NUREG/IA-0107
ICSP-V2-R50-R

International Agreement Report

Assessment of RELAP5/MOD2 Against a Load Rejection From 100% to 50% Power in the Vandellos II Nuclear Power Plant

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U.S. Nuclear Regulatory Commission
Washington, DC 20555

June 1993

Prepared as part of
The Agreement on Research Participation and Technical Exchange
under the International Thermal-Hydraulic Code Assessment
and Application Program (ICAP)

Published by
U.S. Nuclear Regulatory Commission

NOTICE

Available from

Superintendent of Documents
U.S. Government Printing Office
P.O. Box 37082
Washington, D.C. 20013-7082

and

National Technical Information Service
Springfield, VA 22161

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ABSTRACT .

An assessment of RELAP5/MOD2 cycle 36.04 against a load rejection from 100% to 50% power in Vandellós II NPP (Spain) is presented. The work is inscribed in the framework of the spanish contribution to ICAP Project.

The model used in the simulation consists of a single loop, a steam generator and a steam line up to the steam header all of them enlarged on a scale of 3:1; and full-scaled reactor vessel and pressurizer.

The results of the calculations have been in reasonable agreement with plant measurements.

All major trends and phenomena are correctly reproduced. The discrepancies between calculated nuclear power and plant data are likely due to wrong values of the Doppler coefficient, and in less degree to rod worth uncertainty.

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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

An assessment of RELAP5/MOD2 cycle 36.04 against a load rejection from 100 % to 50% power in the Vandellós II nuclear power plant is presented. The work is inscribed in the framework of the spanish contribution to ICAP Project.

Vandellós II is a plant owned by ENDESA (72 %) and HIDROELECTRICA ESPAÑOLA (28 %) located in Tarragona (Spain).

The transient under study was part of the preoperational test program and a large number of plant signals were recorded by the Signal Acquisition System. In this transient all important control systems took into action.

The model used consisted of a single loop, a steam generator and a steam line up to the steam header all of them enlarged on a scale of 3:1, and full-scaled reactor vessel and pressurizer.

The analysis followed the usual steps: modelling of the plant; calculation of the plant steady state previous to the test; calculation of the transient; and comparison with plant measurements.

Calculations were carried out using Cycle 36.04 of RELAP5/MOD2 code installed in the CDC CYBER 830 computer owned by the CSN.

The calculation results are in reasonable agreement with the plant measurements.

All major trends and phenomena are correctly reproduced. The discrepancies between calculated nuclear power and plant data are likely due to wrong values of the Doppler coefficient, and in less degree to rod worth uncertainty.

1. INTRODUCTION .

The results of an assessment of the RELAP5/MOD2 code against a load rejection are presented in this report. This work is inscribed in the Spanish contribution to the International Code Assessment and Applications Program (ICAP). Its main additional objective is to promote the elaboration of a Vandellós II plant model with RELAP5/MOD2 code.

The transient under study was one of the preoperational tests of the Vandellós II nuclear power plant. A Signal Acquisition System recorded a large number of plant signals.

The analysis followed the usual steps: modelling of the plant; calculation of the plant steady state previous to the test; calculation of the transient; and comparison with the plant measurements.

Calculations were carried out using Cycle 36.04 of RELAP5/MOD2 code installed in the CDC CYBER 830 computer owned by the CSN .

This same load rejection test has been analyzed using the TRAC-PF1/MOD1 code by UITESA, in the framework of the Spanish contribution to ICAP [8].

2. PLANT AND TRANSIENT DESCRIPTION .

2.1 PLANT DESCRIPTION .

Vandellós II is a three-loop Westinghouse PWR nuclear power plant owned by ENDESA (72%) and HIDROELECTRICA ESPAÑOLA (28%). It is located in Tarragona, in the North-East of Spain, and uses the Mediterranean Sea as the final heat sink. The plant started its commercial operation in 1988. The nominal power is 982 MWe (2775 MWt).

The reactor vessel is cold head type The plant is equipped with three Westinghouse U-tube steam generators (model F) without preheaters. The feedwater is fed directly to the upper part of the downcomer via J-tubes. The circulation ratio on the secondary side of the steam generators is 3.27 at rated power.

The Auxiliary Feedwater System consists of one turbopump and two motorpumps.

In the plant there are, among others, control systems for the reactivity (rods and boron), primary pressure, pressurizer level, steam dump and steam generator level. The Reactor Protection System includes safety valves in the pressurizer and the steam generator.

The main plant features are shown in Table I.

2.2 PLANT SIGNAL ACQUISITION SYSTEM DESCRIPTION .

To record the main parameters of the plant, during the startup period (including the transient under study), a temporary Signal Acquisition System was installed. It consisted of a digital system with an up to 0.05 seconds and 144 signals trail capacity.

The recorded parameters depended on the test carried out.

The quickness of data attainment was very important to improve the time required for data interpretation. For this reason, once the nuclear plant tests had finished, Vandellós II NPP decided to install a permanent equipment in order to interpret and analyze the transients.

The availability of this great number of signals allows to check the partial performances of the control blocks, specially those of feedwater control, rod control and steam dump.

2.3 TRANSIENT DESCRIPTION

The transient under study is a startup load rejection from 100% to 50% power. It was conducted on February 27th, 1988.

Objectives of this test were to verify the ability of the plant to accept a 50% load rejection, reaching stable conditions; and to make some evaluations (response times of RTD's, changes in control systems setpoints...).

Previously to the test, the plant was in stable regime, at 100% power. All control systems were correctly performing in automatic mode.

The transient started with a manual load rejection programmed with the Digital Electro-Hydraulic system (D.E.H.) which reduced mass steam flow with a rate of 200% per minute. After this, the hot leg temperature decreased, and so did pressurizer pressure and level. The spare heaters activated when the corresponding setpoints were reached.

The load rejection produced a quick secondary pressure increase. This fact deteriorated the primary-to -secondary side heat transfer in the steam generator, and had as a consequence a slight increase in the primary temperatures during the early seconds of the transient.

As a result of the load rejection, the reference temperature suddenly changed from full load to 50% load, and there was a significant temperature error which produced the quick opening of the steam dump valves and control rods insertion at the maximum speed. The combined effect of both systems drove the primary average temperature to the new reference value.

The primary-to-secondary heat transfer decrease (and, in a lower scale, the secondary pressurization) originated a void collapse in the steam generator, resulting in an early fall of the downcomer liquid level. The corresponding control system recovered the level to its reference value (50% narrow range).

During the transient 144 plant signals were monitored by means of a Signal Acquisition System, with a frequency of 0.05 seconds, and stored in a computer.

There were not plant values to know the actual response (dead times and movement velocity) of the steam dump valves, and the valve positions were not recorded.

3. CODE INPUT MODEL DESCRIPTION .

The plant model (Fig. 1) consists of a single loop, a steam generator, and a steam line up to the steam header, all of them enlarged on a scale of 3:1; and full-scaled reactor vessel and pressurizer. It derives from the 1:1 nodalization of each individual component, separately elaborated and tested. The scaling was done by triplicating the values of flow cross sections and heat transmission areas; pump torque, flow and inertia were also multiplied by 3. Such a model is appropriate to the transient under study, which is basically symmetric. The nodalization includes 118 hydrodynamic volumes, 123 junctions and 78 heat structures, with 316 mesh points.

The boundaries of the model are feedwater collector, turbine and CVCS tank, simulated by means of RELAP Time Dependent Volumes (TMDPVOL).

Point kinetics is used to simulate the source of power. So, the plant model will be unable to reproduce the axial power distribution change that take place as the control rods are going up or down through the core and the effect that this change produces in reactivity coefficients.

This plant model was based on a RETRAN two-loop model [3], and incorporated additional plant data. The corresponding nodalization studies are detailed in [6].

3.1 PRIMARY SYSTEM .

Includes the reactor vessel, loops, steam generator primary side, pumps and pressurizer.

The loop is scaled-up 3:1, excluding the vessel and pressurizer, which are full-scale. Each component of the model has been separately tested.

The reactor vessel is cold head type. The dome has been separated in three nodes, representing the upper zone, the inner circular one and the surrounding annulus, respectively. The upper plenum consists of two volumes, to ensure the proper connection of the outlet junction. The lower plenum has been also split in two nodes: one previous to the active core and the other one representing the hemispheric zone.

The reactor core has been simulated with six control volumes and a heat structure with six axial nodes. Use of the point kinetics model of the code has been done, with a null moderator temperature coefficient (because the test under study was done at beginning of life). RELAP5/MOD2 cannot account for the change of this coefficient with control rods position. The Doppler coefficient value and the rod worth were not well known. Design values for beginning of life and all rods off were used.

The core bypass path is divided in six nodes. Both the core bypass and bypass-to-head flow rates have been tuned through the energy loss coefficients.

Cylindric heat structures represent the heat losses through the vessel walls.

The pressurizer nodalization includes ten hydrodynamic volumes. The surge line is split in two PIPE components, accounting for the horizontal and vertical zone, respectively. Heat structures are used to represent the heaters and heat losses to the environment, trying to obtain a realistic temperature distribution. Relief and safety valves have also been simulated.

Homologous curves for the primary coolant pumps performance have been obtained through characteristic curves. Only data for normal operation conditions were included in the input deck. The moment of inertia, and rated flow, torque and motor torque have been triplicated.

The primary side of the steam generator has been split in 12 nodes, two of which represent the inlet and outlet chambers. The U-tubes have 10 nodes, with increasing length in the direction of flow, in order to reproduce in detail the temperature profile and enhance the primary-to-secondary heat transfer.

3.2 SECONDARY SYSTEM

The three steam generators have been unified, and so have been the steam lines up to the collector. Mean values have been assumed in the pipe simulation, because they are not exactly equal in the plant.

The steam generator has been modelled in a great detail [6]. Heat losses to the environment are represented by RELAP heat structures. It is interesting to point the existence of a heat structure which connects the boiler volumes and those of the downcomer, representing the wrapper.

The moisture separators zone has been modelled by means of an "ideal" SEPARATR component.

Relief valves are simulated by VALVE components; and safety valves, by Time Dependent Junctions (TMDPJUN). No one was activated during the transient under study.

Downstream the steam header, the four turbine admission valves are assimilated to one VALVE. Four VALVE components represent the four banks in which gather the 12 steam dump valves, and account for the modulate behaviour of this system. Its capacity is adjusted to ≈36% of the full power steam mass flow at nominal pressure. A Time Dependent Junction accounts for the steam extraction towards the MSR, ejectors, turbopumps, etc...

3.3 CONTROL SYSTEMS

The following control systems have been included in the plant model :

- Control rods.
- Pressurizer level control.
- Pressurizer pressure control.
- Steam dump control.
- Steam generator level control.

The five groups have been simulated according to the plant design [6]. The plant actual control setting values during the test have been used as setpoints.

The CVCS charge was simulated by means of a VALVE and a TMDPVOL. The discharge was represented by a TMDPJUN extracting a continuous mass flow of 2.6 Kg/s from the primary system. Such a model is judged right for the purposes of this analysis.

The steam generator level control system did not include the speed control of the turbine driven pumps, which were not modelled.

The steam mass flow has been used as a measure of the turbine power. It is more closely related to the impulse chamber pressure than the valve position [10].

4. STEADY STATE CALCULATION .

Before the test simulation, a null transient was run to establish the initial conditions.

The STDY-ST code option was used. To adjust the 100% power steady state, use was made of the data measured in the plant previously to the test, and showed in Table II. Other data that were used are :

- Design values of the core bypass mass flow rates
- Standard pressure losses in a PWR-W vessel and loops [3].
- Design steam generator recirculation ratio.
- Design heat losses to the environment.

In this job was very useful the achievement of steady states for isolated components, such as reactor vessel, steam generator and pressurizer.

The energy loss coefficients in the junctions were assigned Handbook values [5], and then tuned to adjust pressure losses or bypass flows. For instance, the core bypass mass flows were adjusted by properly tuning the energy loss coefficients in the reactor vessel.

To adjust the steady state use was made of the real plant control systems. In addition, a dummy control system was added to adjust the primary mass flow rate by tuning the pump speed.

Known shortcomings in the RELAP5/MOD2 heat transfer correlations [2] forced to increase the primary-to-secondary heat transfer area in about 10 % to achieve the desired steady state.

Table II shows the comparison between the steady state values calculated by the code and those measured in plant. Signed with an asterisk are the parameters used to define the steady state [9]; they were thus controlled or imposed in the calculation. The agreement is good. Nevertheless, it is important to point that the calculated steam generator water mass is ~30% lower than the reference full power value.

5. TRANSIENT RESULTS .

5.1 BOUNDARY CONDITIONS .

The simulation started with the turbine valve closure from 37.32% to 17.39% (of around 53%) in ≈15.5 seconds, (Fig. 2). The valve position was imposed in order to match the turbine steam mass flow rate.

A Time Dependent Junction was kept extracting a mass flow of 37.06 Kg/s from the steam collector volume, trying to represent the MSR's effect during the transient.

Header measured temperature and pressure were imposed as boundary conditions in the TMDPVOL representing the main feedwater source (Fig. 3 and 4).

5.2 TRANSIENT RESULTS .

The simulation was initiated from the already described steady state. The calculated sequence of events is compared with the measured one in Table III.

The plant data which appear in the figures are mean values of the three loops. No data uncertainty was available. Some calculation results have been filtered. The hot and cold leg temperatures are filtered by means of a 4 seconds LAG to evaluate the average temperature recorded by the control systems. The steam generator level, feedwater mass flow and steam mass flow, are lagged 0.25 seconds.

The turbine control valve began to close at 0. seconds. Thus the control rods started to be inserted, the steam flow decreased, and the steam line pressure rose.

Fig. 5 compares the calculated reactor power with the measured neutronic flux. The agreement was good until ≈40. seconds. Afterwards, the power was overpredicted, although the rod movement was well reproduced until ≈80 seconds (Fig. 6). The disagreement is likely due to wrong values of the Doppler coefficient, and in less degree to rod worth uncertainty (Fig. 7). This fact biased the evolution of main calculated variables.

In the early seconds, both hot and cold leg temperatures increased (Fig. 8), due to the degradation of the primary-to-secondary heat transfer. After ≈40 seconds both were overpredicted. Fig. 9 compares the calculated primary average temperature with the measured one. This Figure also includes the compensated average temperature, and the reference temperature. The large difference between them (Fig. 10 and 11) produced the early steam dump valves opening (Fig. 12), and the control rods insertion at the maximum speed (Fig. 13).

The vapour generation in the steam generator boiler decreased following the primary-to-secondary power. The combined effect of vaporization, steam dump performance and steam flow to the turbine produced a maximum in secondary side pressure at ≈ 48 seconds (Fig. 14). The position of this maximum depends on the opening velocity and dead times of the steam dump valves. Velocities and delays assumed in the calculation are mean values derived from the measures (in trip mode) taken for each valve during the preoperational tests program.

The combined action of steam dump and control rods brought the primary temperatures down to the 50% power values. The steam dump valves were demanded to start closing in the calculation 17 seconds later than in the plant. The demand of full closure delayed 360 seconds, due to the temperature overprediction.

Following the temperature trend, the calculated pressurizer level was greater than the plant data from ≃40 seconds on (Fig. 15).

The primary pressure is shown in Fig. 16. The peak was truncated due to the PORV and spray actuation. At long term the pressure control system activated heaters at full power and closed the spray valve trying to match the nominal value.

The steam generator level fell at the beginning of the transient due to void collapse. Calculated level dropped faster than measured one (Fig. 17). This may be attributed to the mentioned mass default in the steam generator. Through the whole transient the level was underestimated , but the calculated one matched the reference level from ≃100 seconds on.

The Fig. 18 shows the feed water mass flow rate that is consistent with the calculated steam mass flow rate and and steam generator level.

The steam mass flow rate at the steam generator outlet (Fig. 19) was overpredicted. The turbine flow rate matched the plant data (Fig. 20). So, the quoted discrepancy was due to a excessive steam dump capacity.

6. RUN STATISTICS .

The calculations were run on a CDC CYBER 830, owned by the CSN. The operating system was NOS 2.7 . The code cycle used was 36.04.

Table IV shows the run statistics for the steady-state run, and the transient run. Both in steady state and transient runs, it was specified a maximum time step of 0.05 seconds, lower than the Courant limit (about 0.06 seconds throughout the transient). So the code always used this maximum value.

The CPU time to transient time ratio has been around 42 . The grind time was 17.89 miliseconds

The CPU time and time step are plotted versus transient time in Fig. 21 and 22, respectively.

7. CONCLUSIONS .

The availability of a large number of plant variables through the Signal Acquisition System has allowed the performance of the present assessment exercise.

The calculation results are in reasonable agreement with the plant measurements.

All major trends and phenomena are correctly reproduced. The discrepancies between calculated nuclear power and plant data are likely due to wrong values of the Doppler coefficient, and in less degree to rod worth uncertainty.

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TABLE I

MAIN CHARACTERISTICS OF VANDELLOS II PLANT.

Thermal Reactor Power (MWt)	2775.
Electrical Power (MWe)	992.
Fuel	UO_2
Number of assemblies	157
Number of coolant loops	3
Cladding Tube Material	ZIRCALOY 4
Absorber Material	B_4C + Ag-In-Cd
Reactor Operating Pressure (MPa)	15.4
Coolant Average Temperature	
Zero Load (K)	564.8
100% Load (K)	582.3
Steam Generator	WESTINGHOUSE TYPE F
Number of tubes in SG	5626
Total Tube Length (m)	98759.
Inner Diameter Tubes (m)	0.0156
Tube Material	INCONEL
Pumps Type	WESTINGHOUSE D 100
Discharge Head of Pumps (bar)	18.8
Design Flow Rate (m3/s)	6.156
Speed of Pumps (rad/s)	155.
Primary Volume (m3)	106.19
Pressurizer Volume (m3)	39.65
Heating Power of the Heaters Rods (KW)	1400.
Maximum Spray Flow (Kg/s)	44.2
Steam Mass Flow Rate at 100% (Kg/s)	1515.

TABLE II

STEADY STATE VALUES

PARAMETER	MEASURED ‡	CALCULATED	
PRIMARY SIDE			
Core Power (%)	99.1	100.69	(*)
Mass Flow Rate (Kg/s)	----	14638.	
RCP Speed (Rad/s)	----	158.6	
RCP Head (MPa)	----	0.649	
Hot Leg Temperature (K)	597.3	597.1	
Cold Leg Temperature (K)	564.1	563.9	
Average Temperature (K)	580.7	580.5	
Delta T (%)	99.4	99.2	
Pressurizer Pressure (MPa)	15.41	15.45	(*)
Pressurizer Level (%)	57.2	56.7	(*)
SECONDARY SIDE			
SG Dome Pressure (MPa)	----	6.70	
SG Outlet Pressure (MPa)	6.5	6.60	
Collector Pressure (MPa)	6.35	6.57	
Feedwater Mass Flow (Kg/s)	1542.9	1525.4	
Steam Mass Flow (Kg/s)	1471.8	1528.5	(*)
Feedwater Temperature (K)	494.1	494.0	(*)
SG Level (%)	50.5	50.2	(*)
Recirculation Ratio	----	2.29	

‡ Average values.

(*) Controlled or imposed parameters.

TABLE III

SEQUENCE OF EVENTS .

EVENT	TIME (SECONDS) PLANT	RELAP5/MOD2
LOAD REJECTION	0.0	0.0
TURBINE VALVE START TO CLOSE	0.0	0.0
PERMISSIVE C-7 ON	2.0	
FIRST INSERTION OF CONTROL RODS	2.2-82.0	1.5-88.
STEAM DUMP DEMAND SIGNALS:		
OPENING BANK 1	6.5-9.5	9.5-12.
OPENING BANK 2	9.5-11.5	11.5-14.
OPENING BANK 3	11.5-13.5	13.5-15.5
OPENING BANK 4	13.5-15.5	15.5-16.5
CLOSING BANK 4	70.-78.	87.5-98.5
CLOSING BANK 3	78.-87.	98.5-175.5
CLOSING BANK 2	87.5-116.	175.5-297.
CLOSING BANK 1	116.-138	297.-498.
SPRAY OPENING DEMAND	7.7	10.
TURBINE VALVE STOP TO CLOSE	14.1	15.5
OPENING DEMAND OF PORV	23.0	23.5
CLOSING DEMAND OF PORV	---	24.0
SPRAY CLOSING DEMAND	38.5	62.0
SECOND INSERTION CONTROL RODS	103.-127.	103.5-
PERMISSIVE C-7 OFF	---	
FULL CLOSING DEMAND OF STEAM DUMP	137.5	498.

TABLE IV

CALCULATION	TT (S)	CPU (S)	TS (S)	CPU / TT	CN	TSN	GT (mS)
Steady State	228.4	9505.6	0.05	41.6	116	4570	17.93
Transient	300.	12665.8	0.05	42.2	118	6000	17.89

KEY :

TT : Transient Time
CPU : CPU Time
TS : Maximum Time Step
CN : Cells Number
TSN : Time Steps Number
GT : Grind Time (= CPU/(CN × TSN))

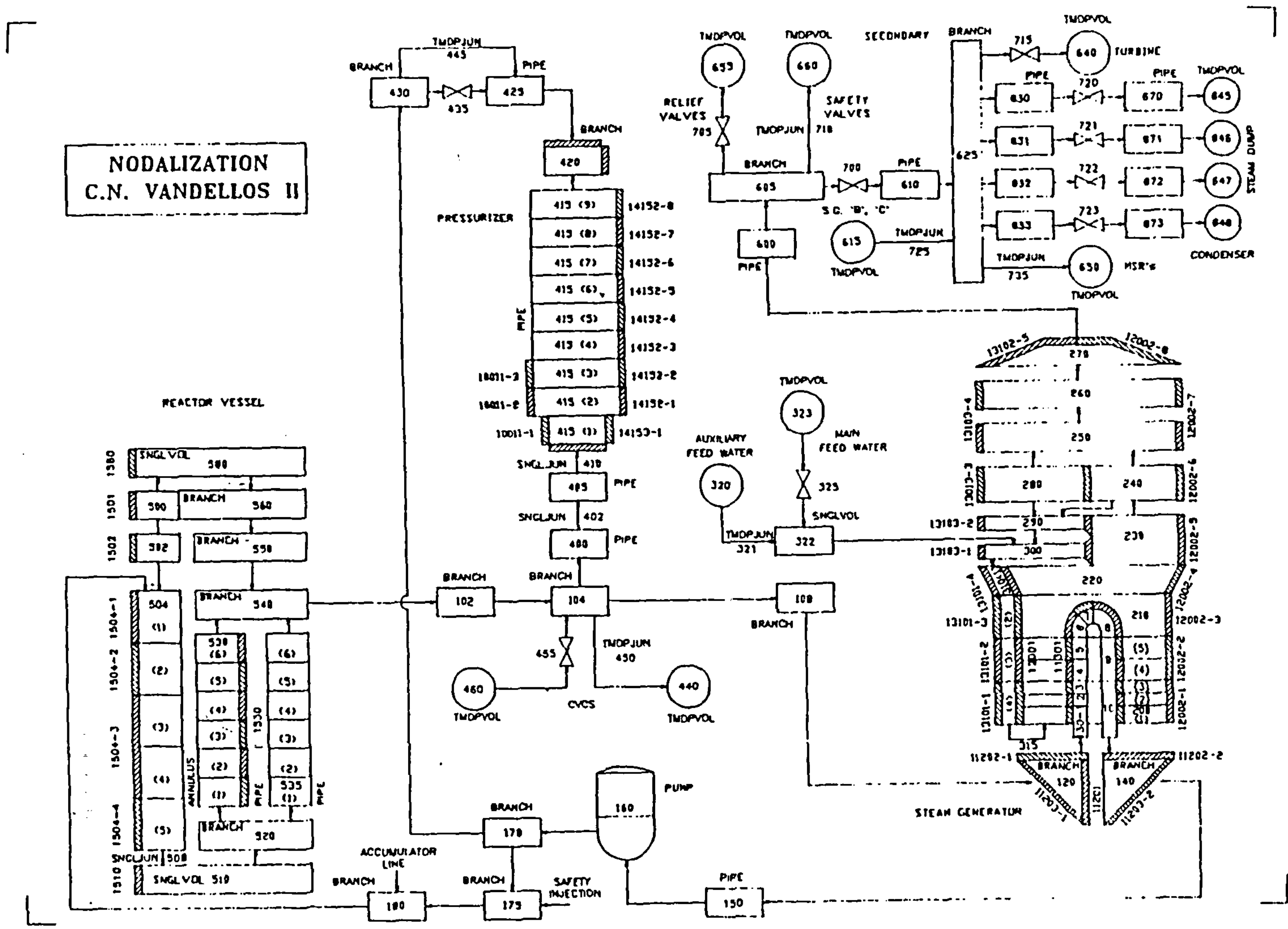

FIGURE 1 . RELAP5 NODING DIAGRAM FOR VANDELLÓS II NPP .

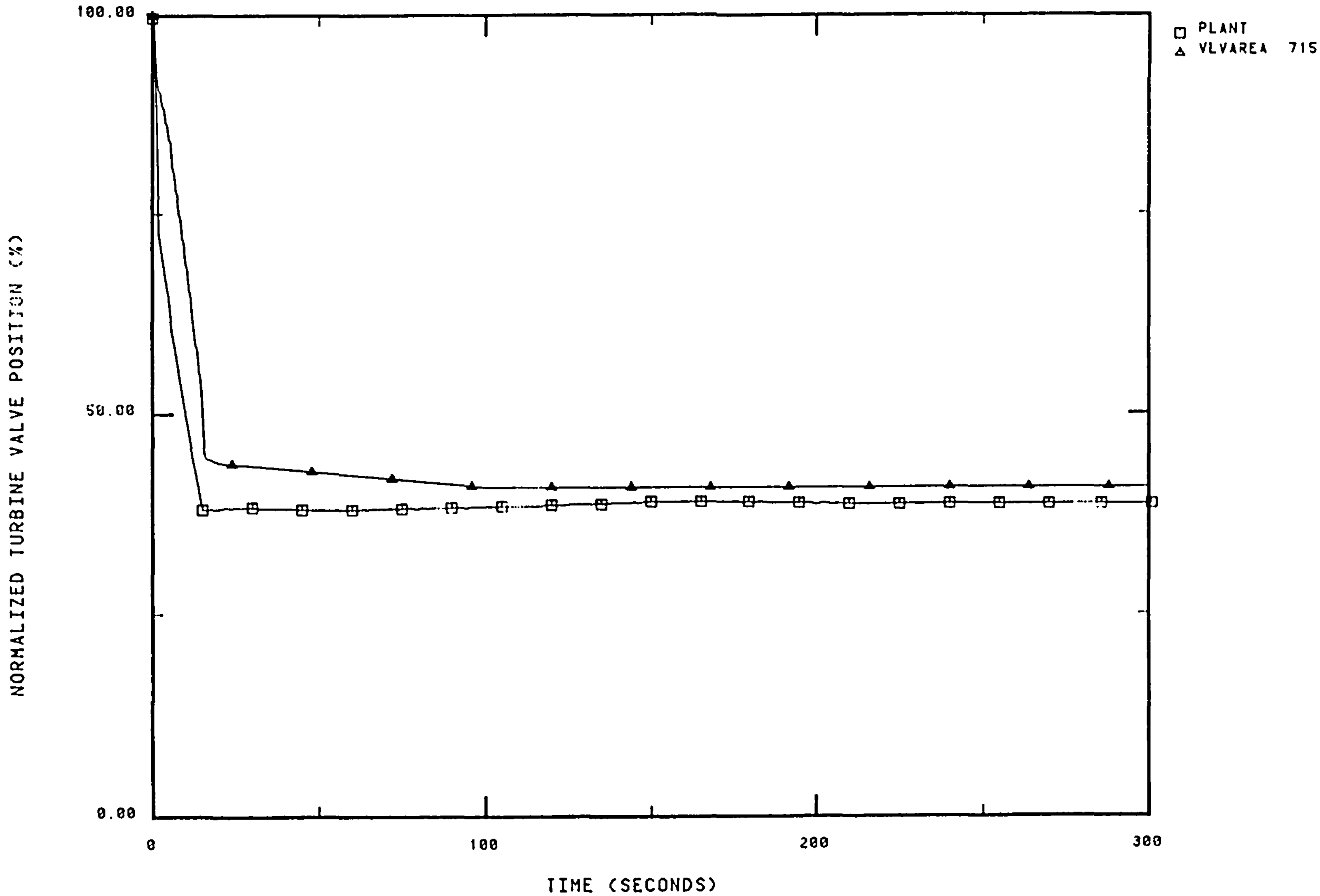

FIGURE 2 : TURBINE VALVE POSITION

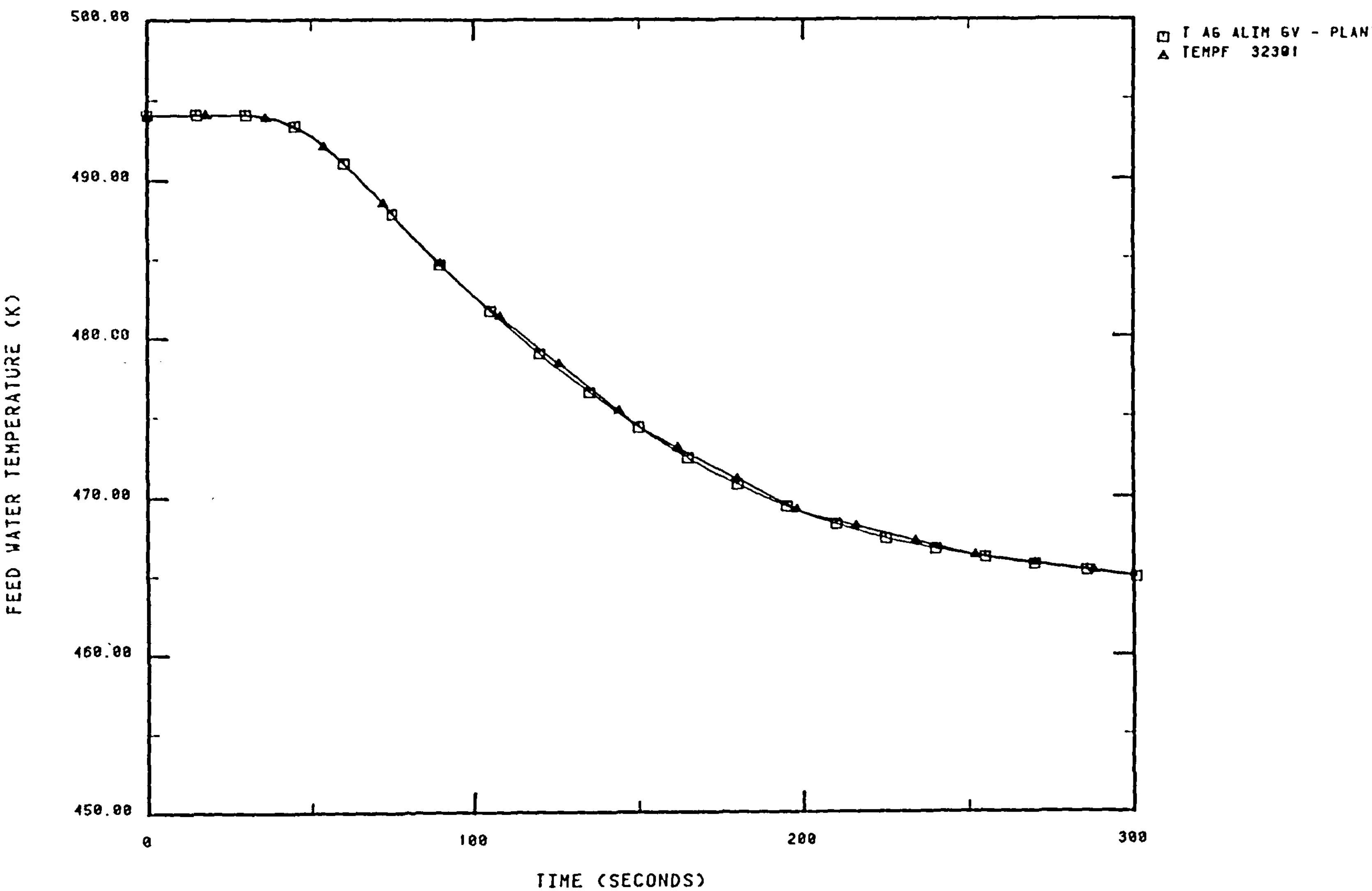

FIGURE 3 : FEED WATER TEMPERATURE

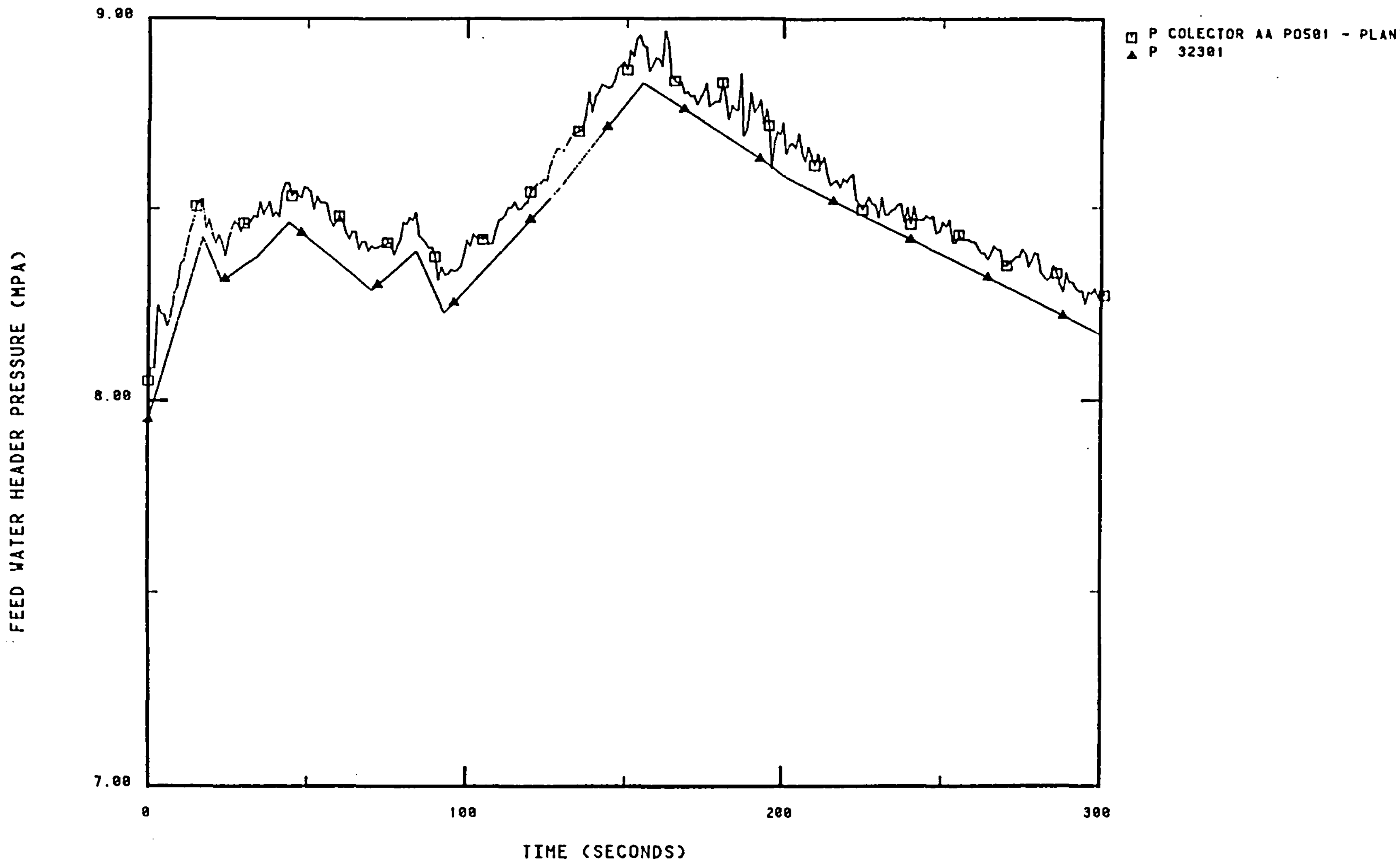

FIGURE 4 : FEED WATER PRESSURE

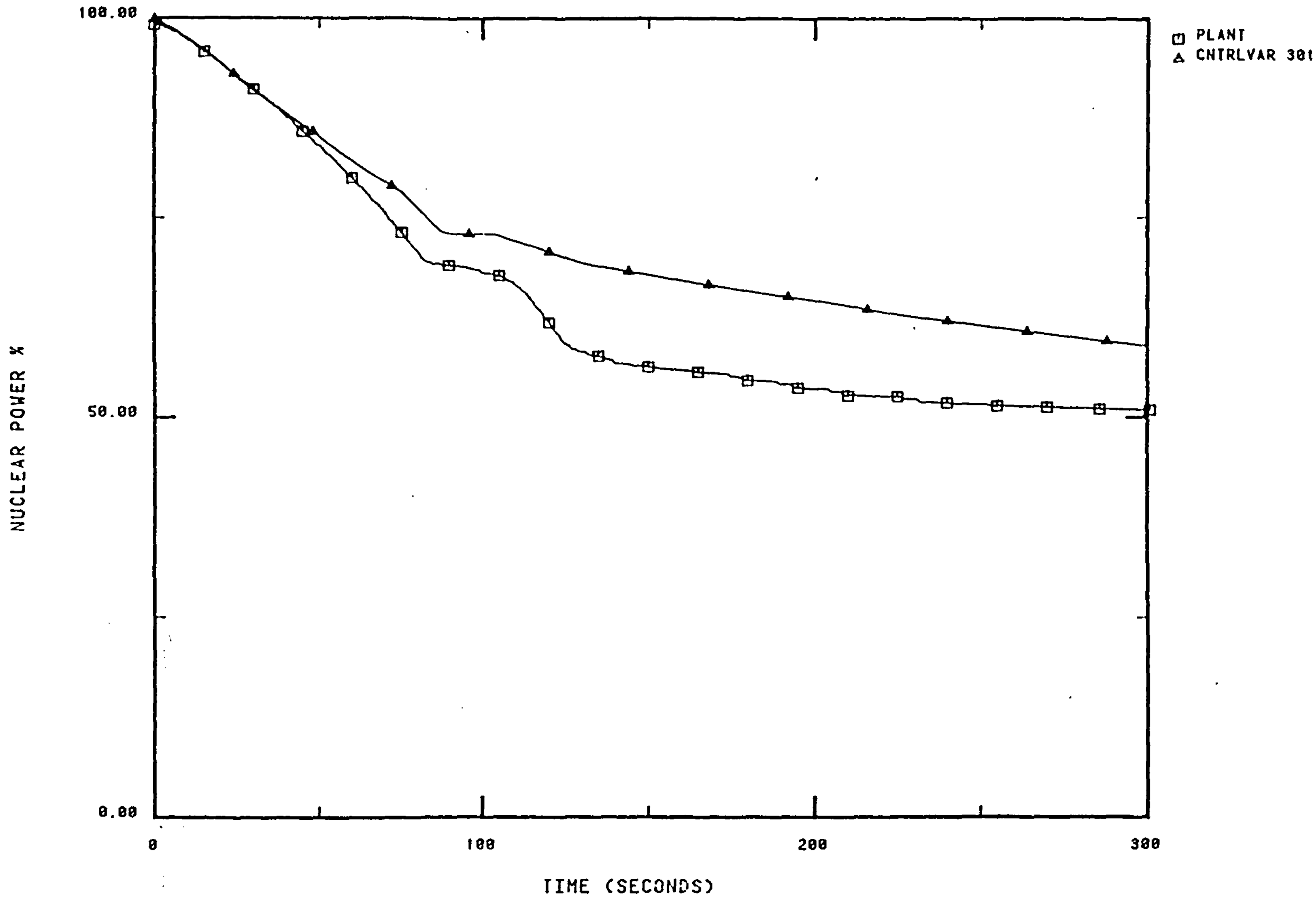

FIGURE 5 : REACTOR POWER

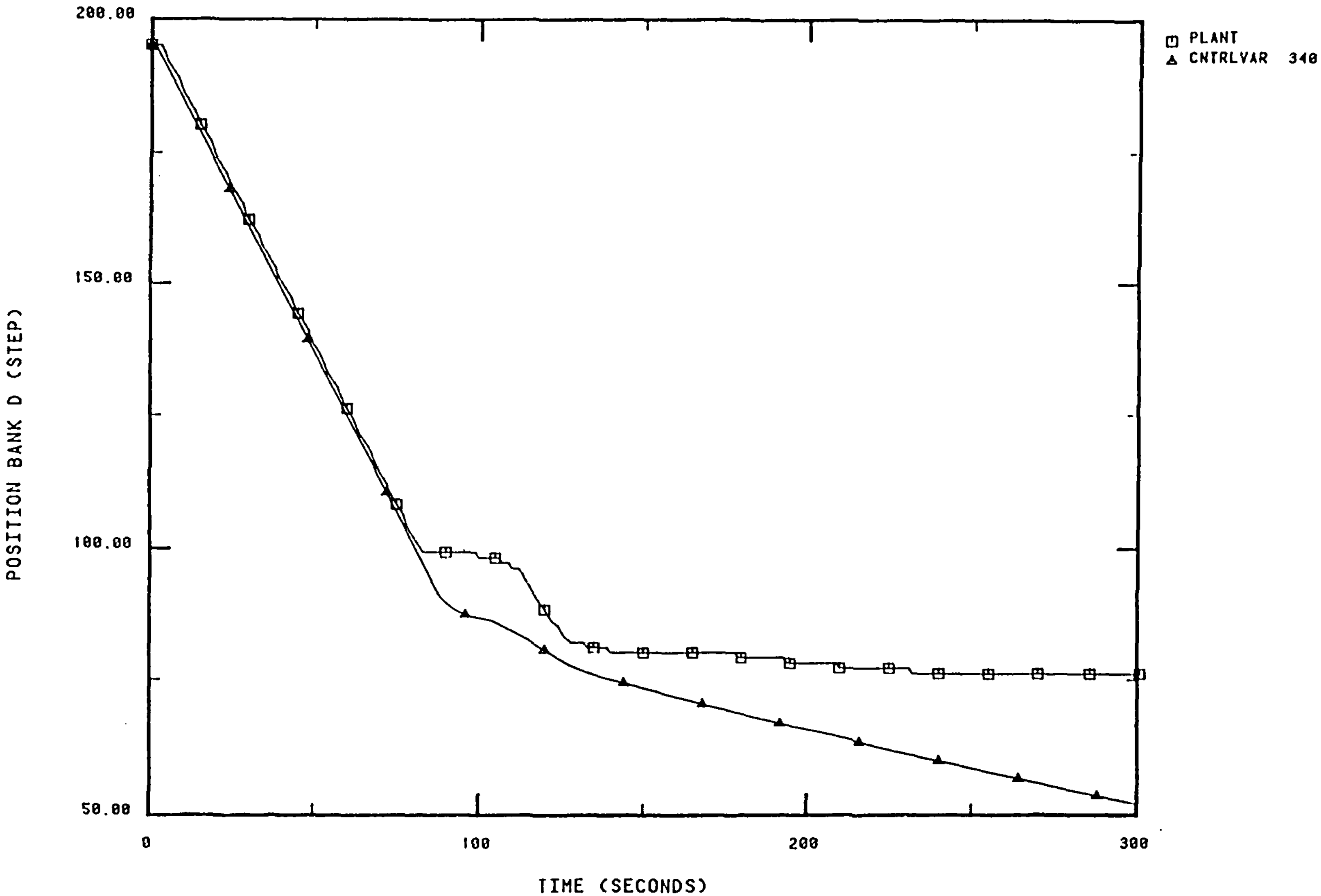

FIGURE 6 : CONTROL RODS POSITION

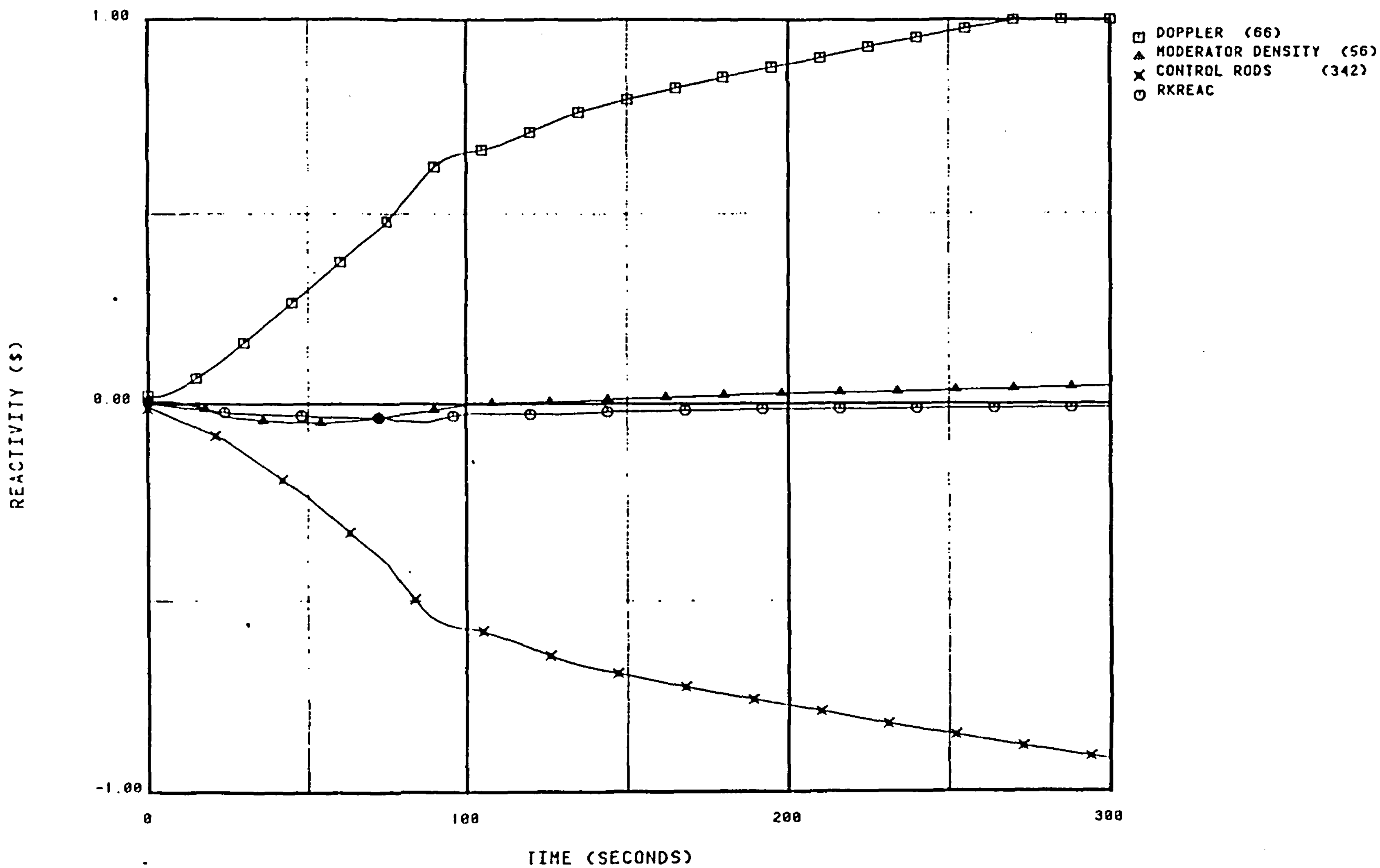

FIGURE 7 : REACTIVITY COMPONENTS

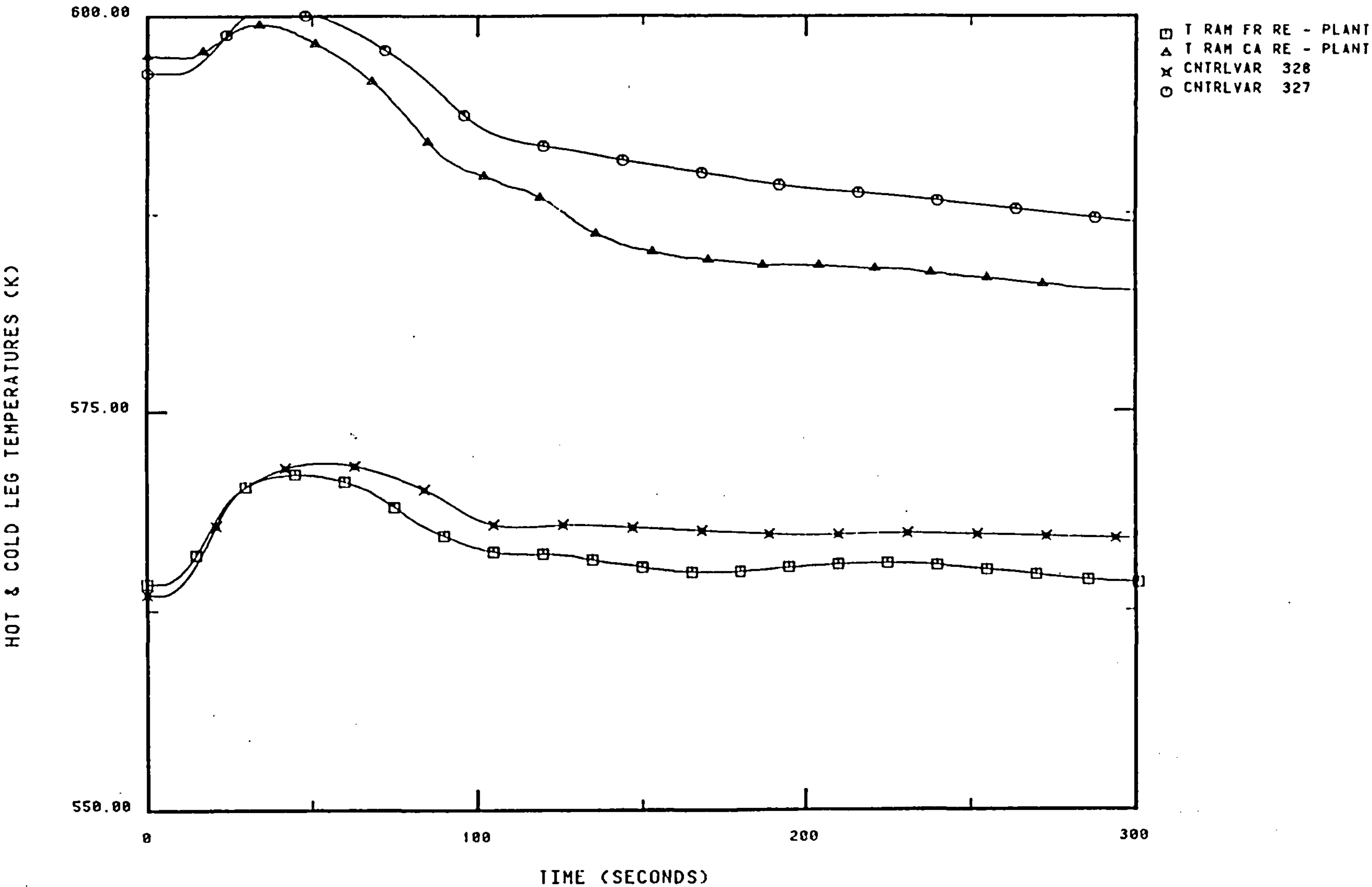

FIGURE 8 : PRIMARY TEMPERATURES

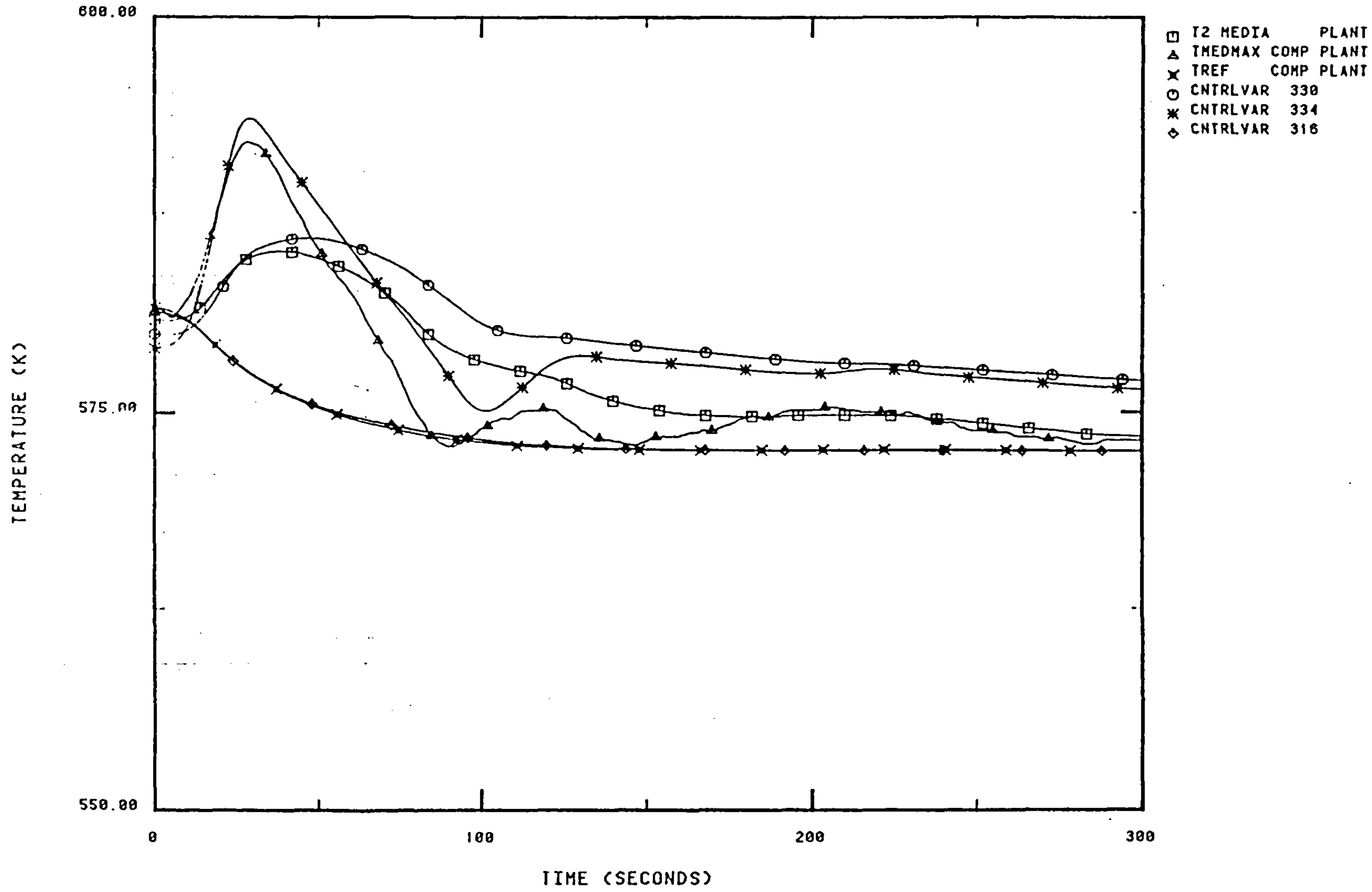

FIGURE 9 : PRIMARY AVERAGE TEMPERATURES

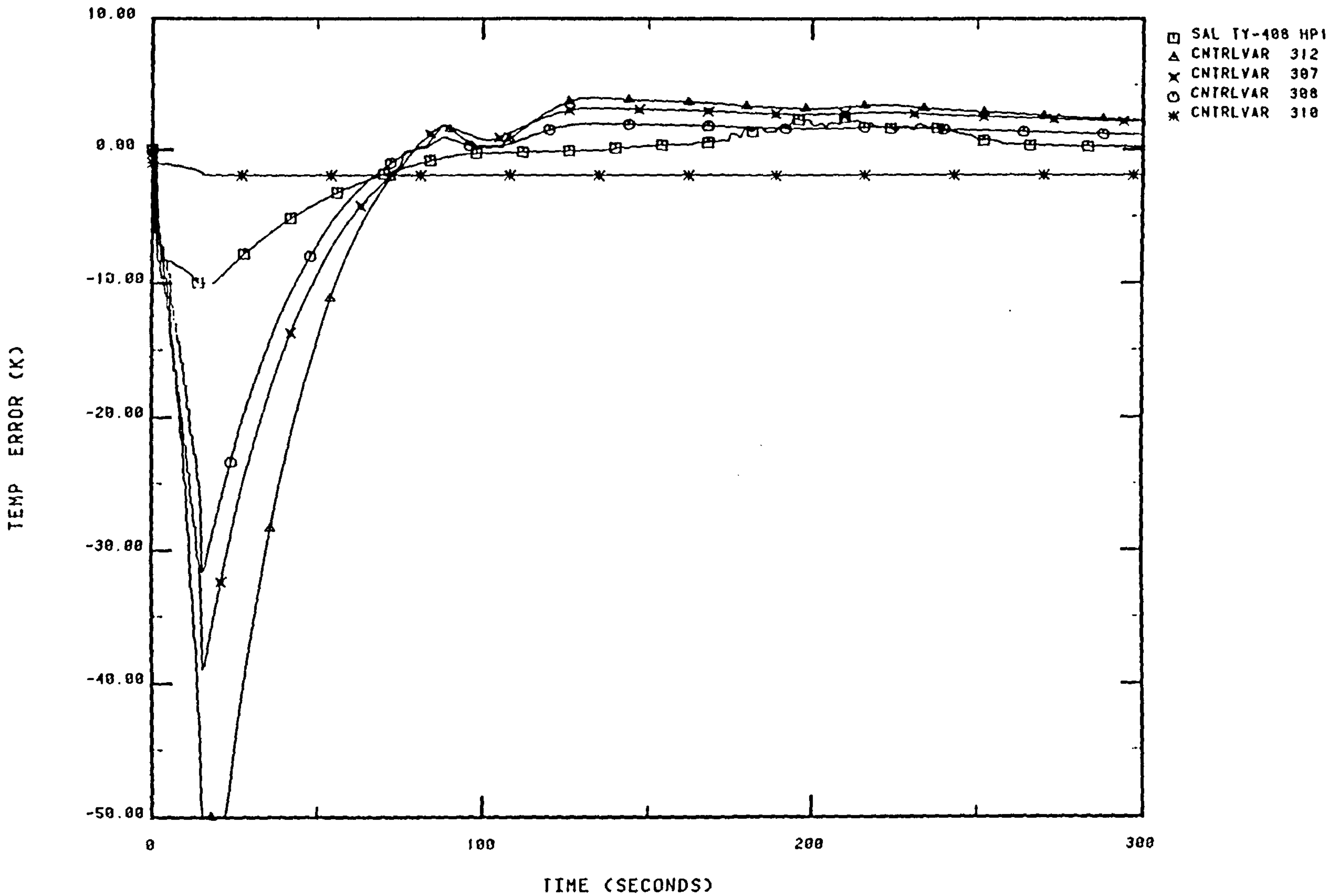

FIGURE 10: STEAM DUMP TEMPERATURE ERROR

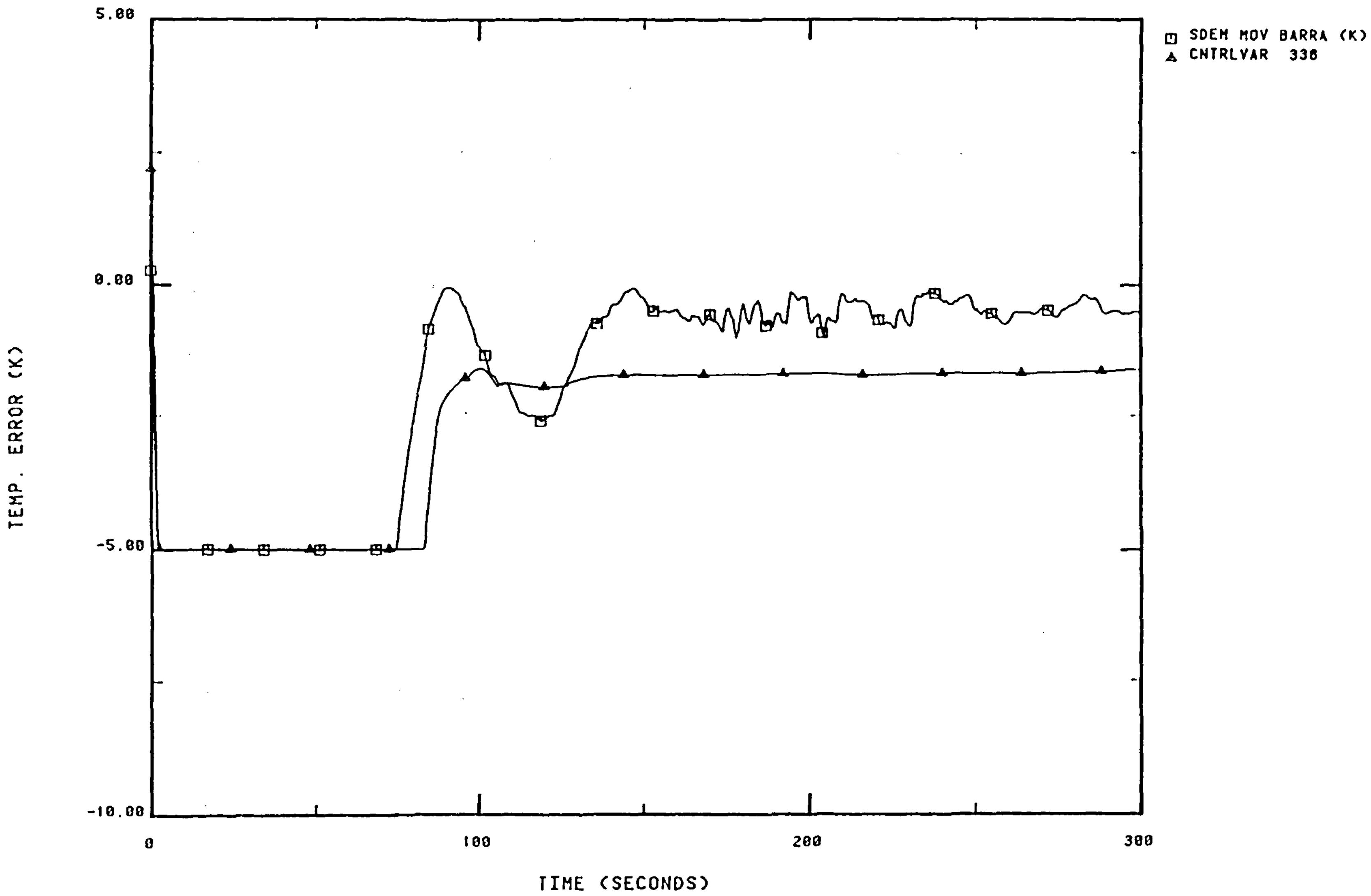

FIGURE 11 : ROD CONTROL TEMPERATURE ERROR

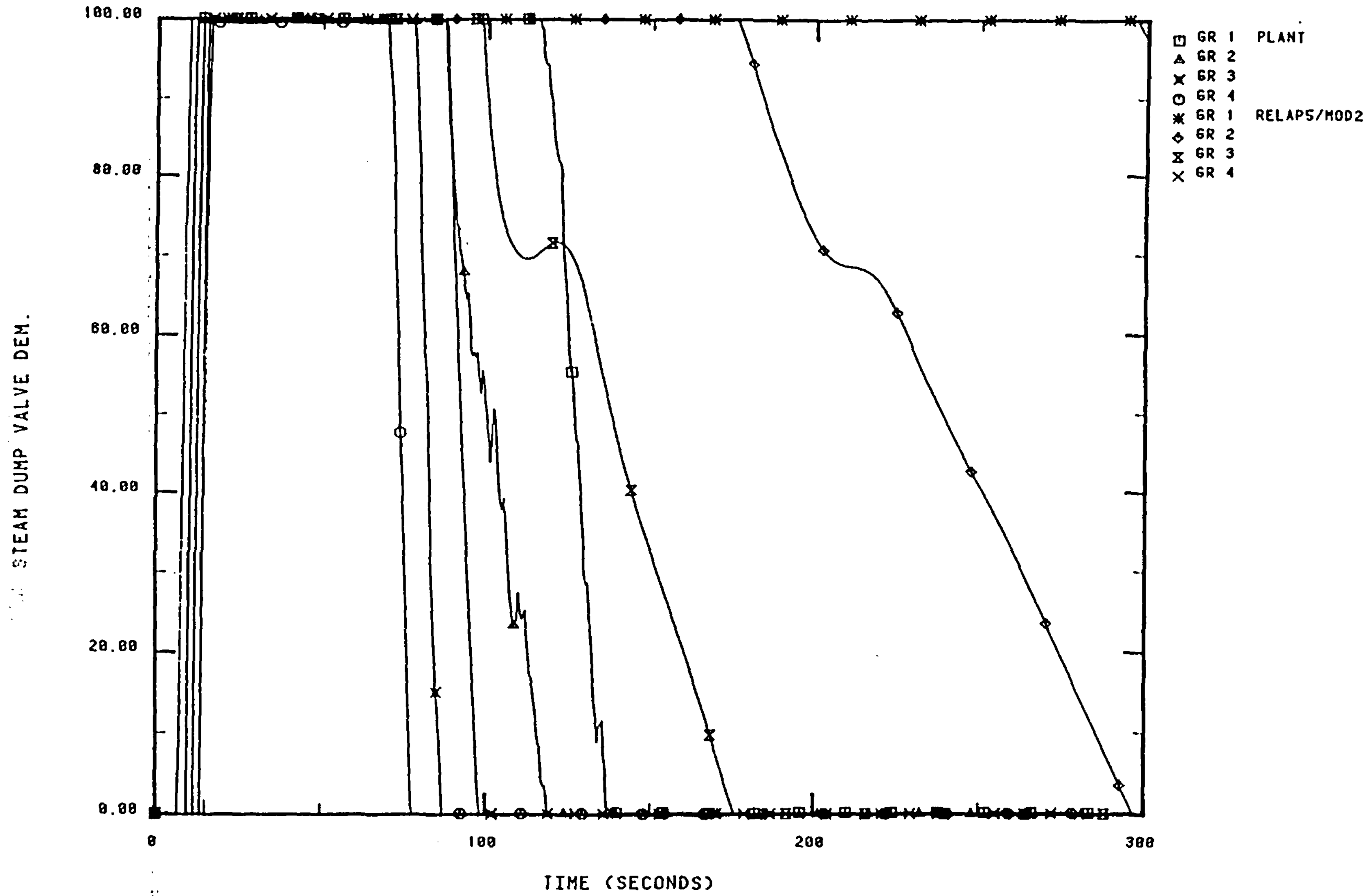

FIGURE 12: STEAM DUMP DEMAND

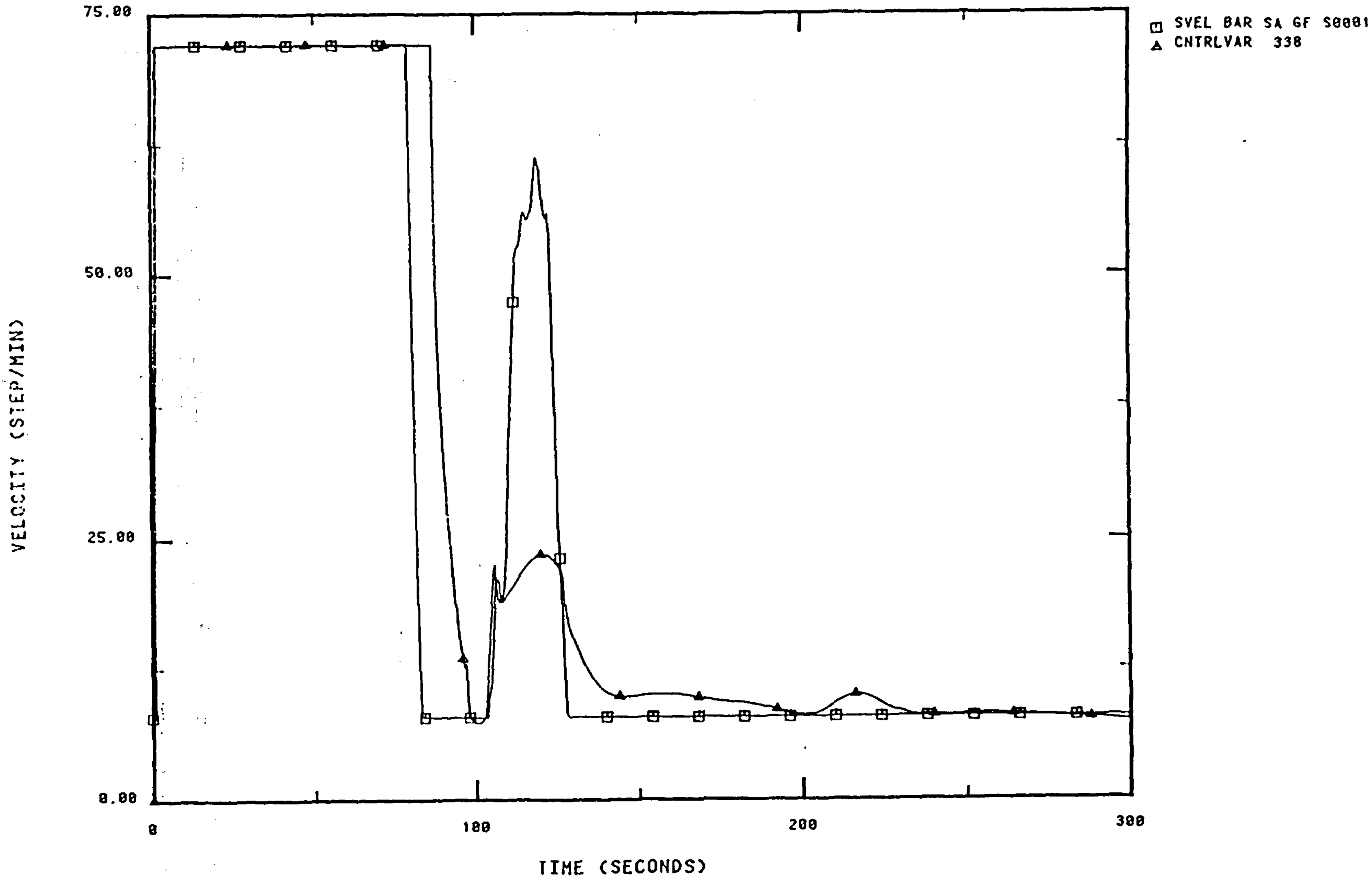

FIGURE 13: CONTROL RODS VELOCITY

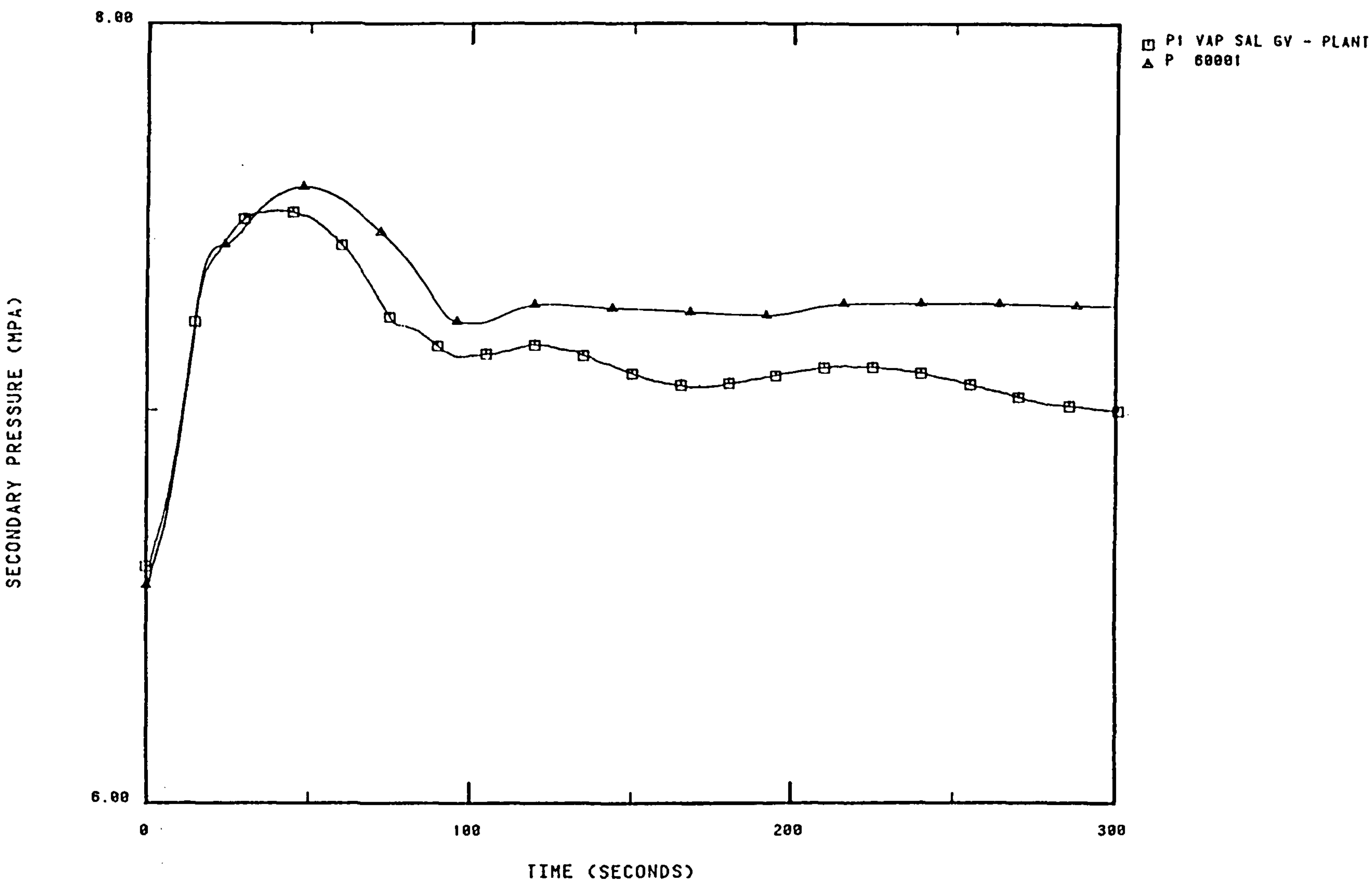

FIGURE 14: SECONDARY SIDE PRESSURE

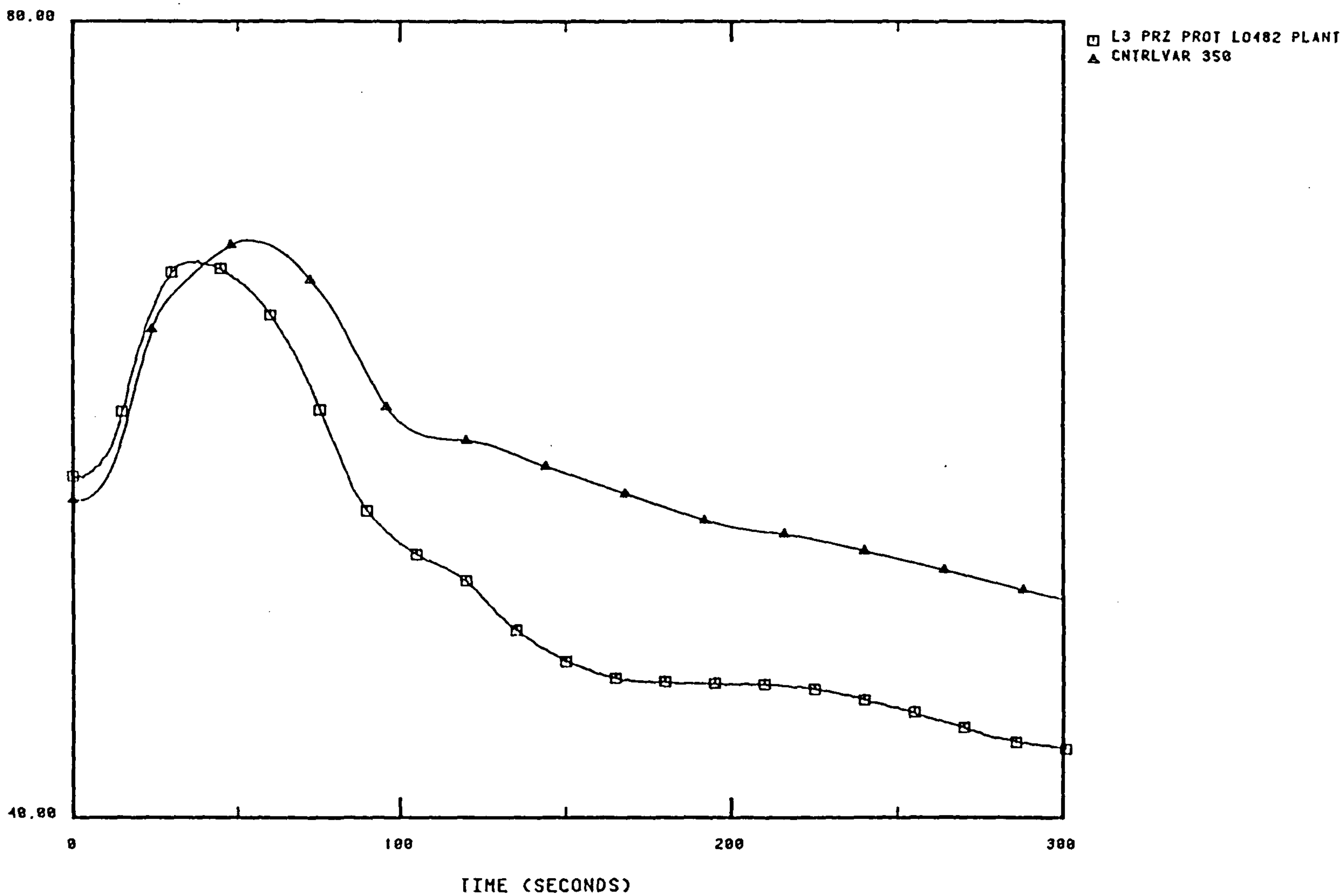

FIGURE 15: PRESSURIZER LIQUID LEVEL

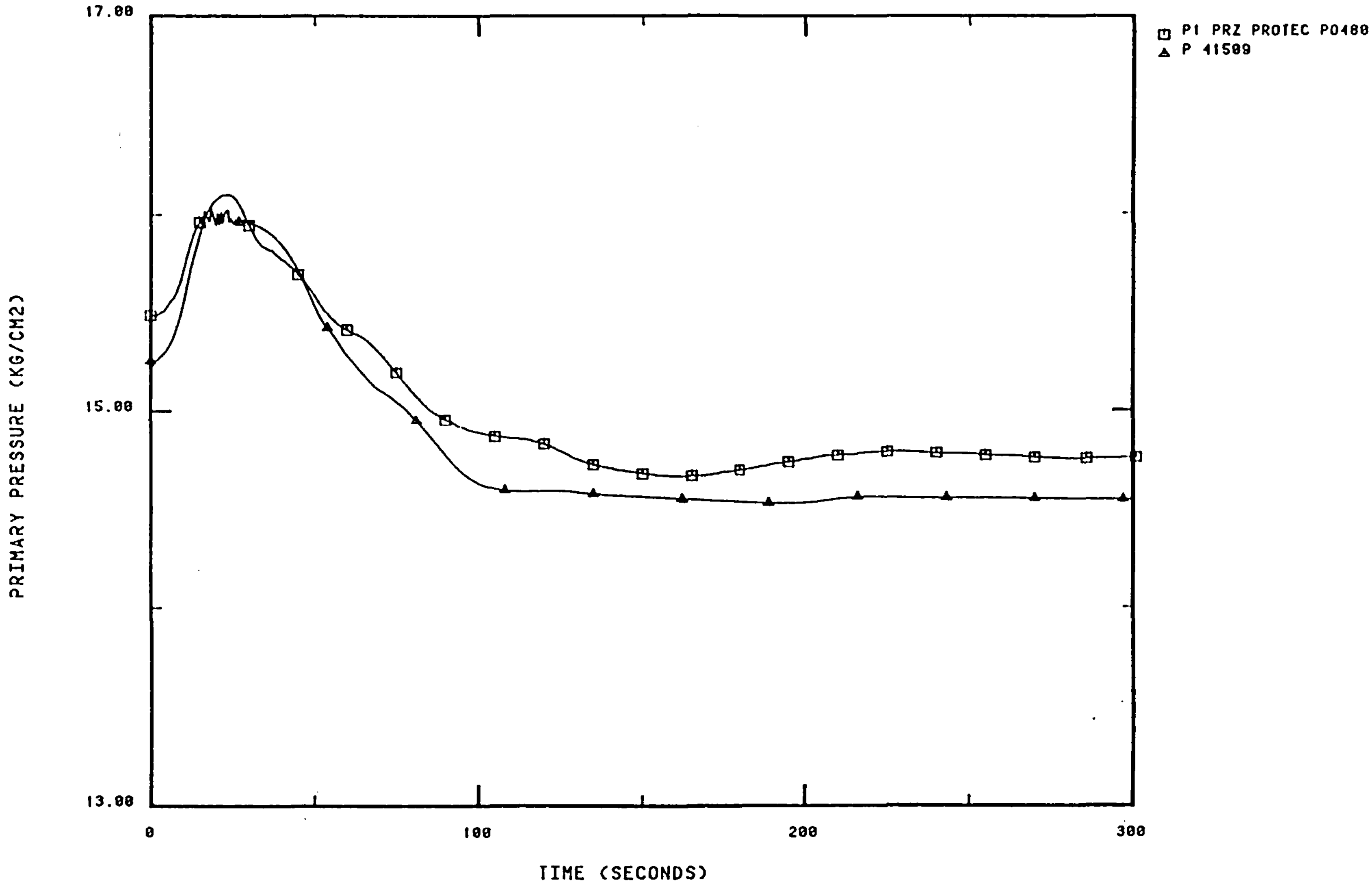

FIGURE 16: PRIMARY SIDE PRESSURE

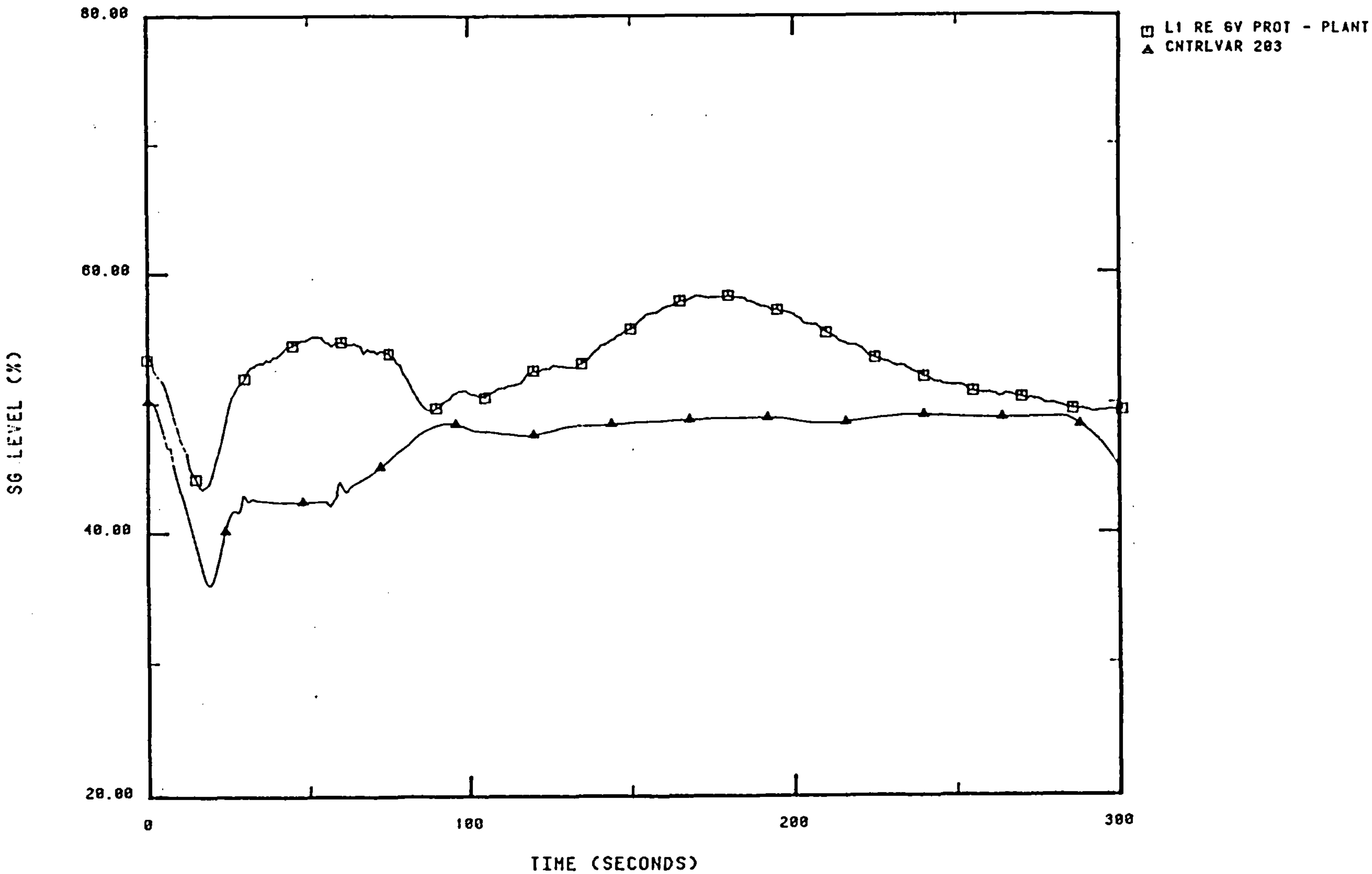

FIGURE 17 : STEAM GENERATOR LEVEL

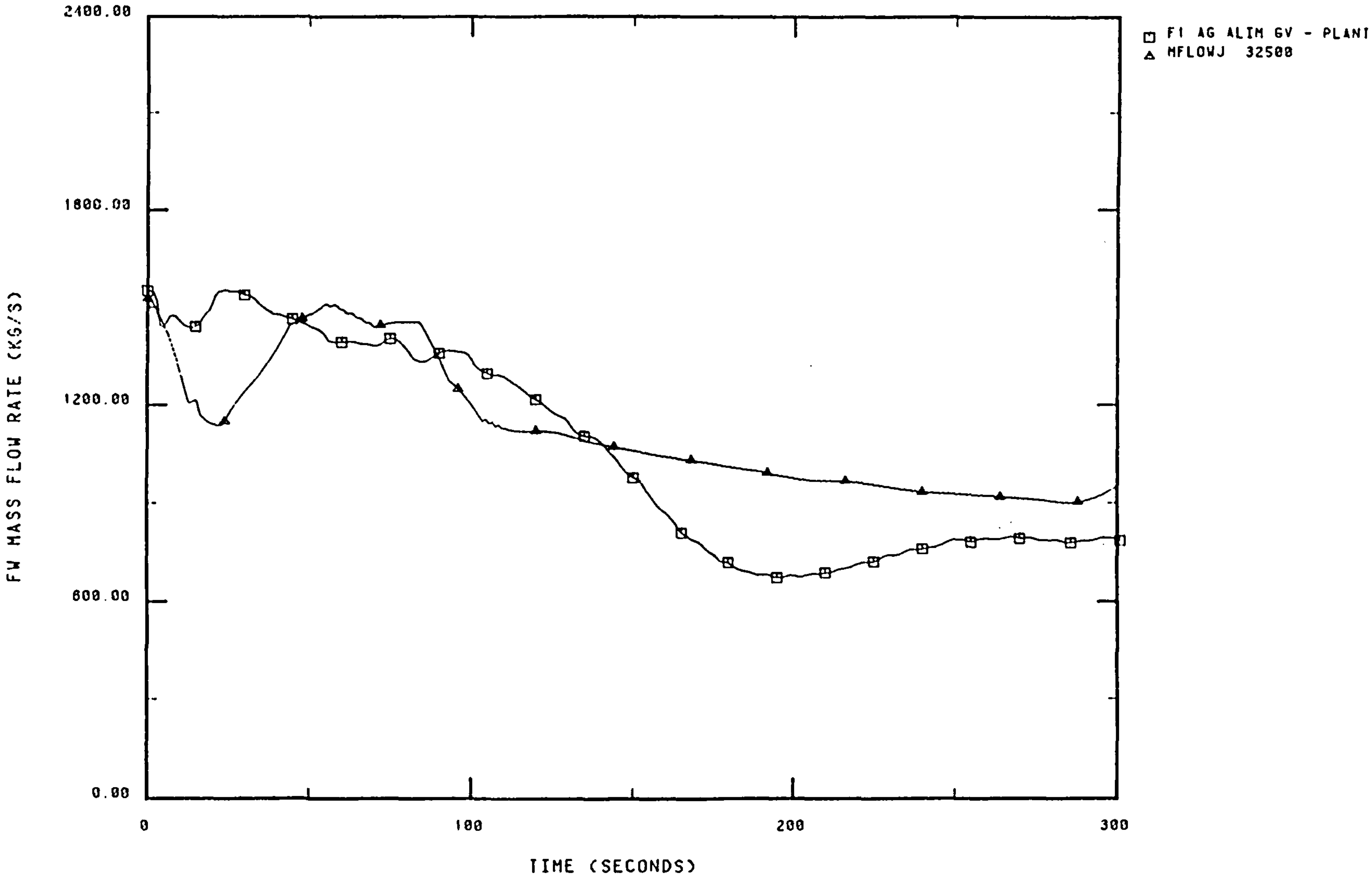

FIGURE 18: FEED WATER MASS FLOW RATE

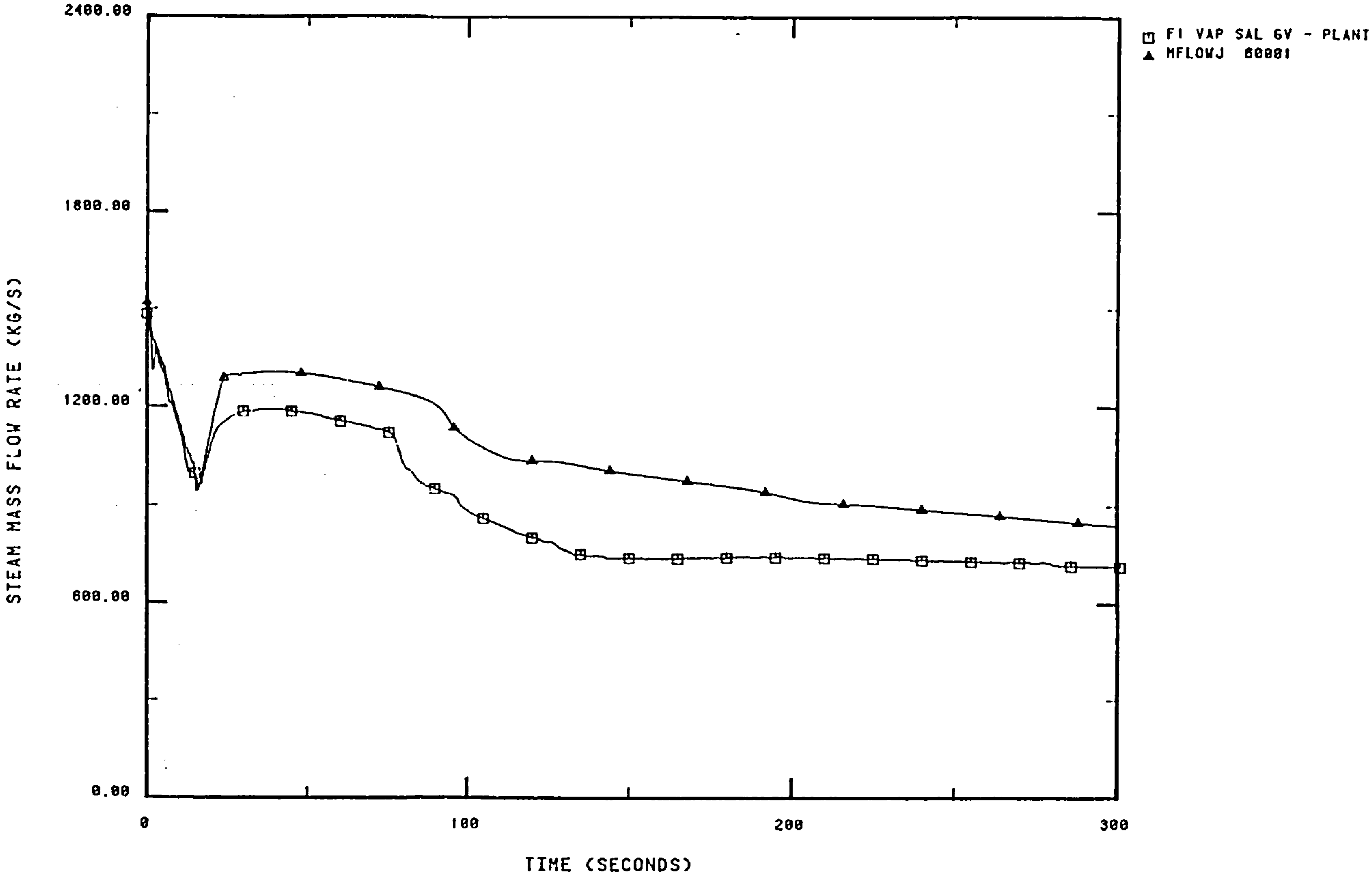

FIGURE 19: STEAM MASS FLOW RATE (SG. OUTLET)

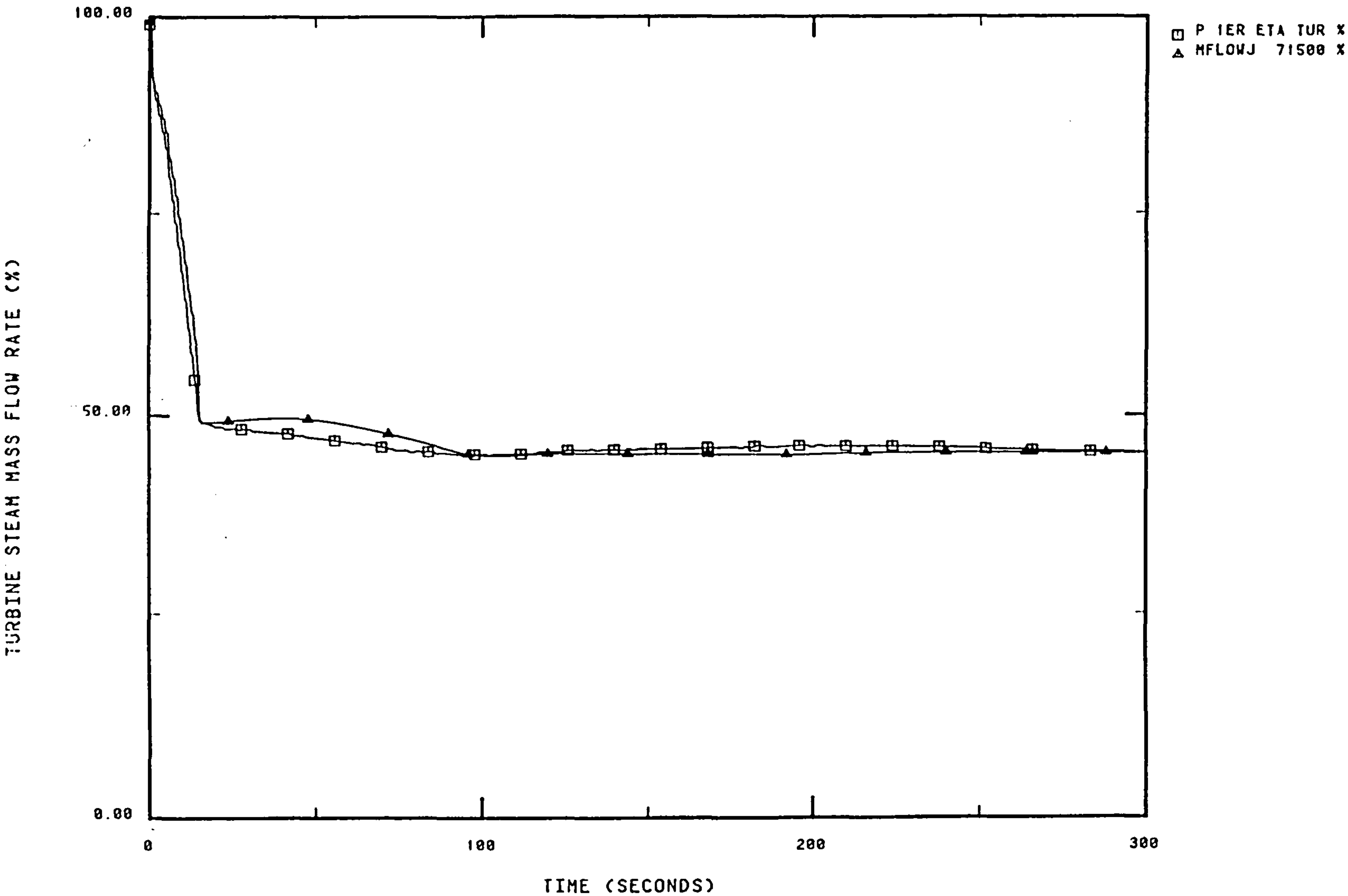

FIGURE 20: STEAM MASS FLOW RATE (TURBINE)

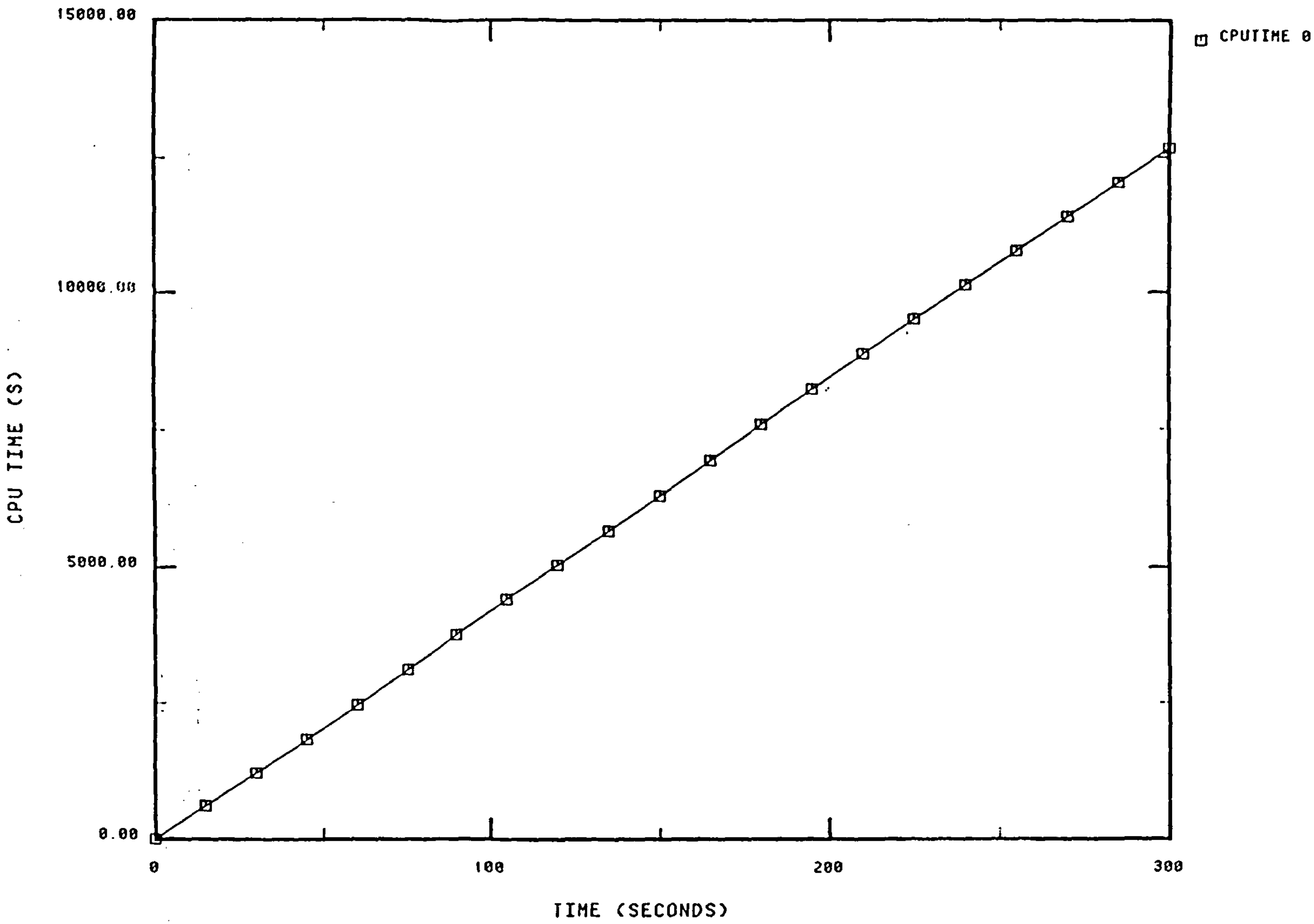

FIGURE 21 : CPU TIME

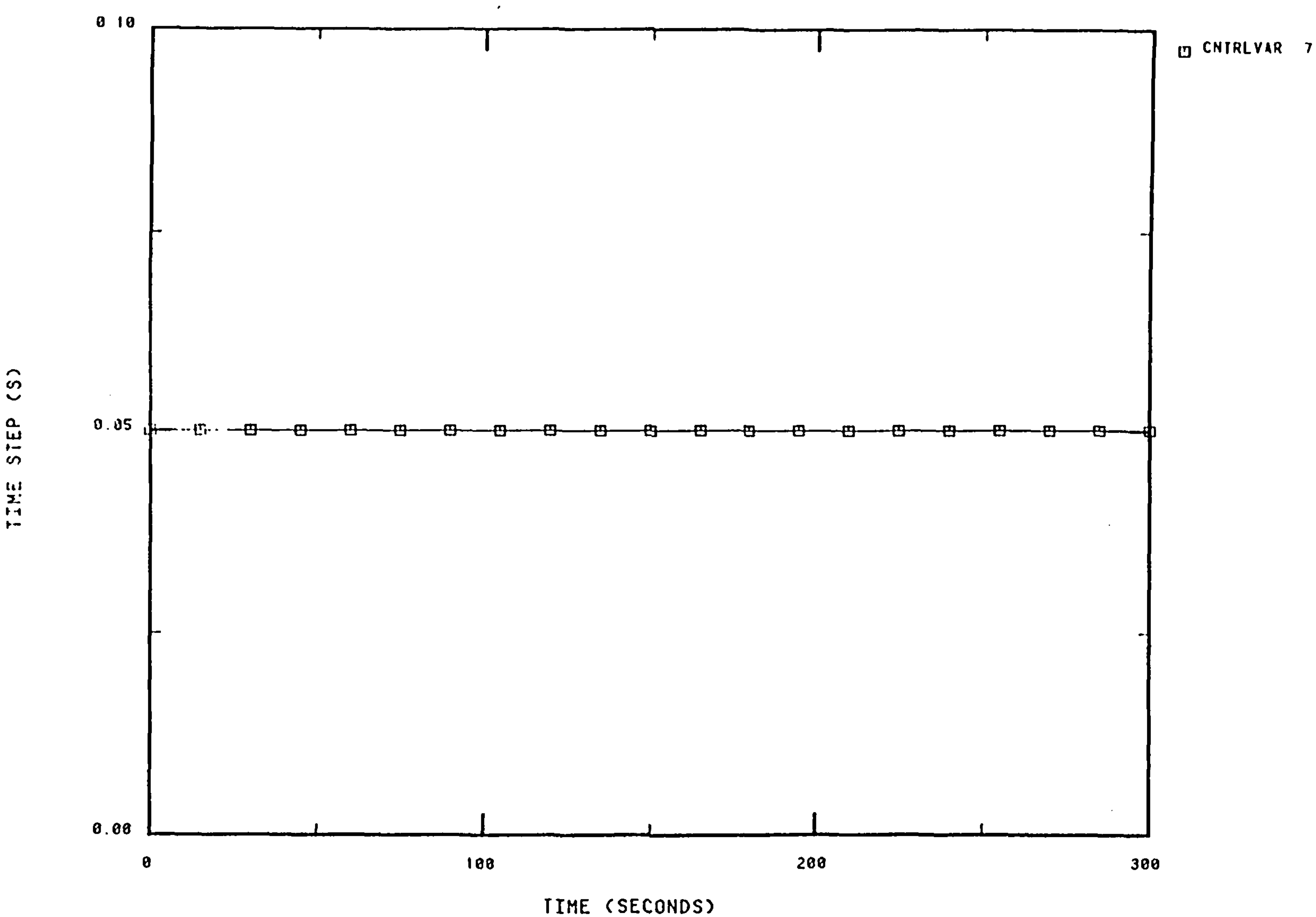

FIGURE 22: TIME STEP

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

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG/IA-0107
ICSP-V2-R50-R

2. TITLE AND SUBTITLE

Assessment of RELAP5/MOD2 Against a Load Rejection from 100% to 50% Power in the Vandellós II Nuclear Power Plant

3. DATE REPORT PUBLISHED

MONTH	YEAR
June	1993

4. FIN OR GRANT NUMBER

L2245

5. AUTHOR(S)

C. Llopis/A.N.V.
R. Mendizabal, J. Perez/C.S.N.

6. TYPE OF REPORT

Technical

7. PERIOD COVERED (Inclusive Dates)

8. PERFORMING ORGANIZATION — NAME AND ADDRESS (If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)

Asociacion Nuclear de Vandellos (A.N.V.)
Travesera de les Corts
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Consejo de Seguridad Nuclear (C.S.N.)
Justo Dorado
11-28040 Madrid, Spain

9. SPONSORING ORGANIZATION — NAME AND ADDRESS (If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)

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

10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

An assessment of RELAP5/MOD2 cycle 36.04 against a load rejection from 100% to 50% power in Vandellós II NPP (Spain) is presented. The work is inscribed in the framework of the Spanish contribution to ICAP Project.

The model used in the simulation consists of a single loop, a steam generator and a steam line up to the steam header all of them enlarged on a scale of 3:1; and full-scaled reactor vessel and pressurizer.

The results of the calculations have been in reasonable agreement with plant measurements.

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

ICAP, Vandellós II, RELAP5,
Transient, Load Rejection

13. AVAILABILITY STATEMENT

Unlimited

14. SECURITY CLASSIFICATION

(This Page) Unclassified

(This Report) Unclassified

15. NUMBER OF PAGES

16. PRICE

Printed on recycled paper

Federal Recycling Program

NUREG/IA-0107

ASSESSMENT OF RELAP5/MOD2 AGAINST A LOAD REJECTION FROM 100% TO 50% POWER IN THE VANDELLOS II NUCLEAR POWER PLANT

JUNE 1993

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

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