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International Agreement Report

Assessment of Full Power Turbine Trip Start-Up Test for C. Trillo I With RELAP5/MOD2

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Rosario, Pino, 14-16
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Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

July 1993

Prepared as part of
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under the International Thermal-Hydraulic Code Assessment
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ABSTRACT

C. Trillo 1 has developed a model of the plant with RELAP5/Mod2/36.04. This model will be validated against a selected set of Start-Up tests. One of the transients selected to that aim is the turbine trip, which presents very specific characteristics that make it significantly different from the same transient in other PWRs of different design, the main difference being that the reactor is not tripped: a reduction in primary power is carried out instead.

Pre-test calculations were done of the Turbine Trip Test and compared against the actual Test. Minor problems in the first model, specially in the Control and Limitation Systems, were identified and post-test calculations had been carried out.

The results show a good agreement with data for all the compared variables.

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FOREWORD

This report represents one of the assessment/application calculations submitted in fulfilment of the bilateral - agreement for cooperation in thermalhydraulic activities between the Consejo de Seguridad Nuclear of Spain (CSN) and the United States Nuclear Regulatoy Commission (US-NRC) in - the form of Spanish contribution to the International Code Assessment and Applications Program (ICAP) of the US-NRC whose main purpose is the validation of the TRAC and RELAP system codes.

The Consejo de Seguridad Nuclear has promoted a coordinated - Spanish Nuclear Industry effort (ICAP-SPAIN) aiming to - satisfy the requirements of this agreement and to improve the quality of the technical support groups at the Spanish - Utilities, Spanish Research Establishments, Regulatory Staff and Engineering Companies, for safety purposes.

This ICAP-SPAIN national program includes agreements between CSN and each of the following organizations:

- EMPRESARIOS AGRUPADOS, S.A.
- Unidad Eléctrica (UNESA)
- Unión Iberoamericana de Tecnología Eléctrica (UITESA)
- Empresa Nacional del Uranio (ENUSA)
- TECNATOM
- LOFT-ESPAÑA

The program is executed by 13 working groups and a generic code review group and is coordinated by the "Comité de Coordinación". This committee has approved the distribution of this document - for ICAP purposes.

EXECUTIVE SUMMARY

C. Trillo I is a PWR Nuclear Power Plant designed by Kraftwerk Union (KWU-Siemens) of the FRG. Commertial operation started in August 1988, and Plant Dynamic Start-Up Tests took place in the spring and summer 1988.

C. Trillo I has a nominal reactor power of 3010 Mw (thermal). Steam generators are typical U-Tubes with preheaters, featuring only some small differences with respect to those of other vendors. The rated generator electrical output is 1041 Mw. All major plant components are similar to those of other PWR plants.

A distintive feature of KWU's plants is however, the so called Limitation System, which plays an intermediate role between the Control and the Protection Systems. The limitation system is intended to avoid unnecessary reactor trips and so increase plant avalaibility.

C. Trillo I received the computer code RELAP5/Mod2/36.0 through the ICAP Project in 1986. In exchange, C. Trillo I should send to ICAP the comparison of code results against actual plant data. C. Trillo I selected for that purpose two transients. The first one is the Turbine Trip (TUSA) from 100% rated power to be described in this report.

The reasons to choose this analysis were, first, that this transient was included in the Start-Up Plant Dynamic Tests so a good information of plant behaviour was going to be available, and, second, that the plant response to this transient for KWU designed nuclear stations is quite different from those of other PWRs. C. Trillo I is designed to respond to this situation by reducing reactor power but avoiding reactor trip.

The C. Trillo I model, with RELAP5/Mod2/36.04, consists of 149 volumes, 158 junctions, 28 heat structures and 273 control variables.

Pretest calculations showed a fair agreement when compared against plant data. However post-test calculations were to be carried out in order to improve code prediction because of the following reasons: a) several parameters of control systems were adjusted during the start-up tests, b) final part load diagram was slightly different from the nominal one, c) primary mass flow used in pretest calculations was not exactly the same as that finally achieved in plant, d) reactivity parameters need adjustment because generic values were used in pretest analyses, and, e) some other minor differences.

Post-test calculations have been carried out on a CYBER 180/855. The CPU TIME/REACTOR TIME ratio was 7.71 and the "ICAP required number" 2.876.

An overall good agreement was obtained in the Post-Test calculations, although minor differences were observed. These are mainly due to the fact that the models for the sophisticated Control and Limitation System of C. Trillo I still need some minor adjustment which will be fully implemented once all Post-test simulations will be finished.

Other important practical conclusions are:

- Increased difficulty in plant assessment calculations when there is not reactor scram and the plant remains at a high power level.

- Large difficulty when comparing code variable values against actual measurement because of uncertainties in the sensor response and signal processing.

1. INTRODUCTION

In 1986, C. Trillo I received the computer code RELAP5/Mod2/36.0 (ref.1) though the ICAP Project. In exchange C. Trillo I should send to ICAP the comparison of code results against actual plant data. C. Trillo I selected for that purpose two transients. The first one is the Turbine Trip (TUSA) from 100% rated power to be described in this report.

The reason to choose this analysis was, first, that this transient was included in the Start-Up Plant Dynamic Tests so a good information of plant behaviour was going to be available, and, second, that the plant response to this transient for KWU designed nuclear stations is quite different from those of other PWRs. C. Trillo I is designed to respond to this situation by reducing reactor power but avoiding reactor trip.

On the other hand, C. Trillo I has a long experience with RELAP5 code, both Mod1 and Mod2. Our Plant Dynamics Group participated in the simulation of OCDE-LOFT LP-SB-3 (ref 2 and 3) with Mod1, made several Small Breaks Analysis for the plant (ref. 4), and pretest calculations of the following Start-Up Tests (ref. 5):

- Reactor Trip
- Turbine Trip
- One Main Coolant Pump Trip
- Plant Black-Out
- Partial Loss of Feed-Water
- Total Loss of Feed-Water
- Isolation Valve Closure
- Control Rod Drop
- Bypass of Feed-Water Preheaters
- Load Ramps and Steps
- S.G. Tubes Break

Pretest calculations agreed fairly well with plant behaviour (ref. 6). The Group is now enagaged in Post-Test calculations in order to improve the initial model and adjust control systems to their final set-point values. By adjusting the model to the results of a selected set of Start-Up tests, we expect to improve it to the point where code predictions are highly reliable, which is our final objective. It is clear that such a model will be of great help for plan operation.

The Group has also simulated the following transients required by the CSN (Spanish Nuclear Council) (ref. 7):

- Turbine Trip without By-Pass. First and Second Scram Signal.
- Black-Out with Second Scram Signal.
- Control Rod Ejection. First and Second Scram Signal.
- Black-Out without Scram.
- Total Loss of Feed-Water without Scram.

Also, some simulations were done to assess the influence of control system modifications on plant response before deciding their actual implementation in the plant (ref. 8 and 9).

This report describes the work done in the Post-Test simulation of the Turbine Trip Test.

2. PLANT AND TRANSIENT DESCRIPTION

2.1. PLANT DESCRIPTION

C. Trillo I is a PWR Nuclear Power Plant designed by Kraftwerk Union (KWU-Siemens) of the FRG. The Plant is owned by a consortium of three Spanish utilities, UNION ELECTRICA-FENOSA S.A., IBERDUERO, S.A. and HIDROELECTRICA DEL CANTABRICO, S.A. Commertial operation started in August 1988, and Plant Dynamic Start-Up Tests took place in the spring and summer 1988.

C. Trillo I has a nominal reactor power of 3010 Mw (thermal). The core contains 177 fuel assemblies, each one with 16x16-20 UO2 fuel rods. Steam generators are typical U-Tubes with preheaters, featuring only some small differences with respect to those of other vendors. The rated generator electrical output is 1041 Mw. All major plant components are similar to those of other PWR plants and are well known. A more complete description is given in Table 1.

The most significant difference with other vendors is the so called Limitation System which plays an intermediate role between the Control and the Protection Systems. The limitation system is intended to avoid unnecessary reactor trips and so increase plant availability. The purpose is twofold: on the one hand, by taking actions before the corresponding Protection System limits are reached, unneccesary scrams are avoided; on the other, the limitation system "pushes" the limits of the variables of interest back within the limits assumed in the transient Analysis, so that these are fulfilled at any time.

Another important difference, although not applicable to the present transient, shows up in the safety injection system which adds water to the primary circuit both in the cold and in the hot legs.

A complete description of the plant can be found in ref. 12.

2.2. DATA ACQUISITION AND ANALYSIS SYSTEM DESCRIPTION

During the Start-Up Plant Dynamic Tests a Data Acquisition System (DAS) able to store and plot required data with a great level of detail was used. The A/D converter was the Hewlett Packard model HP 3852, which is able to record 144 analogic signals and 32 digital signals with a maximum sampling frequency of 100 Hz.

The DAS is connected to a HP 9000 mod 320 computer that supports all the devices required to store and analyse the data. The software of this computer offers different options to handle data. So, the operators can consult a start-up tests data base, represent graphically the evolution of several analogic signals versus time, get a table of digital or analogic signals, make statistic calculations, and so on. The data stored by DAS is being used in all post-test calculations.

2.3. TRANSIENT DESCRIPTION

Plant Dynamics Tests D-100-303 of C. Trillo I consists of a manual turbine trip from Control Room when plant is operating at its rated power.

The objective of this Test is to prove that the plant, by means of the Control and Limitation Systems, can handle this event without reactor scram.

The Control and Limitation Systems relevant for this transient are:

- Maximum Pressure.
- Pressurizer Pressure.
- Primary Average Temperature.
- Feed-Water Mass Flow.
- Load Rejection (STEW LAW)

The transient starts with the closure of the turbine stop valve located between the header and the high pressure turbine stage. The closure time of this valve is 180 milliseconds. The first consequence of this action is an increase in the secondary pressure because of the interruption of steam flow out of the steam generators.

This pressure increase leads to a primary-to-secondary heat transfer impoverishment which in turn, leads to a rise of the primary pressure up to a maximum value of 16.02 MPa. After that, and because of the reactor power reduction and the opening of bypass valve in secondary side, the primary pressure drops to a minimum value of 14.50 MPa leading to pressurizer heaters connection.

The secondary pressure will eventually become greater than the Maximum Pressure setpoint and the bypass valve to the condenser will start to open (this valve allows 60 % of the nominal steam flow when fully open).

The bypass valve control modifies the valve position to maintain the secondary pressure around the final maximum pressure setpoint i.e. 8.14 MPa.

Because the turbine trip does not imply any action on control rod movement, the reactor power is still about 100%. The STEW-LAW Limitation System then detects a strong mismatch between primary and secondary power while primary power is still above the corresponding set-point. This situation leads to the dropping of those control rods required to decrease reactor power below 40 %.

The power reduction is performed, at first, by the actuation of synchronous rod dropping (STEW-SY) and after that, by dropping control rod pairs actuated by STEW-FOLGE (sequential rod dropping).

The lowering of the reactor power leads to a decrease in primary pressure and temperature, which produces a drop in pressurizer level. The pressure and temperature variations imply the actuation of the pressurizer pressure and the primary average temperature control systems in order to take those variables to their corresponding setpoint.

The primary average temperature setpoint is reduced to a value of 575.85 K as soon as the turbine trip has taken place.The average coolant temperature deviation from the setpoint implies the temperature control system actuation by means of control rods movements.

Steam generators water level decreases because of the pressure rise and the reduced steam flow, being eventually restored by the feedwater control system.

The plant conditions at the end of the transient should be as follows:

- PBKORR (see next section) smaller than 40%.
- Primary Average Temperature at its corresponding value of the Partial Load Diagram.
- Secondary Pressure at the corresponding value of the Partial Load Diagram.
- Water levels to their corresponding setpoints.

3. MODEL DESCRIPTION

The C. Trillo I model is shown in figure 1. It consists of 149 volumes, 158 junctions, 28 heat structures and 273 control variables. As can be noticed, the three loops are simulated with actual data specific for each loop. The purpose is to have possibility to simulate non-symmetric transients so that to understand the possible differences between loops in these type of transients.

3.1. PRIMARY SYSTEM

The modelling of the primary includes all the main components of the actual system. Volume 510 represents the core. It is divided into three axial cells. A more detailed modelling was not done because this model will be used for operational transients.

The fuel rods have been simulated as a cylindric heat structure with the dimension of real fuel rod but the length equal to the active length of all fuel rods.

The heat structures have an internal heat source which takes power data from point kinetics calculation.

The reactor point kinetics model of Relap5/Mod2 is used to compute the power behaviour in the nuclear reactor.

The total reactor power is calculated as the sum of immediate fission power and the power from decay of fission fragments. The immediate power is that released at the time of fission and includes power from fission fragment, kinetic energy and neutron moderation.

In this transient a correct simulation of Decay Heat Power is important. It starts at the corresponding value at 100% but should drop following power changes.

The 1979 LANS Standard for Decay Heat Power in Light Water Reactors, built into the code, has been used to calculate the decay power.

The built-in data for fission products and actinides have been used, but data for delayed neutrons have been entered from proper kinetics calculations.

The reactivity feedback model used assumes separability of feedback effects. Two tables, one defining reactivity as a function of coolant density, and the other reactivity as function of volumetric average fuel temperatures have been supplied using C. Trillo first core data.

Control variables simulating the control rods reactivity contribute to reactivity feedback calculations.

The control rods reactivity is calculated by a simulation of control rods movements caused by temperature or power deviations, assuming that reactivity is a function of control rod position.

Volume 520 represents the upper plenum of the vessel while volume 530 simulated the coolant limited by the vessel head.

The downcomer is represented by volume 500, which is divided into two cells, while the vessel bottom and lower plenum by volume 505.

The three loops were analogously simulated. However, in loop 1, where the pressurizer is located, the hot leg is modeled with volume 100 divided into three cells. The steam generator inlet is simulated by volume 110, the tubes volume 120 divided in 8 cells (by dividing tubes and riser into only 4 cells numerical instability was apparent as a stable state was achieved with two different values for plant variables), and the connection with the secondary side by the proper heat structures, where actual data (area, hydraulic diameter, mass material an so on) are used. Steam generator outlet is modeled with volume 130. Volume 140 simulates the intermediate leg (between SG and primary pump).

The pump is modeled by volume 150 using proper homologous curves given by the vendor. Finally the cold leg is modelled by volume 160.

The pressurizer has been modeled by means of volume 410 divided into 5 cells. Safety and relief valves are simulated with valve components 461 and 460. Volume 450 models the spray line. It is connected to the pump outlet and the mass flow is controlled with valve 451: similar volumes exist for the two other loops (specific data vary from loop to loop). Volume 400 is used to simulate the surge line. Finally, the heaters are modeled by means of heat structures governed by the proper control system.

3.2. SECONDARY SYSTEM

That secondary system part which extends from the feedwater control valve to the turbine control valve and the bypass to the condenser station, is included in the model.

Because the three loops are modeled in exactly the same way, (although with its actual dimensions each), only loop 1 is described in the following lines.

Feedwater inlet is modeled with junctions 651,655, and 657. Junction 651 is connected to the top of the downcomer, the other two junctions are connected to the two volumes used to model the preheater. The flow split is 10 percent for the first one, and 40 and 50 percent for the other two, according to steady state plant conditions at power. These junctions are connected to time dependent volumes with the proper temperature and pressure conditions.

The downcomer (volume 600) is modeled by an annulus component, divided into 3 cells, and is connected to volume 640 and to the bottom tubes volume (61001).

The steam generator preheater is simulated by volumes 604 and 606 and the proper heat structures.

Volume 604 is connected to the 40 % feedwater junction and is located below volume 606. It is also connected to the bottom of the tubes volume. Volume 606 is connected to the tubes volume at the proper height and to the 50 % feed water junction.

The tubes area is modeled by means of volumes 602 and 610. The first one is divided into two nodes and connects the tubes plate to the top of the preheater. It represents the zone not included in the preheater. It is connected to the primary by means of heat structures. Volume 610 covers from the top of volumes 606 and 602 to the steam separator inlet. It is divided into 3 nodes. Two are in the tubes area and the other one simulates the riser area.

Proper heat structures are used to link the primary to the secondary system. Actual data are used for these heat structures, except for the heat transfer hydraulic diameter. This value was reduced to about 1/3 of the tubes gap in order to be able to transfer all the heat produced in the primary system without modifying actual plant conditions or geometry.

Volume 620 models both steam separators and steam dryers volumes. It is defined as a separator component and is connected to the riser, (volume 61006), steam generator dome, (volume 630), and to the downcomer. Volume 635 simulates the area outside the separators and dryers. It is connected to the downcomer and to the steam dome.

Volume 670 accounts for the steam line lying from the outlet of the steam generator to the inlet of the steam header (volume 910), which is also connected to the two other lines. At the proper distance, isolation-(661) relief-(662) and safety-(663) valves are connected to the steam lines.

The steam header is modeled by volume 910. A line containing the turbine stop - and control - valves connects Volume 910 to Volume 940, which represents the turbine . There is also a line that connects volume 910 to time dependent volume 920 which models the condenser through the bypass valve (915).

All the valves are either servovalves or motor valves and are governed by the proper control system.

A complete description of the model is given in Ref. 13.

3.3. CONTROL, LIMITATION AND PROTECTION SYSTEMS

The more important systems regarding the dynamic behaviour of the plant have been simulated. A complete description of each of them is beyond the scope of this report and can be found in reference 11. The list of all the simulated systems is in figure 1. In the following lines, a brief description of all the modeled systems is included.

3.3.1. Control Systems

- Maximum Pressure (PSMAX)

Its mission is to limit pressure increases in the secondary side in order to avoid actuation of relief and safety valves. When pressure gets larger than the corresponding set point (this setpoint is not constant but a function of plant conditions) the condenser bypass valve opens so as to keep pressure below a specific value.

- Minimum Pressure (PSMIN)

The setpoint is a function of the Corrected Reactor Thermal Power (PBKORR). When secondary pressure decreases below the PSMIN setpoint, the turbine control valve starts to actuate in order to maintain secondary pressure.

The PBKORR signal is calculated as a function of thermal reactor power and neutron flux signal.

During steady-state power operation the PBKORR signal is calculated as the thermal reactor power, directly proportional to the temperature rises of the three loops, but during rapid transients in power, which cannot be detected quickly enough by measuring the temperature rises, the change of the neutron flux signal is considered to calculate the Corrected Reactor Thermal Power (PBKORR).

- Feedwater

This system controls feedwater flow as a function of steam flow and steam generator level.

- Secondary Relief Valve. (PSOREV)

Its mission is to limit secondary pressure increases.

- Pressurizer Pressure

The control system includes heaters, spray, relief and safety-valves. Its functions are well known.

- Primary Average Temperature (KMT)

It regulates control rod banks in order to keep primary temperature within the values specified by the partial load diagram.

- Cool-Down to 100ºK/hour

This system actuates upon the secondary relief valves to cool-down primary system at a rate of 100ºK/hour.

- Generator Power

It is the target value of the generator power. It is a function of the actual power and the demanded power.

- Secondary and Primary Safety Valves.

Its function is to limit pressure.

3.3.2. Limitation System

- Sliding Limit Power Signal (PBRELEB)

This is one of the signals which limits the maximum reactor power, specially in very fast power increases.

- Permitted Reactor Power Signal (PERL)

It is a complex setpoint that limits reactor power as a function of plant conditions.

- Permitted Generator Power Signal (PERG)

It is a setpoint to limit generator power. It is a function of the PERL.

- Reactor Power Limitation Module. (LRELEB)

Its objective is to limit PBKORR to the values specified by the limitation system.

- Reactor Coolant Pump Malfunction (STEW PUMA)

Whenever the velocity of a reactor coolant pump drops below a specified setpoint, STEW PUMA inserts control rods in order to lower reactor power to the value allowed for operation with only two pumps.

- Loss of Feedwater (SPEISE RELEB)

It detects loss of feedwater flow and reduces both the PERL and the PERG.

- Control Rod Drop (STAFE RELEB)

  It reduces the PERL when a control rod drop occurs.

- Primary-Secondary Overpower (KOL RELEB)

  This system limits the power differences between the primary and the secondary sides. It modifies the PERL in order to protect the condenser.

- High Energy Content in Primary Loop (LOOP RELEB)

  Its mission is to limit the energy content of the primary system calculated as a function of pressurizer pressure and level. It actuates upon control rods.

- Coolant Average Temperature (KMT RELEB)

  Its mission is to limit temperature excursions that the control system cannot handle. It actuates upon control rods.

- Load Rejection (STEW LAW)

  It is activated when primary power is much larger than secondary power and, at the same time, the first one is larger than the corresponding setpoint. It produces control rods insertion into the core.

- Rod Drop for Reactor Power Limitation (STEW RELEB)

  It drops control rods when some selected RELEB are at their highest value.

3.3.3. Protection System

The reactor is scrammed when one or more of the following values reach a specified setpoint:

- Secondary Pressure.
- Steam Generator Level.
- Pressurizer Level.
- Primary Pressure.
- Average Temperature.
- Vessel Inlet Temperature.
- PBKORR larger than PBRESA.
- One Coolant Pump Trip and PBKORR larger than 60%.
- Low Velocity in Two or More Pumps.
- Secondary Pressure Gradient.

The description of the control limitation and protection system can be found in Ref. 14.

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4. STEADY STATE CALCULATION

The final objective is to get a steady-state condition of normal operation of the plant at full power, from which the transient calculation can be initiated.

A consistent state was obtained with the "STEADY-STATE" option of RELAP5/Mod2 code from the input data without the control system.

Particular conditions must be defined for this purpose having a stabilizing effect on the sequence of the steady-state calculation.

- The pressurizer steam zone is connected to a time dependent volume so as to maintain a constant primary side pressure.

- Reactivity and reactor kinetics feedback due to moderator density, moderator temperature and fuel temperature are specified as zero for the steady state calculation in order to maintain the power at a constant level.

- The position of the turbine control valve is constant during the calculation, as well as the feedwater mass flow.

A stable condition for the model has been got after 73.45 s of calculation. The RELAP5/Mod2 code stops the steady state calculation once the stability condition is accepted by its internal checking procedure.

A second step is taken by eliminating the stabilization conditions and introducing real reactor kinetic model, control limitation and protection system, so obtaining the steady state simulation of the plant at full power.

Figures 2 through 10 show the results of the calculations and table 2 the meaning of the different variables Ref. 16 contains the original RELAP output figures).

Table 4 compares main results against plant data at the time of starting of this specific turbine trip test.

A description of sensor and signals is given in Ref. 15.

5. TRANSIENT CALCULATION AND COMPARISON VERSUS ACTUAL DATA

When compared against plant data, pretest calculations showed a general fair agreement. However, post-test calculations had to be carried out in order to improve code prediction because of the following reasons: a) several parameters of control systems were adjusted during the start-up tests, b) final Part Load Diagram was slightly different from the original one, c) primary mass flow used in pretest calculations was not exactly the same as that finally achieved in plant, d) reactivity parameters need adjustment because generic values were used in pre-test analyses, and, e) some other minor differences.

In Figures 11 through 24, post-test model prediction and measured values are plotted together in order to compare the different values(actual data were digitalized from the original figures also contained in Ref. 16). A brief description of each figures is given in the next lines.

- Prymary and secondary pressure.

Figure 11 presents the evolution of primary pressure during the transient.

The calculated primary pressure follows closely the trend of plant data in the early part of the transient (0 to 25 seconds). The main difference occurs between 25 and 60 seconds, when the primary and secondary pressures increase. The reason for this difference is twofold: on the one hand, the difficulties in correctly modelling the closing behaviour of the bypass valve; on the other, the difference between actual and calculated reactor power. In the final part of the transient, both pressures converge to a common value (within the deadband).

The Secondary Pressure is given in figure 12. A good agreement is obtained. As can be seen, the most important discrepancy occurs when the bypass valve is closing.

The Secondary Pressure data ends at 140 seconds because the plant data stops also at that time.

- Steam and Feedwater Mass Flow.

Steam mass flow is represented in figure 13. The comparison with actual data is good. However bypass valve closing behaviour in the model will be improved once all the post-test calculations are finished and all the available information is processed. Notice also that the measured values include a lag which is not exactly known yet. Model assumes a lag of 2 seconds. Feedwater flow is represented in figure 14. As can be seen, the plant measured flow was used in this postest calculation. The simulated feedwater control system has not been used because of the amount of feedwater calculated depends of steam generator level, and as can be seen in figure 17, the differences between the calculated and measured levels should lead to a calculated feedwater flow quite different to the plant data. Temperature changes in feed water during the simulation period, although small, were taken into account.

- Primary coolant average temperature.

The calculated primary average temperature, as shown in figure 15, follows quite closely the temperature measured at the plant. The final stabilization is due to actuation of temperature control system (KMT) which moves the control rod banks in order to keep the primary temperature within the value specified by the partial load diagram.

The calculated hot and cold legs temperatures have been represented in figures 20 and 21 the difference between cold leg temperature loop 1 and loops 2 and 3 is owing to the fact that the loops are not completely symmetric (in the plant and in the model) this then leading to a small difference in average temperature for each loop, as can be observed in figure 22.

- Pressurizer level.

The calculated pressurizer level is shown in figure 16 together with the actual values. The most important discrepancy is due to the fact that we are comparing model prediction values against sensor measures. Some of these sensors sligthly modify actual values, mostly because of lags which are apparent in this level curve. So far, the model does not fully incorporate signal treatment of all the sensors.

Figure 19 shows the measured pressurizer level, the calculated level whithout any lag and the calculated level with a lag of 5 seconds.

- Steam generator level.

Figure 17 presents values of this variable. The lowest value of S.G. level is very similar in both cases, the calculated S.G. level is aproximately 20 cm greater than the measured level, but a difference also exists in the initial value of these variables. The final difference of level is due to the fact that the feedwater mass flow rate was simulated as a table with the same mass flow than that measured at the plant. The dynamic behaviour of the level is not well reproduced. A lot of work was done in the area of S.G. separator modeling, but the results were poor.

The level for each steam generator in the plant have been represented in figure 17 comparing to the calculated steam generator level in loop 2.

Figure 23 presents results for calculated steam generator level in each loop: as can be observed small differences exist between loop 1 and loops 2 and 3.

The Steam Generator Level figure ends at 100 seconds because the Plant data end also at that time.

- Thermal Corrected Reactor Power (PBKORR)

Figure 24 presents values of this variable. The thermal corrected reactor power is not measured directly in the plant but is calculated as a function of thermal reactor power (sum of the temperature rises of the three loops) and of neutron flux signal (calculated using one of the four redundant circuits existing to calculate nuclear power). The resultant thermal corrected reactor power signal approaches the thermal reactor power during steady state and the neutron flux signal during fast power transients.

The RELAP5 simulated PBKORR signal uses the thermal power calculated as sum of temperature rises of the loops and the total fission power calculated by the code.

The results do not compare well because of plant treatment of neutron flux signal and because of the fact that the calibration of measuring equipment is done at 100% and this calibration may be not correct when a large power step occurs.

The figure 18 presents a comparison between primary (PBKORR) and secondary rated power, this last calculated as rated mass flow leaving steam generators. As can be seen a equilibrium stabilization occurs at the end of the transient calculation.

6. RUN STATISTICS

Calculations have been carried out on a CYBER 180/855 NOS 2.5 owned by Consejo Superior de Investigaciones Científicas (CSIC).

RELAP5/Mod2/36.04 version has been used from April 1989. Before this date, preliminary calculations were done with RELAP5/Mod2/36.0.

In table 3, a typical run statistics has been summarized. The table includes the "ICAP required number" that was calculated based on the transient time, the total number of active volumes in the model (time dependent volumes were not considered), the total number of time steps and the total CPU time.

7. CONCLUSIONS

A turbine trip from 100% nominal power at C. Trillo I has been simulated with RELAP5/Mod2 cycle 36.04. The results were compared against actual results from the Start-Up Tests. An overall good agreement was obtained although minor differences were observed. These are mainly due to the fact that the RELAP5 models for the sophisticated Control and Limitation System of C. Trillo I still need some minor adjustments which will be fully implemented once all Post-test simulations will be finished.

However the results have demonstrated that the used nodalization and the control and limitation system simulation can successfully describe the behavior of plant transients, especially those were the control system behavior plays an important role.

Other important practical conclusions are:

- A large experience and knowledgment in plant behaviour has been adquired by the use of the code and especially in post-test simulation that can be later used in predictive analysis.

- A good model of the plant validated against actual plant transients is a effective way to improve plant operation i.e. to assess the influence of control system modifications in plant response before deciding their actual implementation in the plant.

- Increased difficulty in plant assessment calculations when there is not reactor scram and the plant remains at a high power level.

- Large difficulty when comparing code variable values against actual measurement because of uncertainties in the sensor response and signal processing.

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16. Colección de figuras originales de la prueba D-100-303 (Documento interno C. Trillo I).

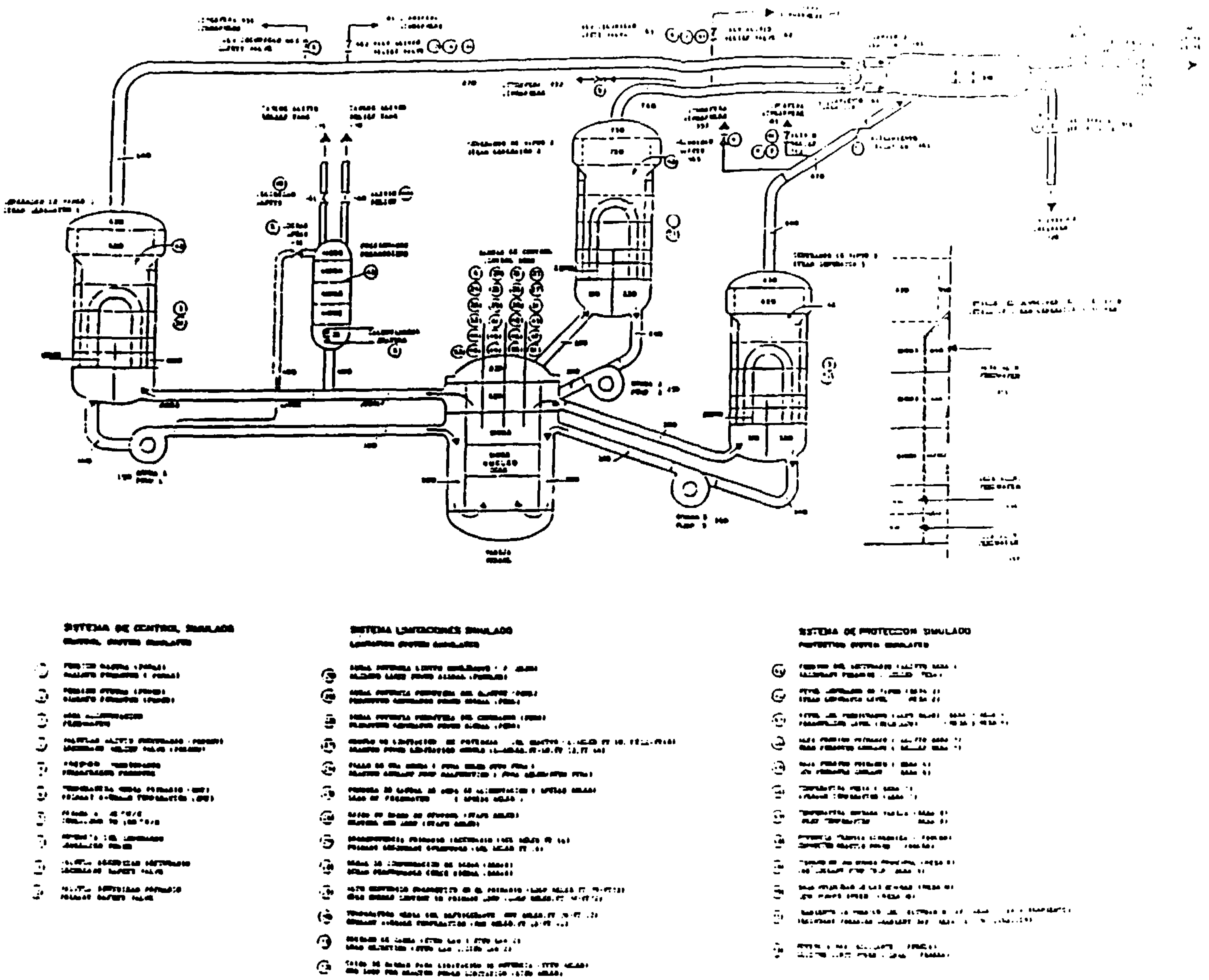

FIGURE 1.- RELAP5/MOD2 MODEL FOR TRANSIENT SIMULATION OF C.TRILLO I

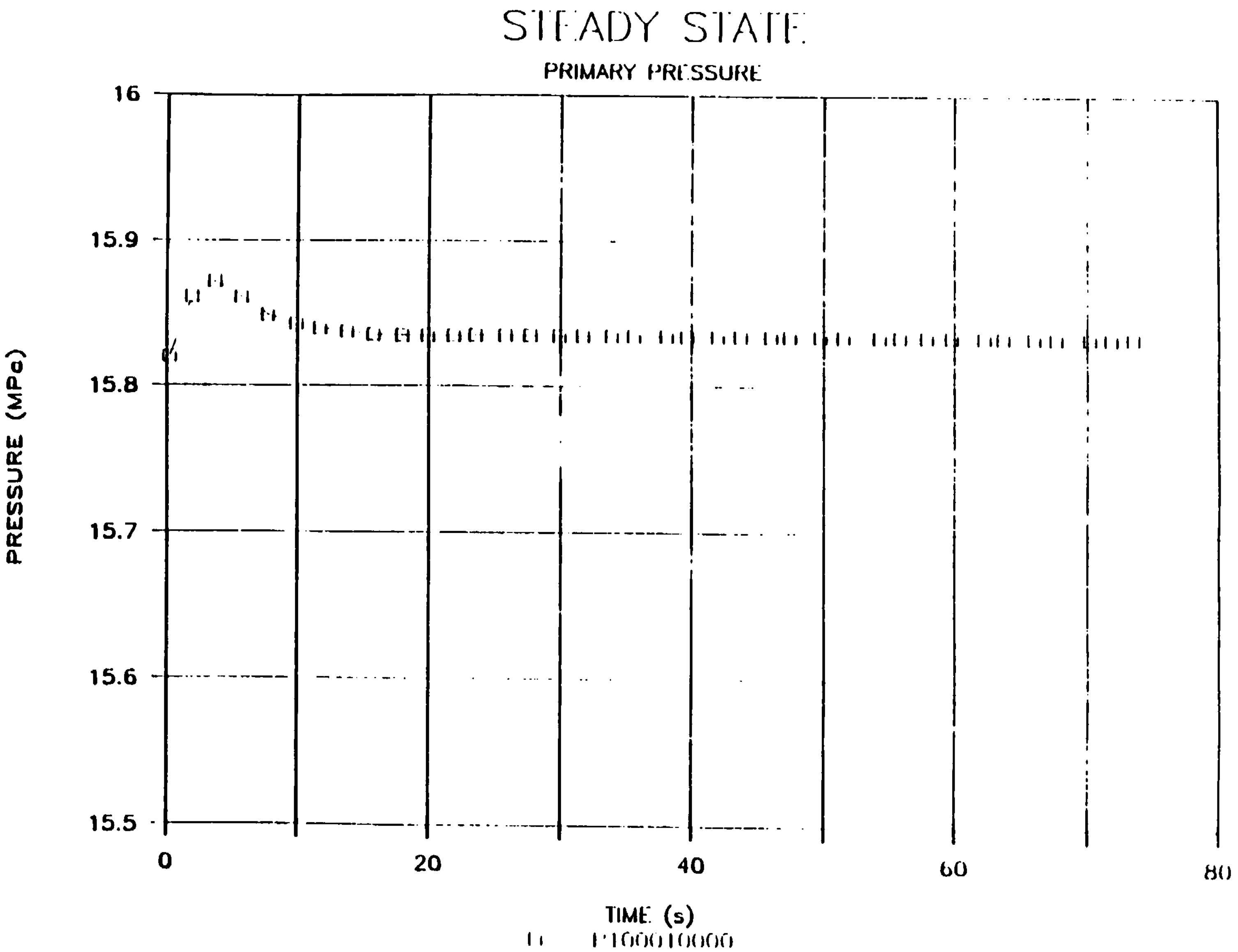

FIGURE 2.- STEADY STATE. PRIMARY PRESSURE

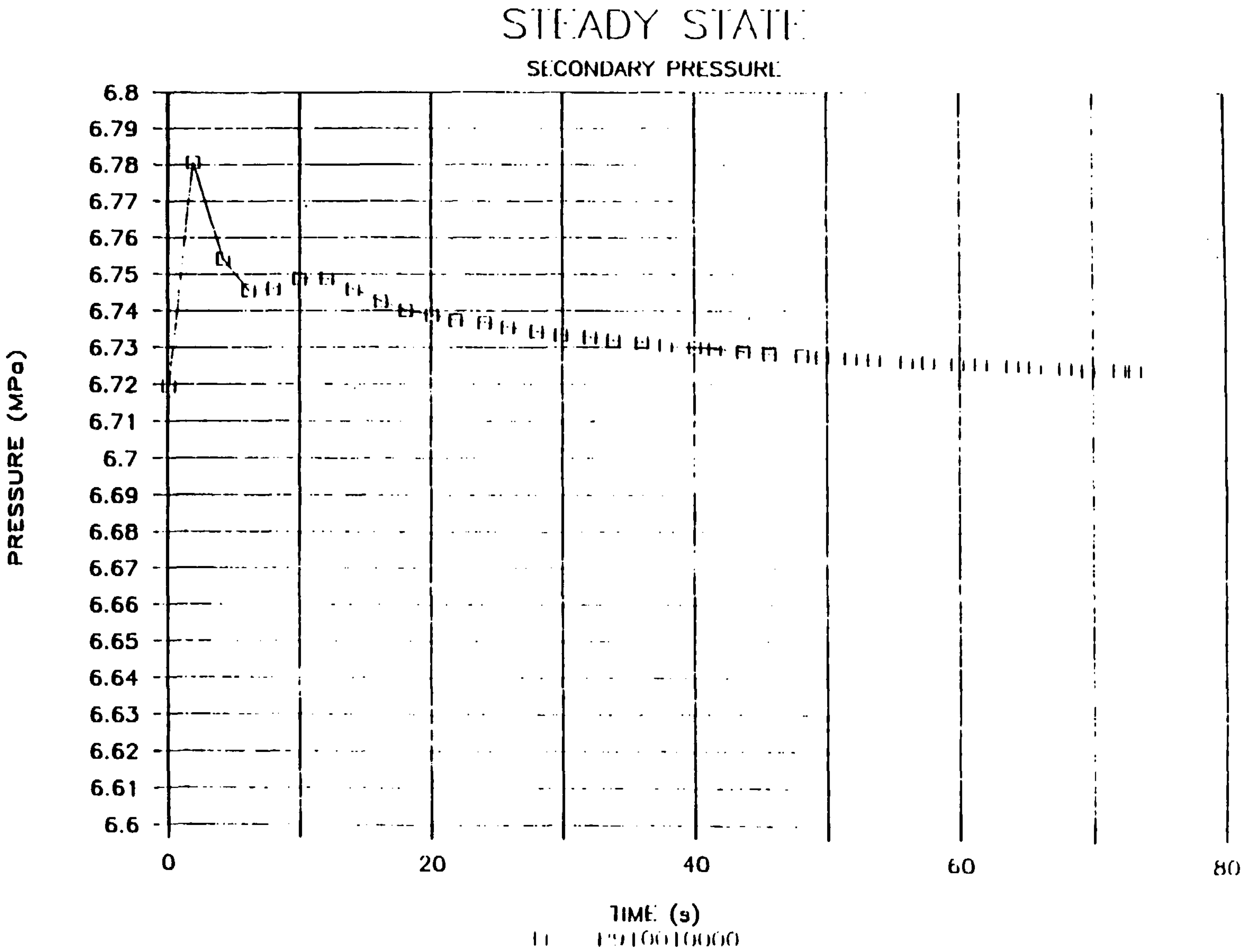

FIGURE 3.- STEADY STATE. SECONDARY PRESSURE

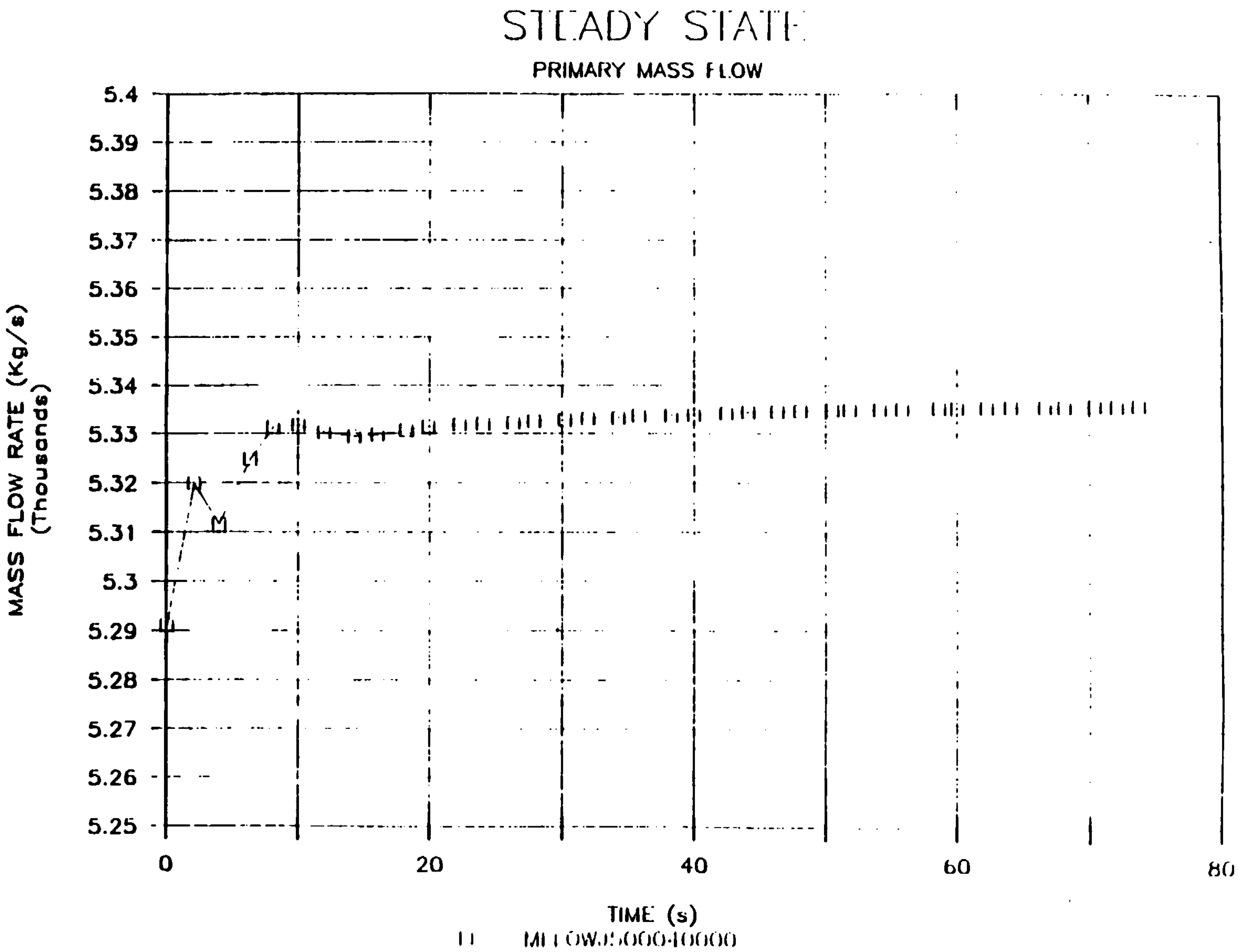

FIGURE 4.- STEADY STATE. PRIMARY MASS FLOW RATE

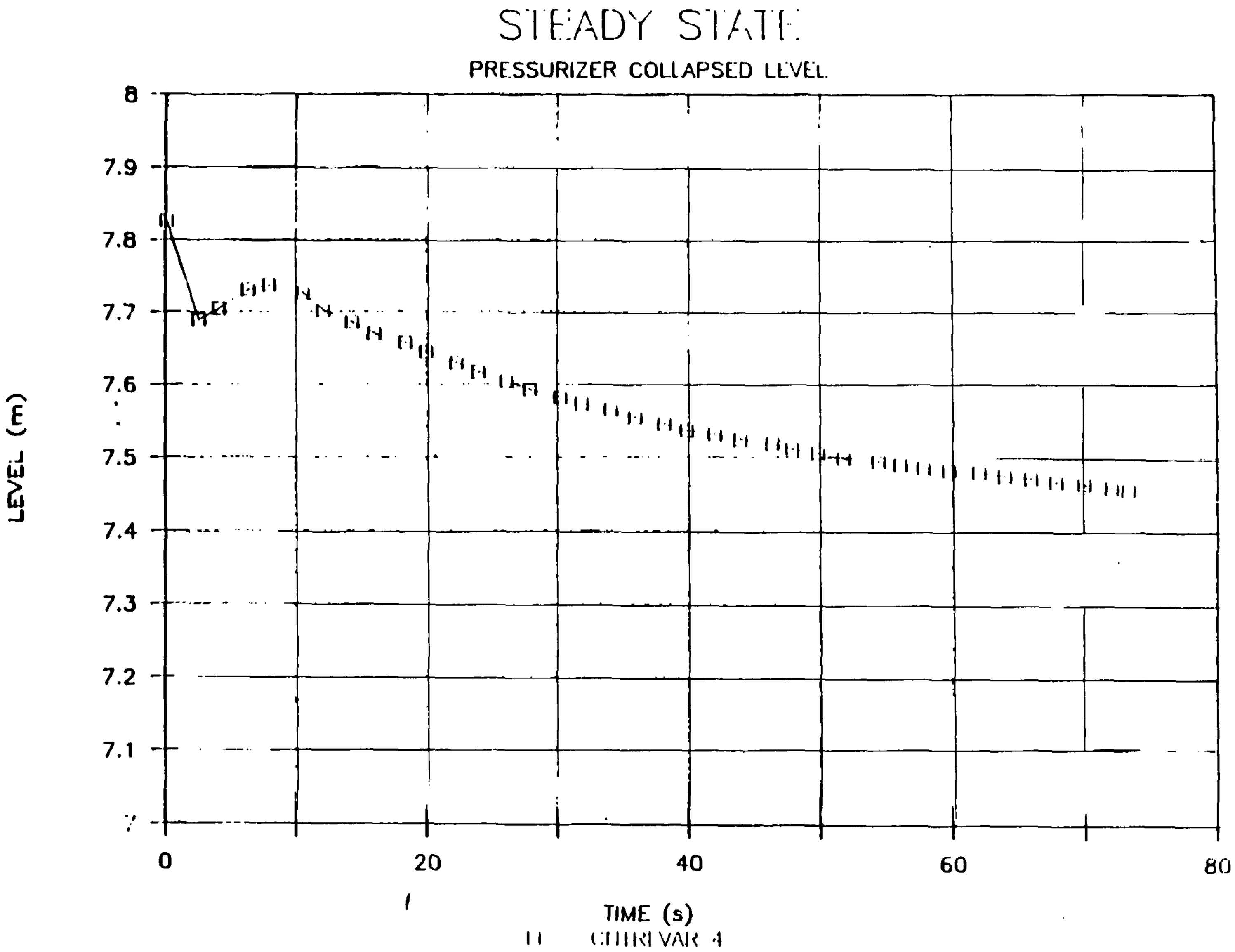

FIGURE 5.- STEADY STATE. PRESSURIZER LEVEL

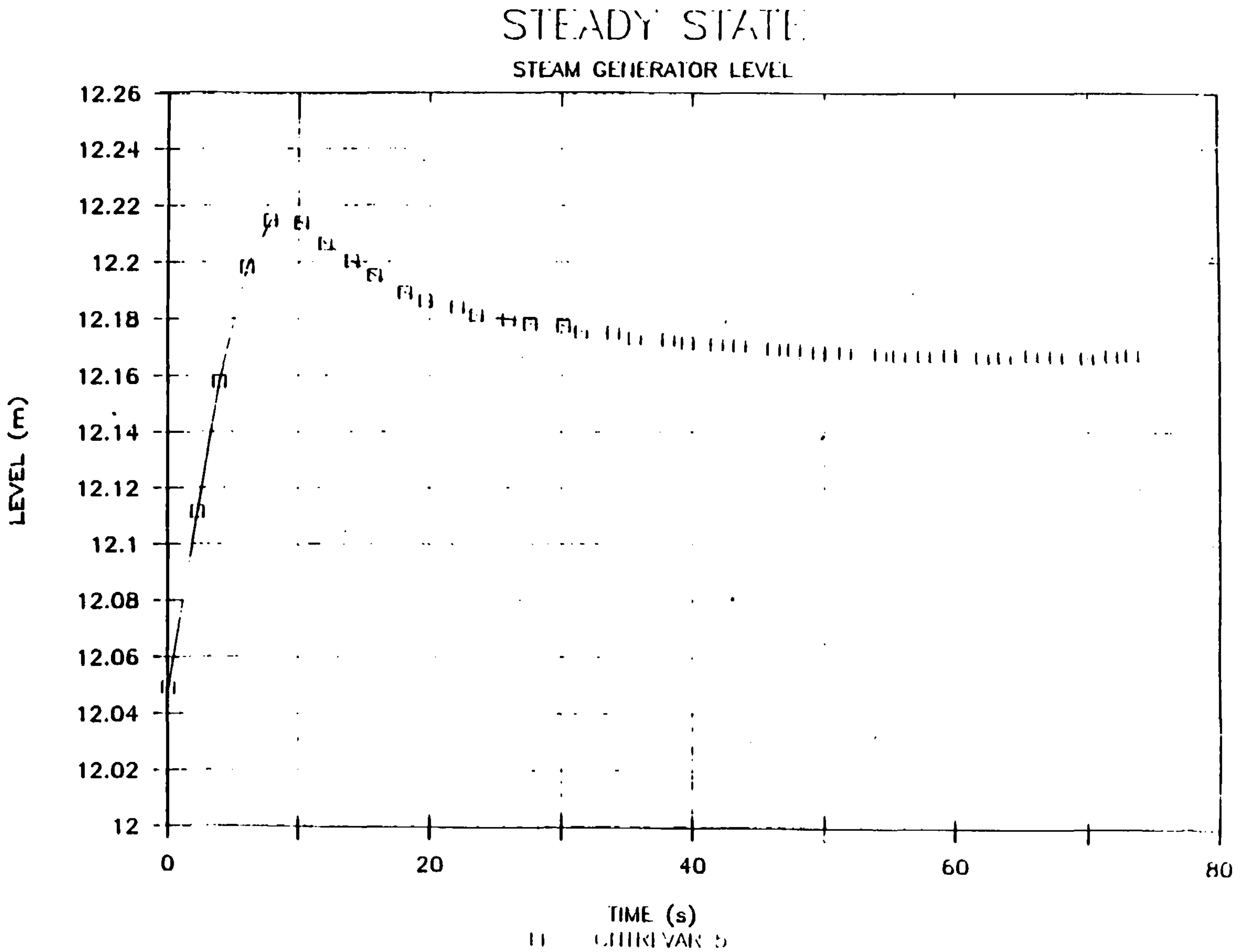

FIGURE 6.- STEADY STATE. S.G. LEVEL

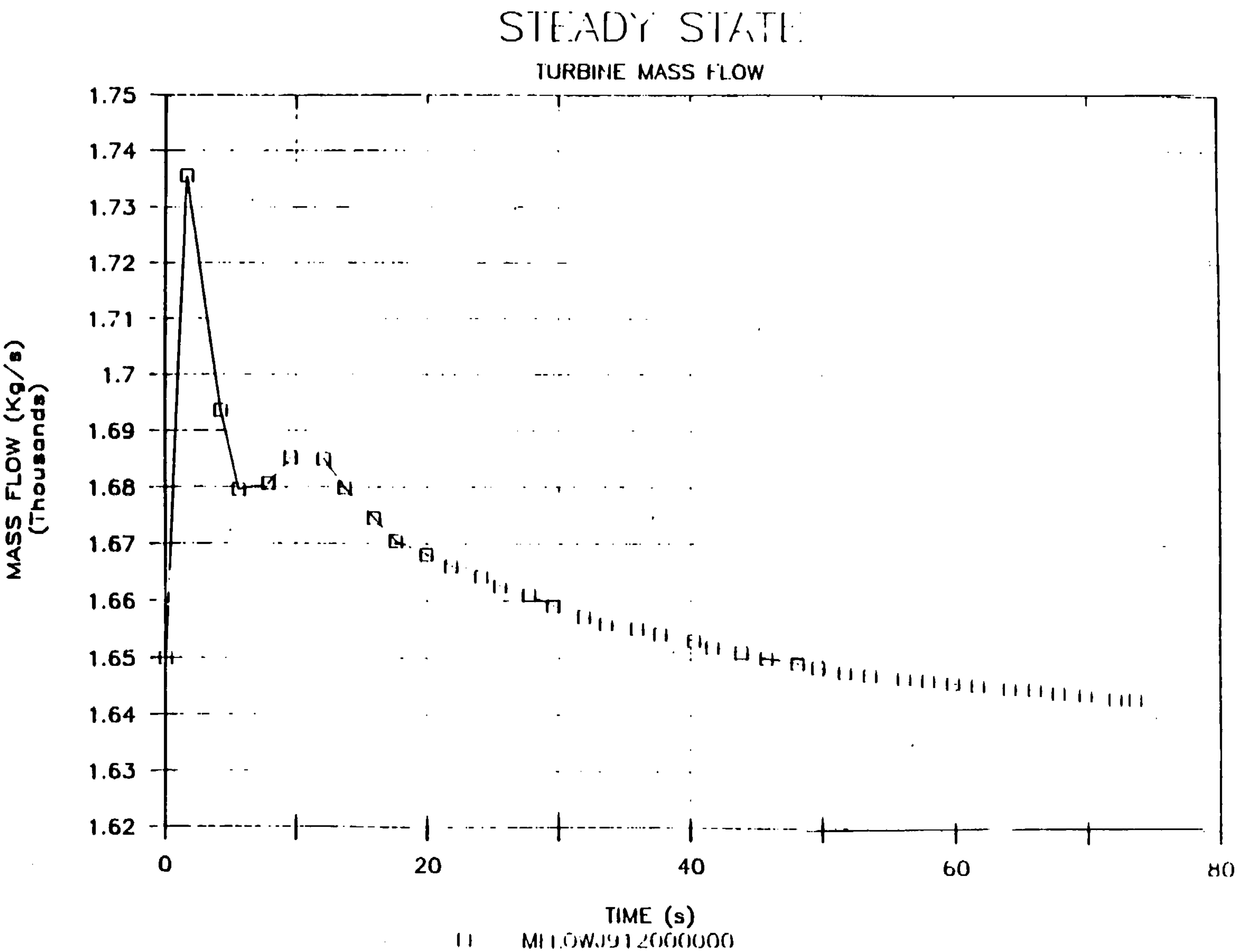

FIGURE 7.- STEADY STATE. TURBINE MASS FLOW RATE

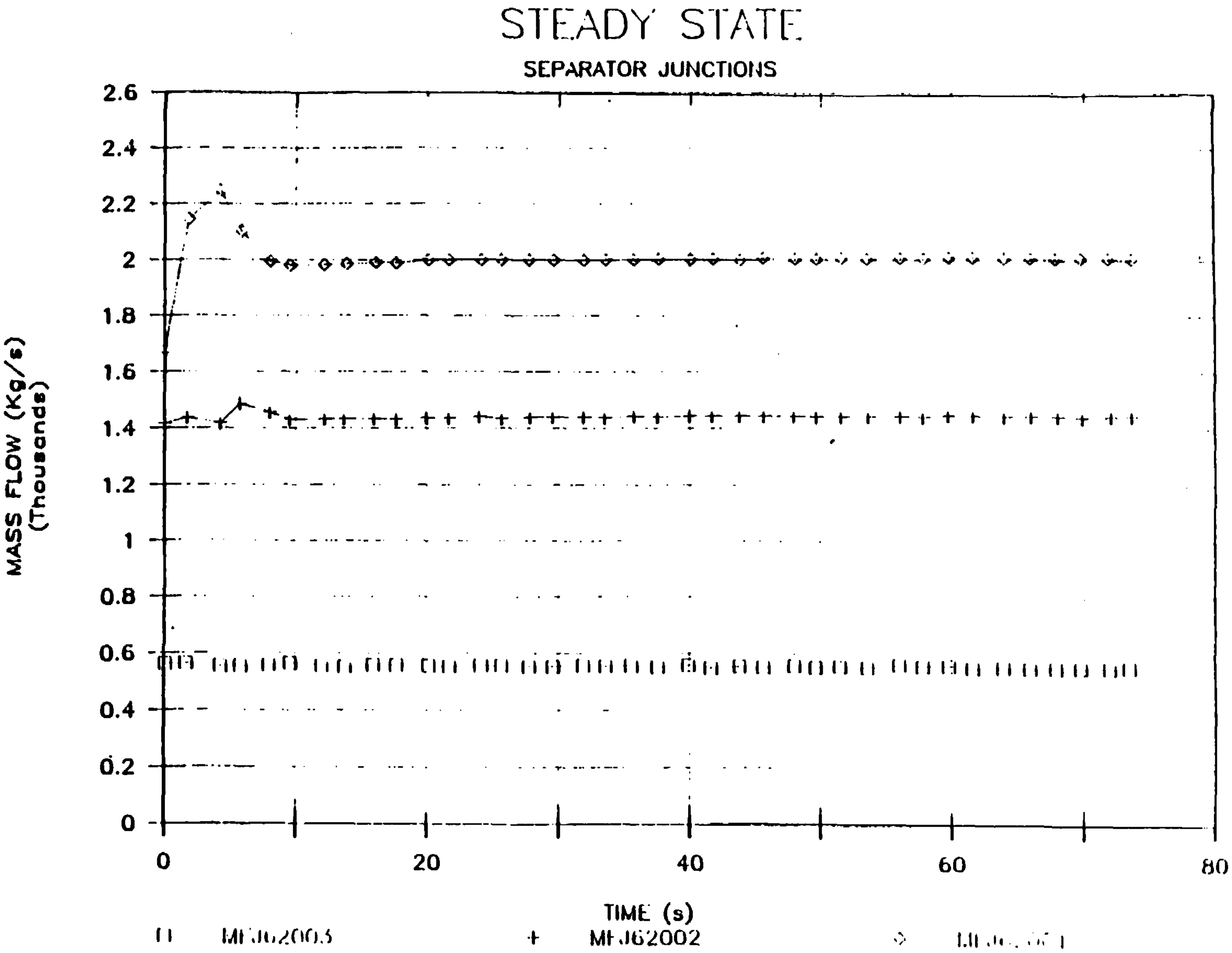

FIGURE 8.- STEADY STATE. STEAM SEPARATOR JUNCTIONS MASS FLOW RATE

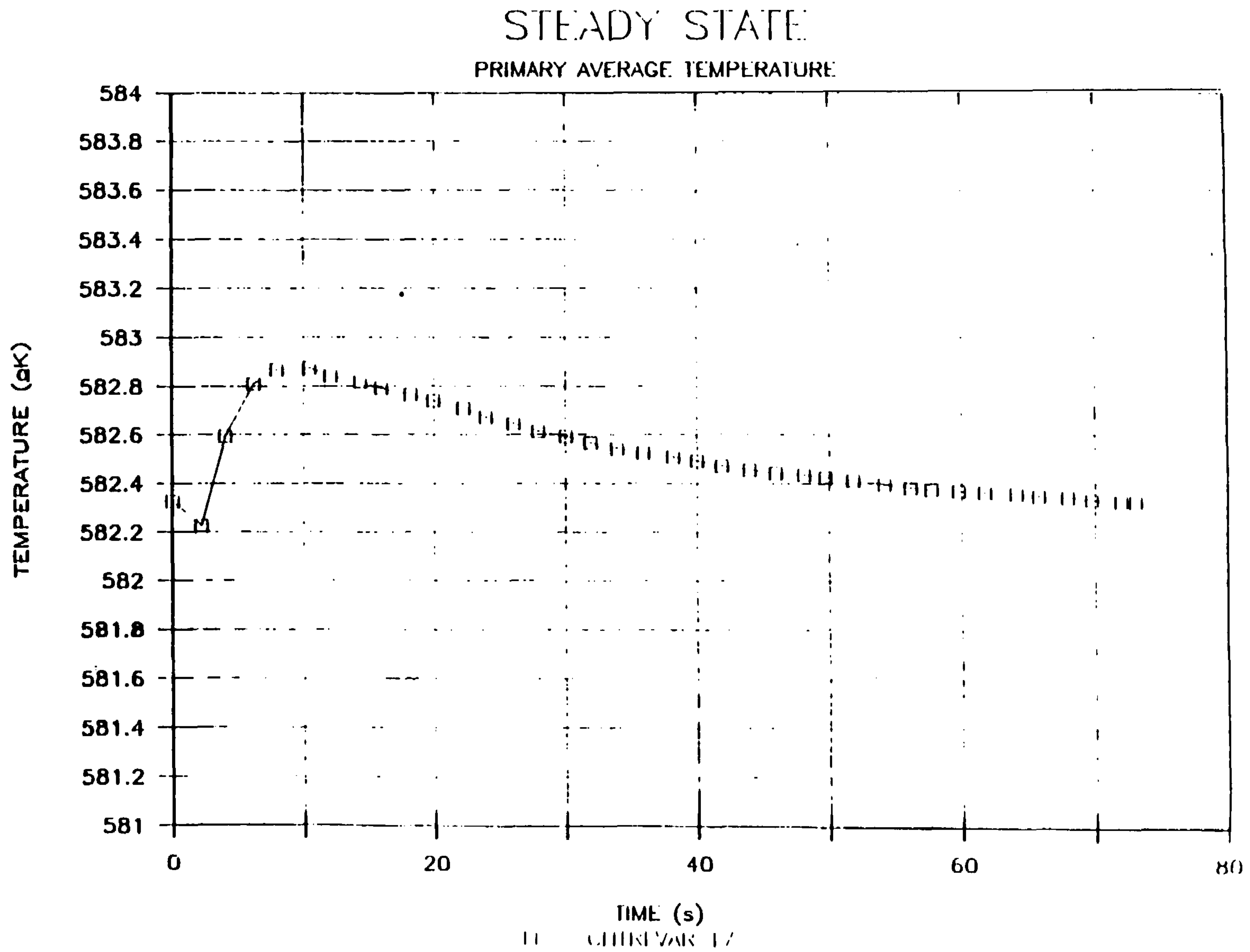

FIGURE 9.- STEADY STATE. PRIMARY AVERAGE TEMPERATURE

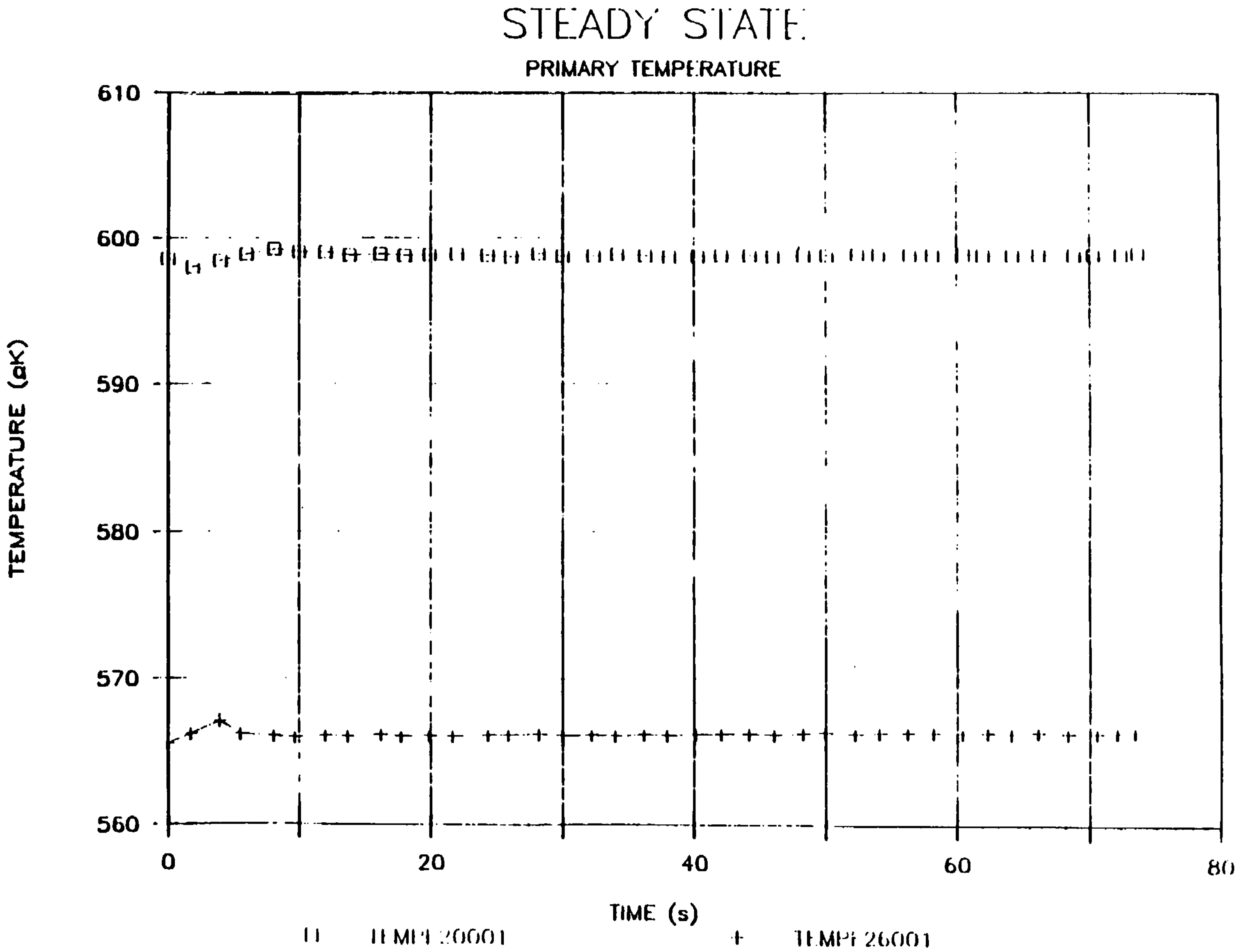

FIGURE 10.-STEADY STATE. HOT AND COLD LEGS TEMPERATURE

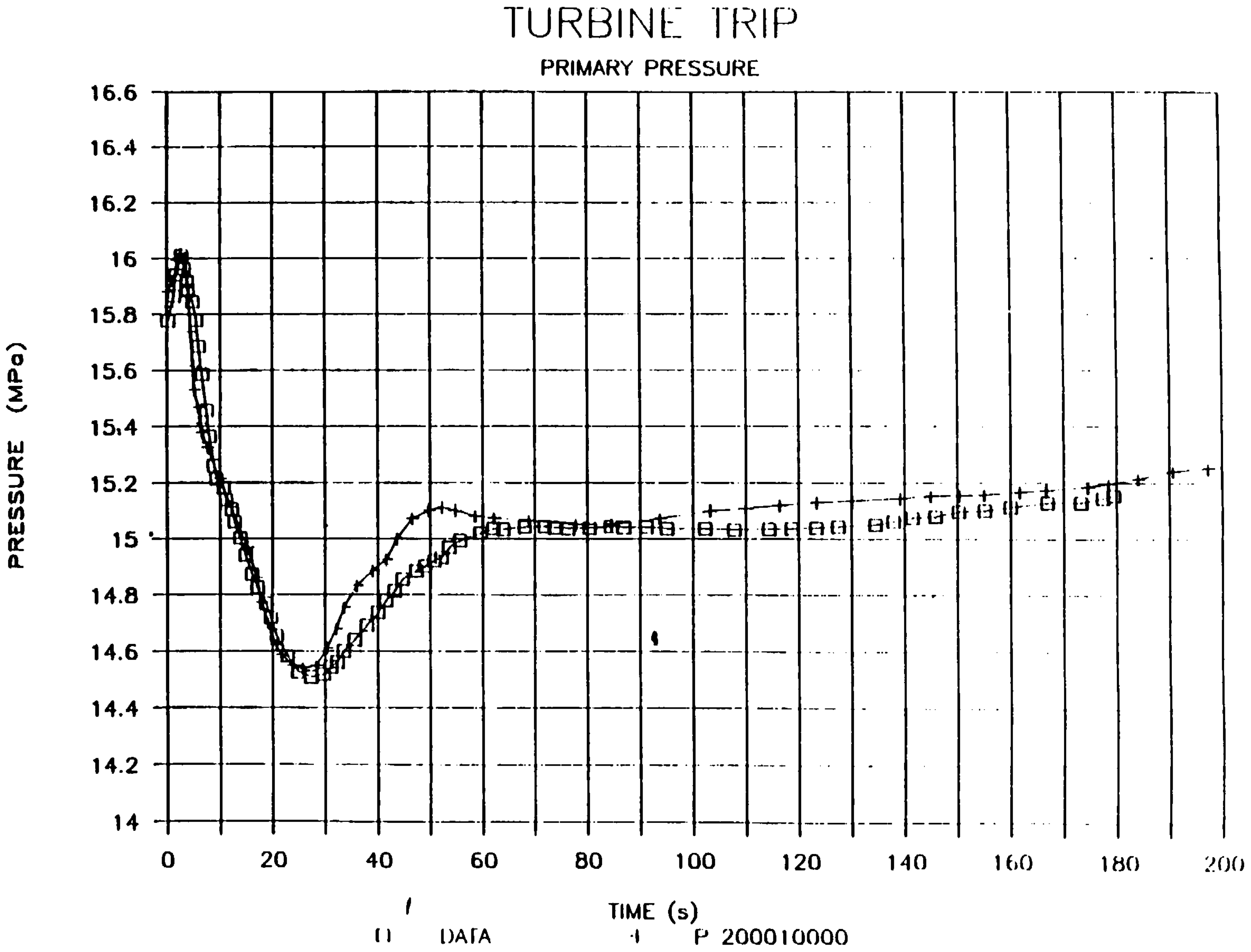

FIGURE 11.-TURBINE TRIP. PRIMARY PRESSURE

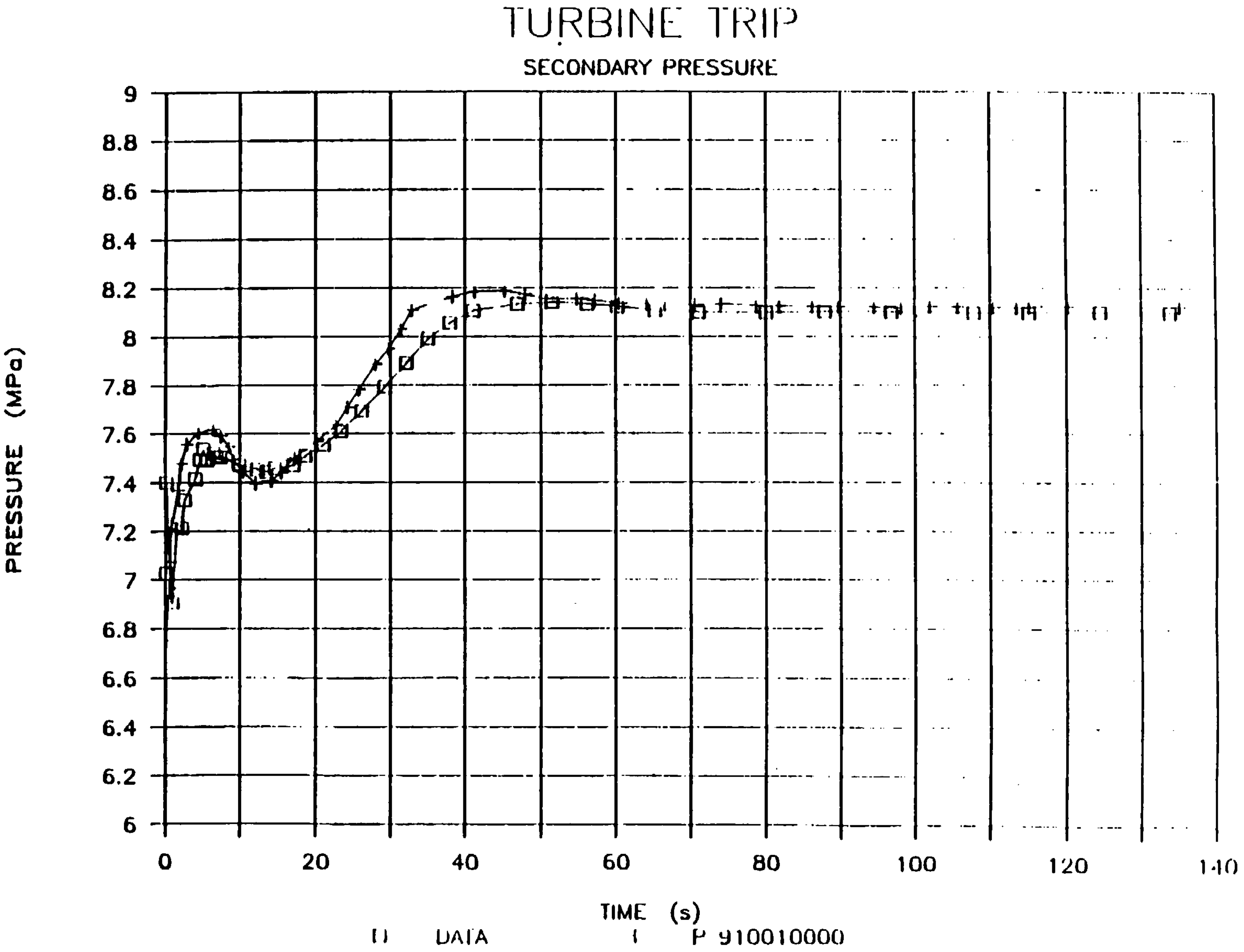

FIGURE 12.-TURBINE TRIP. SECONDARY PRESSURE

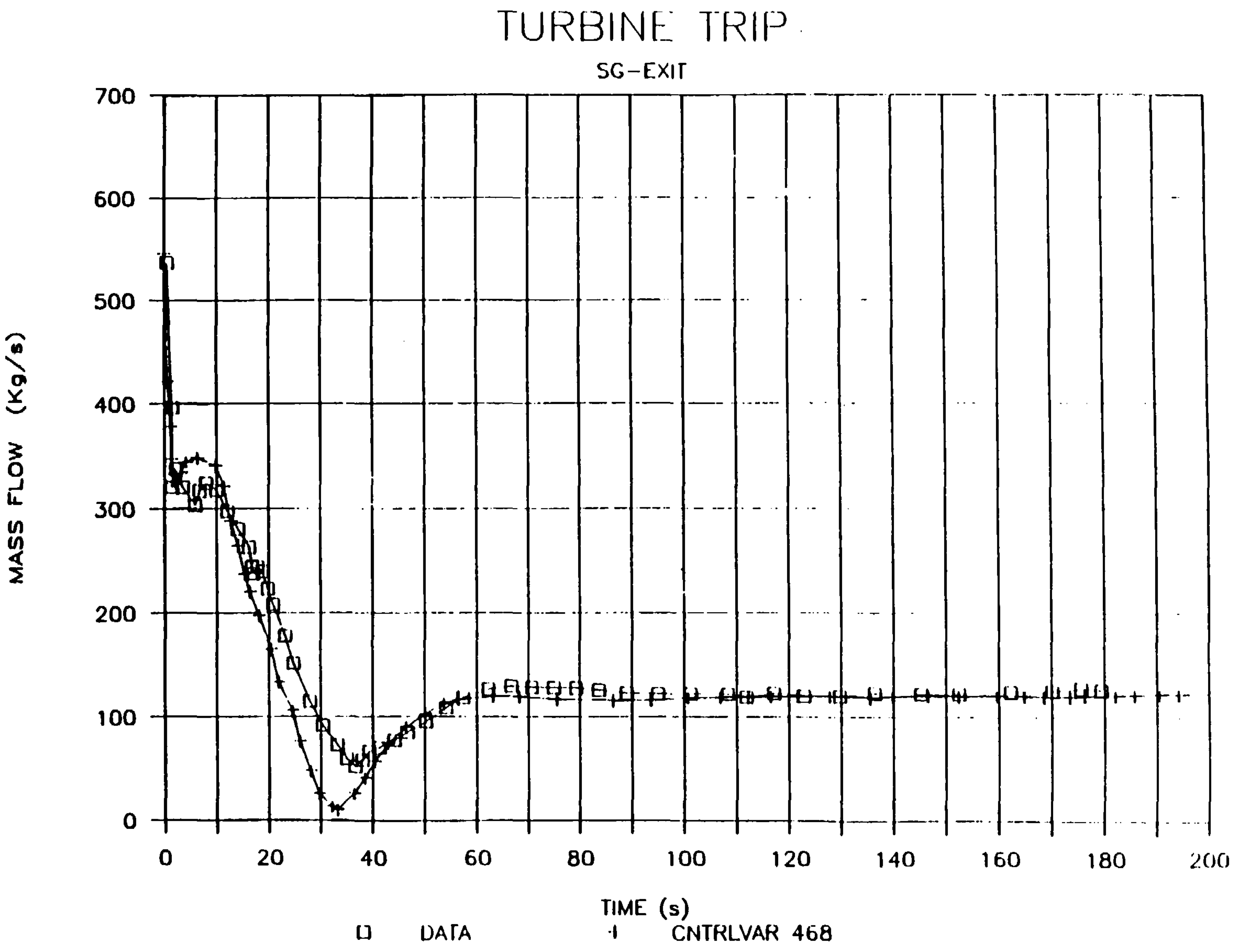

FIGURE 13.-TURBINE TRIP. STEAM MASS FLOW

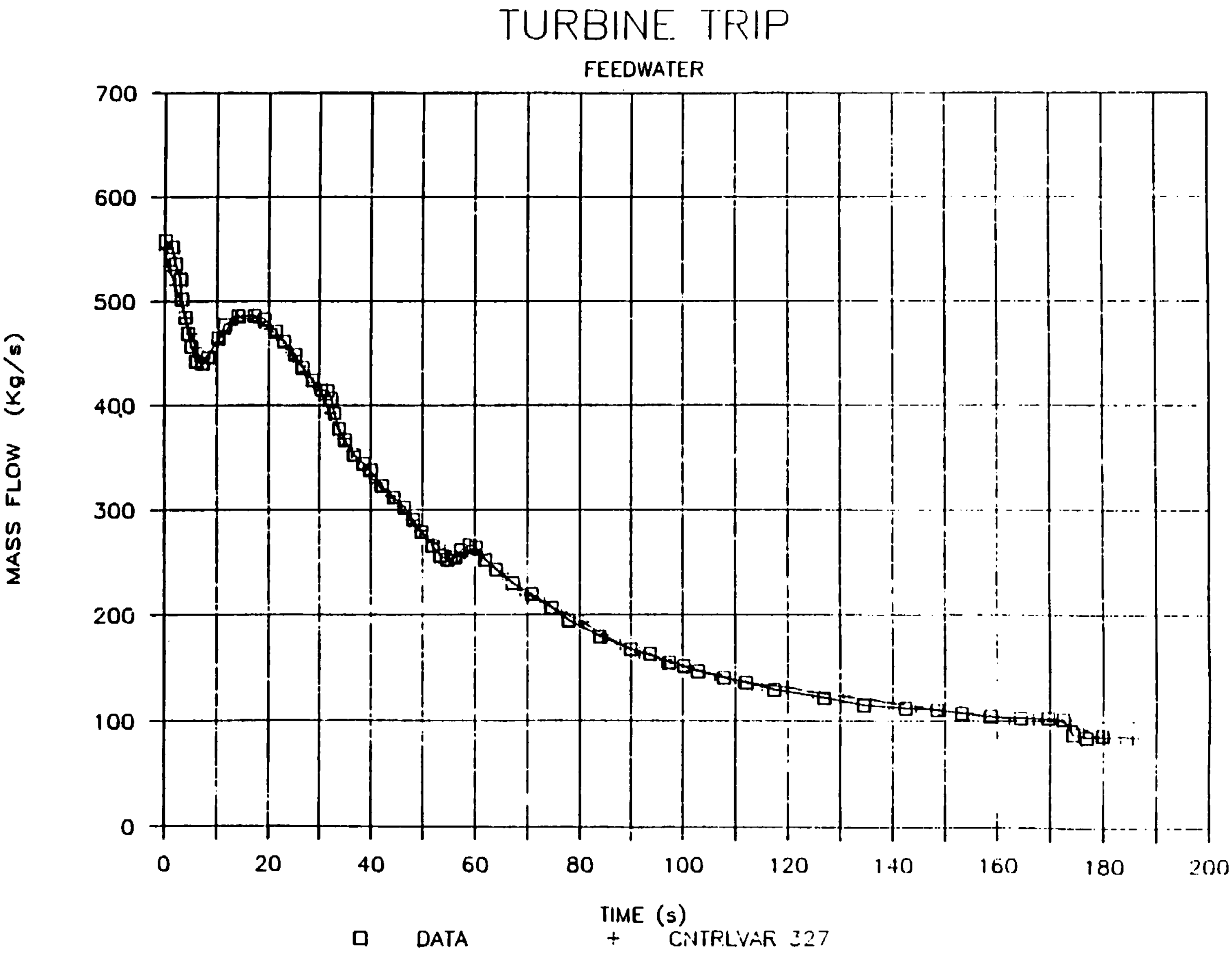

FIGURE 14.-TURBINE TRIP. FEED WATER MASS FLOW

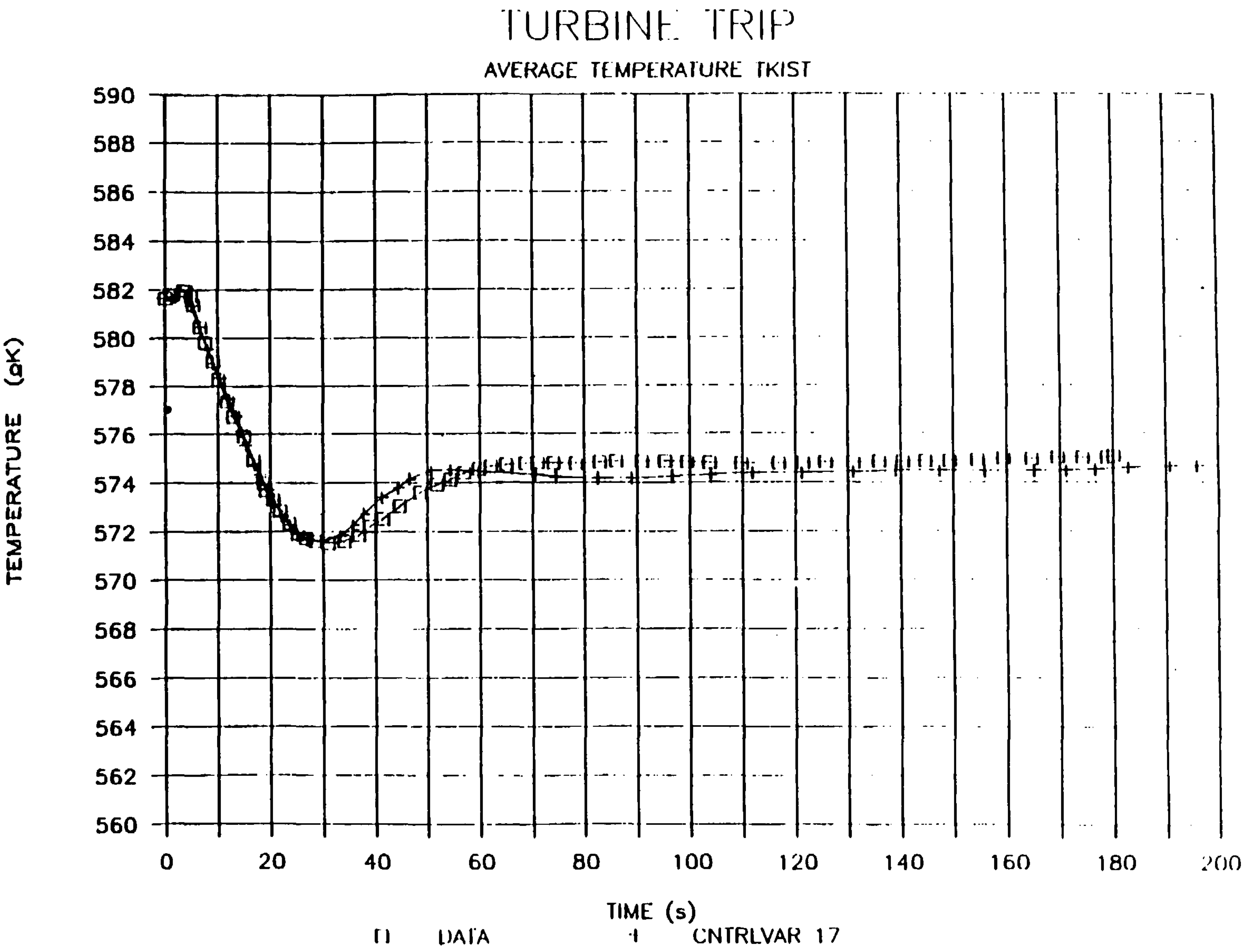

FIGURE 15.-TURBINE TRIP. AVERAGE TEMPERATURE TKIST

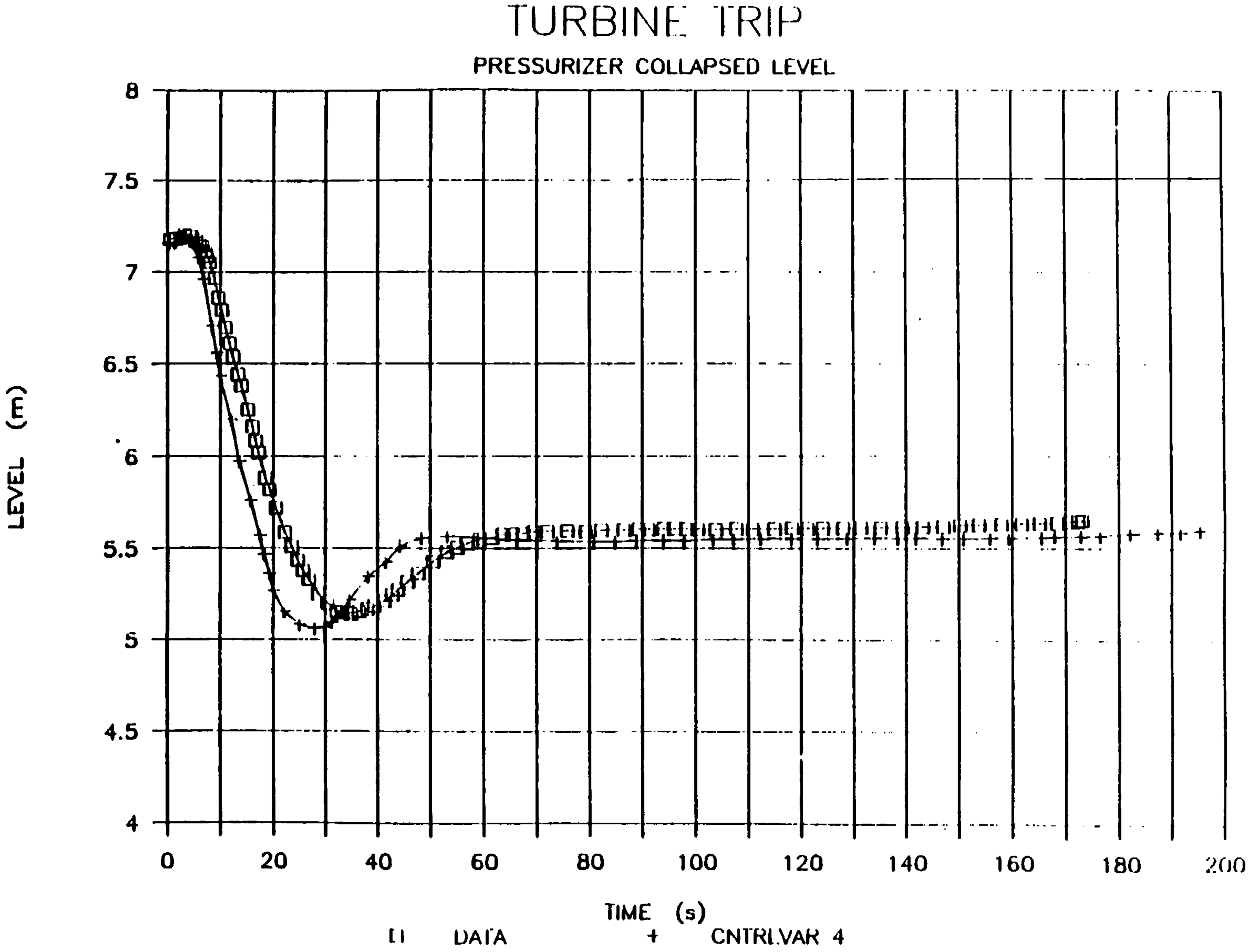

FIGURE 16.-TURBINE TRIP. PRESSURIZER COLLAPSED LEVEL

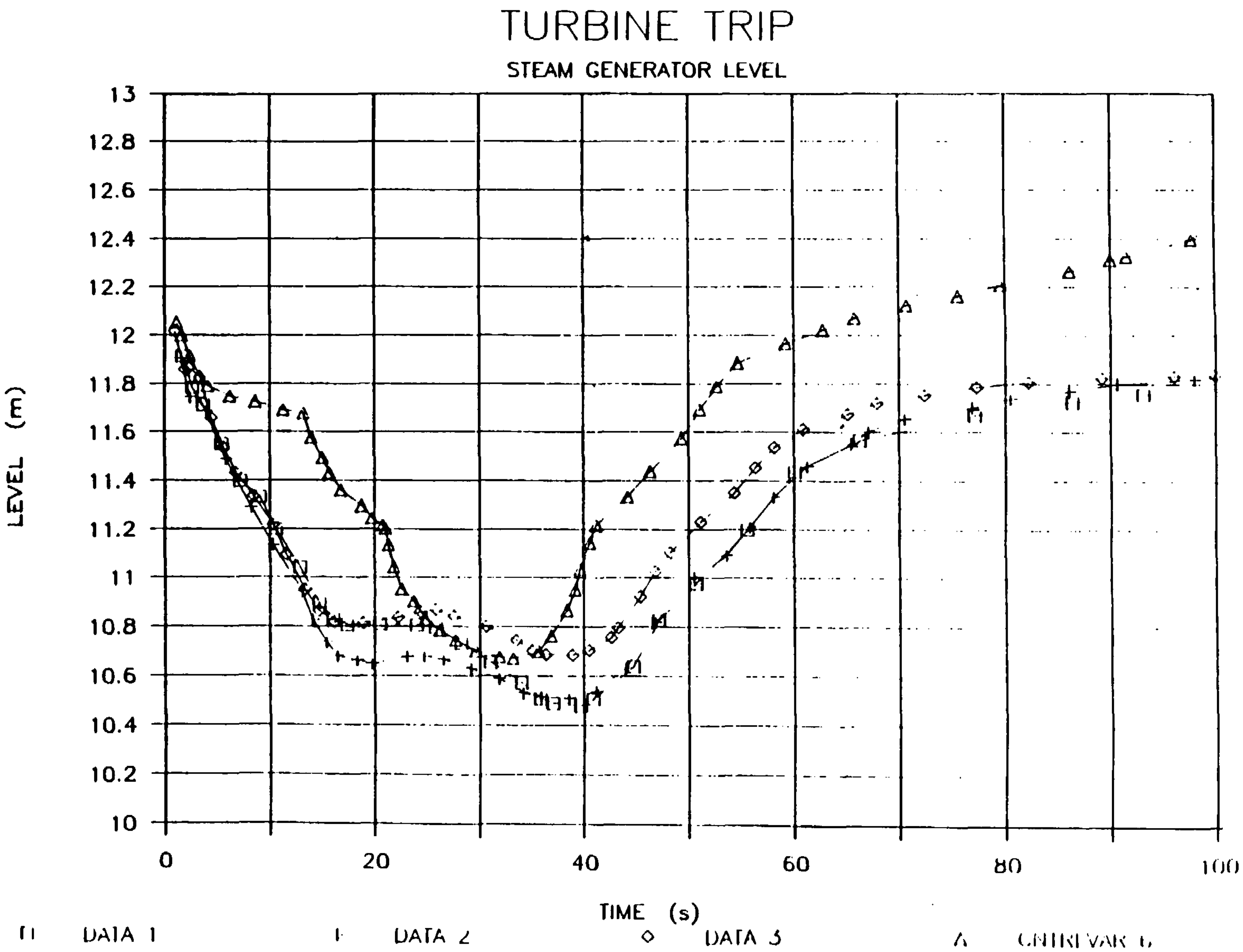

FIGURE 17.-TURBINE TRIP. STEAM GENERATOR LEVEL

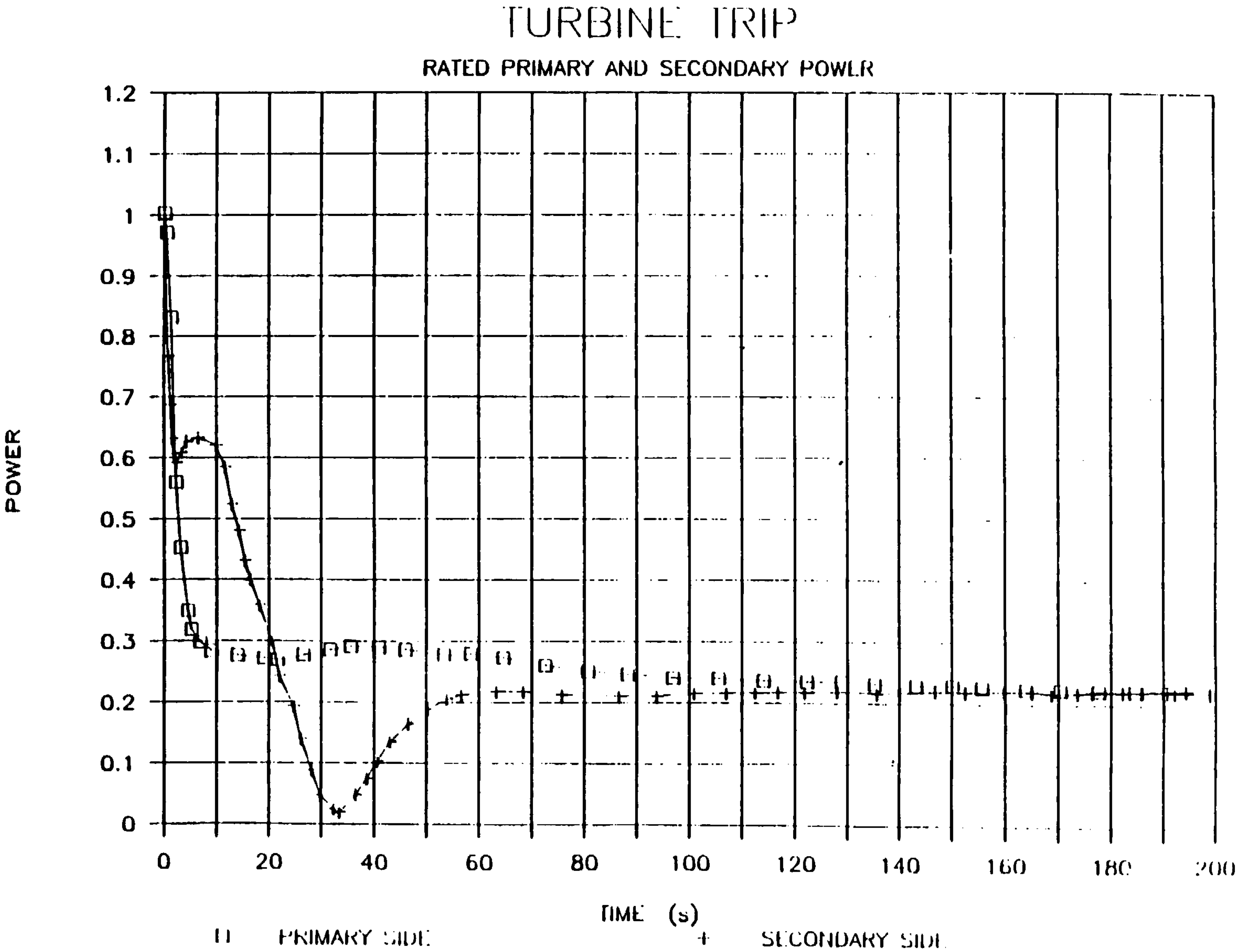

FIGURE 18.-RATED PRIMARY AND SECONDARY POWER

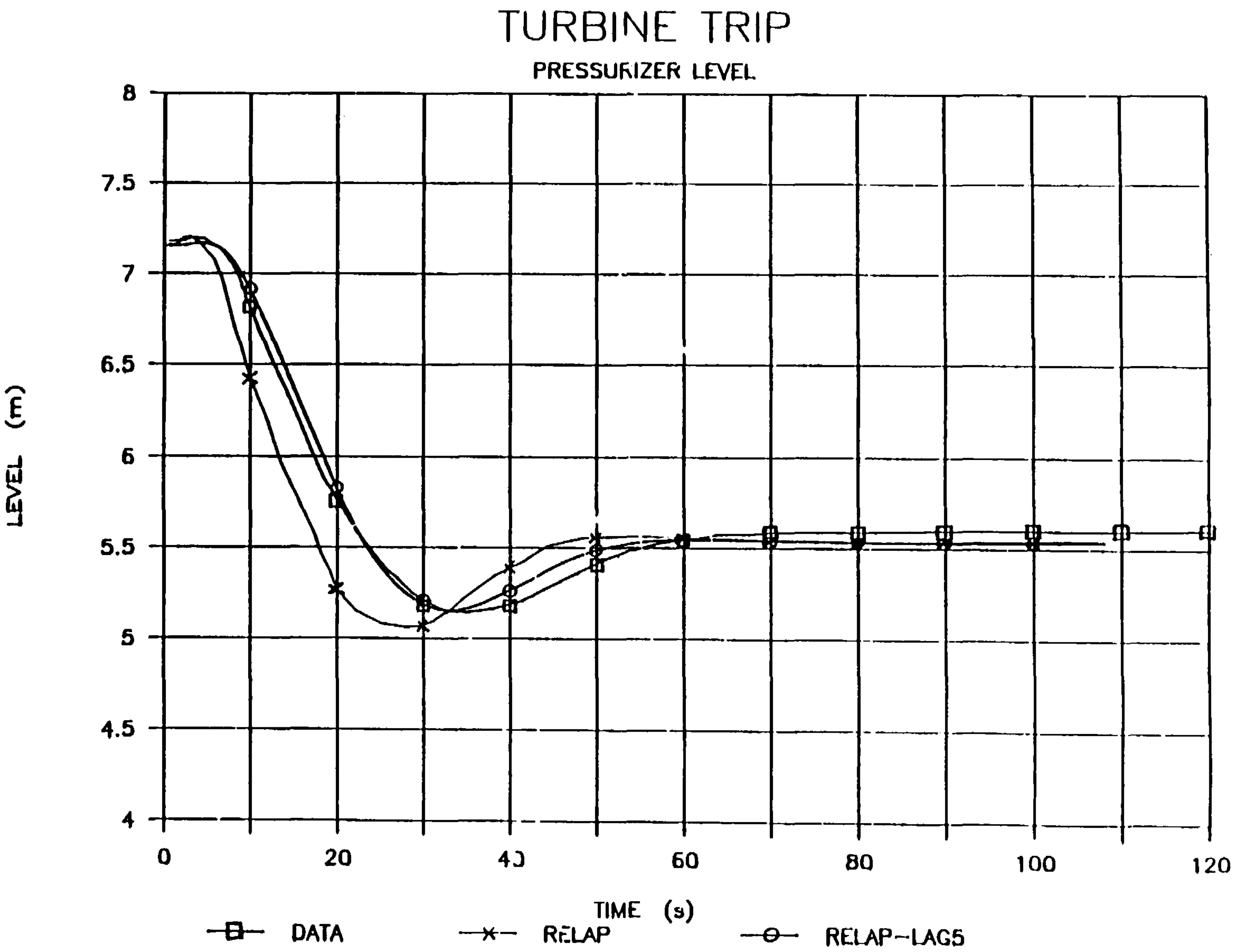

FIGURE 19.-PRESSURIZER LEVEL

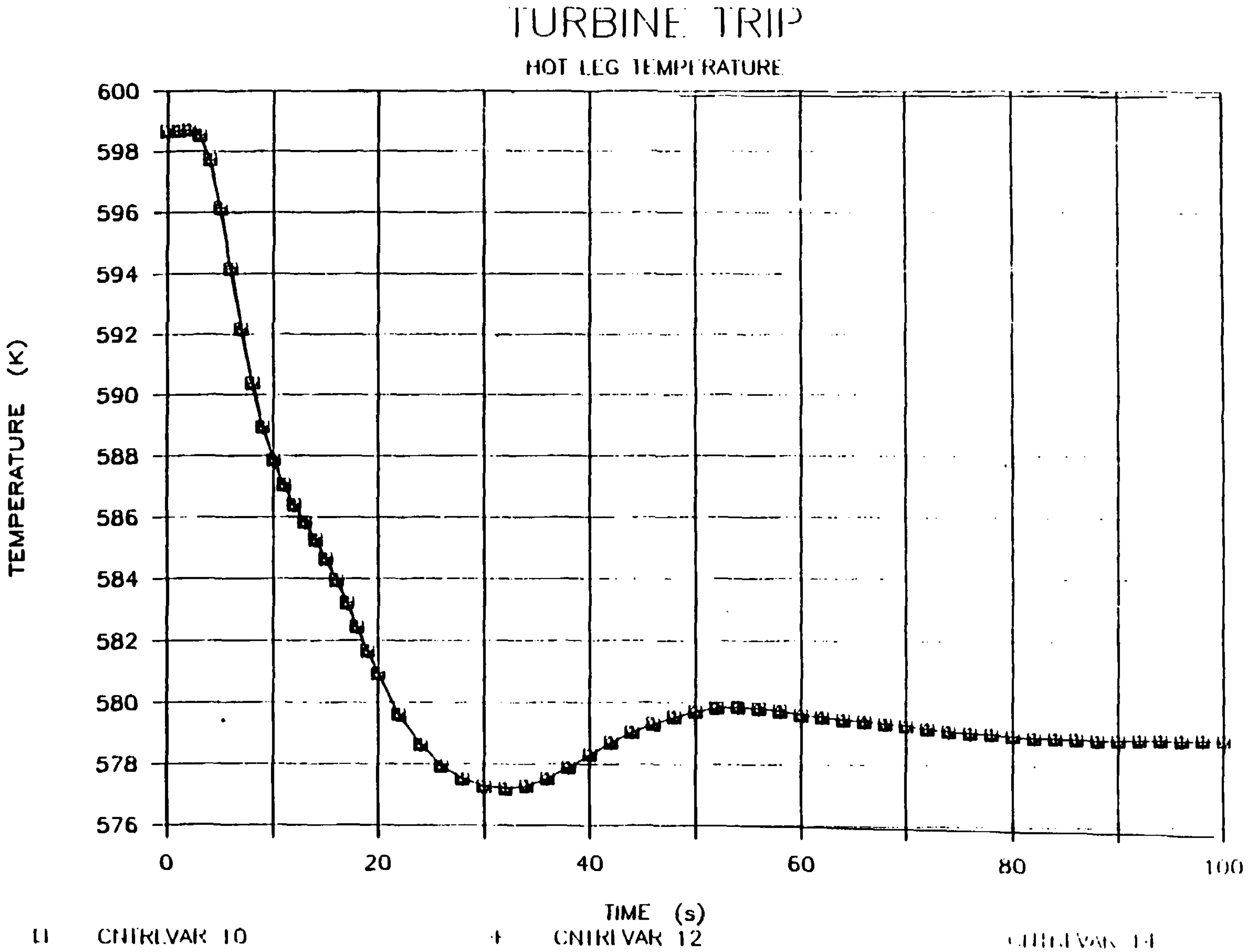

FIGURE 20.-CALCULATED HOT LEG TEMPERATURE

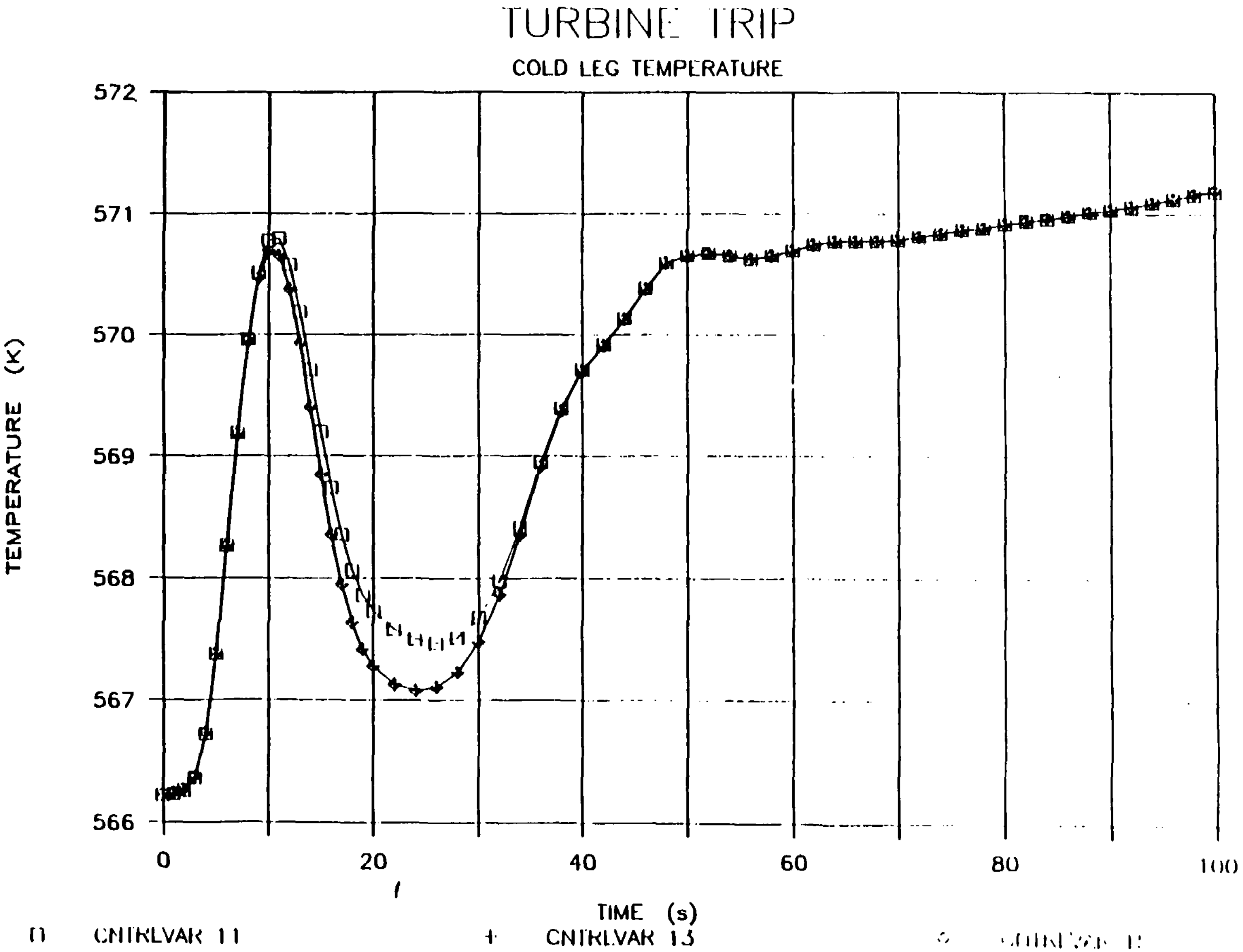

FIGURE 21.-CALCULATED COLD LEG TEMPERATURE

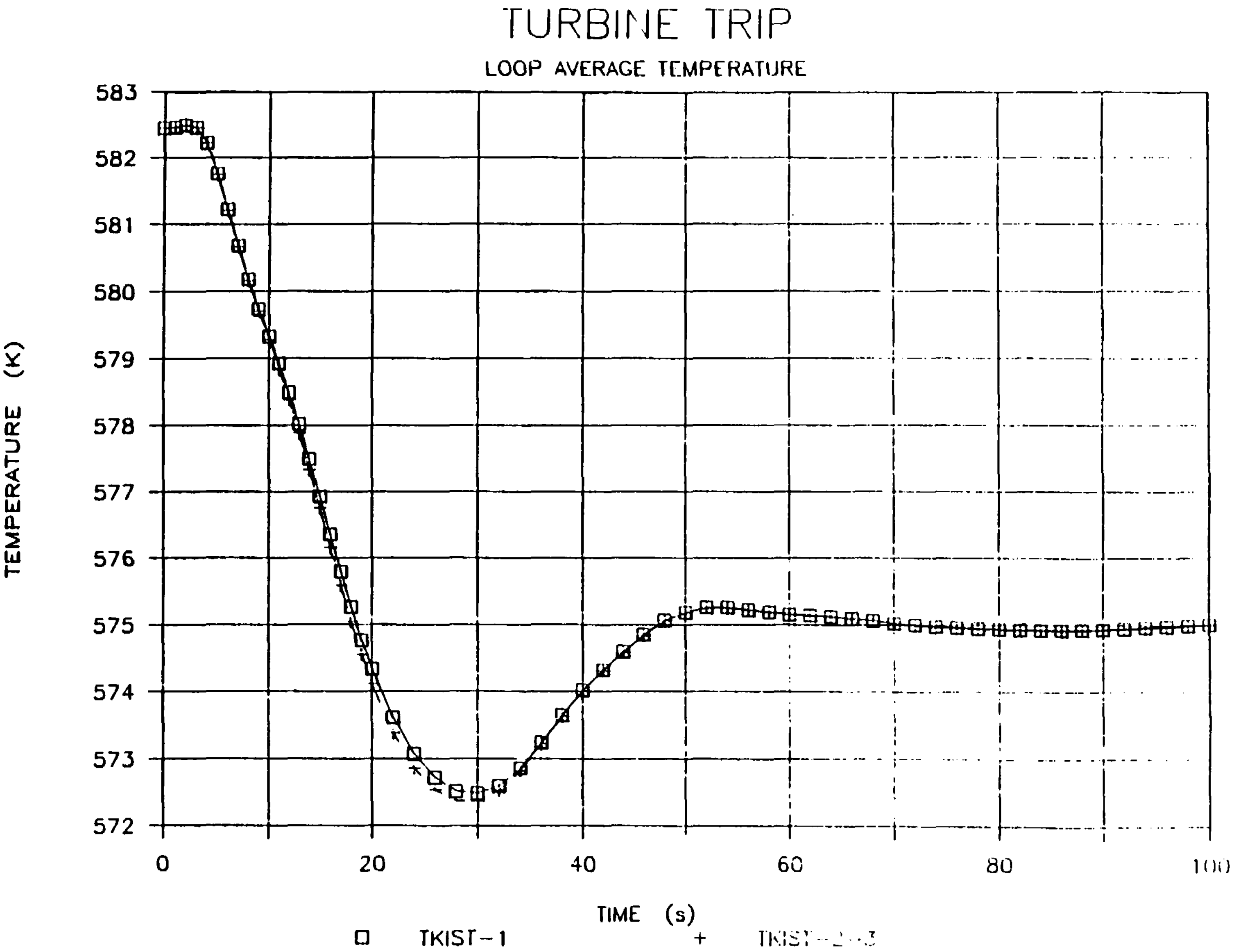

FIGURE 22.-CALCULATED LOOP AVERAGE TEMPERATURE

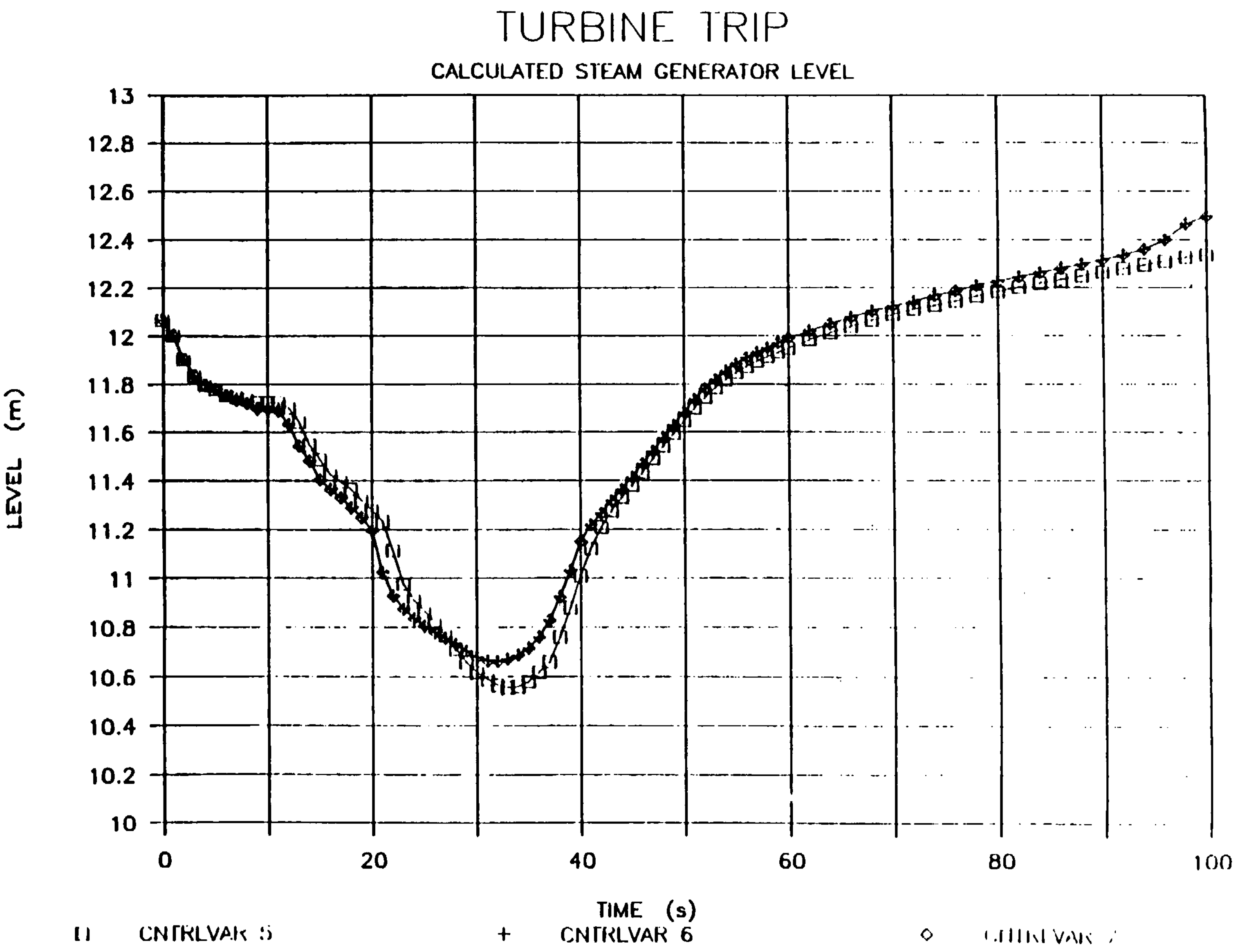

FIGURE 23.-CALCULATED STEAM GENERATORS LEVEL

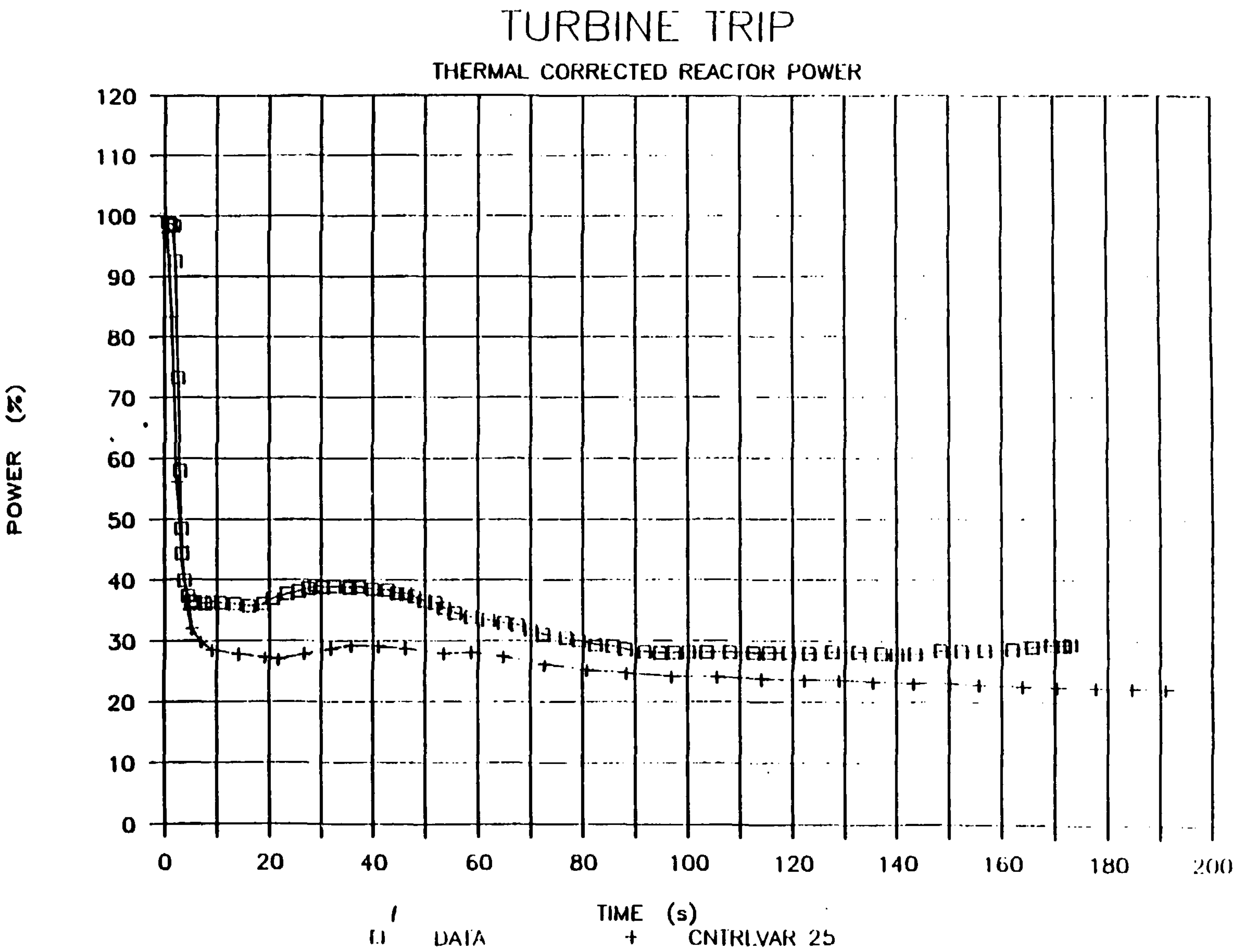

FIGURE 24.-THERMAL CORRECTED REACTOR POWER

- POWER

Gross electrical output	1041 MW
Net electrical output	990 MW
Thermal reactor output	3027 MW

- Reactor Building (Shield Building)

Outside diameter	59.2 m.
Wall thickness in the cylindrical part	0.6 m.
Wall thickness in the dome	0.3 m.

- Steel Containment Structure

Inside diameter	53 m.
Design pressure/temperature	5.3 bar/145º C
Maximum leakage rate	0.25 vol %/d

- Reactor Pressure Vessel

Cylindrical shell inside diameter	4.878 mm.
Wall thickness of cylindrical shell	245 mm.
Material	20 MnMoNi 55
Cladding thickness	up to 7 mm.
Total height. incl. closure head	11,039 mm.
Design pressure/temperature	176 bar/350ºC
Weight without internals	429 t
Weight of internals	137 t

- Reactor Core

Fuel	Sintered UO_2
Number of assemblies	177
Overall weight per assembly	730 Kg
Fuel rods per fuel assembly	236
Arrangement	Square lattice
Overall length of fuel rods	4,185 mm.
Active length of fuel rods	3,400 mm.
Outside diameter of fuel rods	10.75 mm.

Table 1.- C. Trillo I description (1 of 5)

Cladding tube material	Zry 4
Cladding tube wall thickness	0.725 mm.
Overall in-core uranium weight	83t
Enrichment of first core	1.9/2.5/3.2%U235
Enrichment of equilibrium core	3.3% U235
First core burn-up	14.3 MW d/kg
Average heat flux	61.2 W/cm^2.
Equilibrium core burn-up	10.8 MW d/kg
Average linear heat generation rate	207.1 W/cm
Absorber rods per control assembly	20
Absorber material	Ag15In5Cd
Drive mechanism	Magnetic jack
Positioning rate	75 step/min
Step length	10 mm.

- Reactor Coolant System

Number of coolant loops	3
Reactor operating pressure	158 bar
Coolant inlet temperature	293.-292.9 °C
Coolant outlet temperature	325.0-327.6 °C
Coolant flow rate	16684-16640 Kg/s

- Steam Generator

Number	3
Height	21,500 mm.
Diameter	4,812 mm.
Shell material	Fine-grained steel
Tubesheet material	Fine-grained steel
Tube material	Incoloy 800
Average tube length	20.49 m.
Design pressure/temperature (steam plant side)	87.3 bar/350ºC
Overall weight	430 t
Inner diameter of tubes	19.6 mm.

Table 1.- C. Trillo I description (2 of 5)

- Generator (grid dependent)

Active power	1041 MW
Apparent power	1157 MVA
Power factor	0.9
Terminal voltage	27 KV
Control range	+ 7.5%
Frequency	50 Hz
Cooling medium for rotor winding	Hydrogen
Cooling medium for stator winding	Water
Overall length of turbine-generator unit appr.	55 m.

- Generator Transformer(grid dependent)

Type	3 single-phase units
Primary voltage	380 KV
Secondary voltage	27 KV
Bank capacity	1,200 MVA

- Reactor Coolant Pumps

Number	3
Type	Single-stage centrifugal pump
Discharge head	101 m.
Design flow rate	5,292 kg/s
Speed	1,480 rpm
Motor rating; (supply voltage/ frequency)	10/50 KV/Hz

Table 1.- C. Trillo I description (3 of 5)

- Pressurizer

Height	13,800 mm.
Diameter (inner)	2,200 mm.
Volume	45 m^3
Operating temperature	346ºC
Operating saturation pressure	156 bar abs.
Heating power of the heater rods	1639 KW

- Steam/Power Conversion Plant

Main steam flow rate	1658 kg/s
Main steam conditions at steam generator outlet (at 100% power)	68.9 bar/280ºC
Steam moisture at steam generator outlet	max 0.25 %
Condenser circulating water flow rate	36700 l/s
Final feedwater heating temperature	220ºC
Number of feed heating stages	5
Subdivision of feed heating stages	2 lp, 2 hp, 1 feedwater tank

- Main Feedwater Pumps

Number	3
Discharge pressure	79.5 bar
Design flow rate	905 kg/s
Motor rating	9,500 KW

- Circulating Water Pumps

Number	3
Dischange head	18 m.
Normal flow rate	12233 l/s
Motor rating	4,100 KW

Table 1.- C. Trillo I description (4 of 5)

- Turbine

Four-casing tandem-compound condensing turbine with 1 double-flow h.p. turbine and 3 double-flow l.p. turbines. Steam drying and reheating between the h.p. turbine and the l.p. turbines.

Speed	3,000 rpm

Table 1.- C. Trillo I description (5 of 5)

KEYWORD	CONCEPT
P 100010000	Primary pressure (Hot leg)
TEMPF 200010000	Hot leg liquid temperature
TEMPF 260010000	Cold leg liquid temperature
CNTRLVAR 4	Pressurizer collapsed liquid level
CNTRLVAR 10	Measured Hot leg liquid temperature (Loop 1)
11	Measured Cold leg liquid temperature (Loop 1)
12	Measured Hot leg liquid temperature (Loop 2)
13	Measured Cold leg liquid temperature (Loop 2)
14	Measured Hot leg liquid temperature (Loop 3)
15	Measured Cold leg liquid temperature (Loop 3)
16	Thermal reactor power
17	Primary Coolant average temperature TKIST
18	Fission reactor power
25	Thermal corrected reactor power
56	Permitted reactor power
140	Primary coolant average temperature setpoint
170	Primary average temperature for control system
P 910010000	Secondary pressure (header)
MFLOWJ 912000000	Turbine mass flow rate
MFLOWJ 652000000	Steam generator mass flow rate (Loop 1)
MFLOWJ 752000000	Steam generator mass flow rate (Loop 2)
MFLOWJ 852000000	Steam generator mass flow rate (Loop 3)
MFLOWJ 915000000	By-pass mass flow rate
MFLOWJ 651000000	Feedwater mass flow rate (10%)
MFLOWJ 655000000	Feedwater mass flow rate (40%)
MFLOWJ 657000000	Feedwater mass flow rate (50%)
CNTRLVAR 3	Measured secondary pressure
CNTRLVAR 5	S.G. collapsed liquid level (Loop 1)
CNTRLVAR 6	S.G. collapsed liquid level (Loop 2)
CNTRLVAR 7	S.G. collapsed liquid level (Loop 3)
CMTRLVAR 83	Secondary maximum pressure limit
CNTRLVAR 326	Total feedwater mass flow rate (Loop 1)
CNTRLVAR 327	Total feedwater mass flow rate (Loop 2)
CNTRLVAR 328	Total feedwater mass flow rate (Loop 3)
CNTRLVAR 468	Measured S.G. mass flow rate

Table 2.- Variables identification in transient figures(1 of 2)

KEYWORD	CONCEPT
CNTRLVAR 246	D-BANK Reactivity
CNTRLVAR 247	L-BANK Reactivity
CNTRLVAR 616	Total reactivity of control rods
RKREAC 0	Total reactivity
CNTRLVAR 410	Required pressurizer heaters power
CNTRLVAR 411	Effective pressurizer heaters power
MFLOWJ 620010000	Vapor outlet mass flow of separator volume
620020000	Liquid return mass flow of separator volume
620030000	Inlet mass flow of separator volume

Table 2.- Variables identification in transient figures (2 of 2)

COMPUTER	CYBER 180/855
CPUTIME (S)	1796.
REACTOR TIME	232.95
C(Total number of actives volumes in the model)	134
DT (Total number of time steps)	4659
CPU E+3/C x DT	2.876
CPUTIME/REACTOR TIME	7.71

Table 3.- Run statistics

VARIABLE	UNITS	C.TRILLO MEASURED	RELAP5/MOD2 CALCULATED
Primary Pressure	Pa	$1.585\ 10^7$	$1.583\ 10^7$
RCS average temperature	K	581.65	582.45
Pressurizer level	m	7.178	7.144
Reactor power	Mw	3002.11	3004.25
Secondary Pressure	Pa	$6.6875\ 10^6$	$6.7375\ 10^6$
Steam flowrate (S.G.1)	Kg/s	534.8	552.0
Steam flowrate (S.G.2)	Kg/s	544.5	552.8
Steam flowrate (S.G.3)	Kg/s	544.12	551.9
Feedwater flowrate (S.G.1)	Kg/s	559.12	550.
Feedwater flowrate (S.G.2)	kg/s	566.12	550.
Feedwater flowrate (S.G.3)	kg/s	549.06	550.
Steam generator level (S.G.1)	m	11.919	12.06
Steam generator level (S.G.2)	m	11.919	12.06
Steam generator level (S.G.3)	m	12.02	12.06

Table 4.- Steady state results versus plant data at the starting of turbine trip test (17 August-1988).

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10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

C. Trillo I has developed a model of the plant with RELAP5/MOD2/36.04. This model will be validated against a selected set of start-up tests. One of the transients selected to that aim is the turbine trip, which presents very specific characteristics that make it significantly different from the same transient in other PWRs of different design, the main difference being that the reactor is not tripped: a reduction in primary power is carried out instead. Pre-test calculations were done of the Turbine Trip Test and compared against the actual test. Minor problems in the first model, specially in the Control and Limitation Systems, were identified and post-test calculations had been carried out. The results show a good agreement with data for all the compared variables.

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

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Turbine Trip
Trillo

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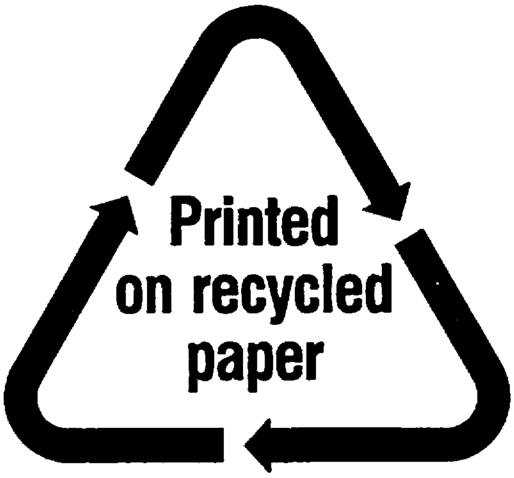
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