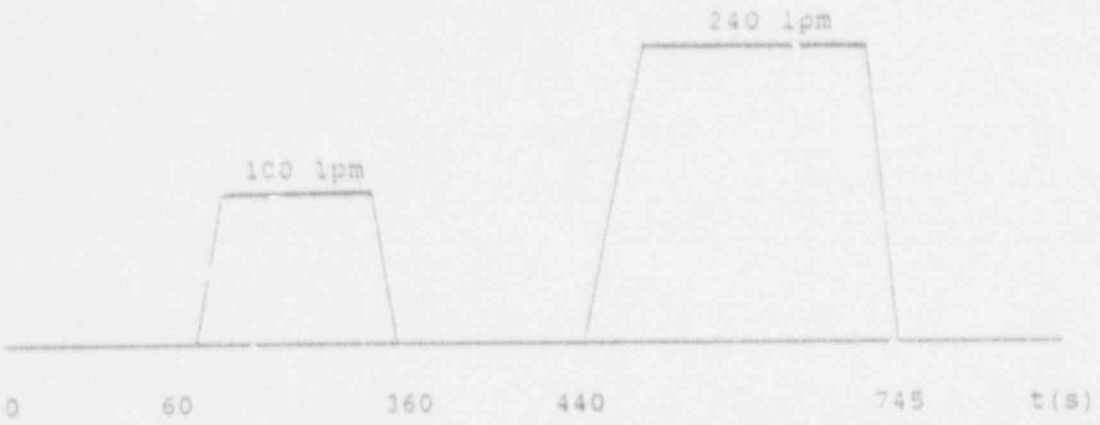
VARIABLE	UNITS	JOSE CABRERA	TRAC-PF1/MOD1
Reactor power	(M W)	495.50	495.50
RCS average temperature	(ºC)	292.90	292.90
Pressurizer level	(%)	62.30	62.30
Pressurizer pressure	(MPa)	13.82	13.82
RCS flow rate	(gpm)	75000.00	75000.00
Reactor coolant pump speed	(rpm)	990.00	996.00
Steam generator pressure	(MPa)	4.55	4.56
Steam generator circulation rate	(--)	1.96 (*)	2.02
Steam generator collapsed liquid level	(m)	8.68	8.68
Steam flow rate	(Kg/s)	257.00	256.40
Feedwater temperature	(ºC)	203.70	203.70

(*) 100% FULL POWER

TABLE 4.- STEADY STATE RESULTS (97% FULL POWER)

TIME (s)	OPENING
0.	0.5044
60.	0.5044
65.	0.4340
90.	0.4340
95.	0.3900
1.E + 6	0.3900

TABLE 5.- LOAD DECREASING BY TURBINE CONTROL VALVE



TIME (s)	FLOW RATE (lpm)
0.	0.
60.	0.
120.	100.
300.	100.
360.	0.
440.	0.
445.	240.
685.	240.
745.	0.
1.E+6	0.

TABLE 6.- MANUAL CHARGING PUMP

TIME (s)	TEMPERATURE (ºC)
0.	203.7
140.	184.0
500.	184.0
860.	174.0
1040.	105.0
3020.	60.0
3380.	45.0
3980.	35.0

TABLE 7.- FEEDWATER TEMPERATURE

TIME (s)		EVENT
0.0	→	Spray valve opening
6.5	→	Pressurizer back-up heaters on
60.0-90.0	→	Load decreasing (2)
60.0-360.0	→	Manual charging pump actuation (Table 6)
397.6	→	Low pressure reactor trip (123.97×10^5 Pa) Steam dump by primary average temperature (bypass to condenser and relief valves)
414.6	→	Safety injection signal without actuation (primary pressure $< 117.11 \times 10^5$ Pa)
432.0-439.4	→	Relief valves begin to close
440.0	→	Steam dump changes to pressure mode (average temperature < 548 K) Manual charging pump starting Feedwater to manual control
745.0	→	Manual charging pump is stopped
1800.0	→	Main coolant pump tripped and begining of the primary pressure recovery (96.1×10^5 Pa)
3100.0	→	End of the calculations; primary presure recovery (115.7×10^5 Pa)

TABLE 8.- CALCULATIONS EVENTS SEQUENCE

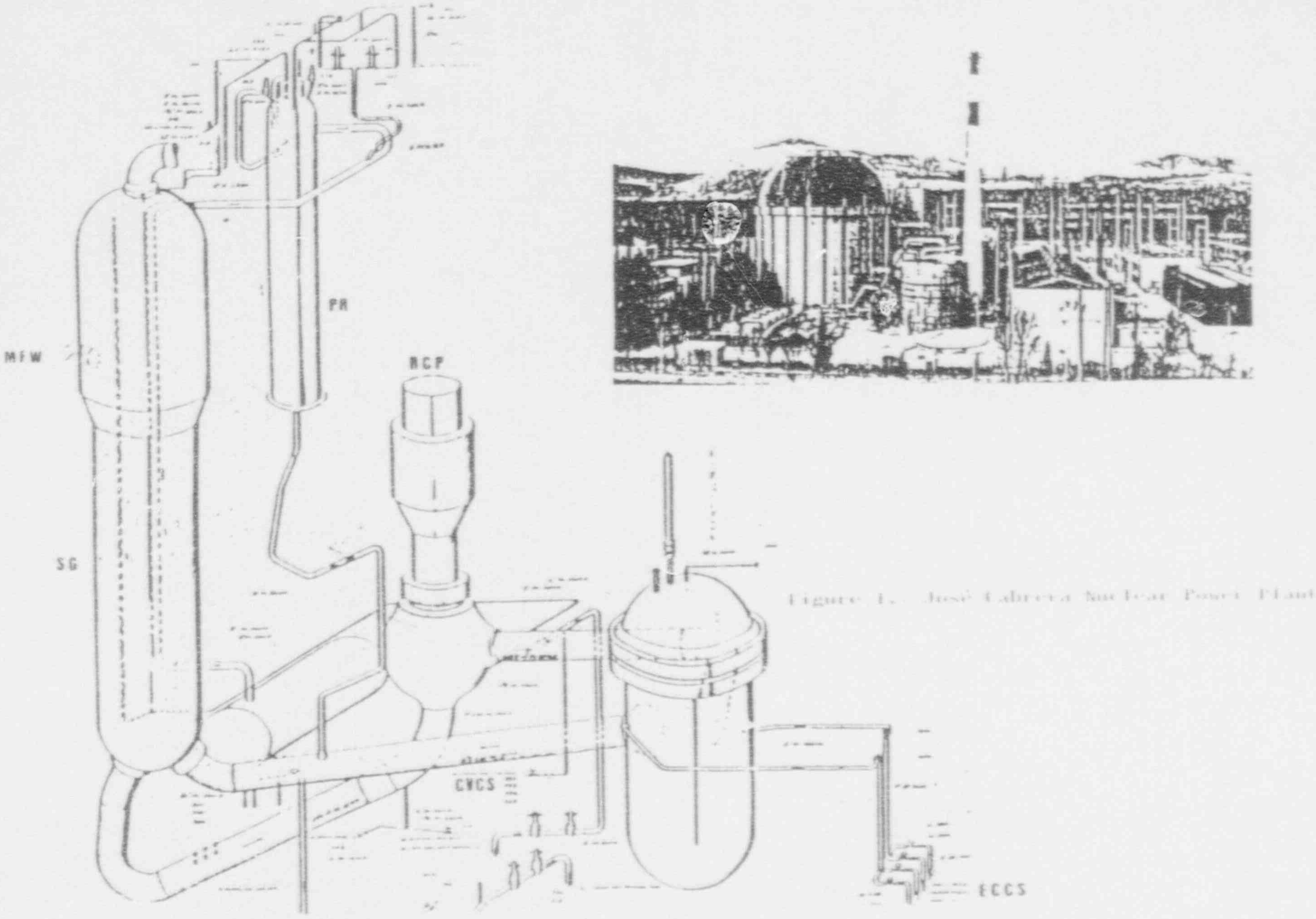


Figure 1. José Cabrera Nuclear Power Plant

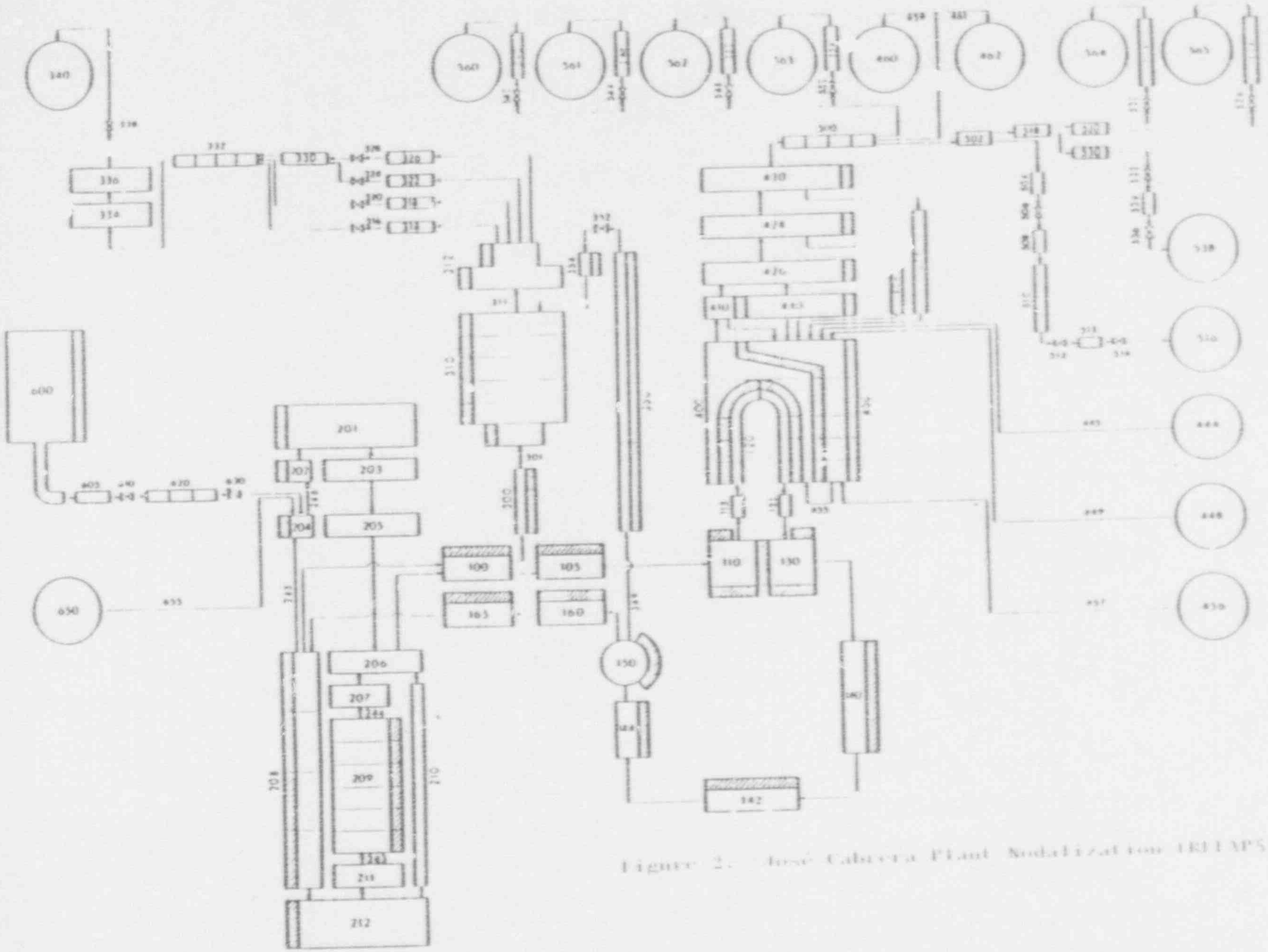


Figure 2. José Cabrera Plant Nodalization (RELAP5 MOD2)

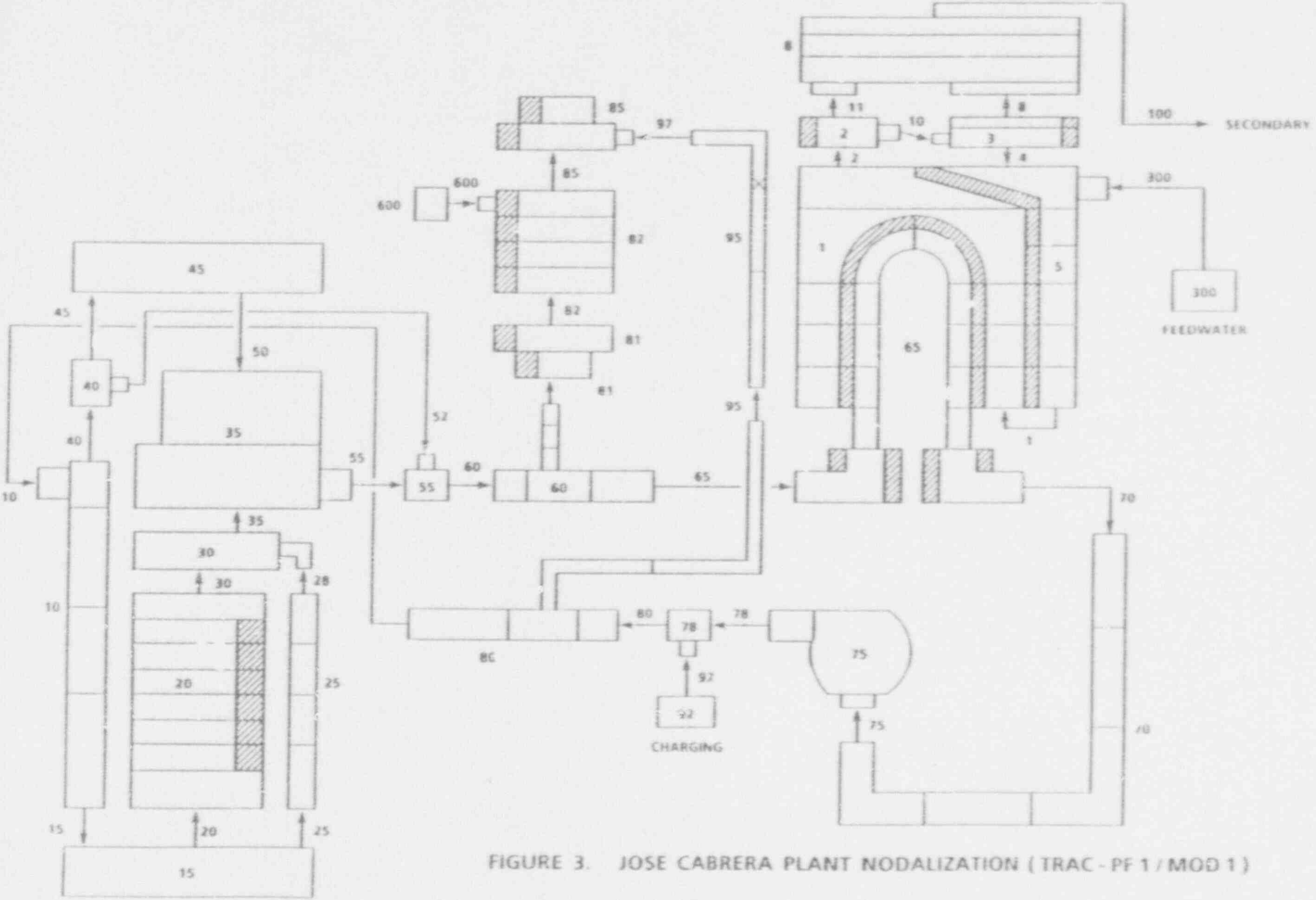


FIGURE 3. JOSE CABRERA PLANT NODALIZATION (TRAC - PF 1 / MOD 1)

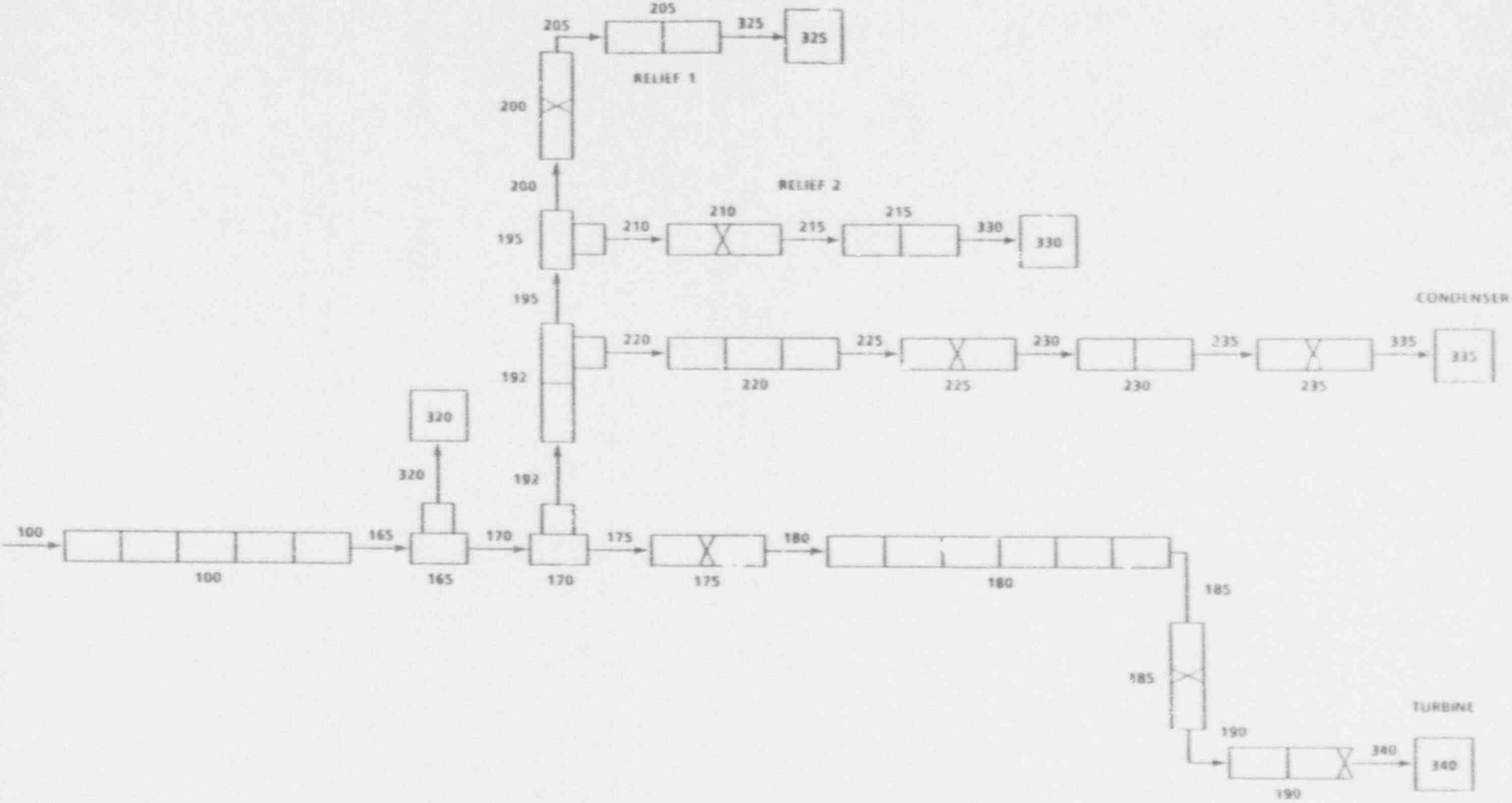


FIGURE 4. JOSE CABRERA PLANT NODALIZATION (TRAC-PF1/MOD1)

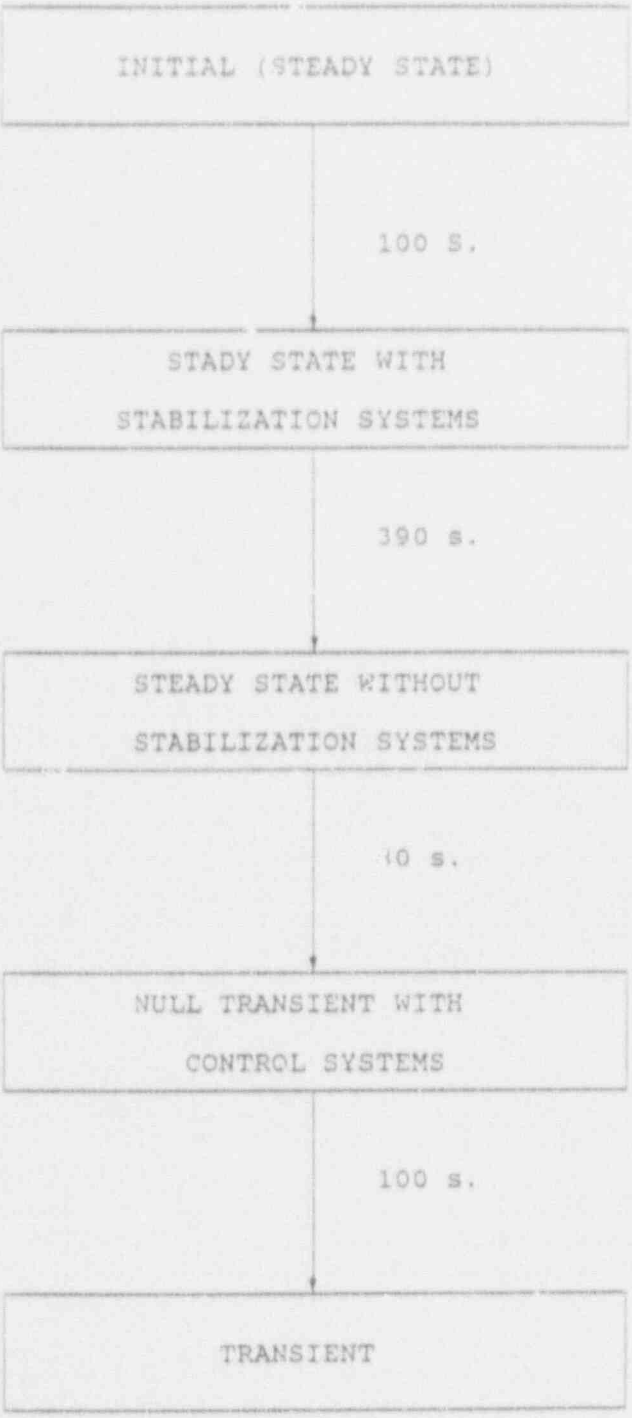


FIGURE 5.- STEADY STATE CALCULATION

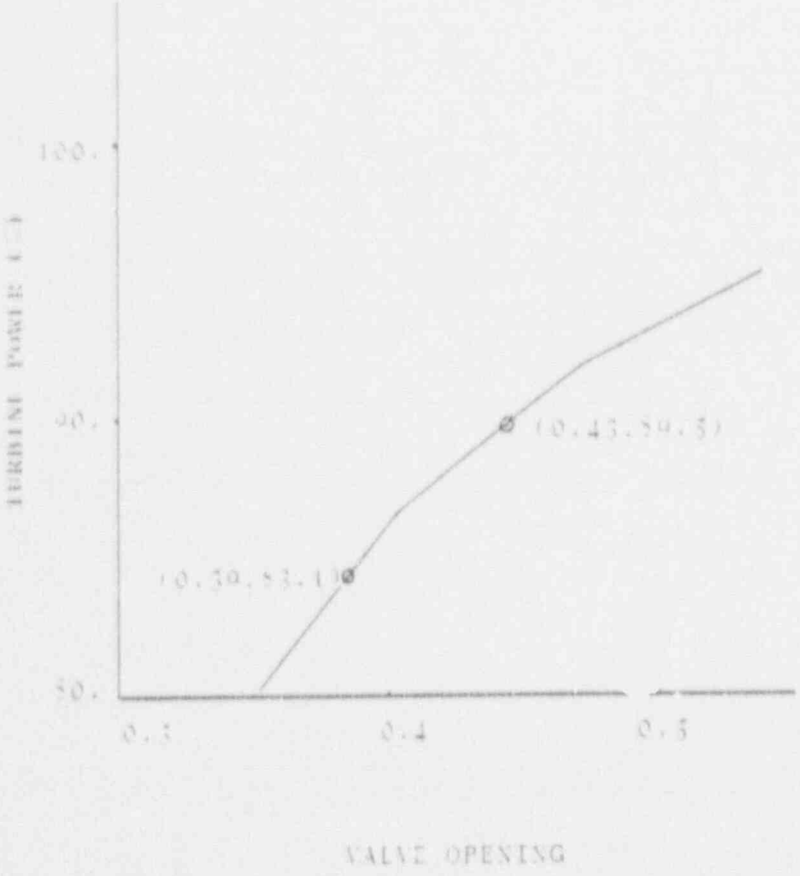
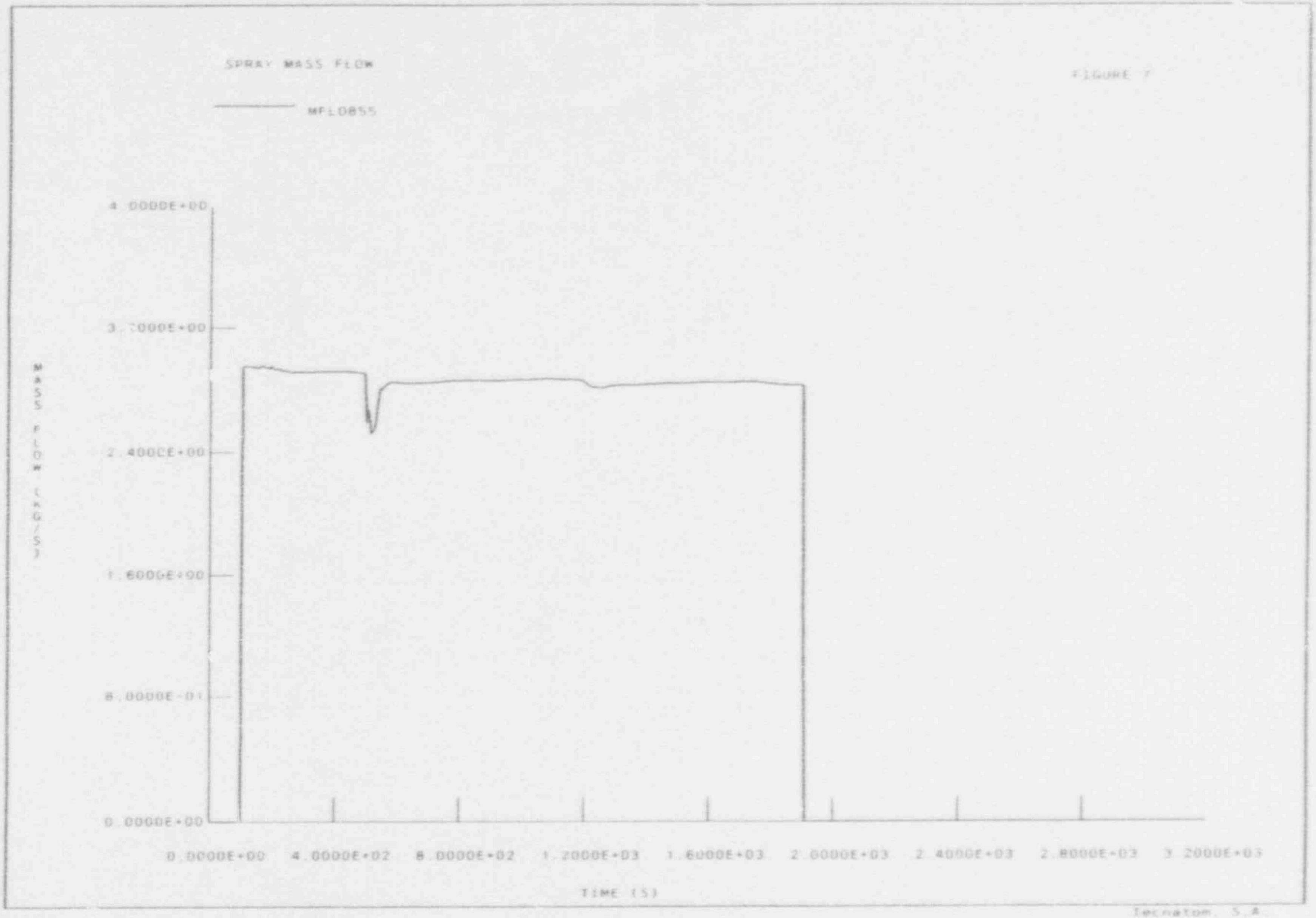


FIGURE 6.- CONTROL VALVE OPENING

FIGURE 7



Tecnatom, S.A.

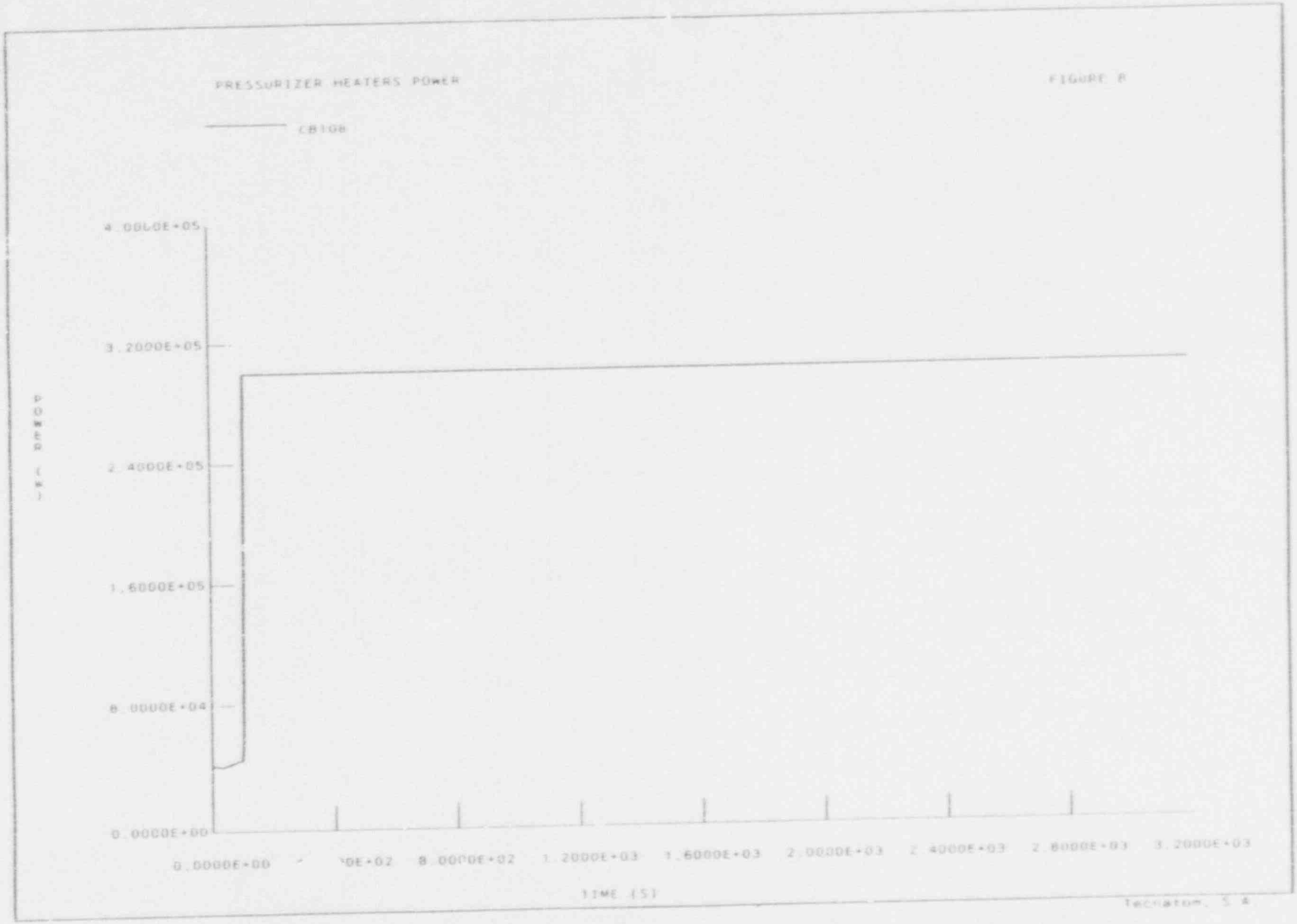

PRESSURIZER HEATERS POWER

FIGURE 8

Tecnatom, S.A

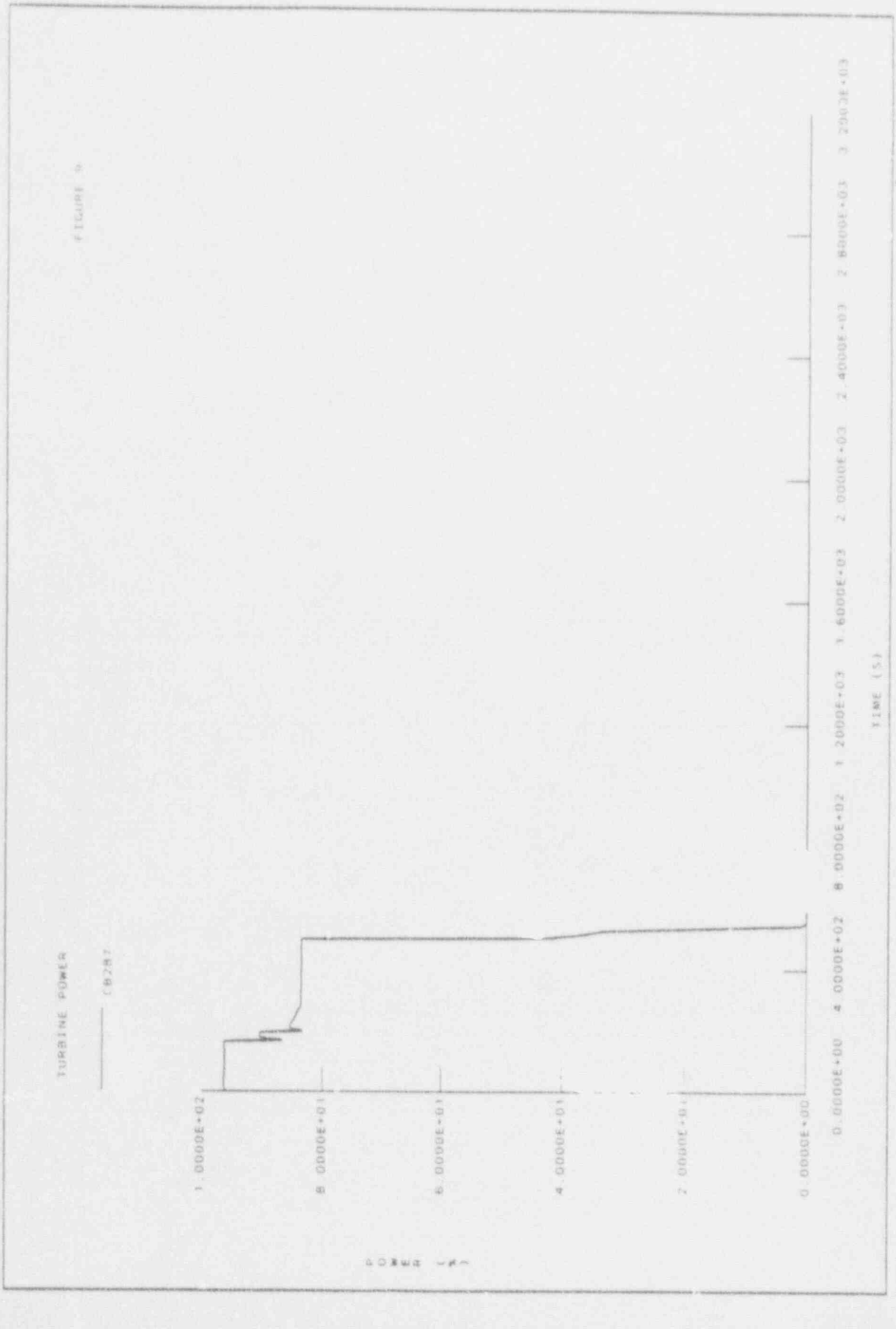
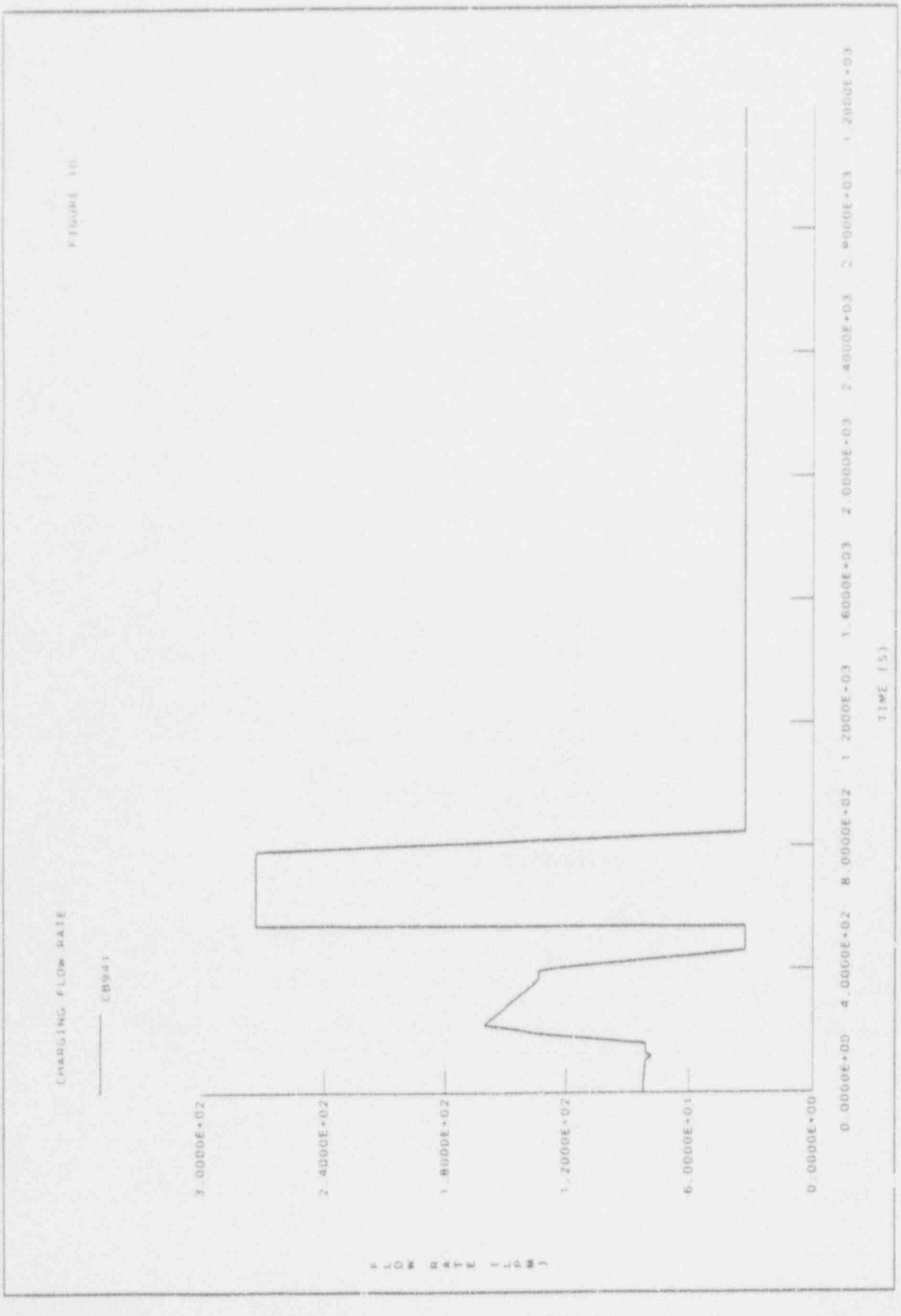
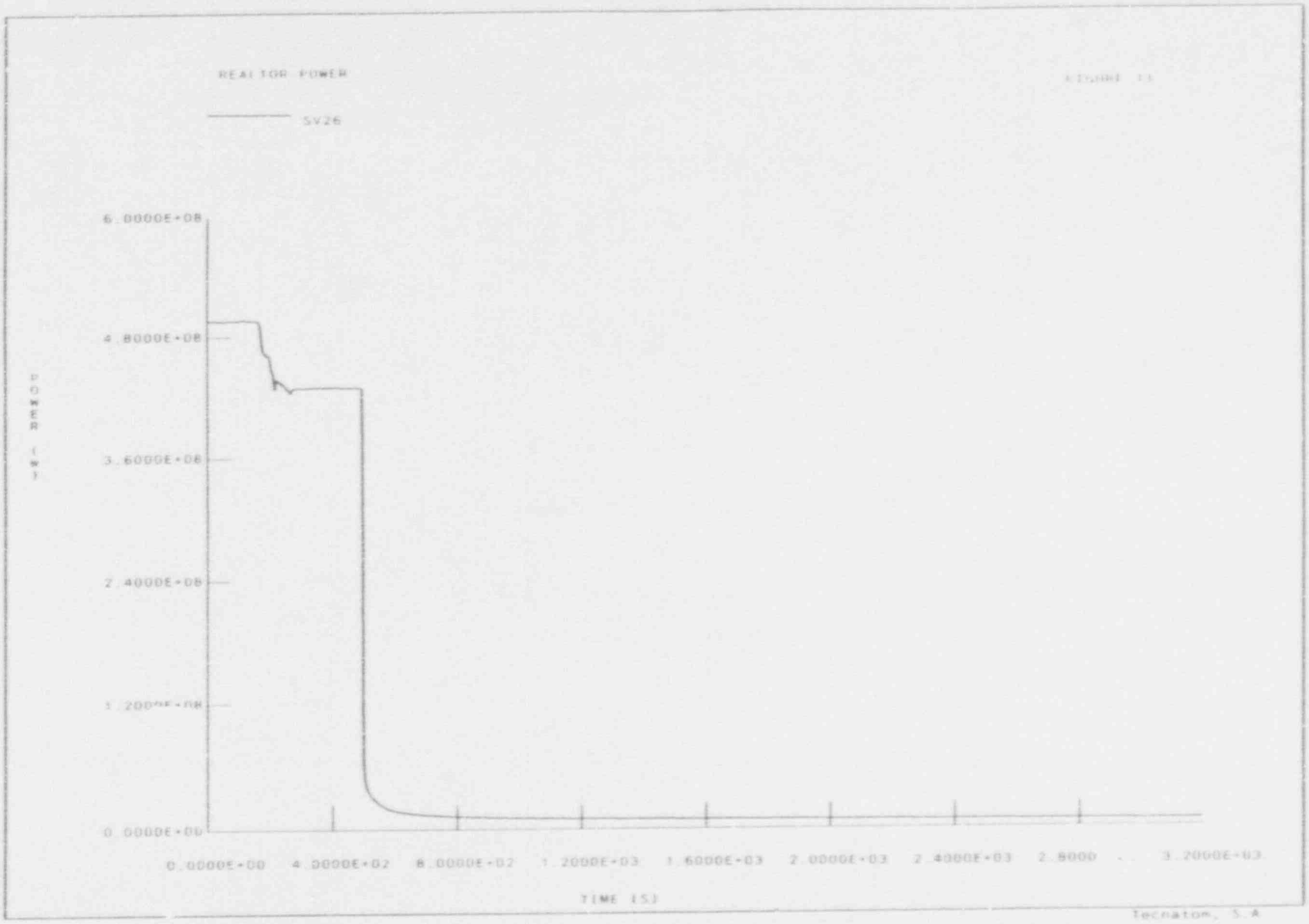


FIGURE 9

TURBINE POWER
C6287
POWER (%)
1.0000E+02
8.0000E+01
6.0000E+01
4.0000E+01
2.0000E+01
0.0000E+00
0.0000E+00
4.0000E+02
8.0000E+02
1.2000E+03
1.6000E+03
2.0000E+03
2.4000E+03
2.8000E+03
3.2003E+03
TIME (S)
Tecnatom, S.A.


CHARGING FLOW RATE
CB941
FIGURE 10
FLOW RATE (LPM)
3.0000E+02
2.4000E+02
1.8000E+02
1.2000E+02
6.0000E+01
0.0000E+00
0.0000E+00
4.0000E+02
8.0000E+02
1.2000E+03
1.6000E+03
2.0000E+03
2.4000E+03
2.8000E+03
3.2000E+03
TIME (S)
Tecnatom, S.A.


REACTOR POWER
SV26
FIGURE 11
POWER (W)
6.0000E+08
4.8000E+08
3.6000E+08
2.4000E+08
1.2000E+08
0.0000E+00
0.0000E+00
4.0000E+02
8.0000E+02
1.2000E+03
1.6000E+03
2.0000E+03
2.4000E+03
2.8000
3.2000E+03
TIME (S)
Tecnatom, S.A

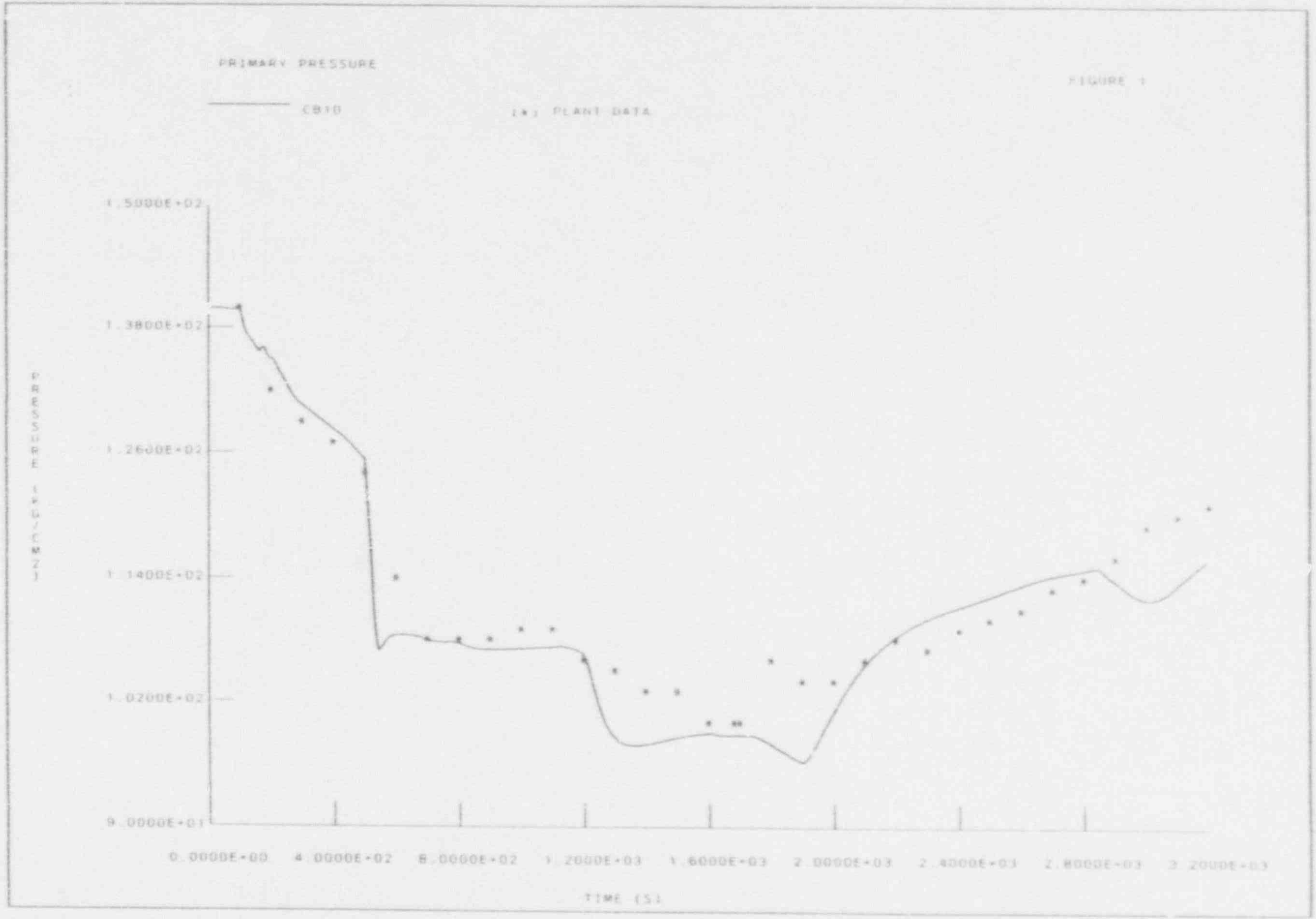


FIGURE 1

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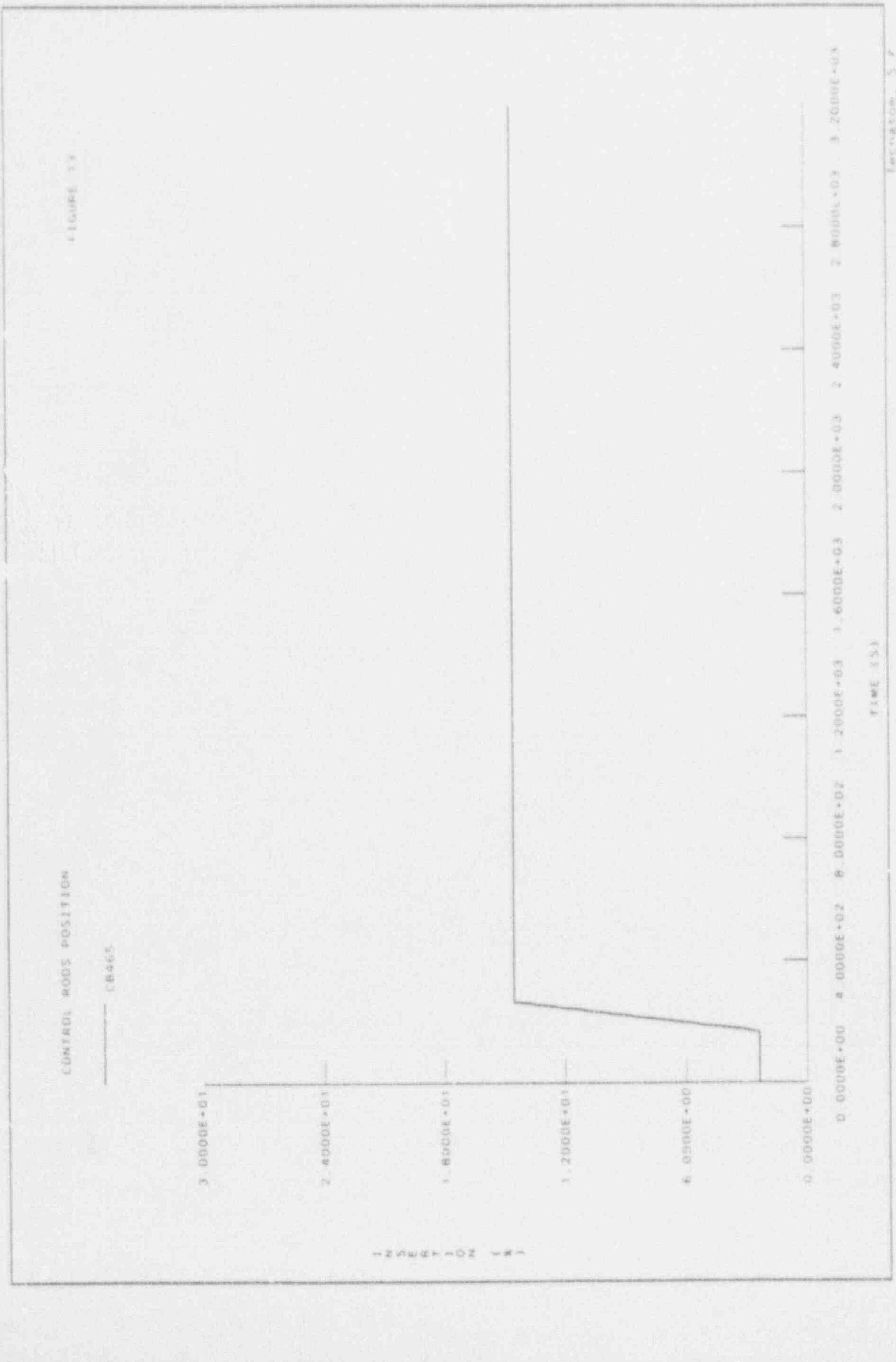

CONTROL RODS POSITION
FIGURE 13
CB465
INSERTION (%)
3.0000E+01
2.4000E+01
1.8000E+01
1.2000E+01
6.0000E+00
0.0000E+00
0.0000E+00
4.0000E+02
8.0000E+02
1.2000E+03
1.6000E+03
2.0000E+03
2.4000E+03
2.8000E+03
3.2000E+03
TIME (S)
Tecnatom, S.A.

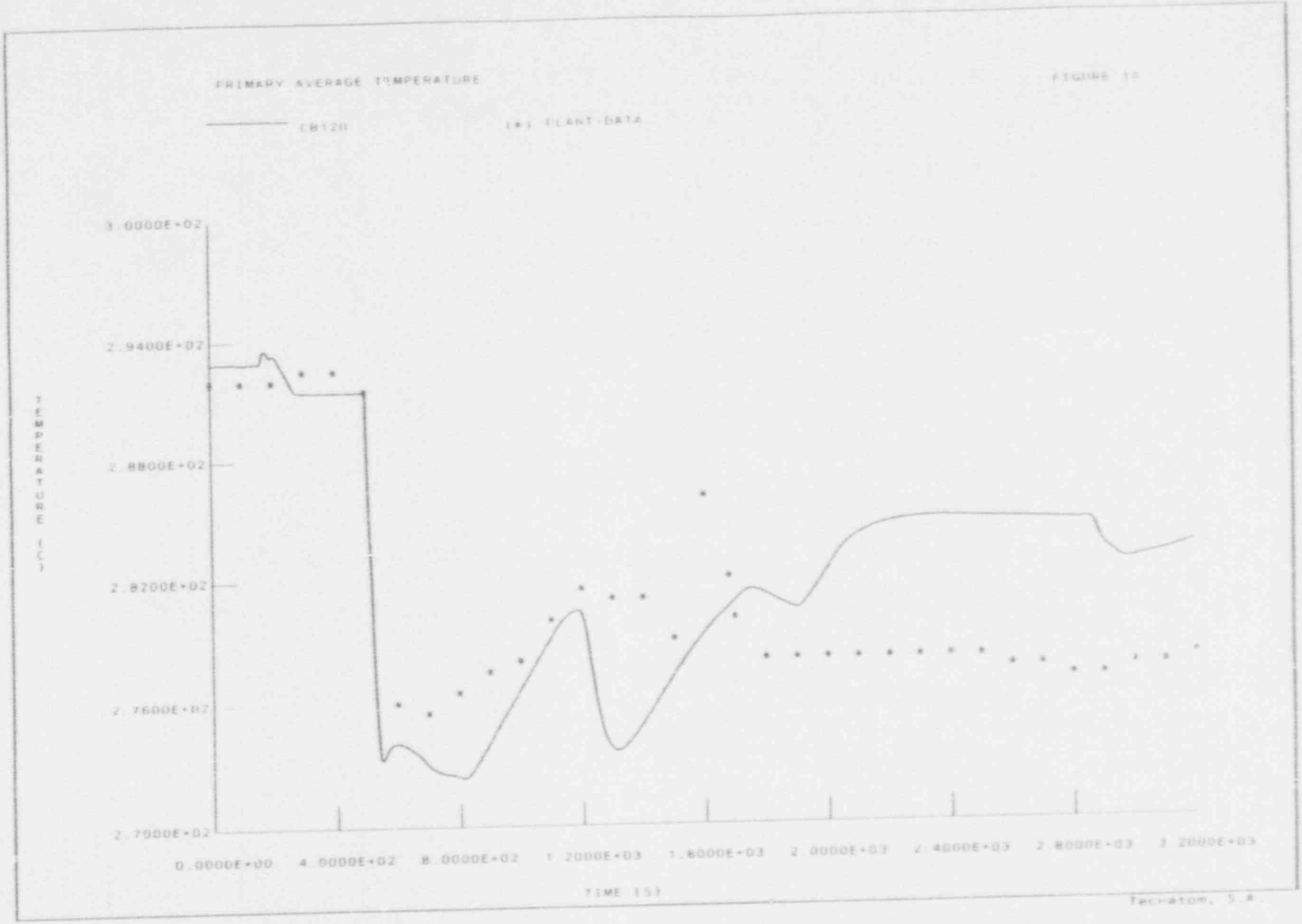
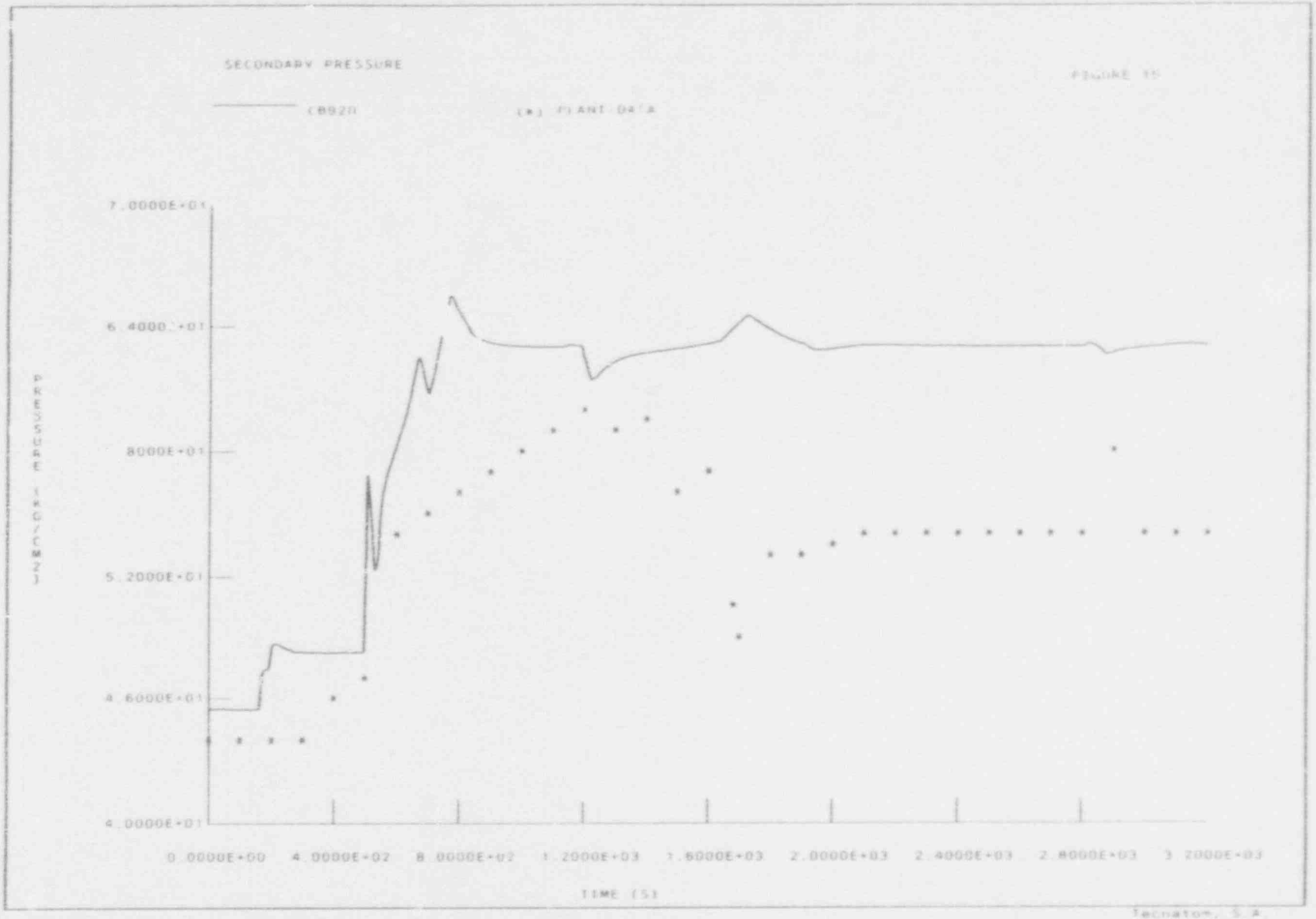
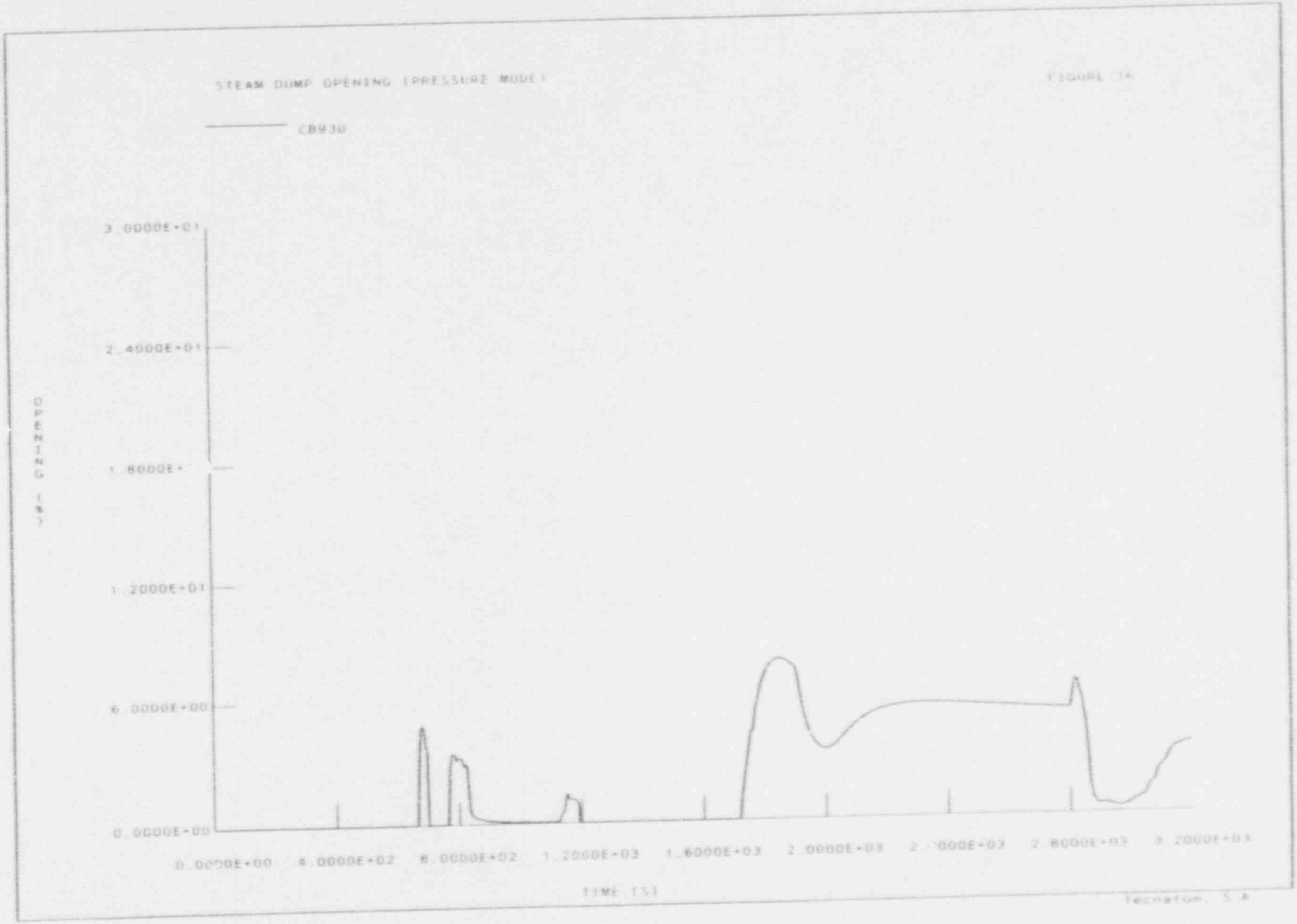


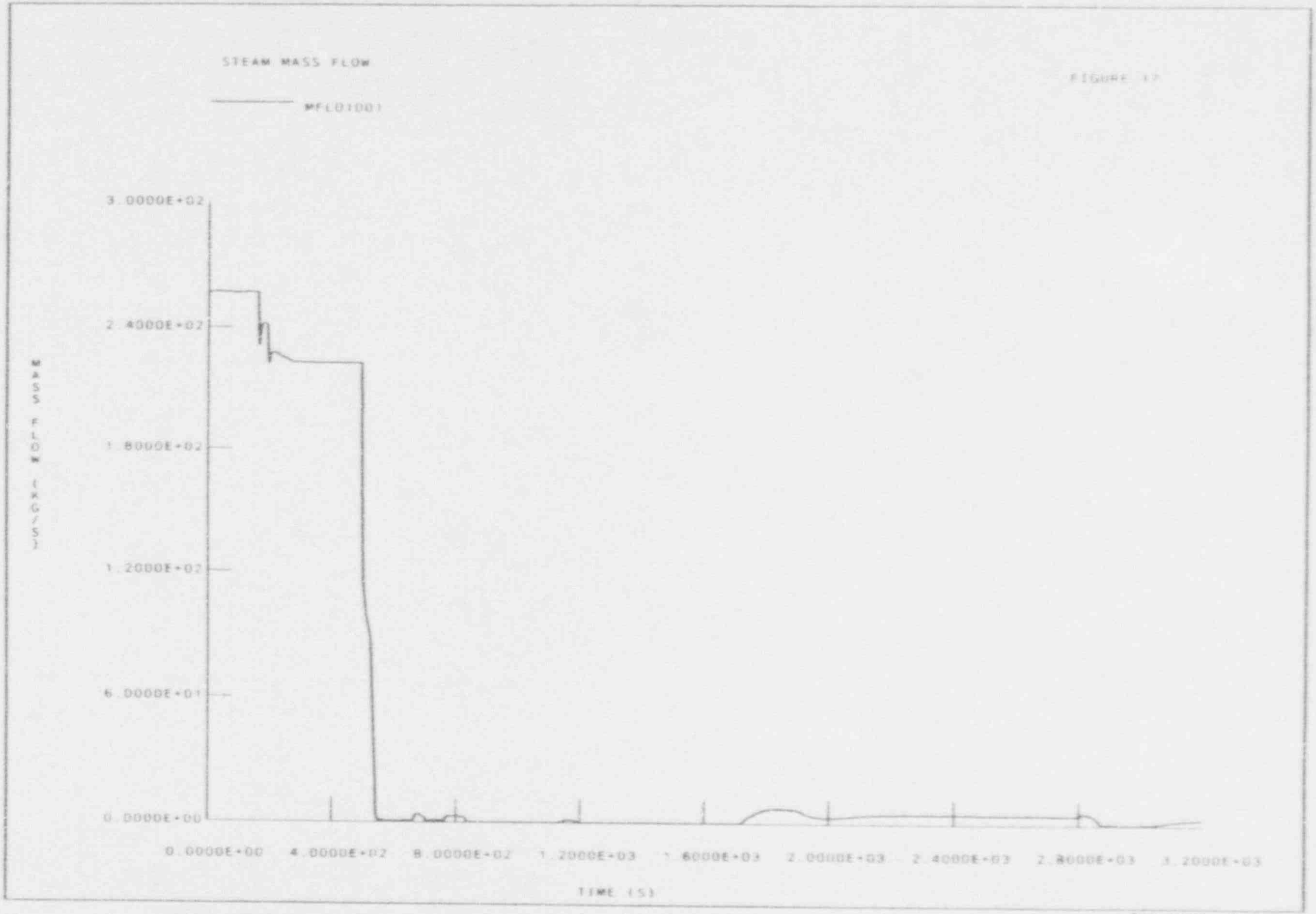
FIGURE 12

PRIMARY AVERAGE TEMPERATURE


SECONDARY PRESSURE
FIGURE 15
CB920
(*) PLANT DATA
PRESSURE (KG/CM2)
7.0000E+01
6.4000E+01
5.8000E+01
5.2000E+01
4.6000E+01
4.0000E+01
0.0000E+00
4.0000E+02
8.0000E+02
1.2000E+03
1.6000E+03
2.0000E+03
2.4000E+03
2.8000E+03
3.2000E+03
TIME (S)

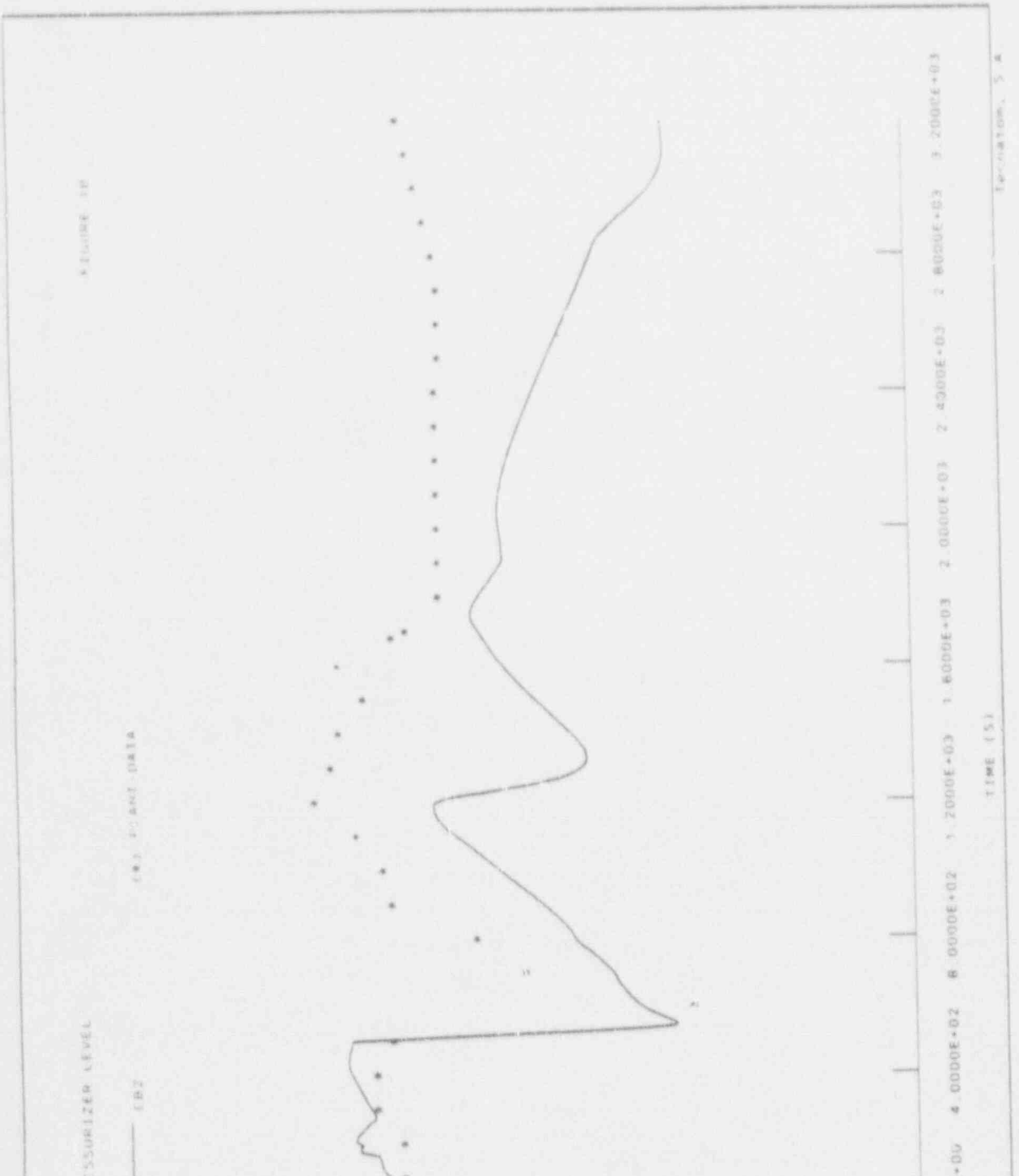
Tecnatom, S.A.

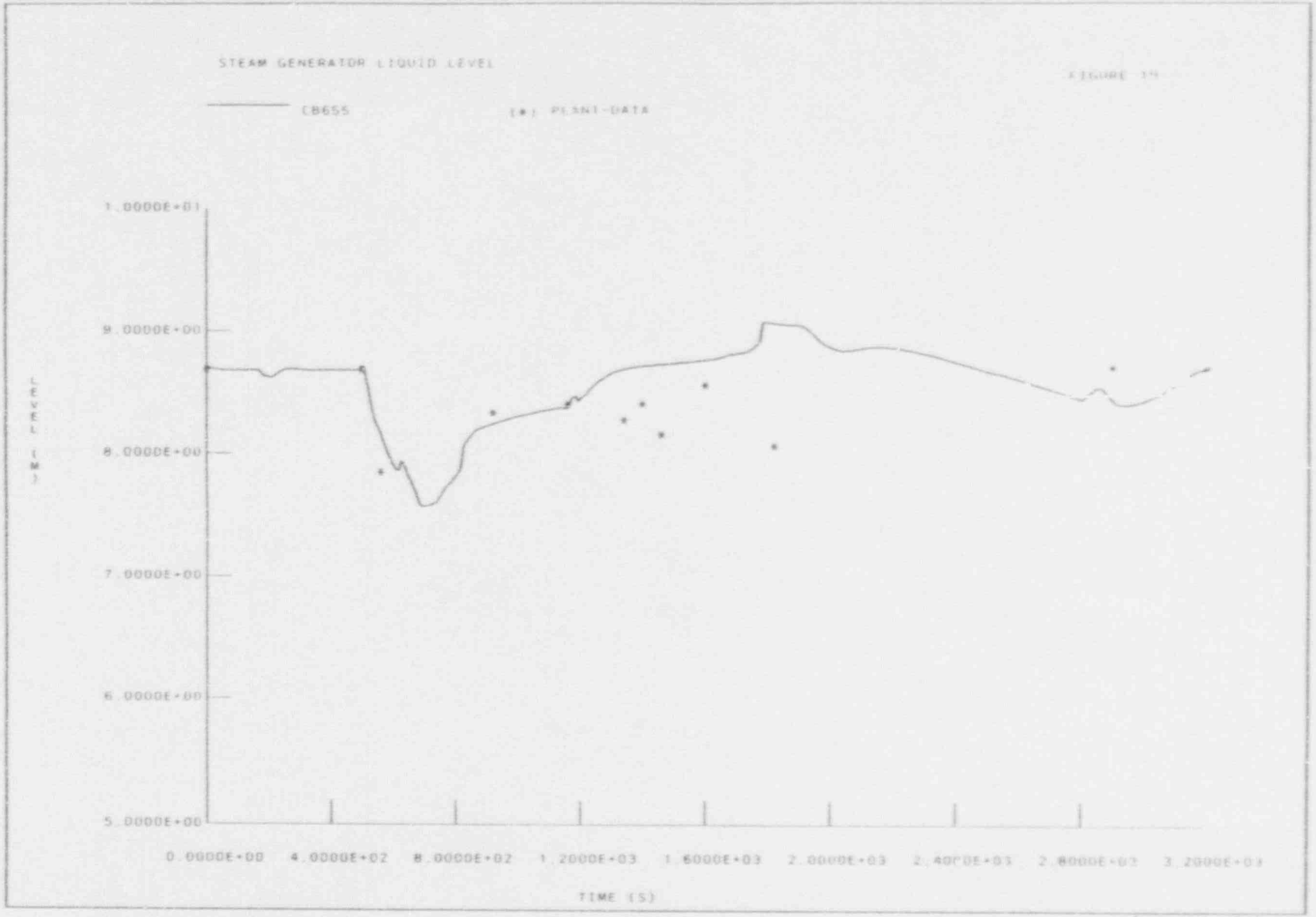

STEAM DUMP OPENING (PRESSURE MODE)
FIGURE 34
CB930
OPENING (%)
3.0000E+01
2.4000E+01
1.8000E+
1.2000E+01
6.0000E+00
0.0000E+00
0.0000E+00
4.0000E+02
8.0000E+02
1.2000E+03
1.6000E+03
2.0000E+03
2.4000E+03
2.8000E+03
3.2000E+03
TIME (S)
Tecnatom, S.A.



STEAM MASS FLOW
MFL01001
FIGURE 17
MASS FLOW (KG/S)
3.0000E+02
2.4000E+02
1.8000E+02
1.2000E+02
6.0000E+01
0.0000E+00
0.0000E+00
4.0000E+02
8.0000E+02
1.2000E+03
1.6000E+03
2.0000E+03
2.4000E+03
2.8000E+03
3.2000E+03
TIME (S)

Tecnatom, S.A.


PRESSURIZER LEVEL
FIGURE 19
EB2
(*) PLANT DATA
LEVEL (%)
8.0000E+01
6.4000E+01
4.8000E+01
3.2000E+01
1.6000E+01
0.0000E+00
0.0000E+00
4.0000E+02
8.0000E+02
1.2000E+03
1.6000E+03
2.0000E+03
2.4000E+03
2.8000E+03
3.2000E+03
TIME (S)
Tecnatom, S.A.


STEAM GENERATOR LIQUID LEVEL
FIGURE 19
CB655
(*) PLANT-DATA
LEVEL (M)
1.0000E+01
9.0000E+00
8.0000E+00
7.0000E+00
6.0000E+00
5.0000E+00
0.0000E+00
4.0000E+02
8.0000E+02
1.2000E+03
1.6000E+03
2.0000E+03
2.4000E+03
2.8000E+03
3.2000E+03
TIME (S)

Tecnatom, S.A.

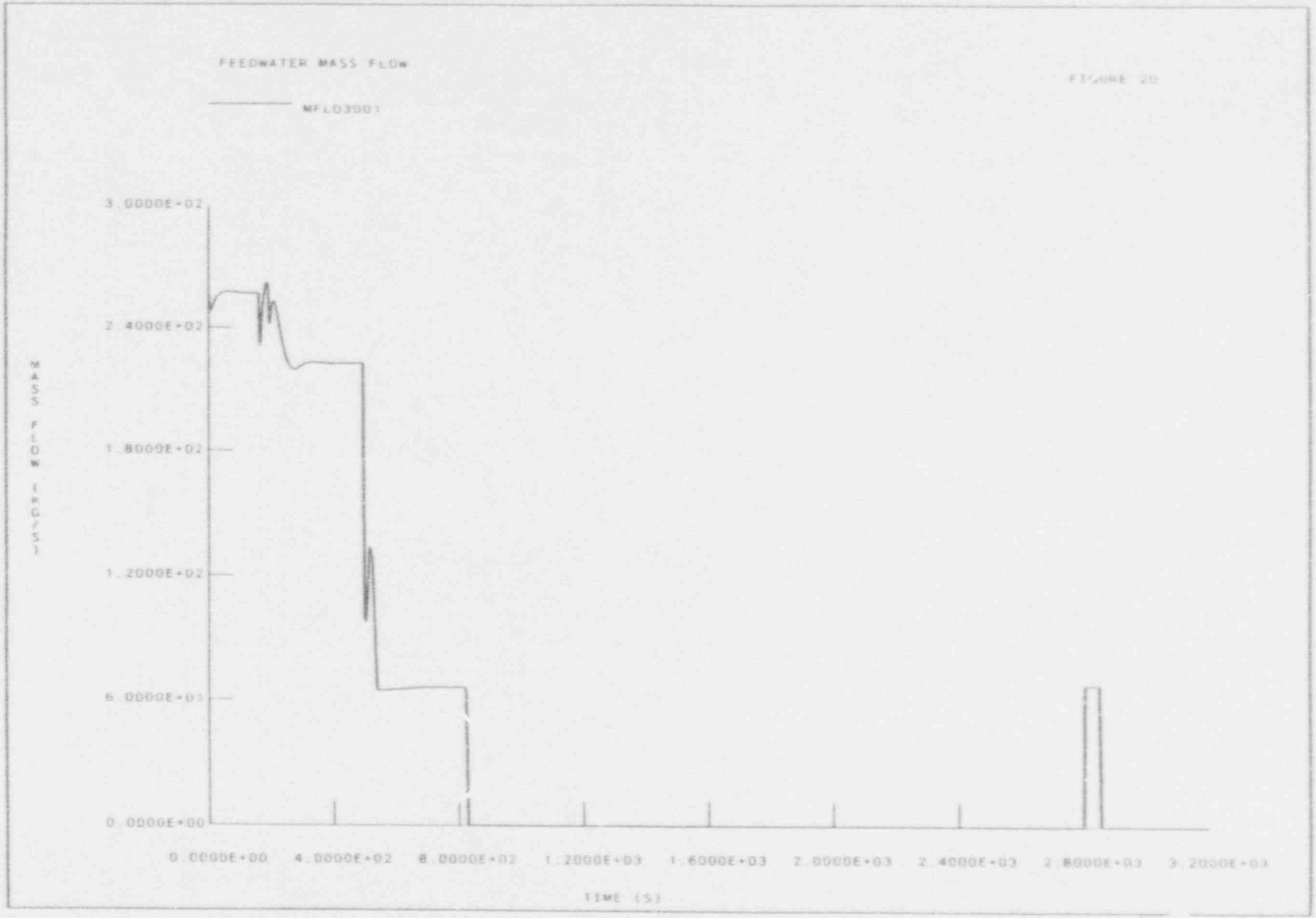


FIGURE 20

Tec om, S.A.

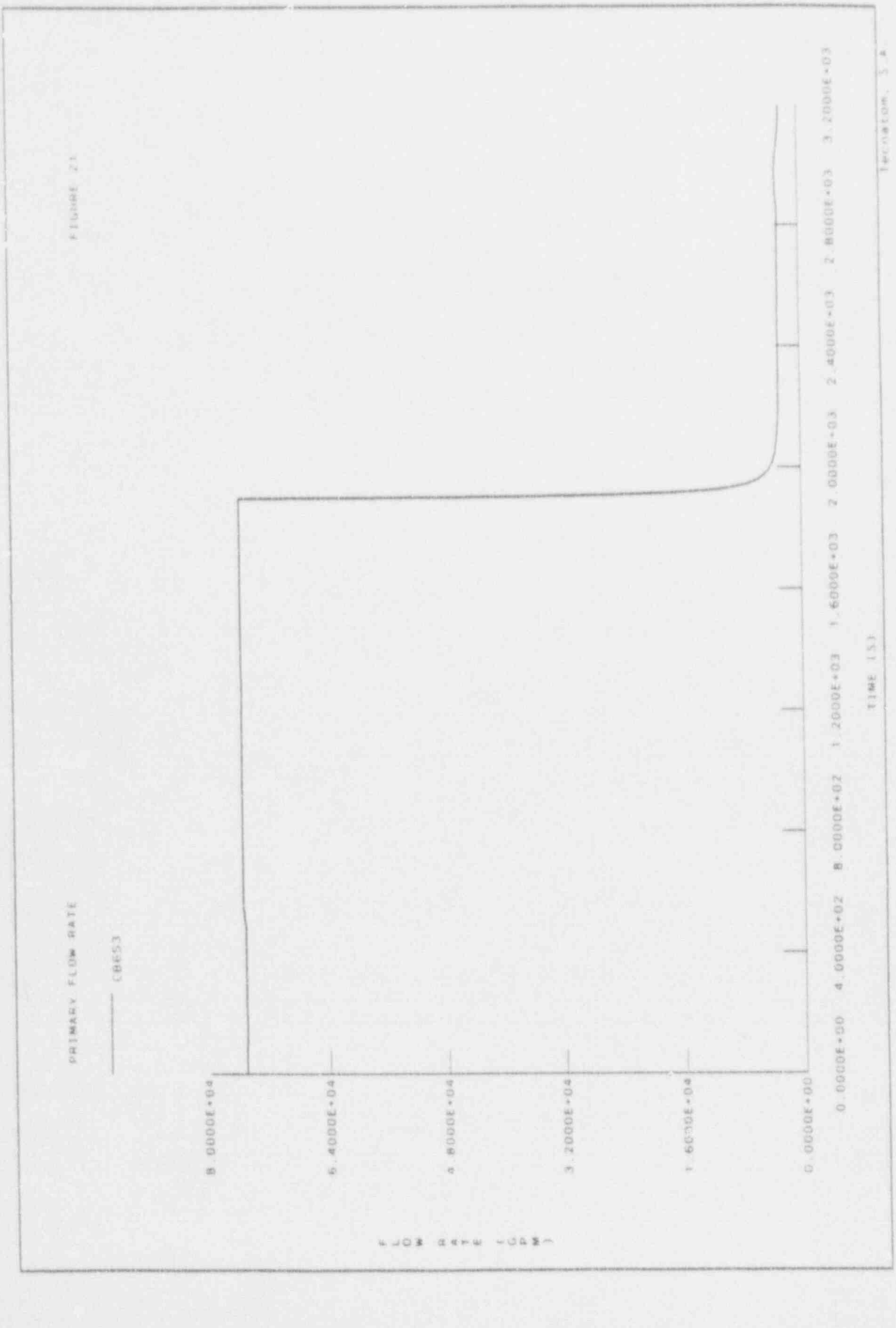
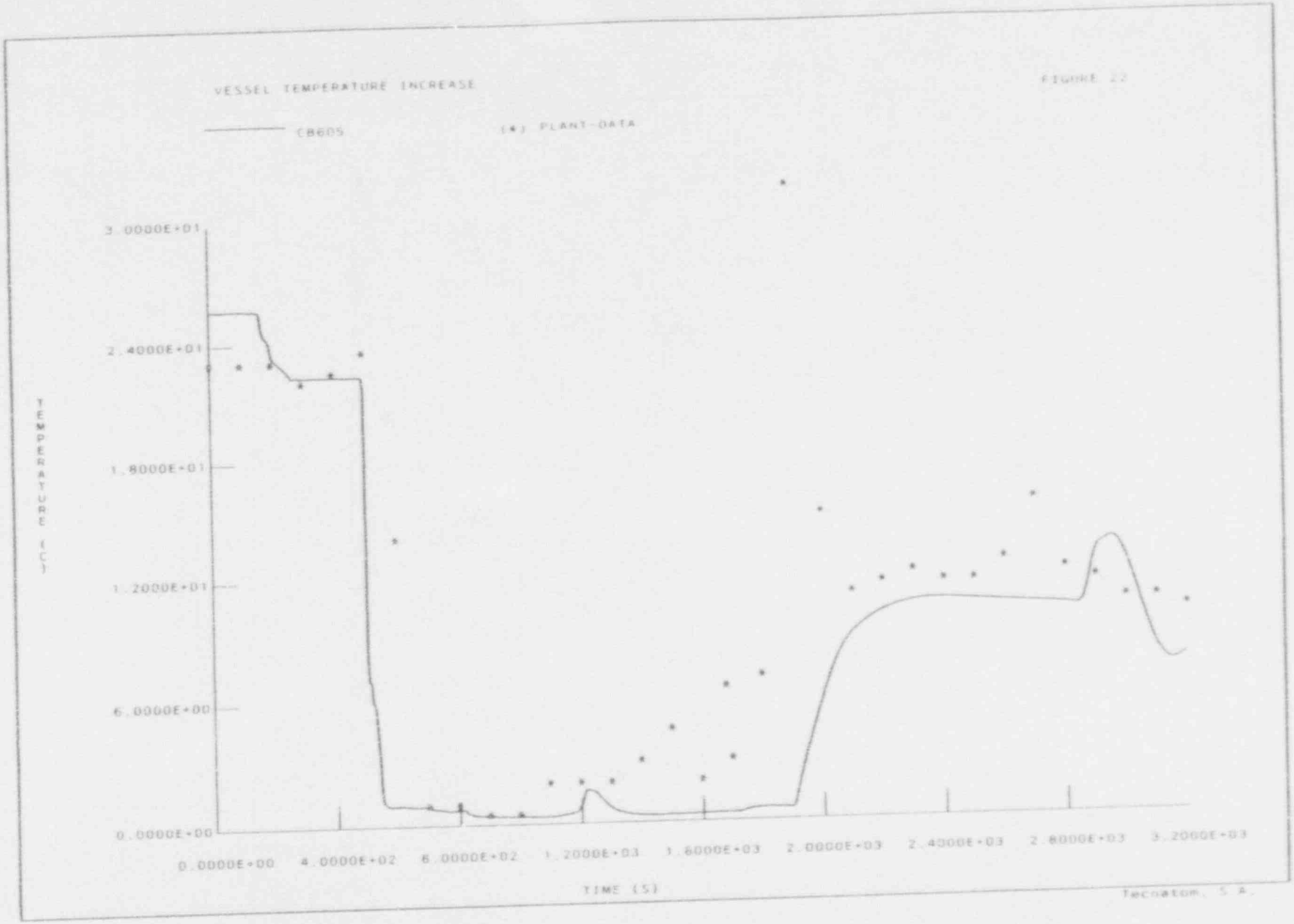


FIGURE 21

PRIMARY FLOW RATE
CB653
FLOW RATE (GPM)
8.0000E+04
6.4000E+04
4.8000E+04
3.2000E+04
1.6000E+04
0.0000E+00
0.0000E+00
4.0000E+02
8.0000E+02
1.2000E+03
1.6000E+03
2.0000E+03
2.4000E+03
2.8000E+03
3.2000E+03
TIME (S)
Tecnatom, S.A.


VESSEL TEMPERATURE INCREASE
FIGURE 22
CB605
(*) PLANT-DATA
TEMPERATURE (C)
3.0000E+01
2.4000E+01
1.8000E+01
1.2000E+01
6.0000E+00
0.0000E+00
0.0000E+00
4.0000E+02
8.0000E+02
1.2000E+03
1.6000E+03
2.0000E+03
2.4000E+03
2.8000E+03
3.2000E+03
TIME (S)
Tecnatom, S.A.

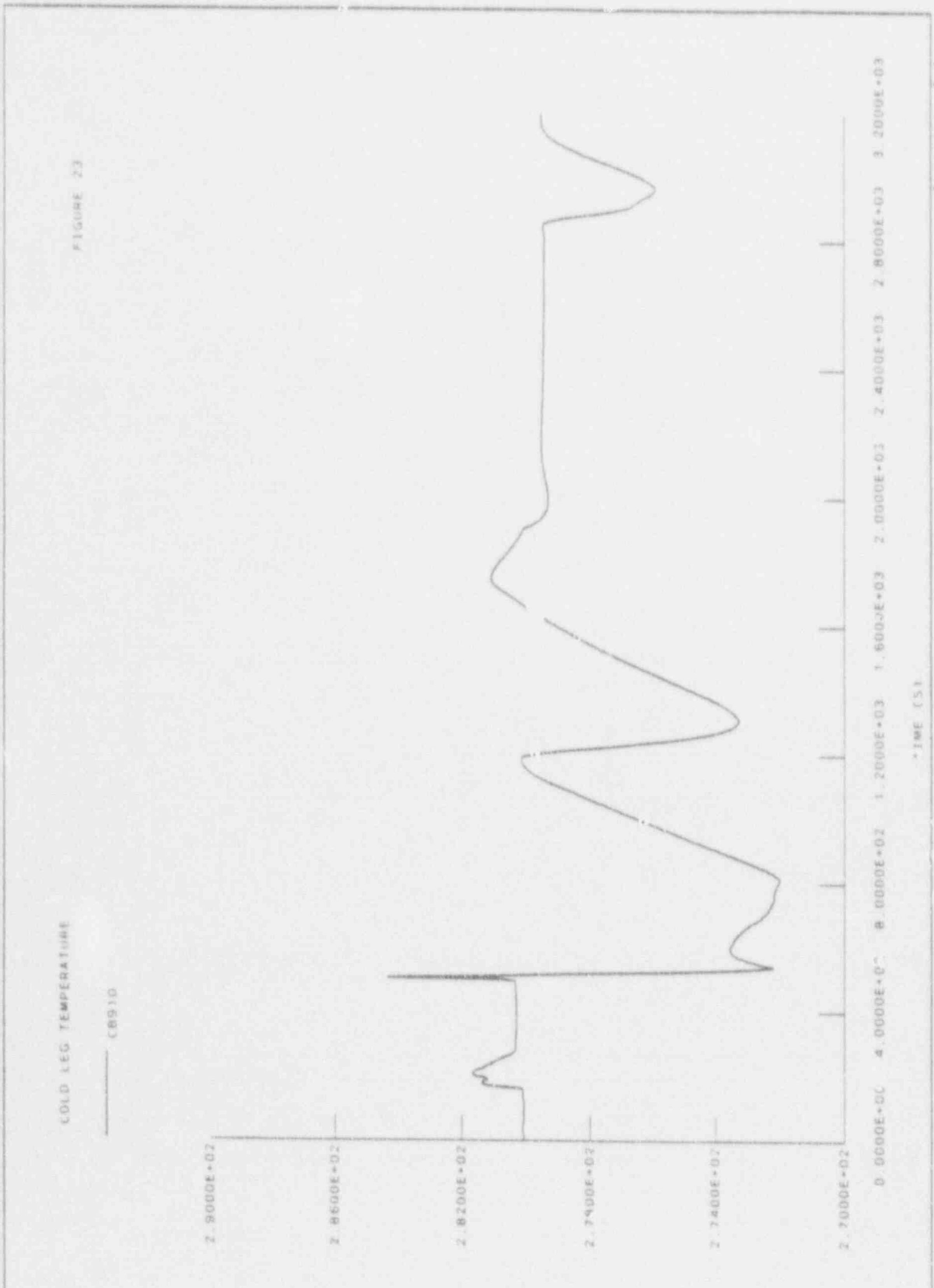


FIGURE 23

COLD LEG TEMPERATURE
CB910
2.9000E+02
2.8600E+02
2.8200E+02
2.7800E+02
2.7400E+02
2.7000E+02
TEMPERATURE (K)
0.0000E+00
4.0000E+02
8.0000E+02
1.2000E+03
1.6000E+03
2.0000E+03
2.4000E+03
2.8000E+03
3.2000E+03
TIME (S)
Tecnatom, S.A.

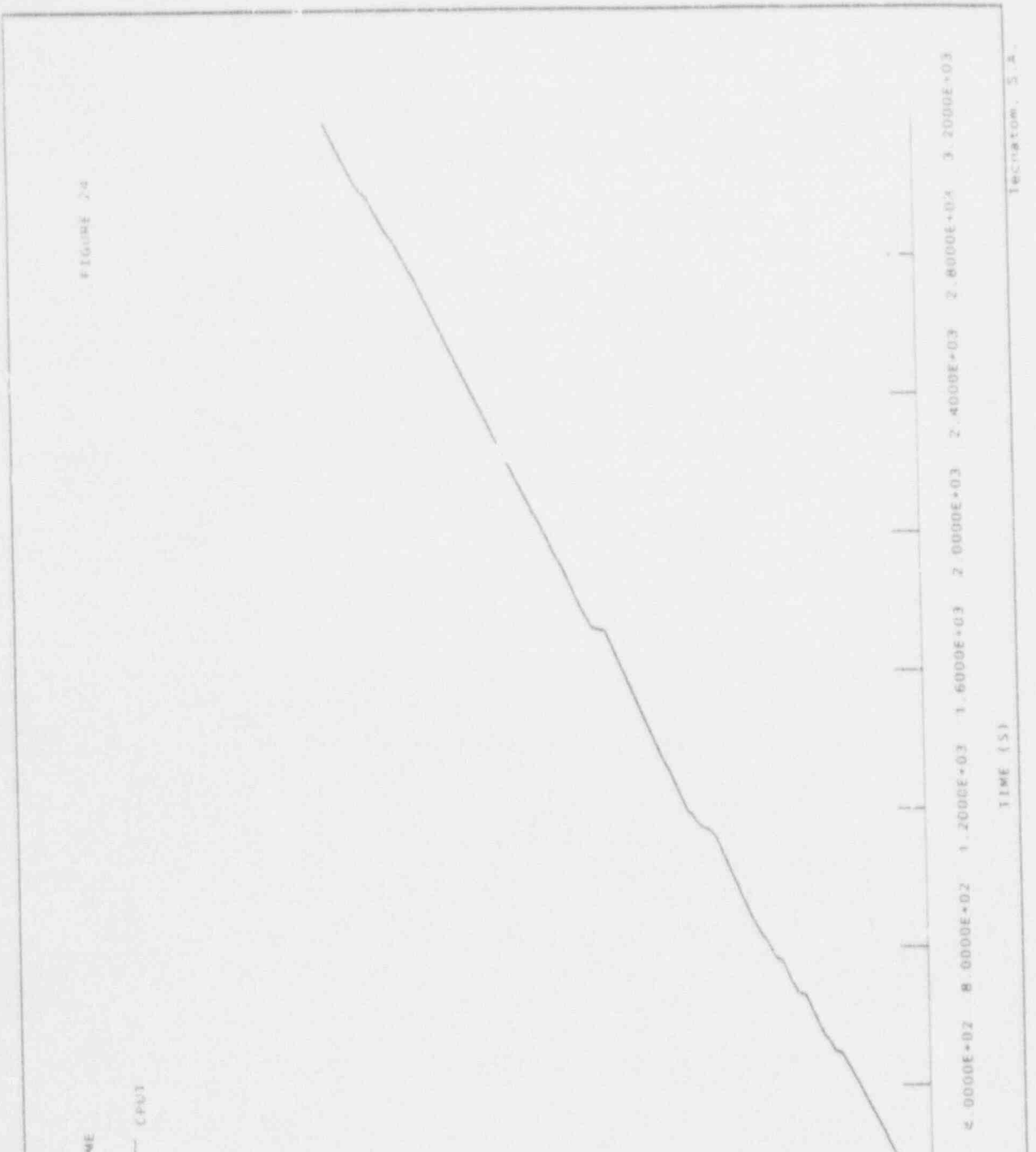


FIGURE 24

CPU TIME
CPUT
CPU TIME (S)
6.0000E+03
4.8000E+03
3.6000E+03
2.4000E+03
1.2000E+03
0.0000E+00
0.0000E+00
4.0000E+02
8.0000E+02
1.2000E+03
1.6000E+03
2.0000E+03
2.4000E+03
2.8000E+03
3.2000E+03
TIME (S)
Tecnatom, S.A.

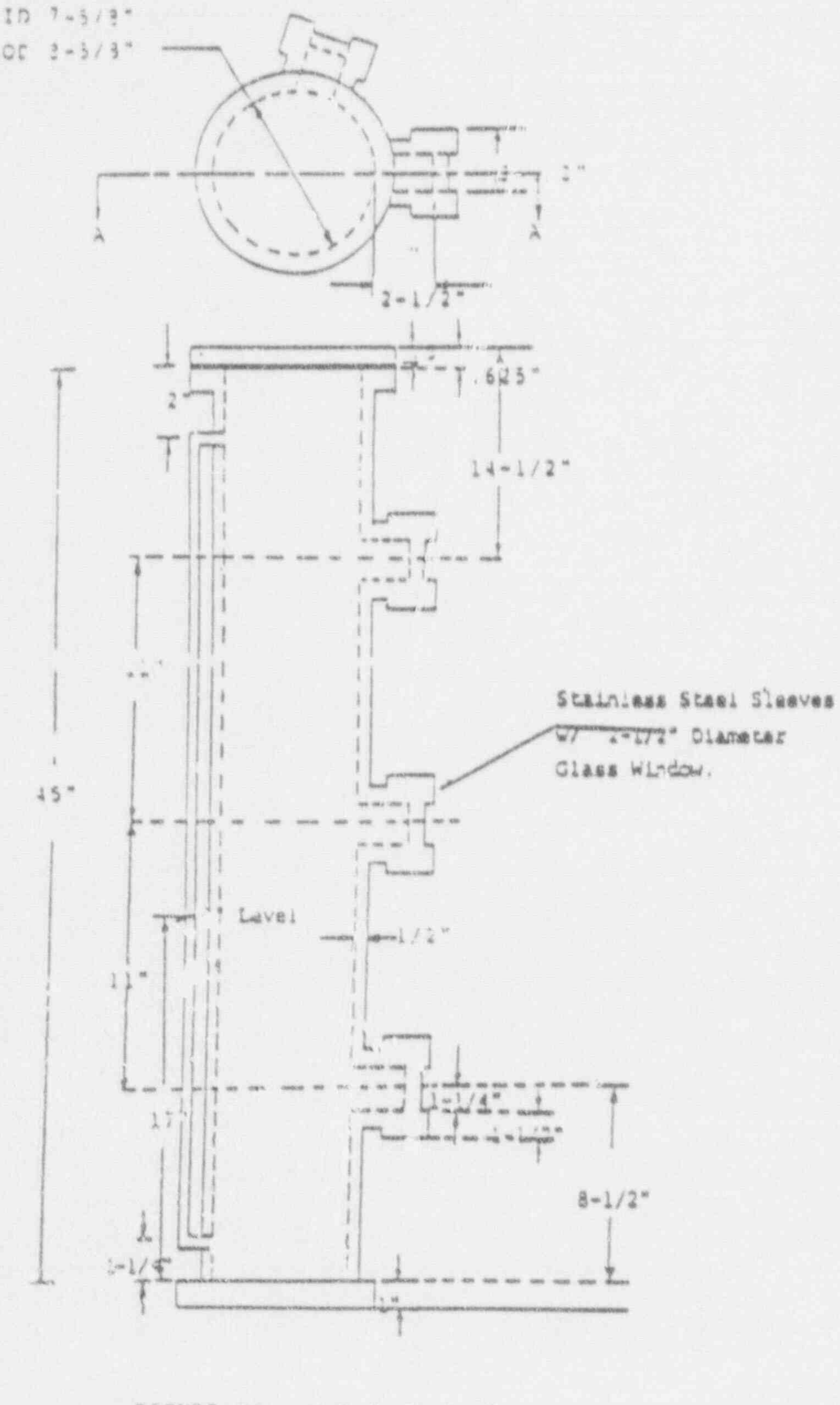


FIGURE 26.- M.I.T. MAIN TANK

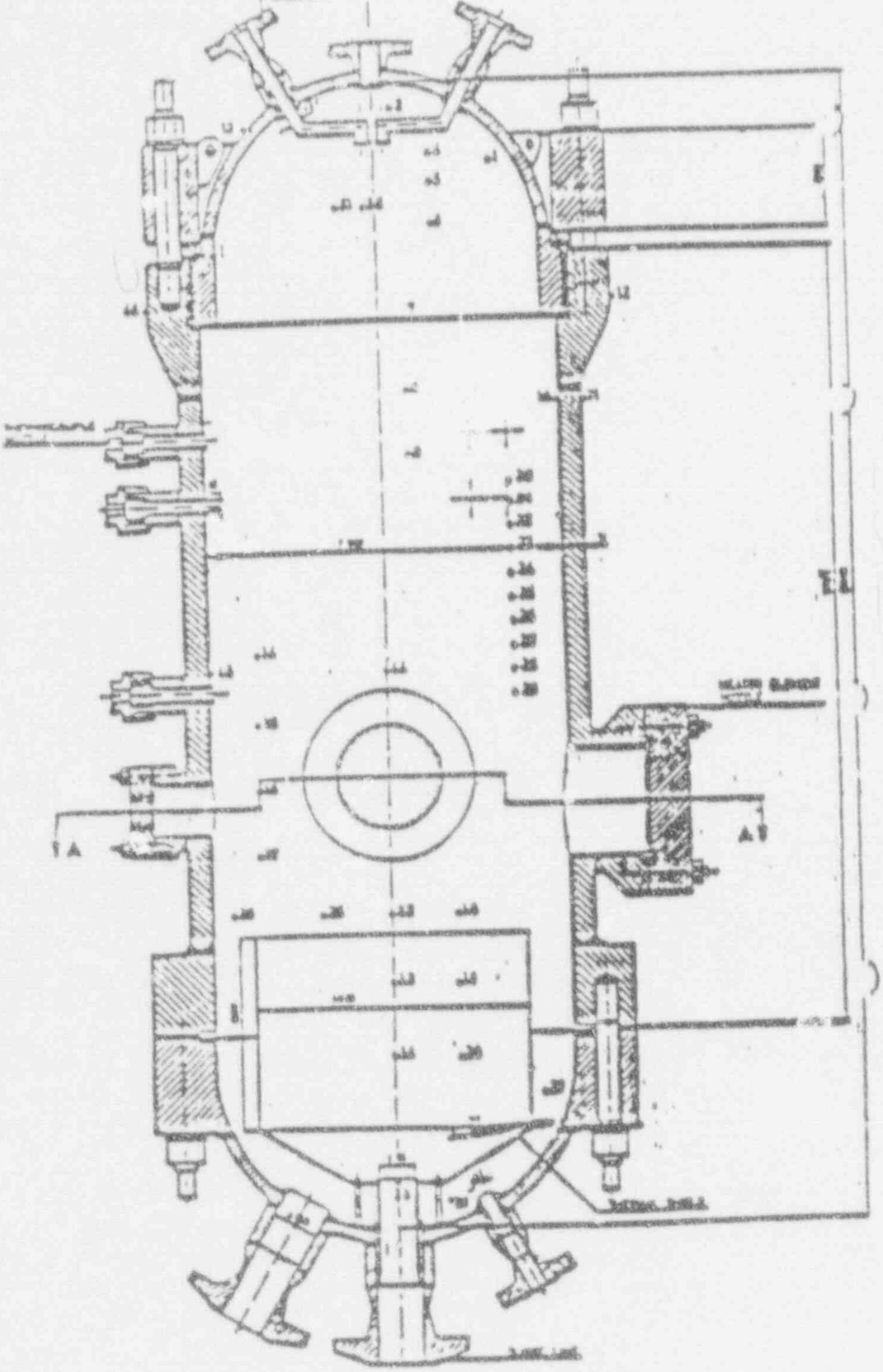


FIGURE 25.- NEPTUNUS TEST VESSEL

NRC FORM 335
(2-89)
NRCM 1102,
3201, 3202

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BIBLIOGRAPHIC DATA SHEET

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10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

The work consists of using the TRAC-PF1/MOD1 code to reproduce the actual transient that occurred at Jose Cabrera Nuclear Power Plant on August 30, 1984 and is thus part of an assessment exercise within the framework of the ICAP program.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

TRAC-PF1/MOD1
total opening transient
Jose Cabrera Power Plant
inadvertent pressurizer spray

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APRIL 1992

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

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