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International Agreement Report

Assessment of RELAP5/MOD3.2-NPA3.4 Against a Transient of High Nuclear Flux Variation Reactor Trip, Natural Circulation and the Start of a Main Pump in the VANDELLOS II Nuclear Power Plant

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ABSTRACT

This report is an assessment calculation with RELAP5/MOD3.2 – NPA3.4 against a transient that took place in Vandellòs II Nuclear Power Plant on December 2, 1991

This work is part of the Spanish contribution to the Code Assessment and Maintenance Program (CAMP). Vandellòs II is a member of UNIDAD ELECTRICA, S.A. (UNESA)

Vandellòs II is a 2775 Mwt three loop Westinghouse PWR owned by ENDESA, SA (72%) and IBERDROLA (28%) it is on the Mediterranean coast, near Tarragona (Spain). The commercial Operation began in 1988

The simulation has been running on a Pentium II 266MHz PC under Windows NT. This version has been tested and results are exactly the same as those obtained with a DECStation 500/200.

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EXECUTIVE SUMMARY

The transient calculated with RELAP5/MOD3.2 – NPA3.4 began due to a ray that produced electrical perturbations and the electrical isolation of the plant.

After a short nuclear transient, the three main pumps tripped and natural circulation was established.

About nine minutes after the trip of the reactor, one of the three pumps was started manually and after about fifteen minutes the main steam isolation valves were closed manually in order to prevent a non-desirable depressurization of the primary.

The model of the plant with RELAP5/MOD3.2 – NPA3.4 includes detailed models of main and auxiliary feedwater, high and low pressure injection, safety valves and all the protection systems and automatic signals in accordance with the plant design.

NPA3.4 has been extensively used and has been improved with modifications in order to obtain a friendly interface and provides a graphic representation of the physical phenomenon.

1. INTRODUCTION

A transient which occurred in Vandellòs II Plant, consisting of turbine, reactor and reactor coolant pumps trip, followed by natural circulation conditions and further switching on of one of the pumps, has been simulated with the model of Vandellòs II NPP for RELAP5/mod3.2 /1/,/2/.

This model is an evolution of RELAP5/mod2.5 model for Vandellòs Plant /3/. After migration to mod3.2 /14/, using some features of this revision such as hydraulic diameter in junctions, bundle models in core and steam generators and crossflow junctions where applicable, several subsystems have been incorporated to extend the range of applicability of the model.

The results of a comparison of RELAP5/MOD3.2 calculations against Plant Data are presented in this report.

Also mod2.5 and mod3.2 models are compared in steady states at different load.

This work is part of the Spanish contribution to Code Assessment and Maintenance Program (CAMP). The transient under study occurred at Vandellòs NPP on 02-Dec-1991.

1.1. Plant description

Vandellòs II is a three-loop Westinghouse PWR nuclear power plant owned by ENDESA (72%) and IBERDROLA (28%). It is located in Tarragona, in the Northeast of Spain, and uses the Mediterranean Sea as the final heat sink. The plant started its commercial operation in 1988. Its nominal power is currently 1004 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 secondary side of the steam generators is 3.27 at rated power.

The Auxiliary Feedwater System consists of one turbine driven pump and two motor driven pumps.

In the plant there are, among others, control systems for reactivity (rods and boron), primary pressure, pressurizer level, steam dump and steam generator level.

The Reactor Protection System includes boron rods, safety valves in the pressurizer and the steam generator, and Emergency Core Cooling System.

The main plant features are shown in Table 1

Table 1. Main Characteristics of Vandellòs II Plant

Thermal Reactor Power (MWt)	**2775.**
Electrical Power (Mwe)	**1004.**
Fuel	**UO_2**
Number of Assemblies	**157**
Number of Loops	**3**
Cladding Tube Material	**ZIRCALOY 4**
Absorber Material	**B_4C + Ag-In-Cd**
Reactor Operating Pressure (Mpa)	**15.5**
Coolant Average Temperature (K) **Zero Load** **100%**	 **564.8** **582.3**
Steam Generators	**WESTINGHOUSE type F**
Number of Tubes (per SG)	**5626**
Total Tube Length (per SG) (m)	**98759.**
Tube Inner Diameter (m)	**0.0156**
Tube Material	**INCONEL**
Pumps Type	**WESTINGHOUSE D 100**
Pump Discharge Head (bar)	**6.2**
Design flow Rate (m^3/s)	**6.156**
Pump Speed (rad/s)	**155.**
Primary Volume (m^3)	**257.7**
Pressurizer Volume (m^3)	**39.65**
Heating Power of Pressurizer Heaters (KW)	**1400.**
Maximum spray flow (Kg/s)	**44.2**
Steam Mass Flow Rate at 100% (Kg/s)	**1565.**

1.2. Plant Signal Acquisition System description.

To record the main parameters of the plant during the startup period, a temporary Signal Acquisition System was installed. It consisted of a digital system with a trail capacity of 144 signals with a sample frequency of 0.05 seconds. The recorded parameters depended on the test carried out. The speed of data attainment was very important to improve the time required for data interpretation.

For this reason, once the nuclear plant tests had finished, Vandellòs II NPP decided to install permanent equipment, with a capacity of 400 signals with a sample frequency of 4 ms, in order to interpret and analyze the transients.

The availability of this great number of signals allows the partial performances of the control blocks to be checked, especially those of pressurizer pressure and level control, feedwater system, rod control and steam dump.

2. VANDELLOS MODEL FOR RELAP5/MOD3.2-NPA

2.1. Model description

Since the beginning of commercial operation of Vandellòs II Plant, a model of NSSS for RELAP code has been developed and validated. In its first stages the model consisted of a collapsed single loop, the reactor vessel and core, a pressurizer, a simplified feedwater system and the most important control and protection systems. This model has been improved to simulate the three loops and almost every control and protection system directly related to NSSS, and adapted to RELAP5/mod3.2.

The model is shown in diagrams 1,2 and 3, and in its current state, contains the following system and components:

Primary Circuit

- Reactor Vessel
- Reactor Coolant Pumps
- Three Loops
- Pressurizer
- CVCS (including pump seal injection)

Secondary Circuit

- Steam Generators
- Steam Lines
- Main Feedwater system
- Auxiliary Feedwater system

Emergency Core Cooling System

- High Pressure Injection system
- Low Pressure Injection system
- Accumulators

Heat Structures

- Reactor Core
- Pressurizer Heaters
- Steam Generators Tubes

- High Pressure Feedwater Heaters

Protection System

- All reactor Trips
- All turbine Trips
- AMSAC
- All security Injection Signals
- All permissive and Interlock Circuits
- Automatic signals of Main Steam Isolation
- Automatic signals of pressurizer Heater Shutoff
- Automatic signals of Main Feedwater Isolation

Control System

- Average Primary Temperature:
- Control Rods
- Steam-dump
- Primary Pressure
- Pressurizer Level
- CVCS (including Manual Boron Concentration Control)
- Accumulators, HPI and LPI
- Turbine Control Valves, Including Manual Operation and Runback Actuation
- Steam Generator Level
- Main Feedwater Pumps and Valves (Auto and Manual modes)
- Manual Control for Auxiliary Feedwater

The switch manual/auto of the control system incorporates tracking of PID in accordance with the feature of the plant

The total model components are:

Hydrodynamic volumes:	367
Heat structures:	57
Control and Trips:	1689
Interactive variables:	92

A special study of the behavior of the steam generators at all levels of power has been carried out on the migration from RELAP5/MOD2.5 to RELAP5/MOD3.2 and the results are presented in chapter 5.2

Instabilities are observed in the transition between "slug" and "annular-mist" regimes in RELAP5/MOD3.2 that cause oscillations in the level of steam generators. A change in the "phantv" and "phantj" routines has reduced considerably this effect. The change is discussed in chapter 5.1

The Vandellòs model for RELAP5/mod3.2 has been validated against five Plant transients /15/, selected to cover as much subsystems and conditions as possible, these transients are:

- Turbine and reactor trip
- Main Steam Isolation
- High Nuclear Flux Rate trip, natural circulation and start of a RCP. (Presented in chapter 4)
- Loss of Load from 100 to 50%
- One Main Feedwater Pump trip.

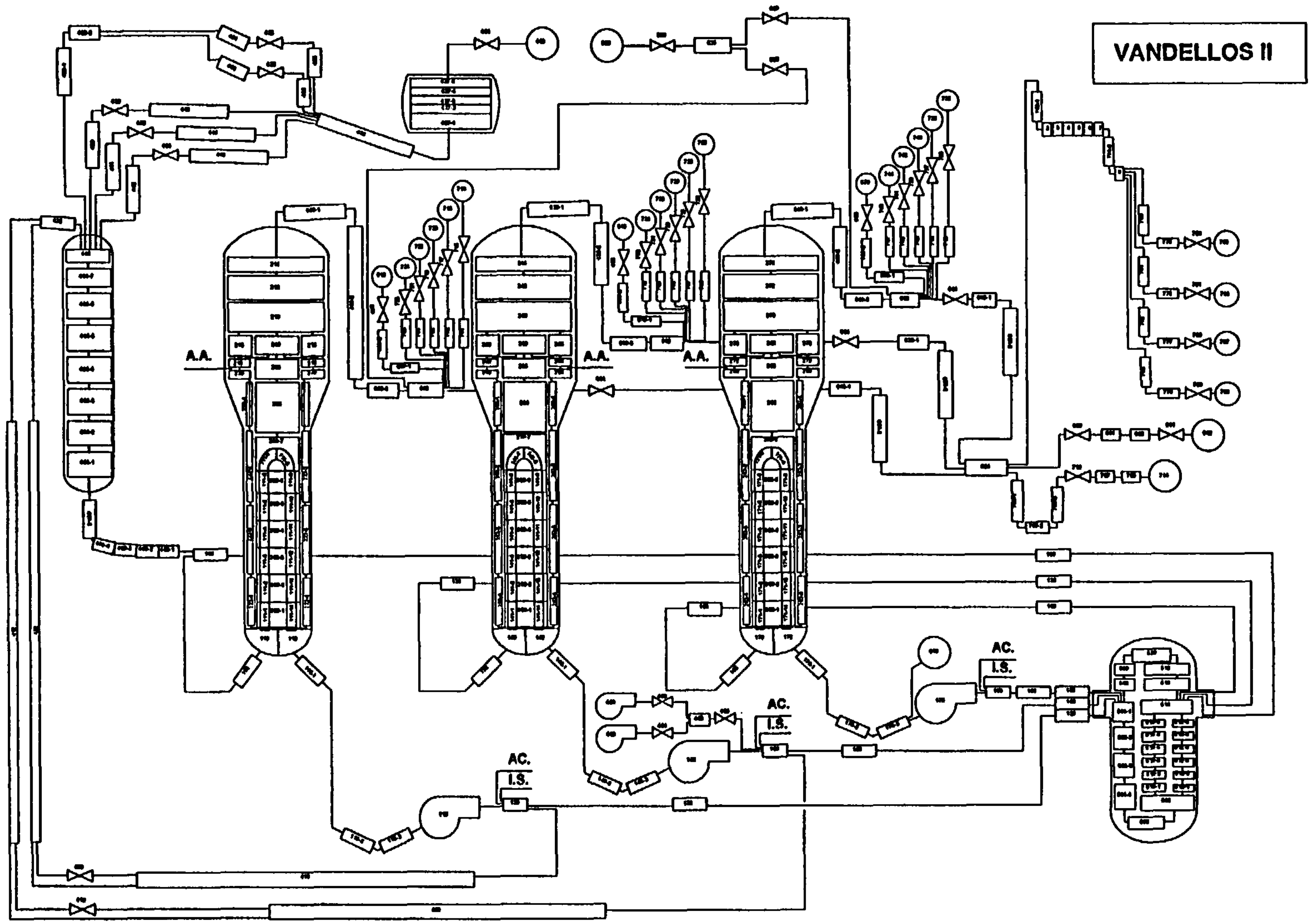


Diagram 1. Vandellòs II NPP. Nodalization

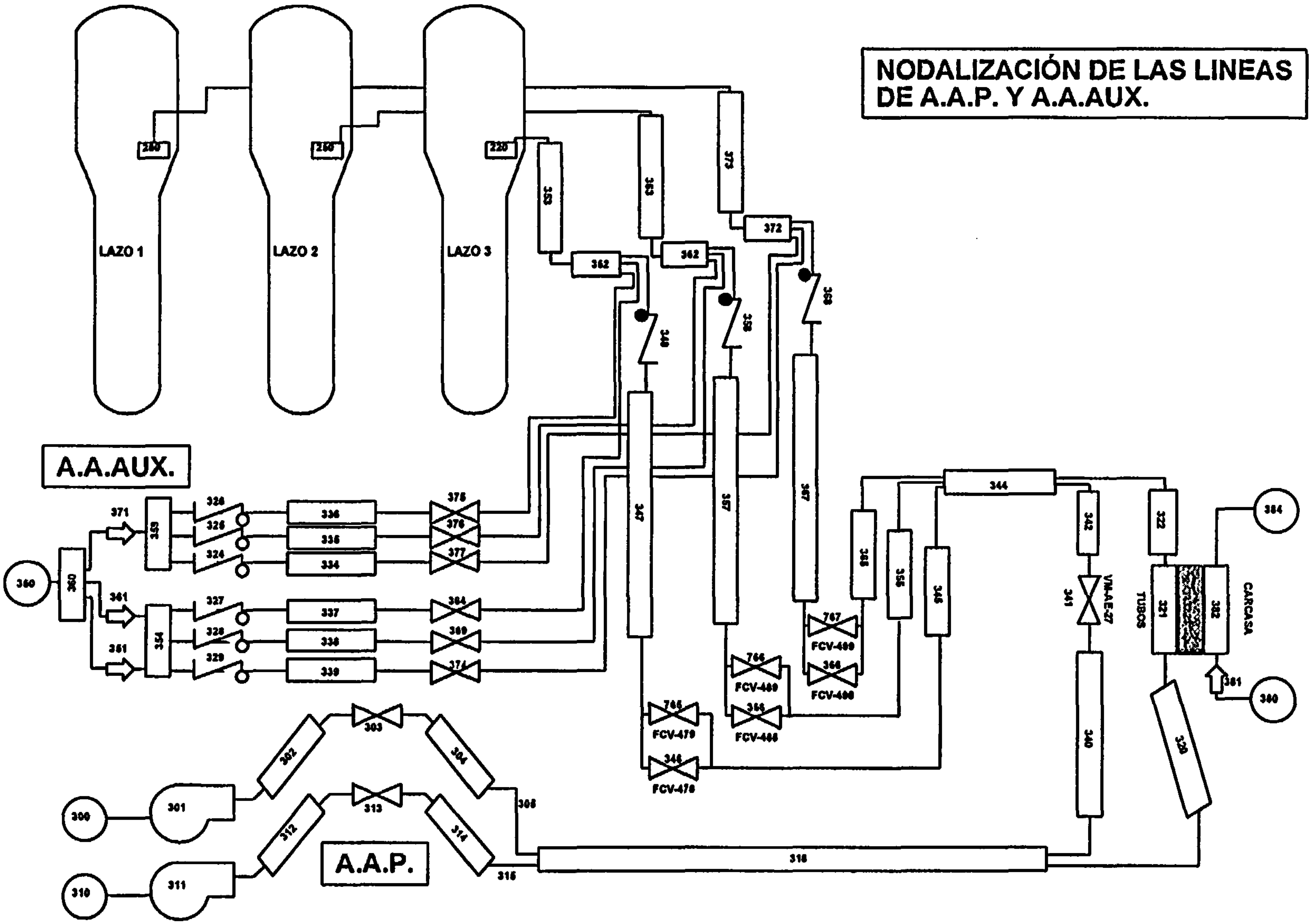


Diagram 2. Feedwater System Nodalization

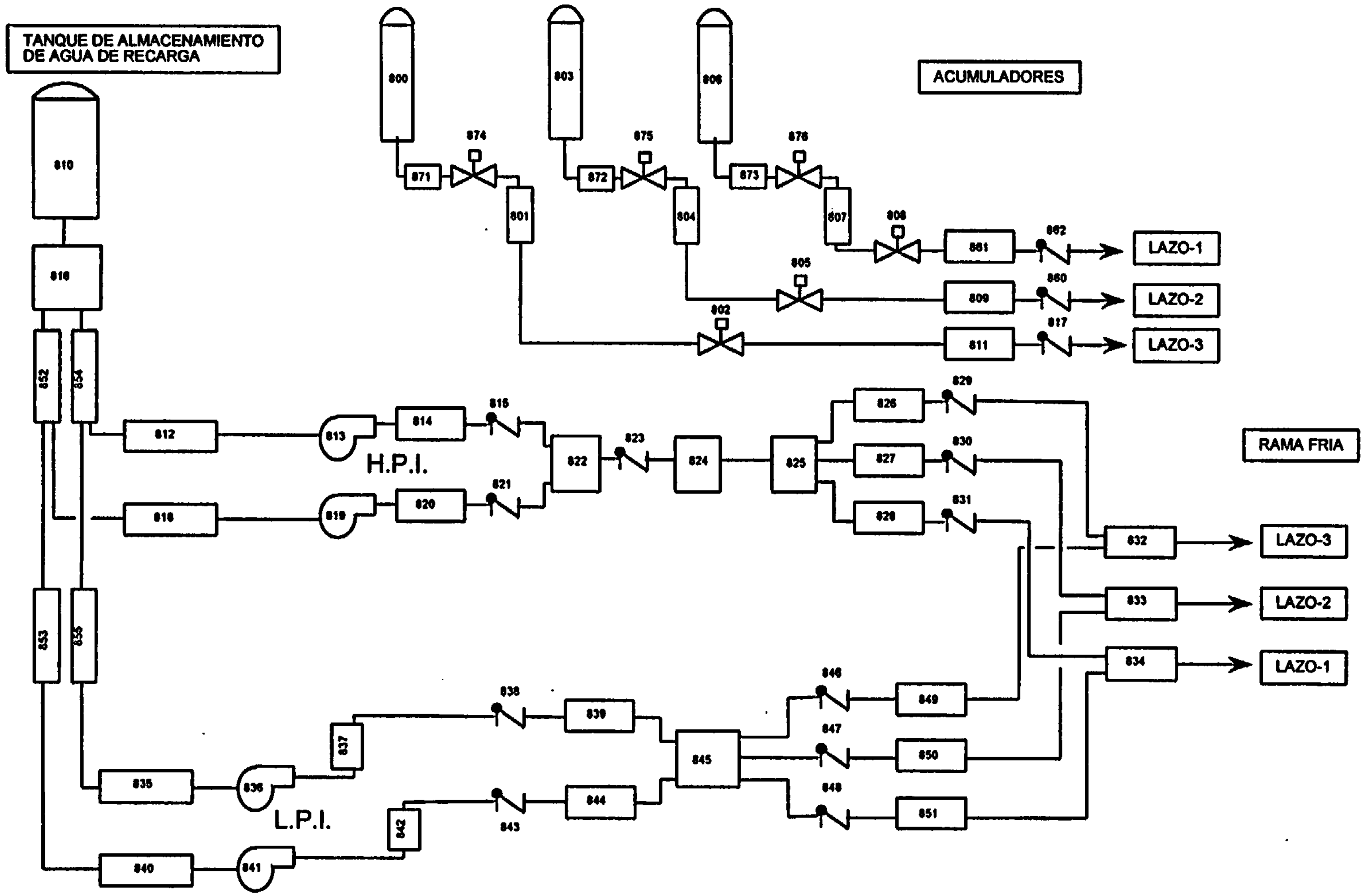


Diagram 3. HPI, LPI and Accumulators Nodalization

2.2. Graphical Interface

A graphic representation of the model, consisting of five masks, has been developed with Nuclear Plant Analyzer (NPA), these masks are:

Main. Provides a global view of Nuclear Steam Supply System, and is a true representation of the model.

Graphics. This mask shows trend graphs of the most important variables in the model.

State Panel. Presents the current state of control and protection systems with ON/OFF indicators.

Feedwater System.

High and Low Pressure Injection System.

The following pages show a hardcopy of the masks.

Since usual operation of the model is through NPA interface, manual activation or modulation on control and protection systems and many of the typical transient initiators can be activated from NPA menus.

During the development of the model some improvements have been added to RELAP-NPA code:

RESTART It is now possible to go back to a previous state where a restart block has been recorded. It is also possible to record a restart block when desired during an interactive simulation.

Push - button Permits simulating actuation on buttons that can be reset by the model.

LINKS Special icons are used to indicate one-click links to another mask.

ALIAS Plot variables can be selected through user selected names associated to RELAP variables.

COMPARE This option compares calculation results with data from an external file, containing plant data or expected results.

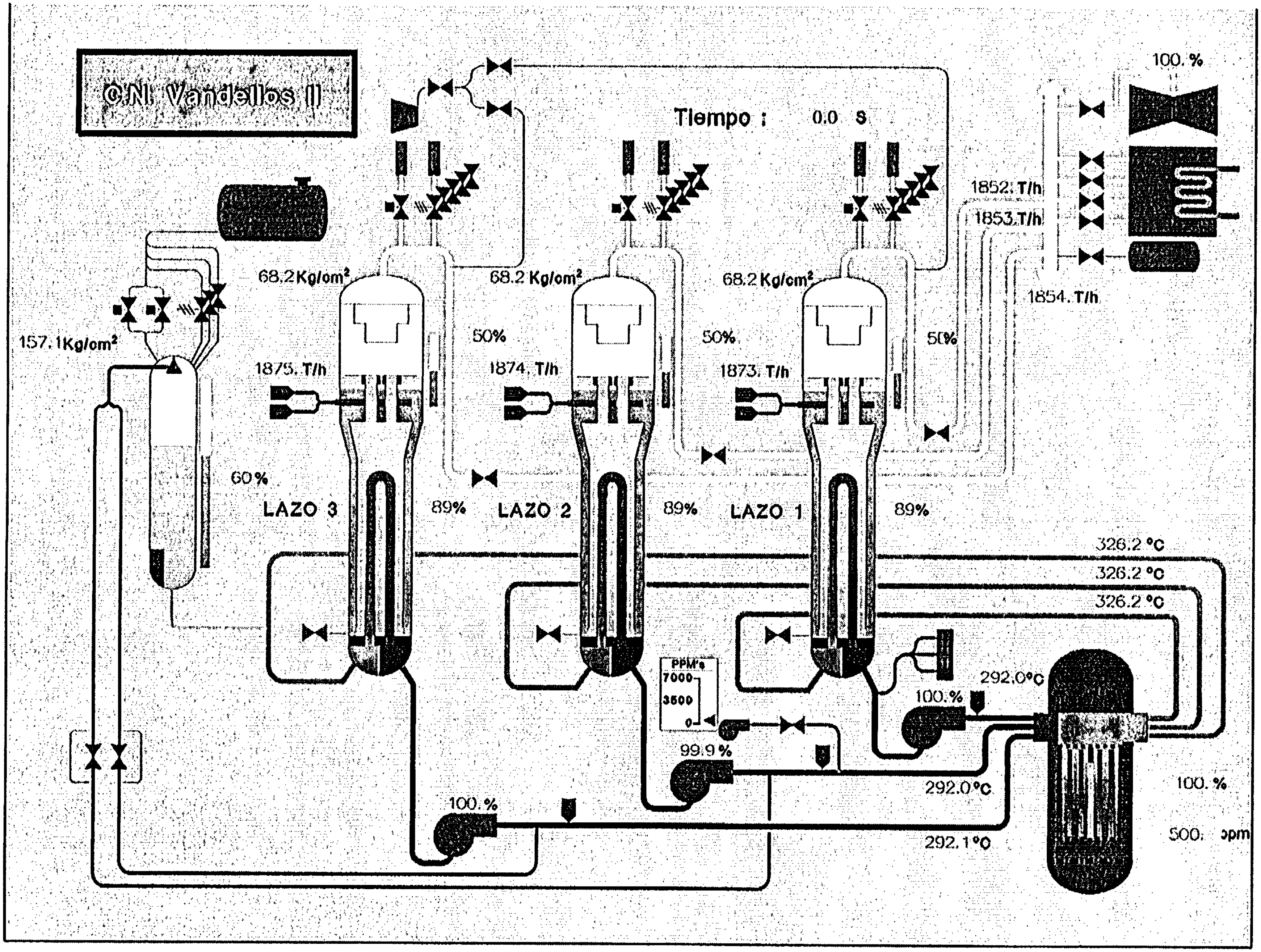
REDRAW Permits the actualization of Plot graphs with results calculated after the graph was plotted.

New ON/OFF dynamic function The new function drives ON/OFF indicators without consuming dynamic colors.

Thermocolor function The color set of this function has been reduced to give a more intuitive view of the thermodynamic situation in the component.

PLOT Minor changes on plots scale selection and postscript file generation.

The result of this development is an Interactive Graphical Analyzer /16/ that can be used as an engineering or teaching tool and has been very useful while checking models and control subsystems, due to its highly intuitive presentation of results


C.N. Vandellos II
Tiempo : 0.0 S
100. %
1852. T/h
1853. T/h
1854. T/h
68.2 Kg/cm²
68.2 Kg/cm²
68.2 Kg/cm²
157.1 Kg/cm²
50%
50%
50%
1875. T/h
1874. T/h
1873. T/h
60 %
LAZO 3
LAZO 2
LAZO 1
89%
89%
89%
326.2 °C
326.2 °C
326.2 °C
PPM's
7000
3500
0
292.0°C
100. %
99.9 %
292.0°C
100. %
100. %
292.1°C
500.

PANEL DE ESTADO

Tiempo = 65.0 s

DISPARO REACTOR	■
DISPARO TURBINA	□
ALTO FLUJO NEUTRONICO	
BAJO	□
ALTO	□
ALTA VARIACION FLUJO	□
BAJO CAUDAL 1/3 LAZOS	□
BAJO CAUDAL 2/3 LAZOS	□
OTDT	□
OPDT	□
ALTO NIVEL PRESIONADOR	□
BAJA P PRESIONADOR	□
ALTA P PRESIONADOR	□
BAJO NIVEL 1/3 GV	■
INYECCION SEGURIDAD	□
MANUAL	□
AISLAMIENTO VAPOR	■
ALTO Qv + BAJA (P o Tm)	□
POR ALTA P CONTENCION	□
MANUAL	■
RUNBACK TURBINA	□
POR OTDT	□
POR OPDT	□
DISPARO 1 TBAAP	□
MANUAL	□

DISPARO TURBINA	■
DISPARO REACTOR	■
ALTO NIVEL 1/3 GV	□
INYECCION SEGURIDAD	□
AMSAC	■
MANUAL	■
INYECCION SEGURIDAD	□
ALTO Qv + BAJA (P o Tm)	□
ALTA P DIFERENCIAL VAPOR	□
ALTA P CONTENCION	□
BAJA P PRESIONADOR	□
MANUAL	□
INYECCION DE BAJA	□
AISLAMIENTO A.A.PRAL.	■
POR SIS	□
POR DISP. REACTOR + BAJA Tm	■
POR ALTO NIVEL 1/3 GV	□
CVCS	
CARGA AUTO □ MANUAL	□
AISLAMIENTO POR SIS	□
AISLAMIENTO DESCARGA	
BAJO NIVEL PZR	□
MANUAL	□

PERMISIVOS

P7	□	P12	□	C1	□	C5	□	C12	□
P8	□	P13	□	C2	□	C7	□	C20	□
P10	□	P14	□	C3	□	C9	□		
P11	□			C4	□	C11	□		

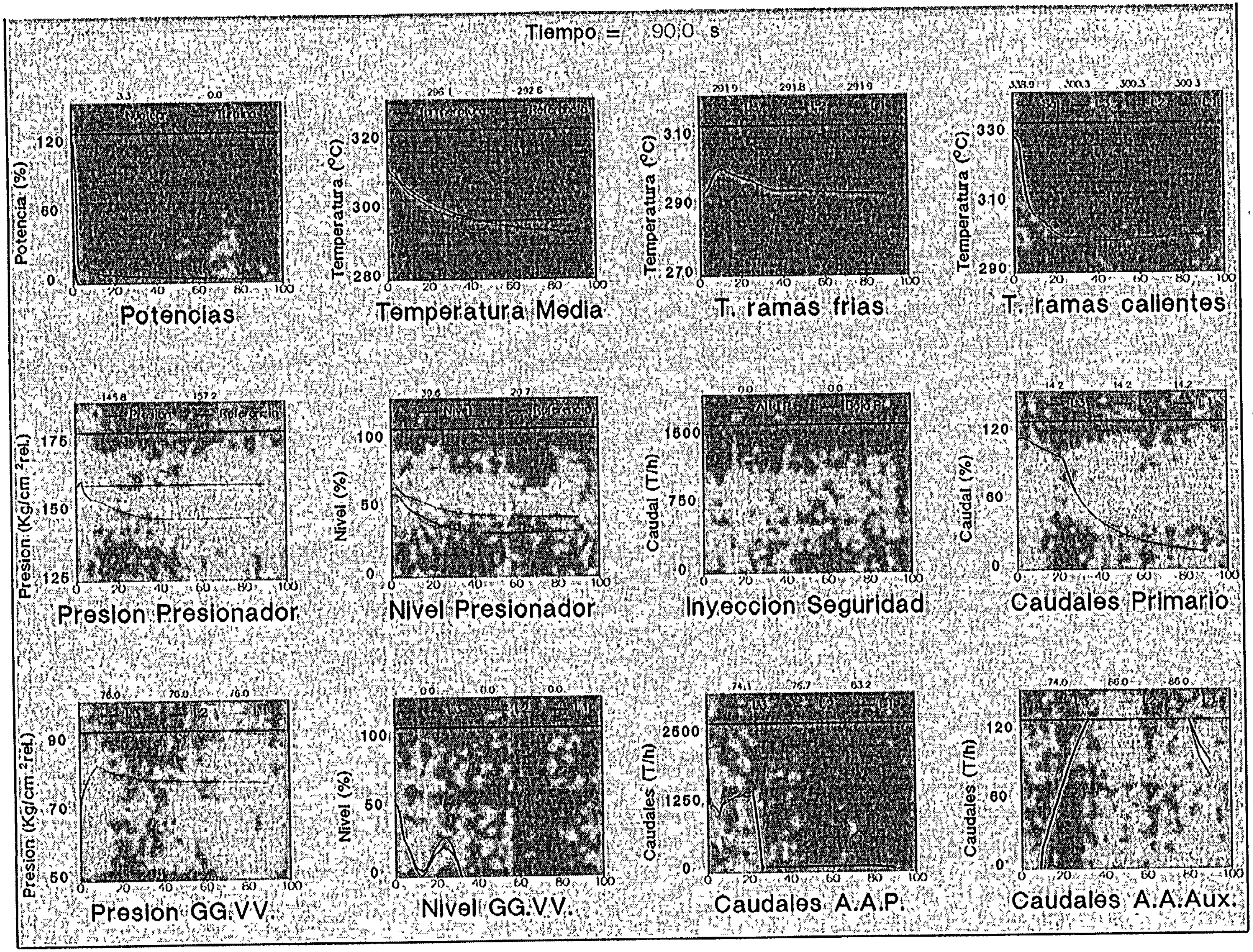
BLOQUEO BARRAS ■

	AUT	MAN1	MAN2
ROCIADO PRESIONADOR	□	□	□
ALIVIO PRESIONADOR	□	□	□

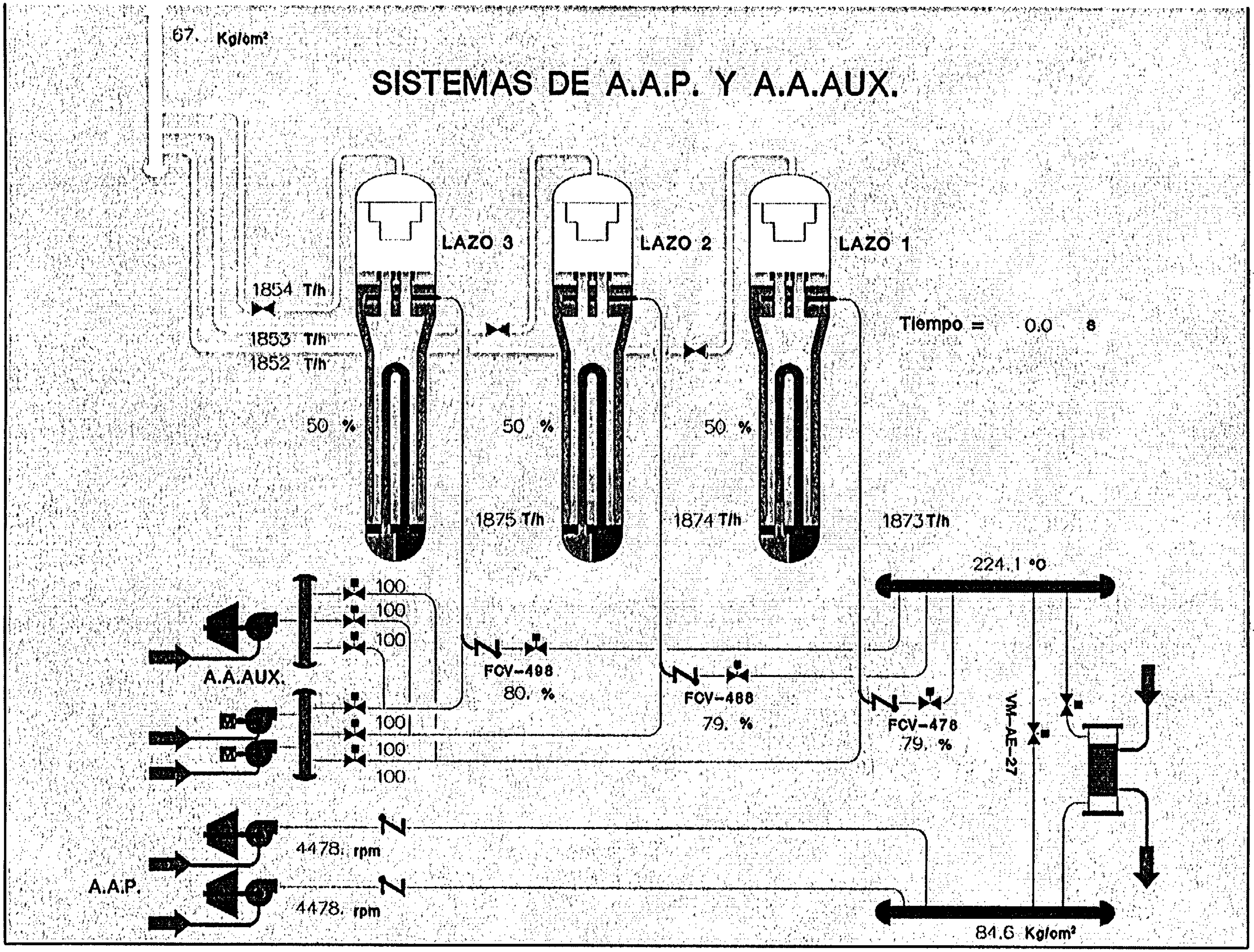
ALIVIO GV1	AUTO	□	MANUAL	□
ALIVIO GV2	AUTO	□	MANUAL	□
ALIVIO GV3	AUTO	□	MANUAL	□
STEAM-DUMP	MODO T	□	MODO P	□

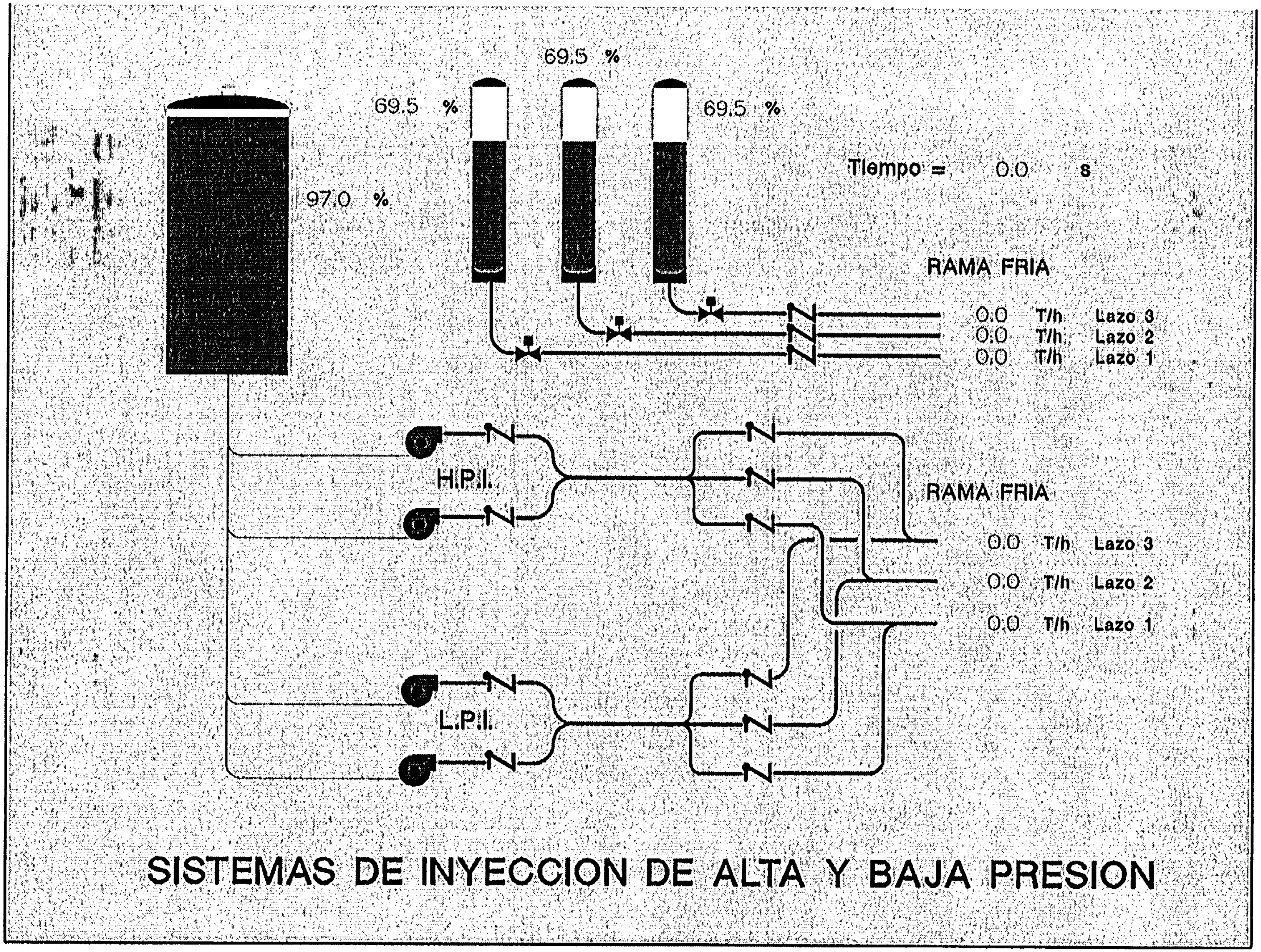
	MOTOR	TURBO
ENTRADA A.A.AUXILIAR	■	■
DISPARO AAP	■	
MUY BAJO NIVEL GV's	1/3 ■	2/3 ■
AMSAC	■	■
PERDIDA SUMINISTRO	□	□
SIS	□	
MANUAL	□	□

CALENTADORES RESPALDO ■



Tiempo = 90.0 s
Potencia (%)
Potencias
Temperatura (°C)
Temperatura Media
T. ramas frias
T. ramas calientes
Presion (Kg/cm 2rel.)
Presion Presionador
Nivel (%)
Nivel Presionador
Caudal (T/h)
Inyeccion Seguridad
Caudal (%)
Caudales Primario
Presion GG.VV.
Nivel GG.VV.
Caudales (T/h)
Caudales A.A.P.
Caudales A.A.Aux.


67. Kg/cm²
SISTEMAS DE A.A.P. Y A.A.AUX.
LAZO 3
LAZO 2
LAZO 1
1854 T/h
1853 T/h
1852 T/h
Tiempo = 0.0 s
50 %
50 %
50 %
1875 T/h
1874 T/h
1873 T/h
224.1 °C
100
100
100
A.A.AUX.
FCV-498
80. %
FCV-488
79. %
FCV-478
79. %
VM-AE-27
100
100
100
4478. rpm
A.A.P.
4478. rpm
84.6 Kg/cm²


69.5 %
69.5 %
69.5 %
97.0 %
Tiempo = 0.0 s
RAMA FRIA
0.0 T/h Lazo 3
0.0 T/h Lazo 2
0.0 T/h Lazo 1
H.P.I.
RAMA FRIA
0.0 T/h Lazo 3
0.0 T/h Lazo 2
0.0 T/h Lazo 1
L.P.I.
SISTEMAS DE INYECCION DE ALTA Y BAJA PRESION

3. TRANSIENT DESCRIPTION

The transient under study took place in Vandellòs II NPP on Dec 2nd, 1991, with the Plant operating at nominal condition. It began with disturbances on the 400 KV line, which produced an isolation of the Plant, with the following effects:

- Turbine speed increases.
- Turbine control valves closing.
- Reactor Coolant Pumps speed and flow increase due to initial frequency increase.
- Primary temperature decreases.
- Reactor power increases.
- High neutron flux rate Reactor trip at 0.92 seconds.
- One of the main feedwater pumps tripped after 4 seconds, the other one after 22 seconds.
- After approximately 20 seconds the reduction on frequency gives RCP trip, beginning natural circulation and 500 seconds later one of the Reactor Coolant Pumps is manually switched on.
- Manual Main Steam Isolation took place 798 seconds after the beginning of the transient.
- Primary variables return to zero load values.
- Temperature measures are not the actual temperatures while primary is in natural circulation, because there is no flow to RTD's bypass. This occurs from the pumps trip until the RCP pump is switched on at t=520.s, so all the setpoints that are a function of average temperature are affected by this measurement error. To account for this effect data collected from Plant is used to fix CVCS Charge flow demand.

Disturbances in electrical power also caused some data not to be recorded in the first seconds of the transient.

In the following table all the relevant events that occurred within the time analyzed are summarized, together with the actions required in RELAP to simulate each event.

Table 2. Events sequence.

TIME	Malfunction	Automatic events	Manual events	RELAP Simulation
< 0.			SG Relief Setpoint 7.7Mpa	Input modification
< 0.			PZR level setpoint: 21—56%	Input modification : Imposed CVCS Charge Demand
0.	RCPs Speed increase			Input modification
0.		Steam dump unavailable		NPA Man. C9
0.1		Turbine OverSpeed Protection closes turbine control valves		Input modification
0.92		High Neutron Flux Rate Reactor Trip		Occurs at t=1.0s
4.		FWP "A" Trip		NPA Man. Trip
20.5		RCPs Trip		NPA Man. Trip
22.		FWP "B" Trip		NPA Man. Trip
80.			AuxFW TurboPump: valve loop 1: 7% valves loops 2,3: 15%	NPA Man. modulation
160.			AuxFW TurboPump: valve loop 2: 7%	NPA Man. modulation
200.			AuxFW TurboPump: valve loop 3: 7%	NPA Man. modulation
520.			RCP3 on	NPA Man Start
520.		PZR Level <15%: PZR Heaters OFF Letdown Isolation		Occurs at t=521.0s
550.			AuxFWTurbine trip	NPA Man Trip
550.			AUXFWMotorPump valves 1,2,3: 75%	NPA Man. Modulation
798.			Main Steam Isolation	NPA Man Isolation
900.			AUXFWMotorPump valves 1,2,3: 55%	NPA Man. Modulation
1010			Primary Letdown: One restrictor opens	NPA Man. Open
1600			Charge FCV-122 : 10%	NPA Man Modulation

4. RELAP5/MOD3.2 SIMULATION

The transient has been simulated with the Vandellòs II NPP model, using NPA interface. All actions, except RCP speed variation, PZR level setpoint change and Turbine Control Valves closure due to Overspeed Protection, can be done through NPA menus.

Calculations have been done running on a PentiumII/266MHz PC under Windows NT, this compilation of the code has been tested, and the results have been presented in the last RELAP5 International Users Seminar /17/. As an example two of the figures of that paper are here copied, to show that results are exactly the same than those obtained with one of the "official" platforms (DECStation 5000/200).

In Figure 1 a hypothetical transient consisting of a simultaneous RCPs trip is analyzed with ASCO model. Figure shows that results are exactly the same in a DECStation 5000/200 (labeled with the suffix DEC) than in a PC under Windows NT (PC_W). Linux version, delivered by INEL, produces results that are slightly different, the cause can be modifications in the code incorporated to LINUX version.

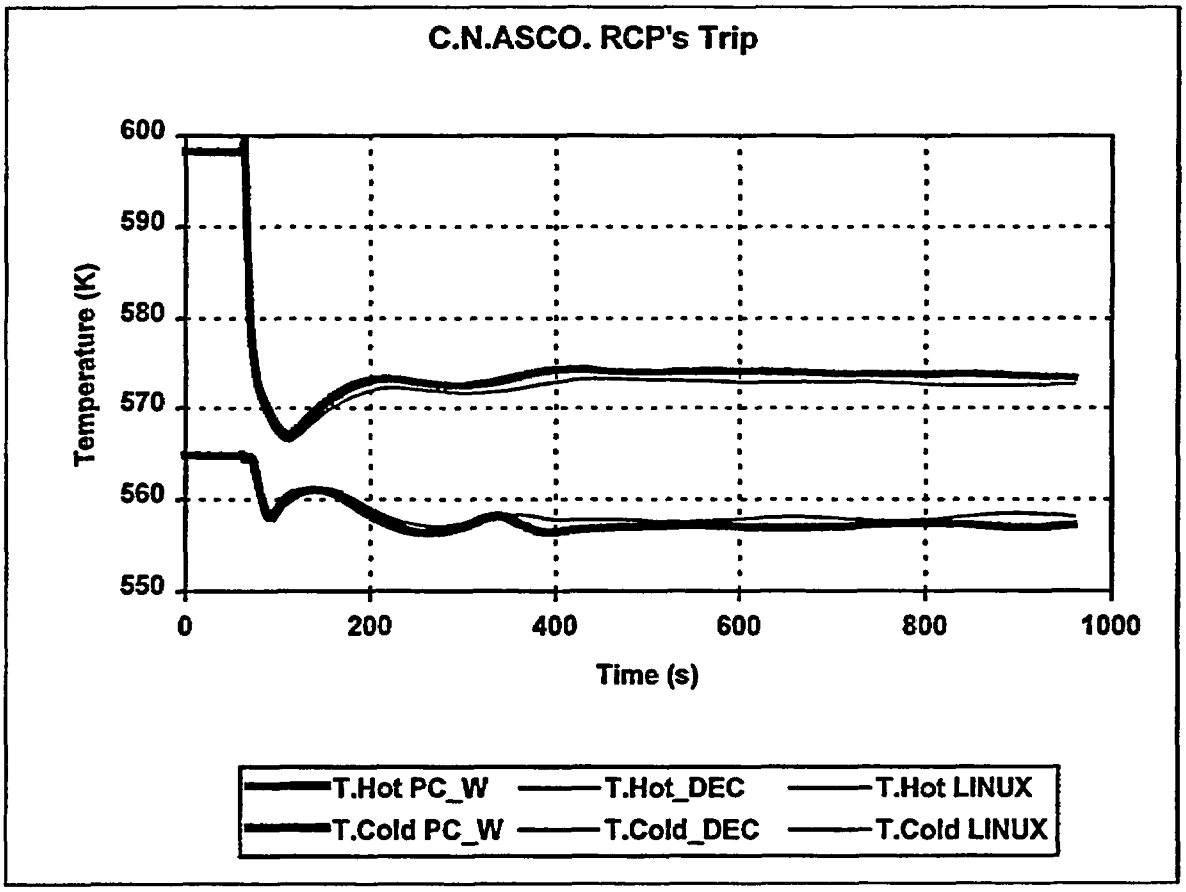


Figure 1. RELAP-PC. ASCO NPP. RCPs Trip. Primary Loop Temperatures

Figure 2 shows the evolution of Secondary Pressure in a Loss of Load Test, compared with Plant data. In this case results in PC Windows version and in Linux version are exactly the same.

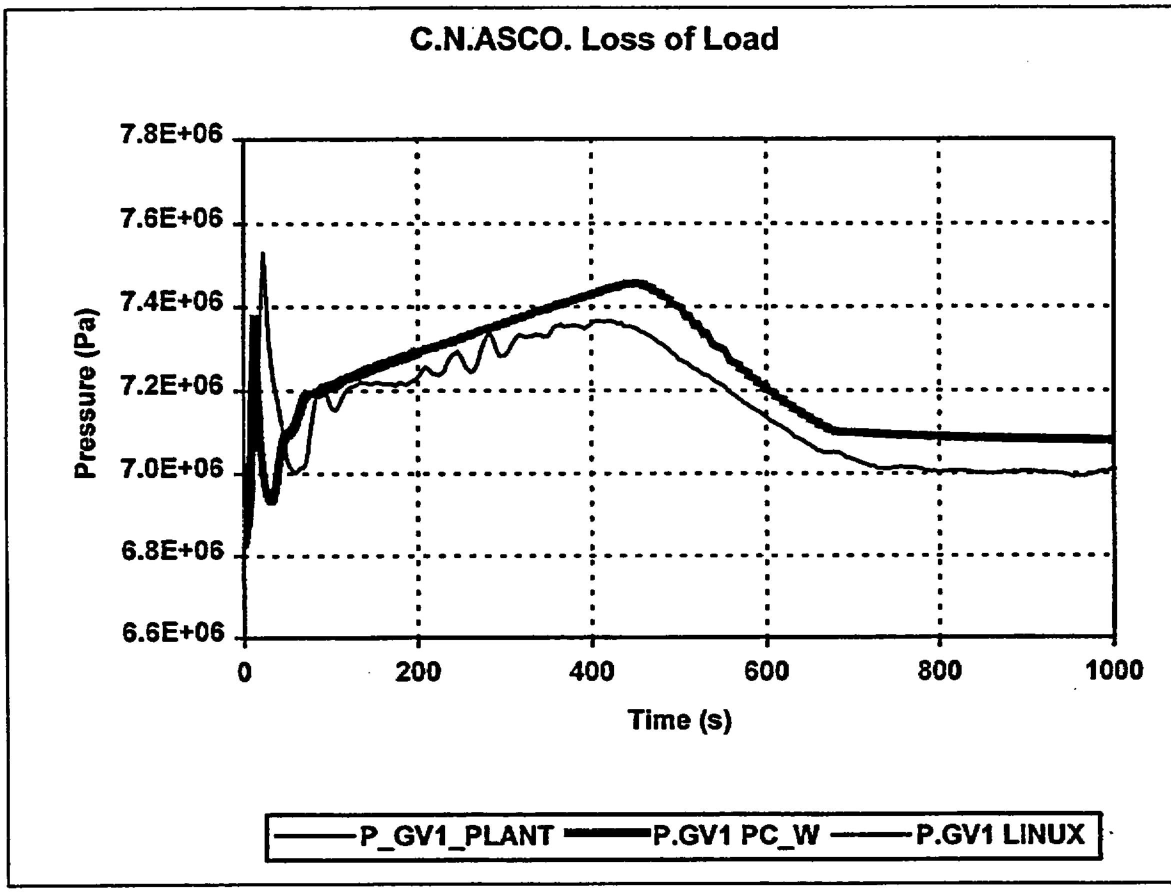


Figure 2. RELAP-PC. ASCO NPP. Loss of Load, 100-50%. Secondary Pressure.

4.1. Boundary Conditions and manual activation and modulation

Data collected in the Plant permit us to come to some conclusions about the actual state of the setpoints and about operator actions, the most important are:

Pressurizer level setpoint was 4% lower than nominal.

The setpoint of steam generators relief valves was 77 kg/cm^2.

After a few seconds Steam-dump system became unavailable due to loss of Condensate Pumps

One of the main feedwater pumps tripped 4 seconds after the beginning of transient. The other one tripped at t=22. s

Auxiliary Feedwater was manually modulated to control SG pressure and level.

To reproduce the conditions of the transient the events and manual activation and modulation collected in the last column in Table 2 are required.

4.2. Analysis and comparison of results

In the figures below the most significant results are compared with Plant data, labeled with the suffix P in figures.

During the first tenths of a second of the transient the reactor power increases as a consequence of the coolant flow variation, reaching high neutron flux rate setpoint, which trips the reactor. Figure 3 shows the comparison between reactor power and fission power in RELAP (reactor power includes decay terms), and Plant data corresponding to excore detectors.

Figure 4 shows the evolution of primary flow in the first seconds of the transient.

In Figure 5, Figure 7, Figure 9 (first 100 seconds) and Figure 6, Figure 8, Figure 10 the evolution of average temperature in the three loops is shown, compared against Plant data. Figure 6, Figure 8 and Figure 10 show that while reactor coolant pumps are tripped, measured temperatures decrease as the RTD's cool by means of heat transfer to atmosphere. When the pump in loop 3 is switched on (at 520 seconds), average temperature in that loop suddenly increases to the same value calculated by RELAP. The other two measures also increase but at a lower rate.

Steam generators pressure is compared against Plant data in Figure 11 to Figure 16 showing a very good agreement. It is necessary to note that a wide variety of phenomena is simulated in this transient: natural circulation, one loop operation with one heat sink in the secondary circuit, and after isolation, with three independent sinks in secondary.

The simulation of this transient permitted to identify the cause of the continuous depressurization in secondary pressure occurring in natural circulation. To reproduce its evolution a constant steam flow out of the steam header has been imposed.

To mitigate the effect of steam consumption in secondary circuit several corrective actions have been taken in the Plant, in order to reduce steam flow out of the steam header after turbine trip.

Figure 17 compares steam collector pressure. Steam flow from collector to secondary circuit (MSR's, turbine driven pumps), causes the evolution of pressure before and after isolation.

In Figure 18, Figure 19 and Figure 20 the demanded position of steam generators relief valves is shown, proving the assumption made to change the setpoint.

Pressurizer pressure (Figure 21) and level (Figure 22) are also well reproduced with RELAP.

In this transient Pressurizer Pressure is mainly governed by coolant temperature, which while in natural circulation decreases because of the secondary side steam consumption. When the pump is switched on an additional sudden cool of primary system occurs, due to the increase in heat transfer rate in the steam generator. As a consequence Pressurizer Pressure falls near Security Injection setpoint. Main Steam Isolation at 798 s reduces heat transfer to secondary, thus increasing temperature and pressure in primary system.

The above-mentioned evolution of Pressurizer Pressure is modulated by charge and letdown flows, since there is no system operable to control Pressure. So we have noted the importance of CVCS, specially the proportional-integral controller acting on Pressurizer Level error to determine charge flow demand, and the way that kinds of controllers act when output reaches saturation values.

To account for the error in the measured temperatures in natural circulation, CVCS flow demand has been imposed while this system was operating in automatic mode. At t=1600. s the system was switched to manual mode to fix charge flow.

If the charge flow demand were not imposed, the difference in pressurizer level when isolation is done, that is 2%, will produce a change in integral component of 14% (Gain = 7%/%), that means that charge flow would be delayed about 100 seconds (Integral time=720s). In this case Pressurizer pressure would continue rise during 100 seconds more than in the Plant.

The calculation with demand flow charge imposed due to a great coincidence between the evolution of the pressurizer pressure calculated and the plant data record, as is shown in the figure 21.

Charge and letdown flow are compared against Plant data in Figure 23 and Figure 24

Figure 25 to Figure 30 present the steam generators narrow range level signals obtained with RELAP and those collected from Plant data. Both short term and long term value are in good agreement.

In Figure 31, Figure 33 and Figure 35 main feedwater flow is shown in the first seconds of the transient, proving that feedwater control system is well simulated in the model.

Figure 32, Figure 34 and Figure 36 present the auxiliary feedwater flow reproduced with the actions reported below.

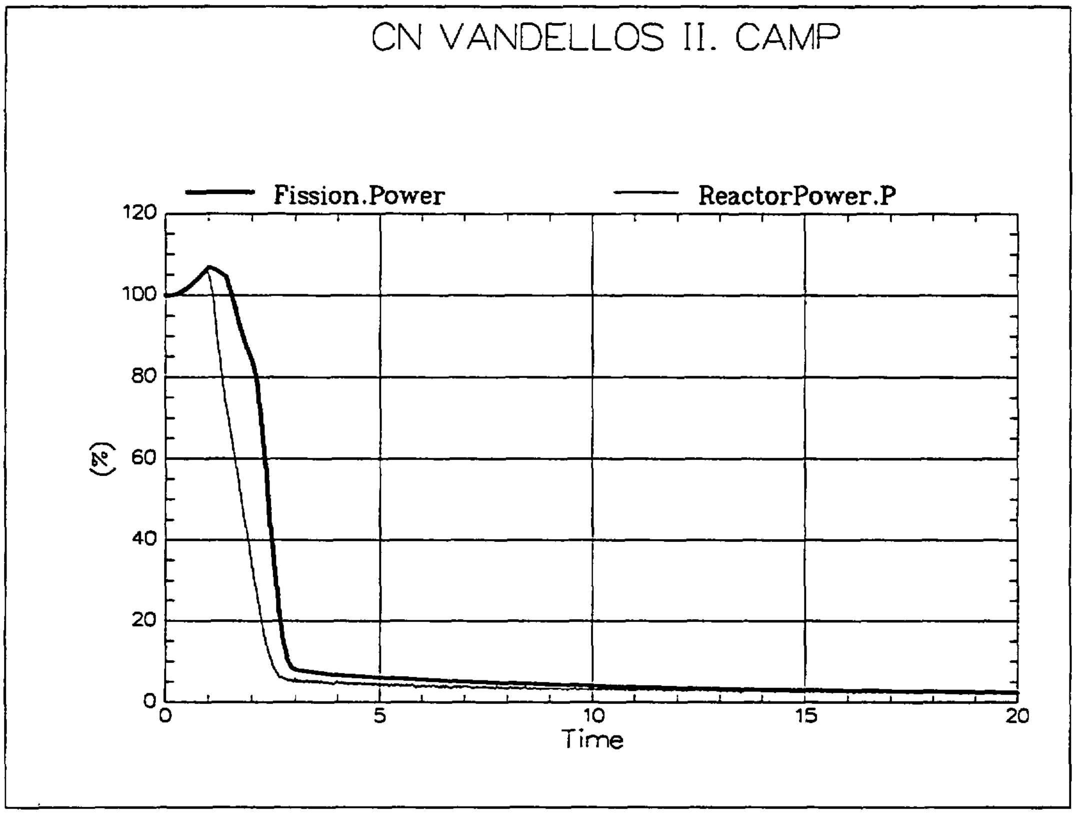


Figure 3. Reactor Power

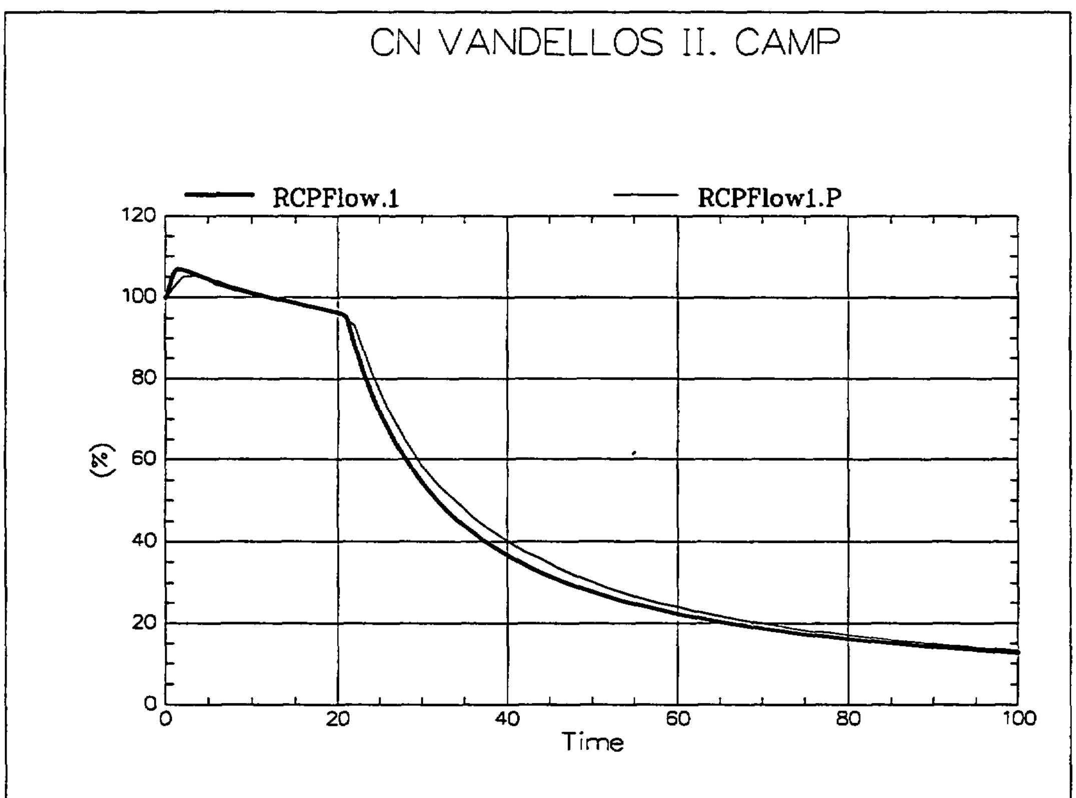


Figure 4. Primary Flow

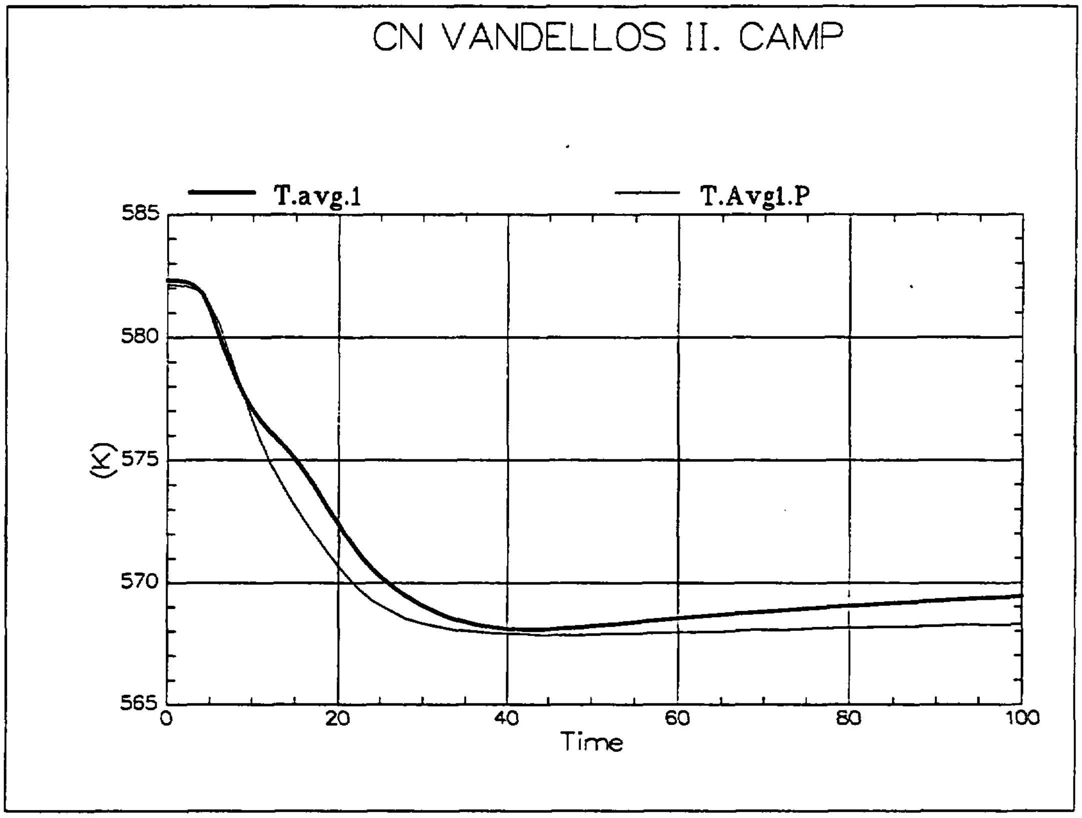


Figure 5. Average Temperature Loop 1 (100s)

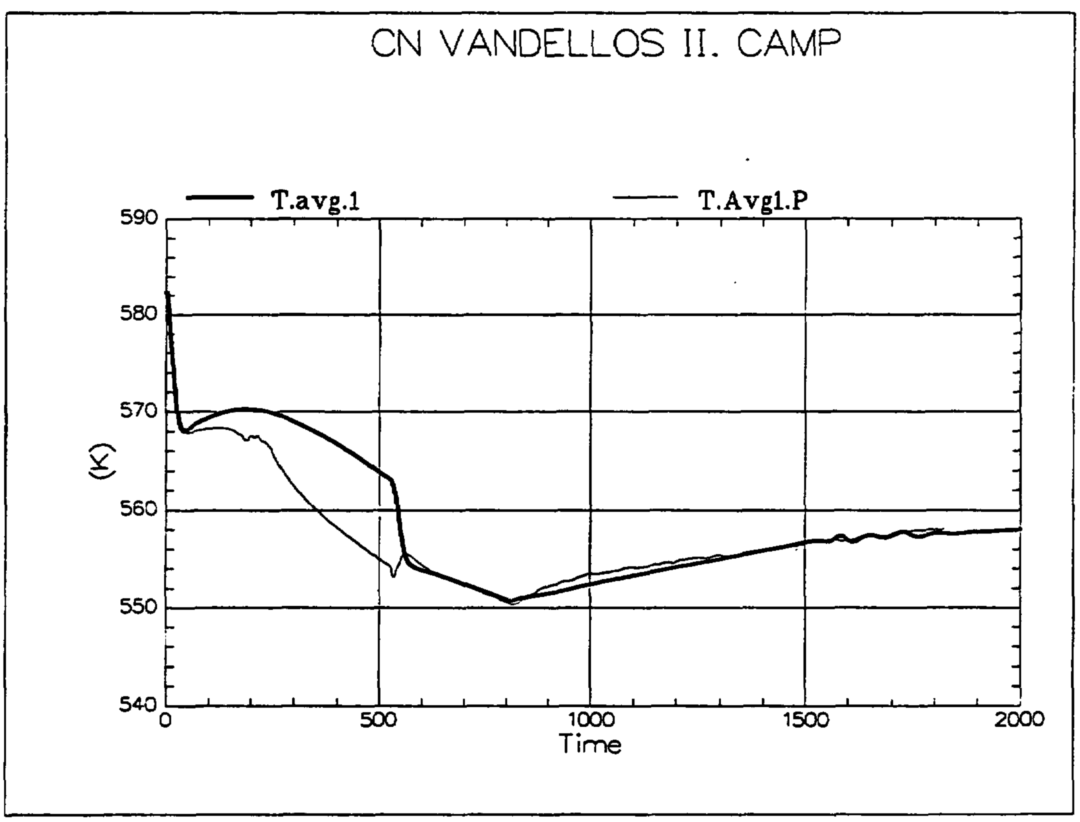


Figure 6. Average Temperature Loop 1

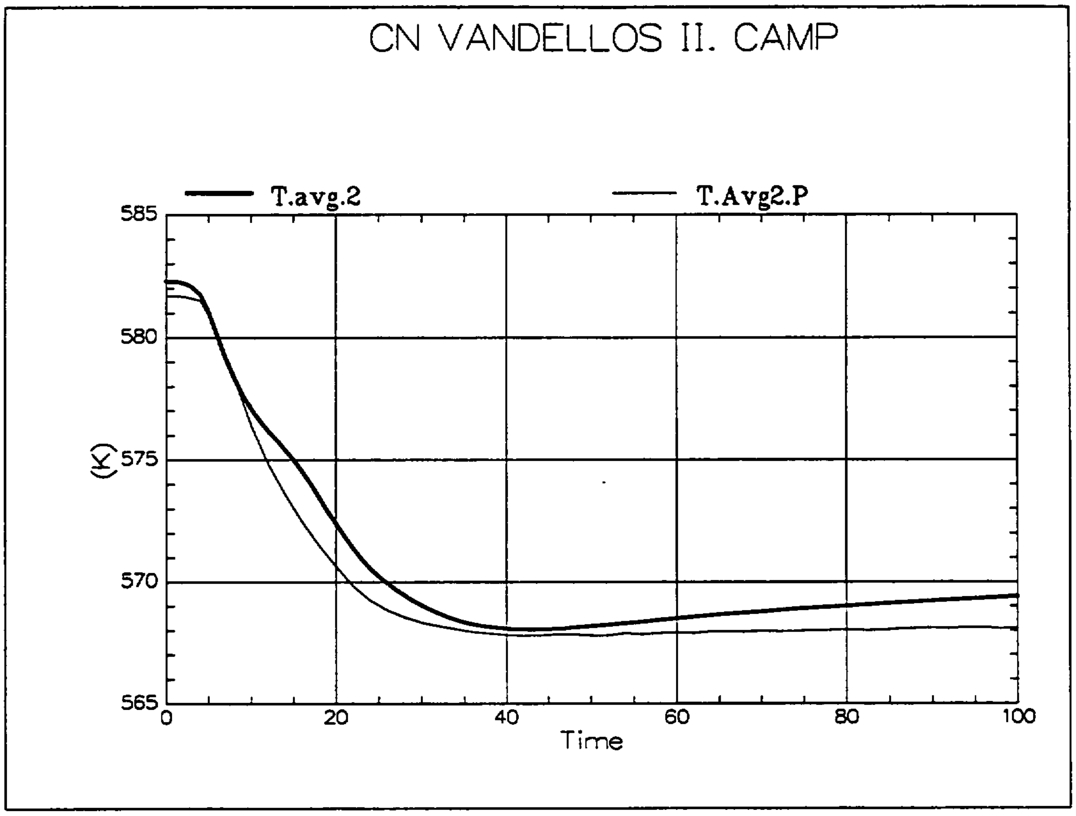


Figure 7. Average Temperature Loop 2 (100s)

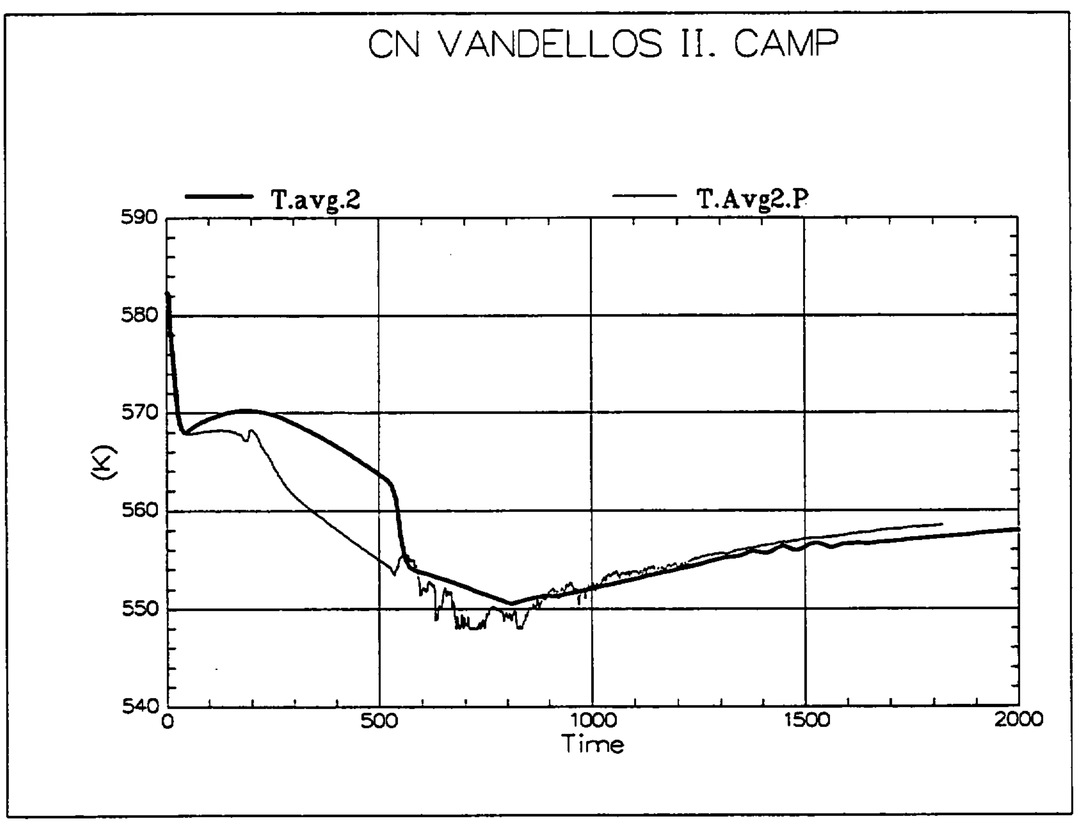


Figure 8. Average Temperature Loop 2

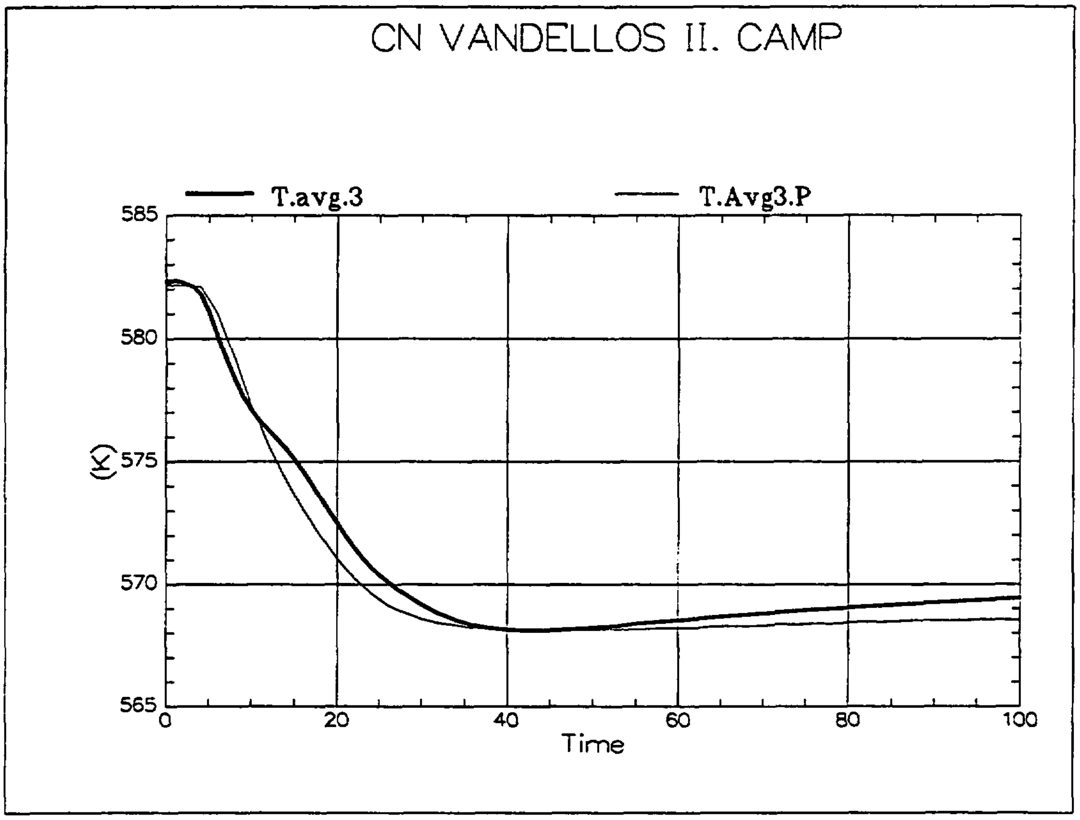


Figure 9. Average Temperature Loop 3 (100s)

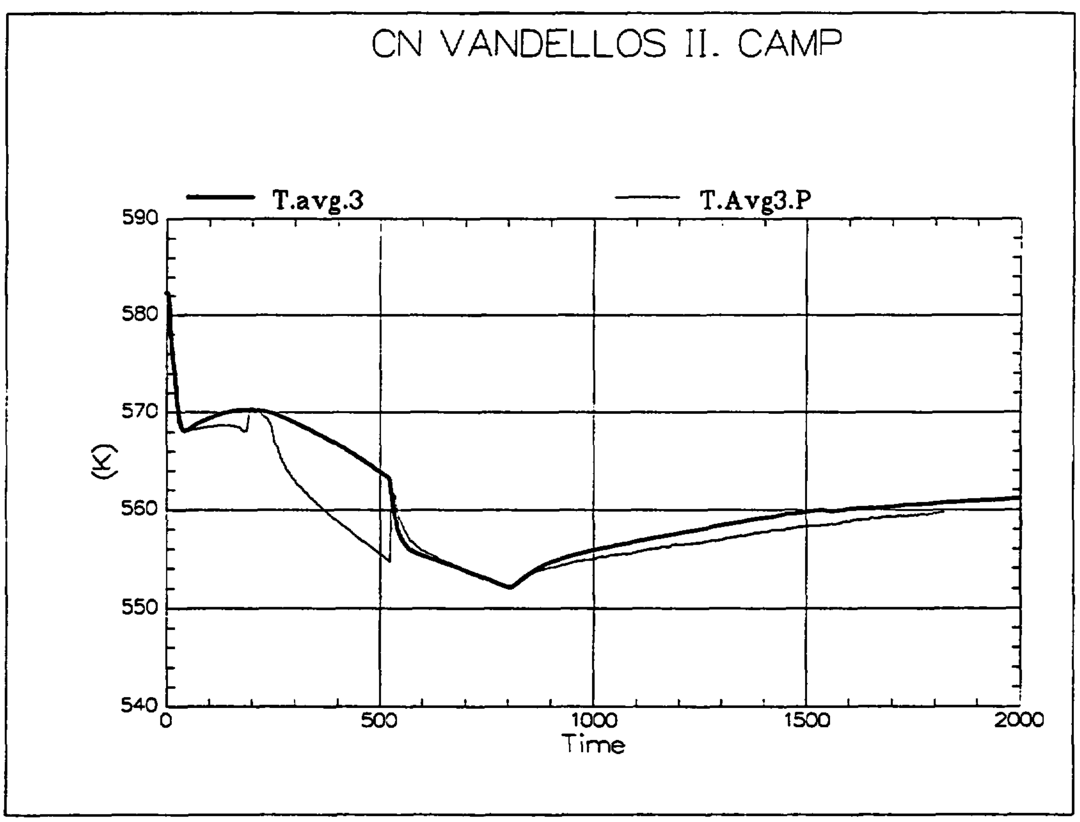


Figure 10. Average Temperature Loop 3

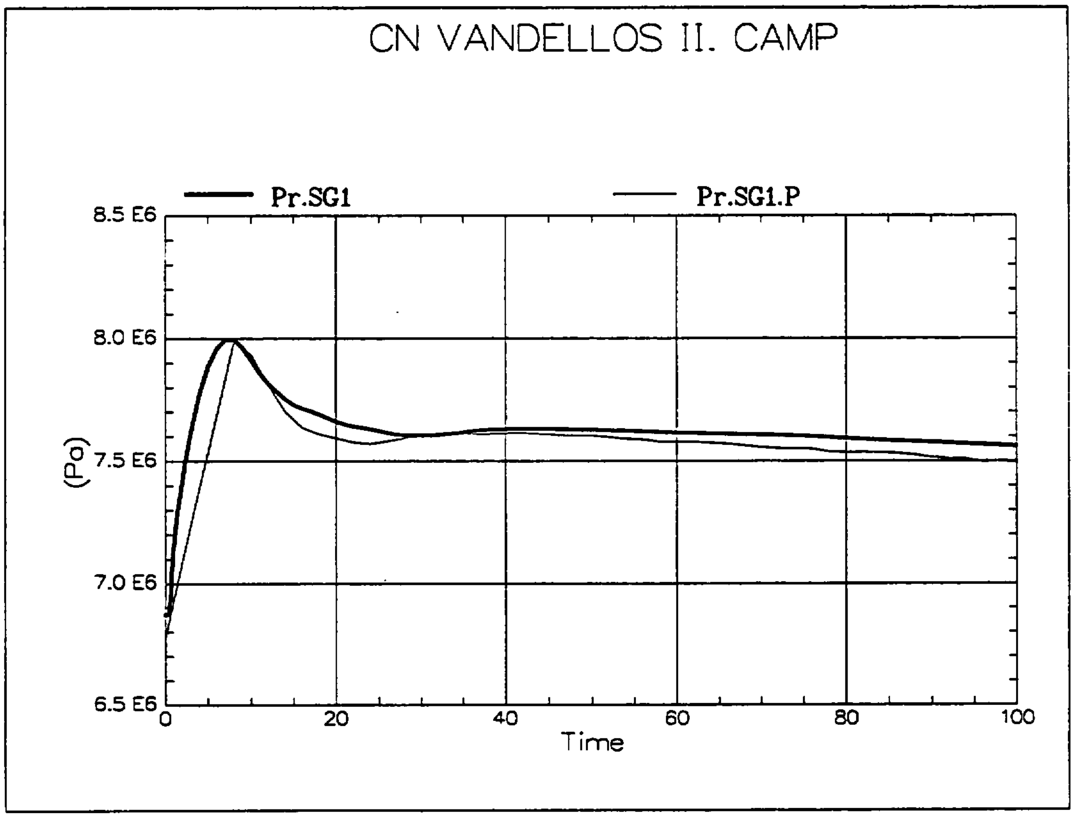


Figure 11. Steam Generator Pressure Loop 1 (100s)

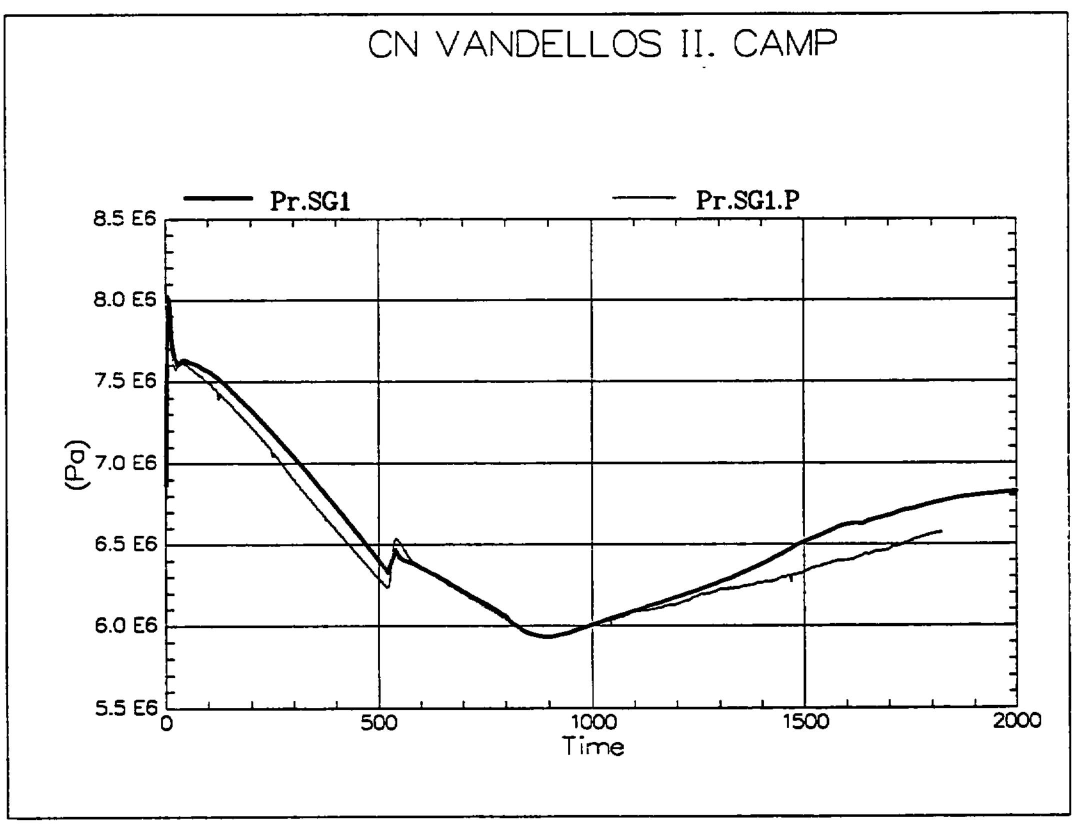


Figure 12. Steam Generator Pressure Loop 1

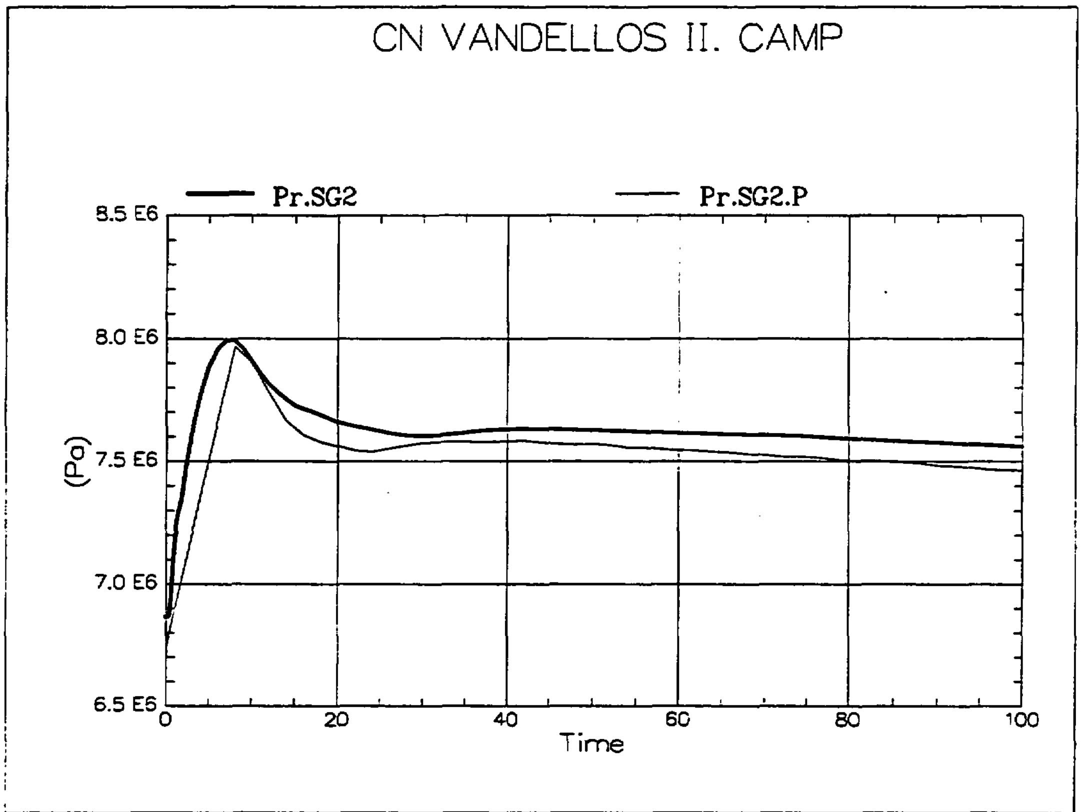


Figure 13. Steam Generator Pressure Loop 2 (100s)

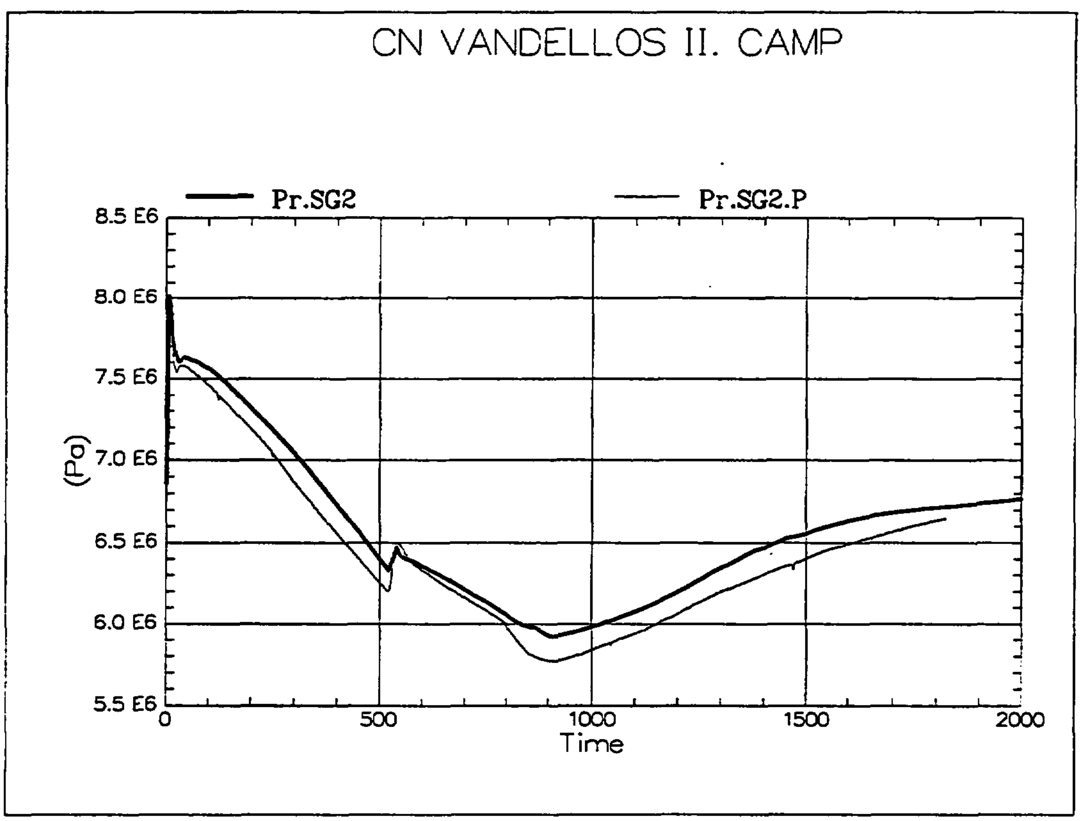


Figure 14. Steam Generator Pressure Loop 2

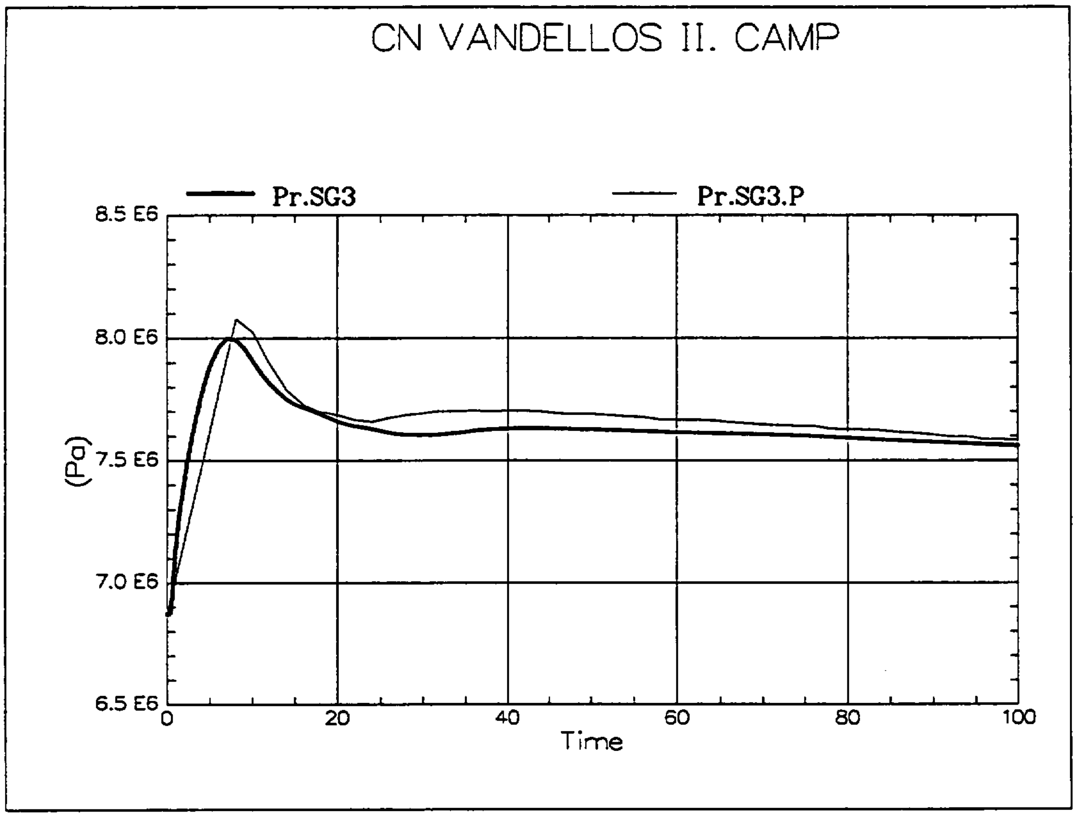


Figure 15. Steam Generator Pressure Loop 3 (100s)

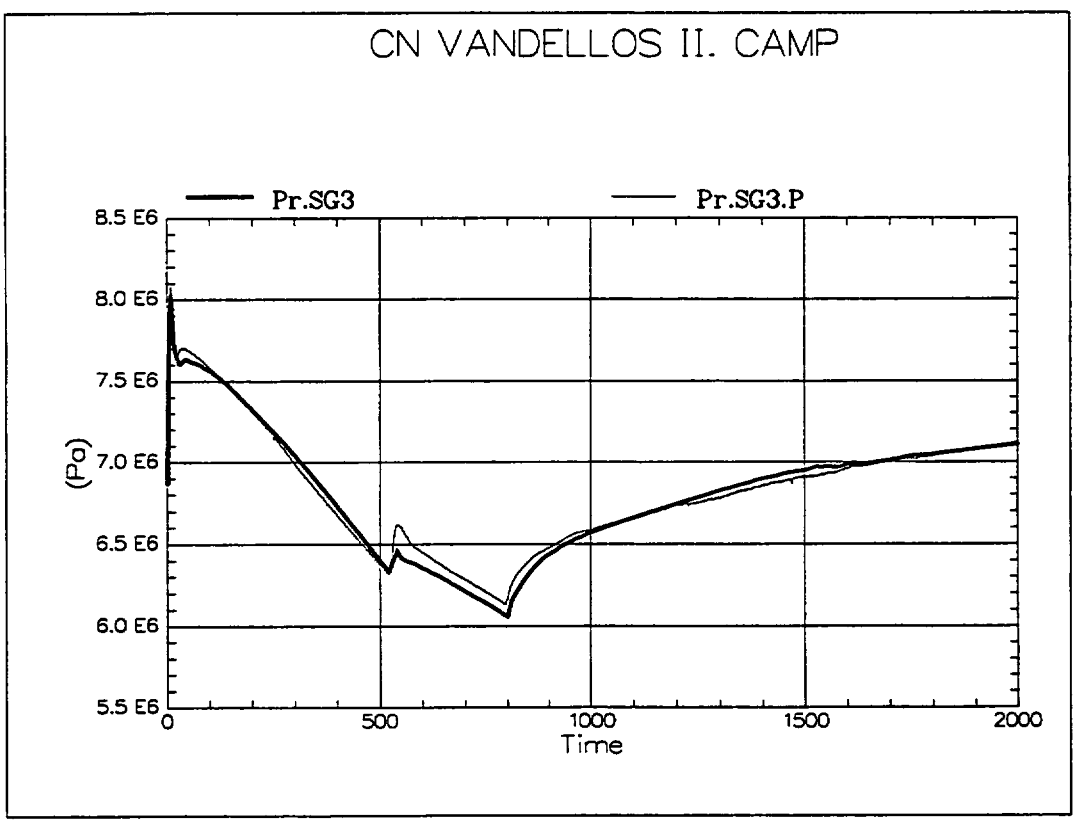


Figure 16. Steam Generator Pressure Loop 3

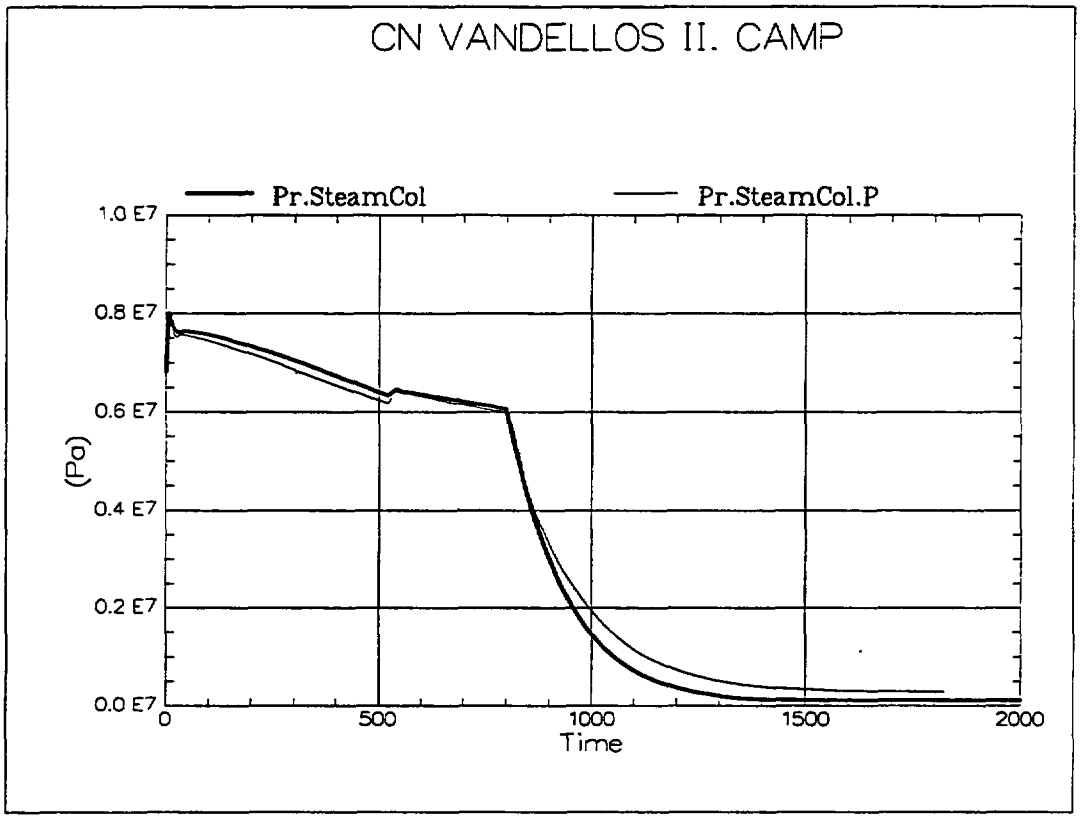


Figure 17. Steam Collector Pressure

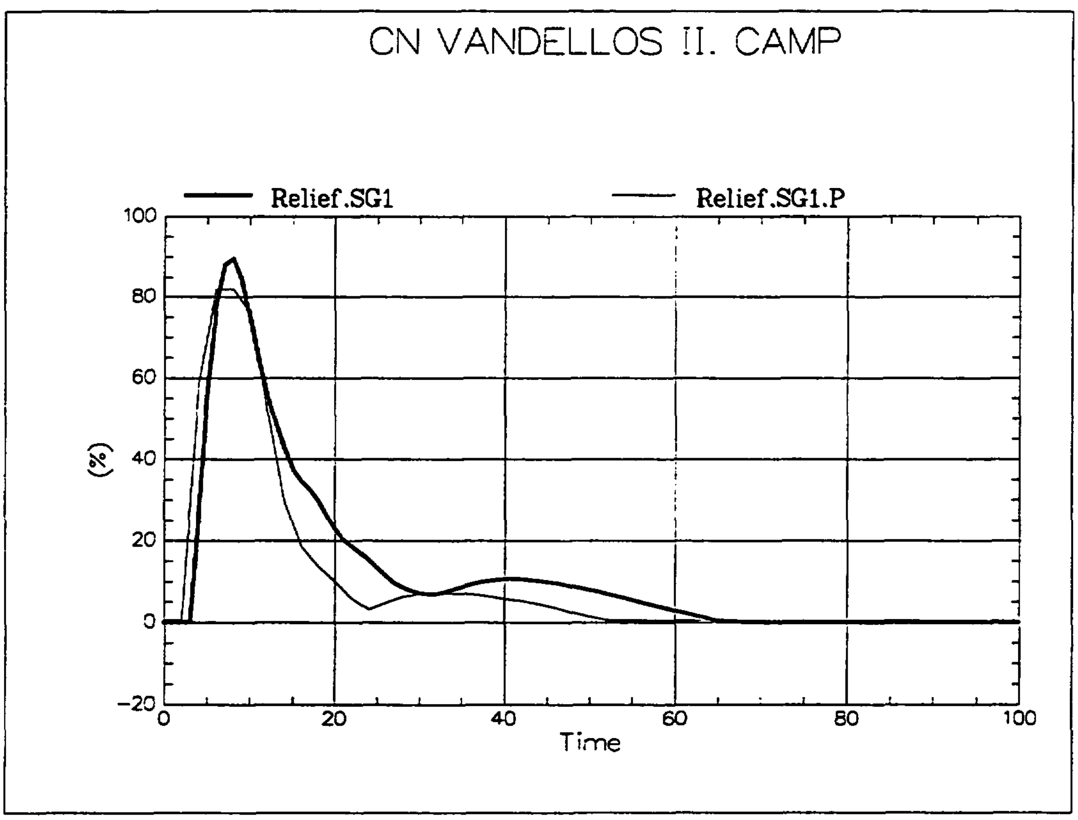


Figure 18. Steam Generators Relief Valves Demand Loop 1

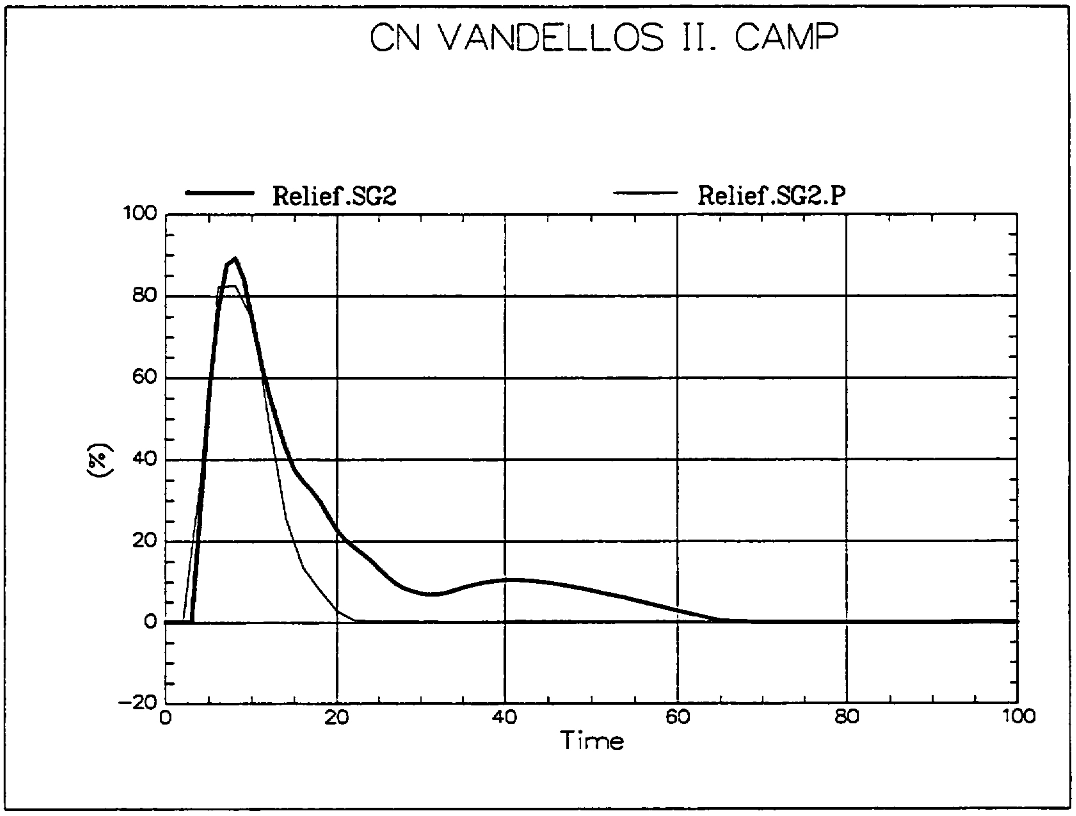


Figure 19. Steam Generators Relief Valves Demand Loop 2

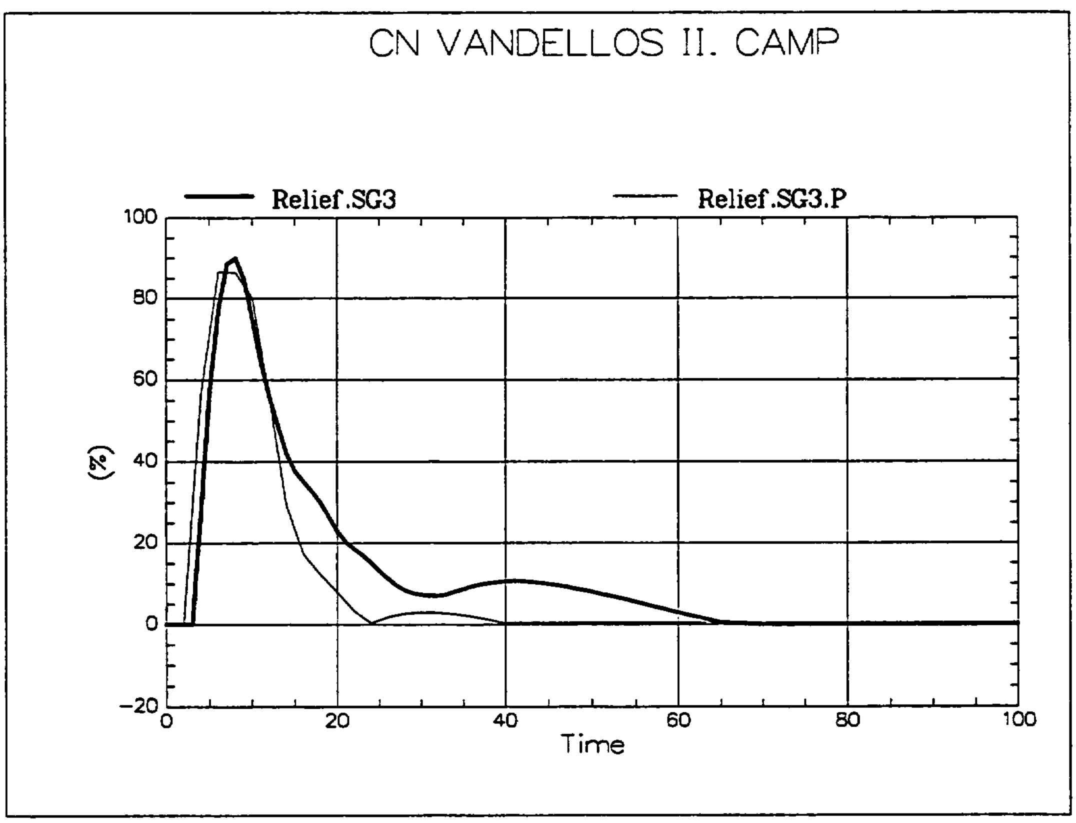


Figure 20. Steam Generators Relief Valves Demand Loop 3

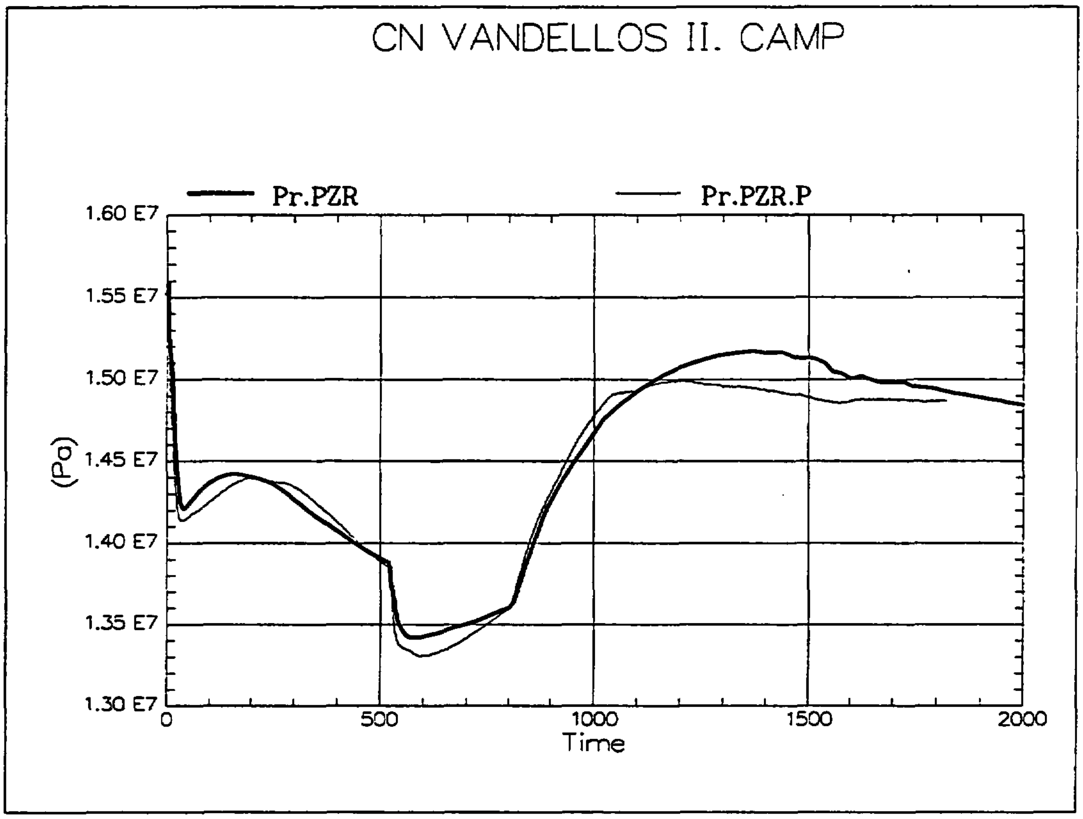


Figure 21. Pressurizer Pressure

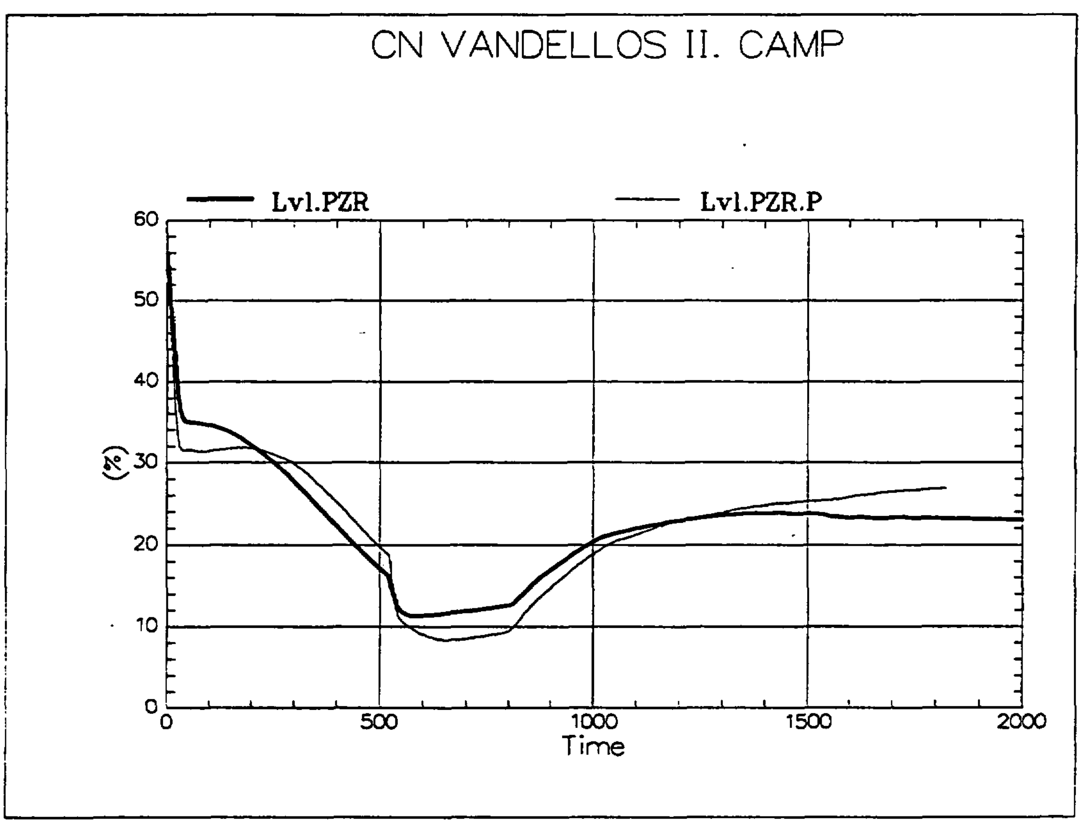


Figure 22. Pressurizer Level

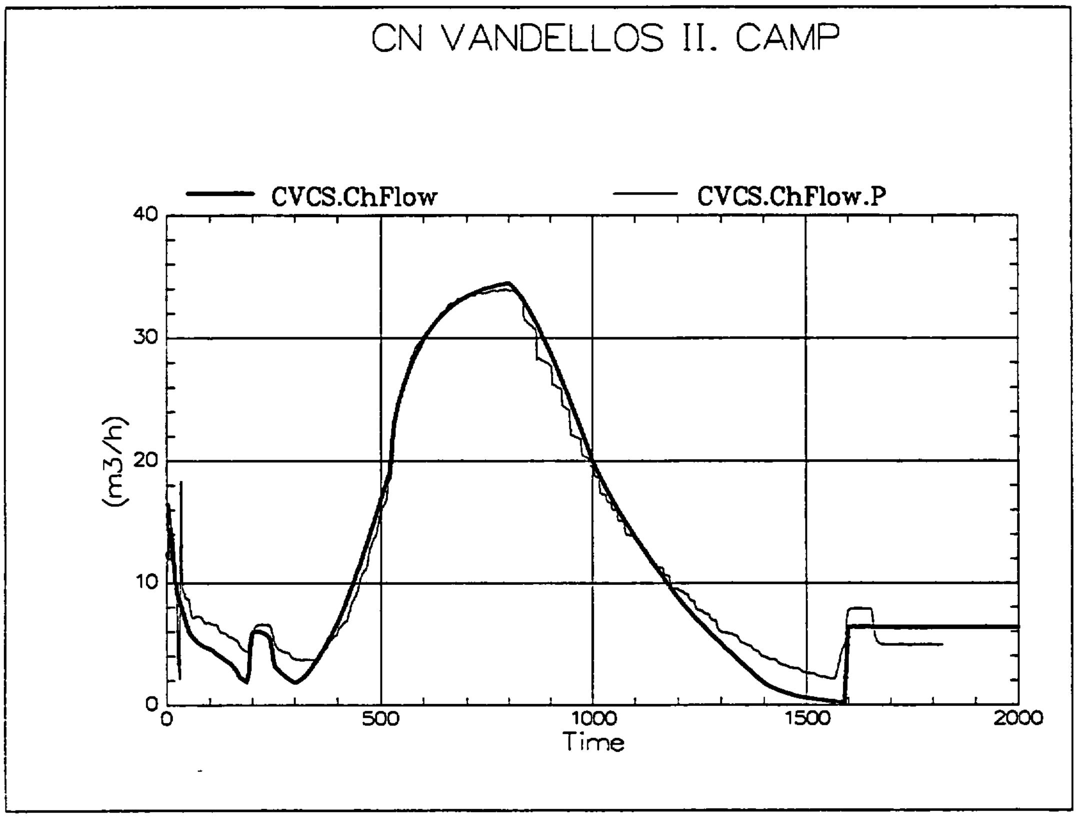


Figure 23. CVCS Charge Flow

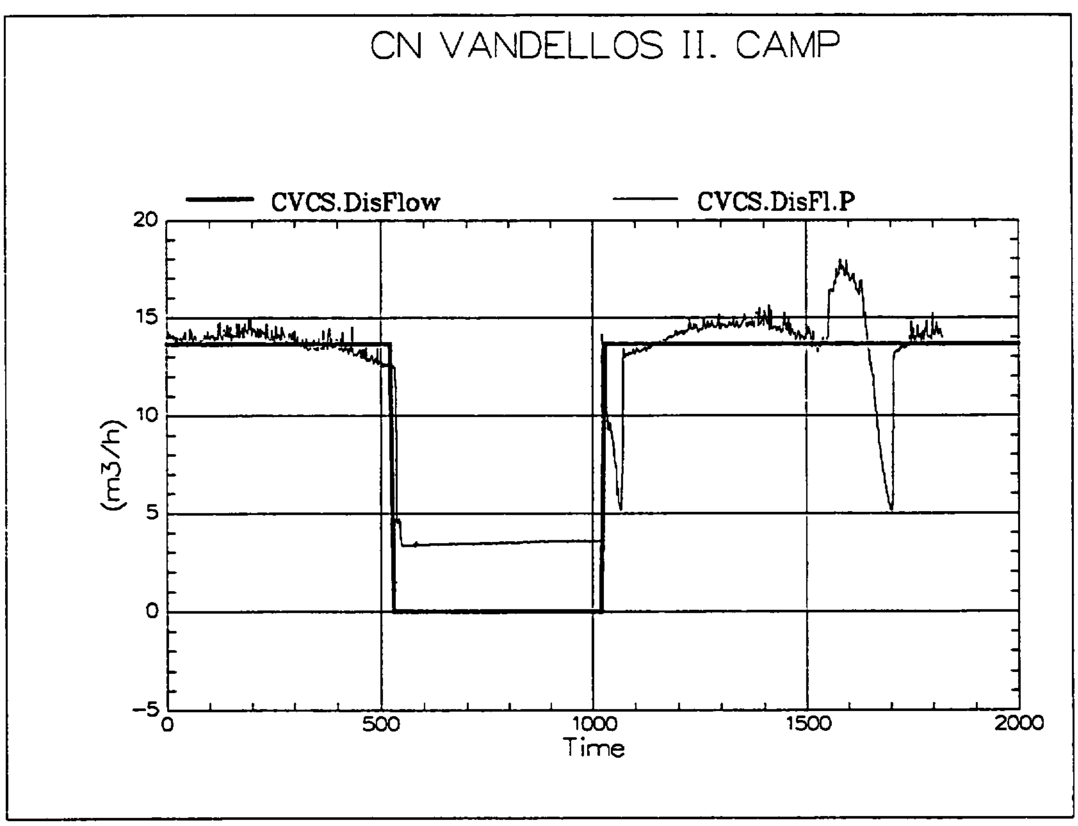


Figure 24. CVCS Letdown Flow

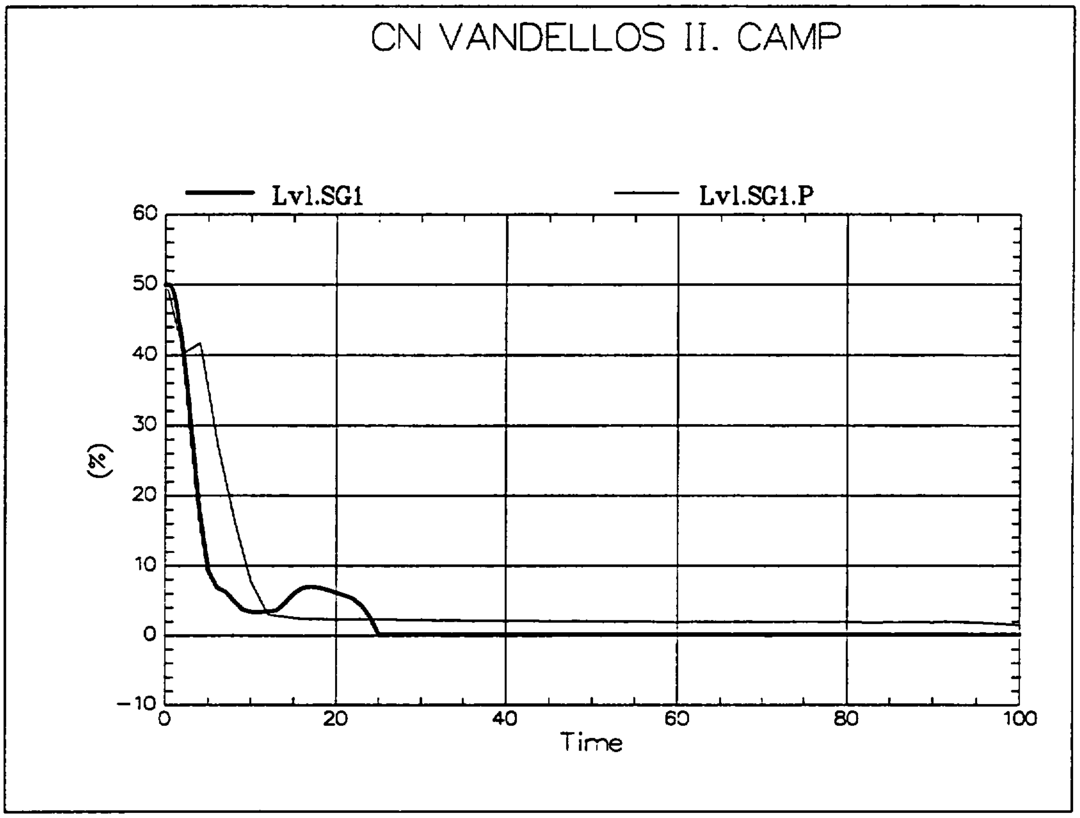


Figure 25. Steam Generators Level Loop 1 (100s)

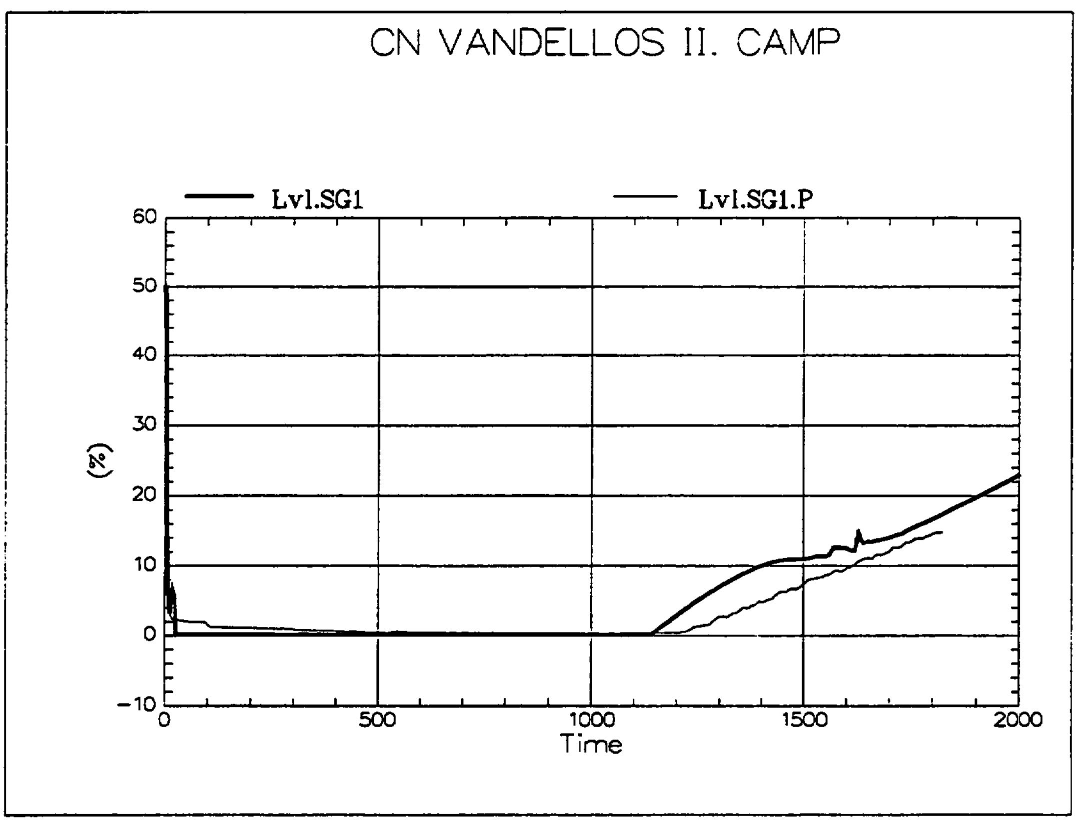


Figure 26. Steam Generators Level Loop 1

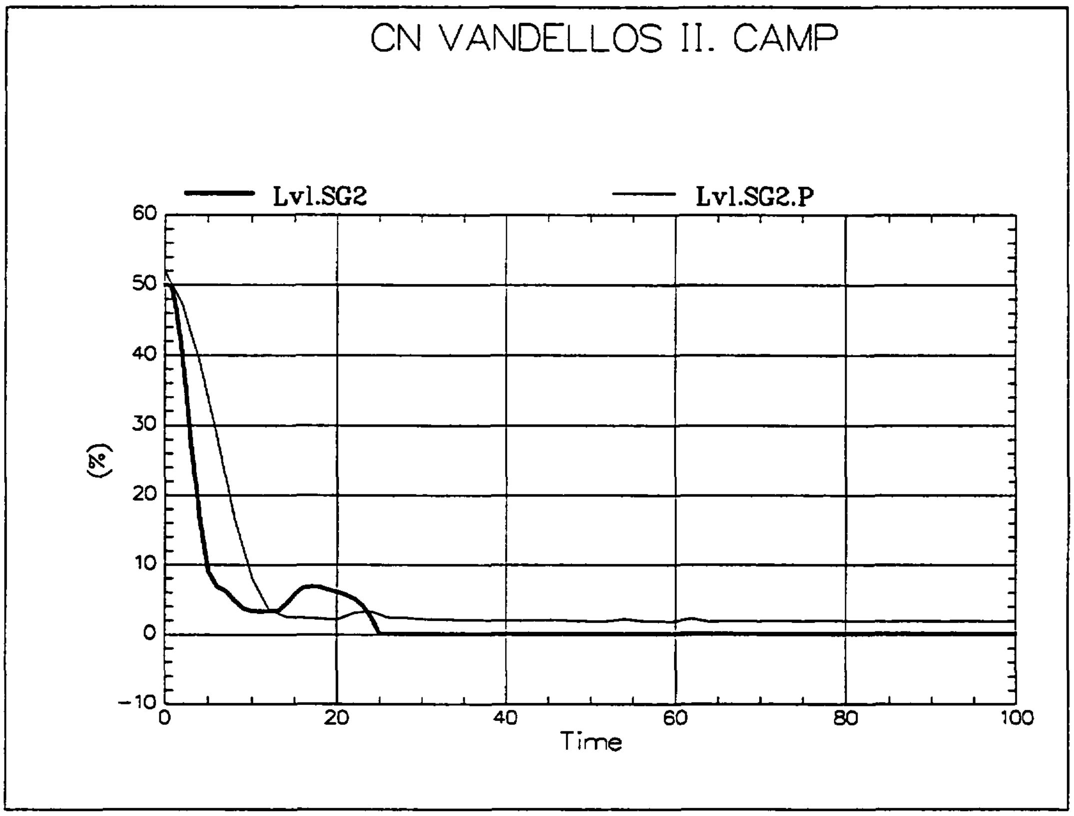


Figure 27. Steam Generators Level Loop 2 (100s)

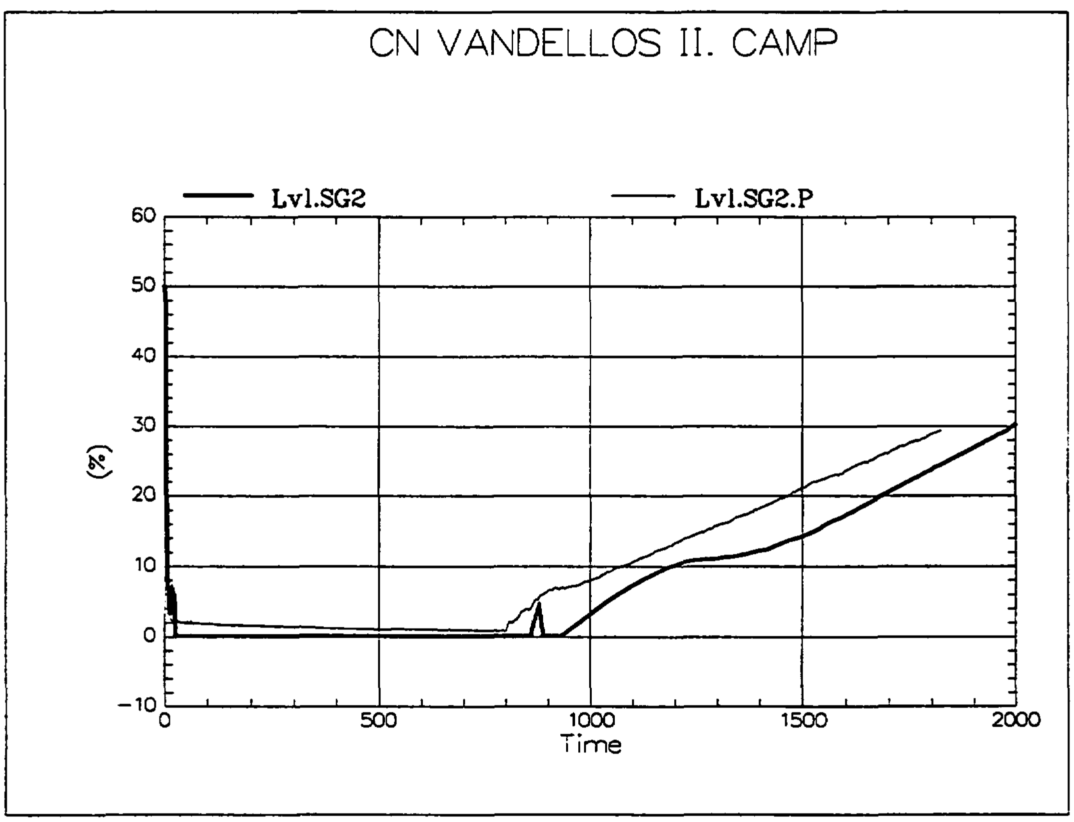


Figure 28. Steam Generators Level Loop 2

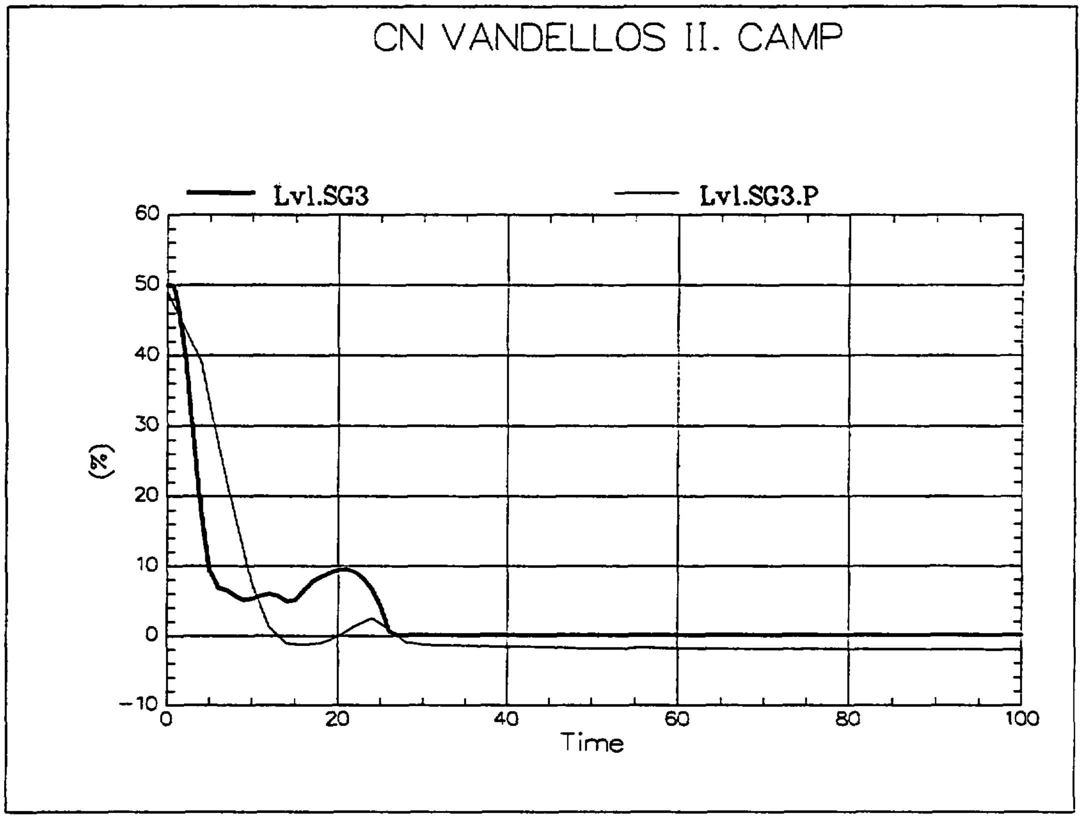


Figure 29. Steam Generators Level Loop 3 (100s)

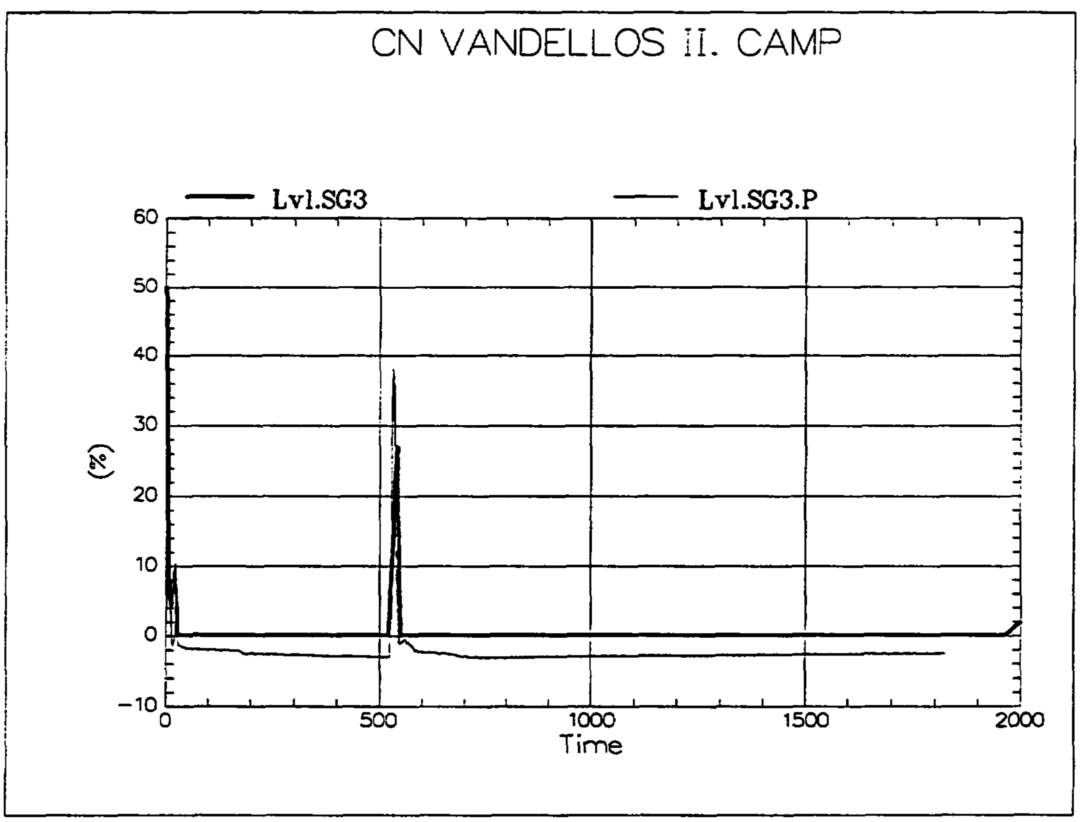


Figure 30. Steam Generators Level Loop 3

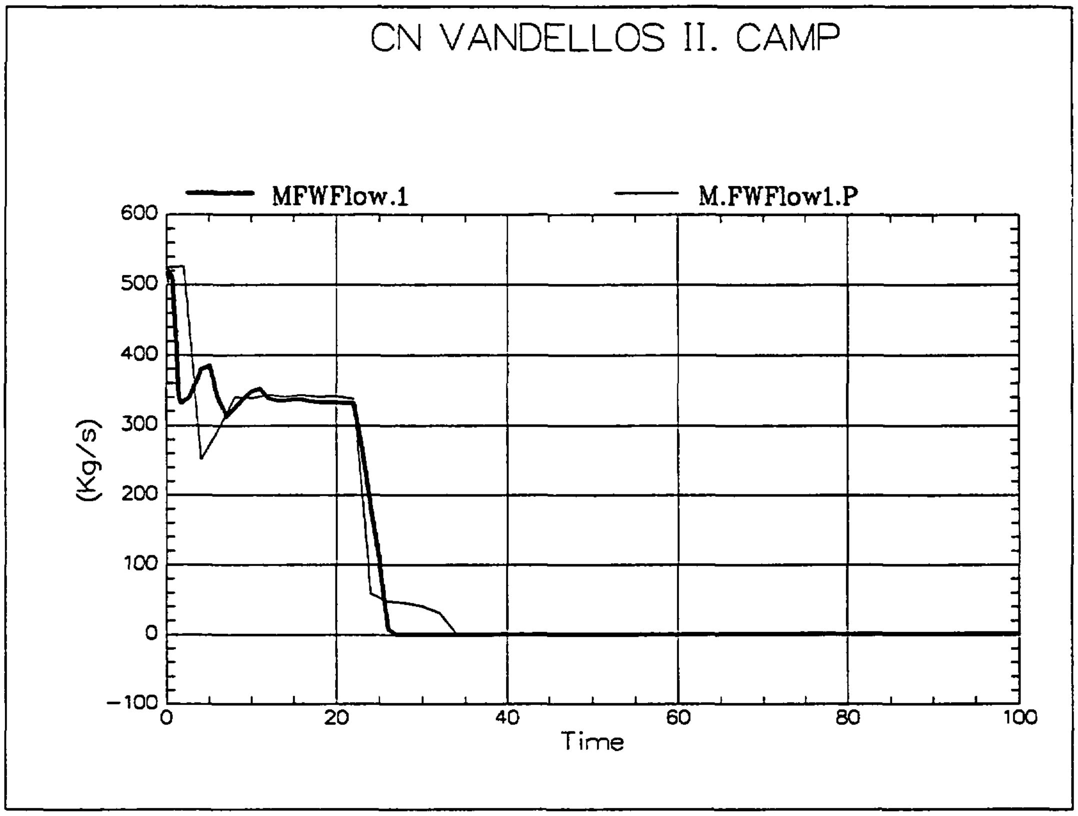


Figure 31. Main Feedwater Flow Loop 1

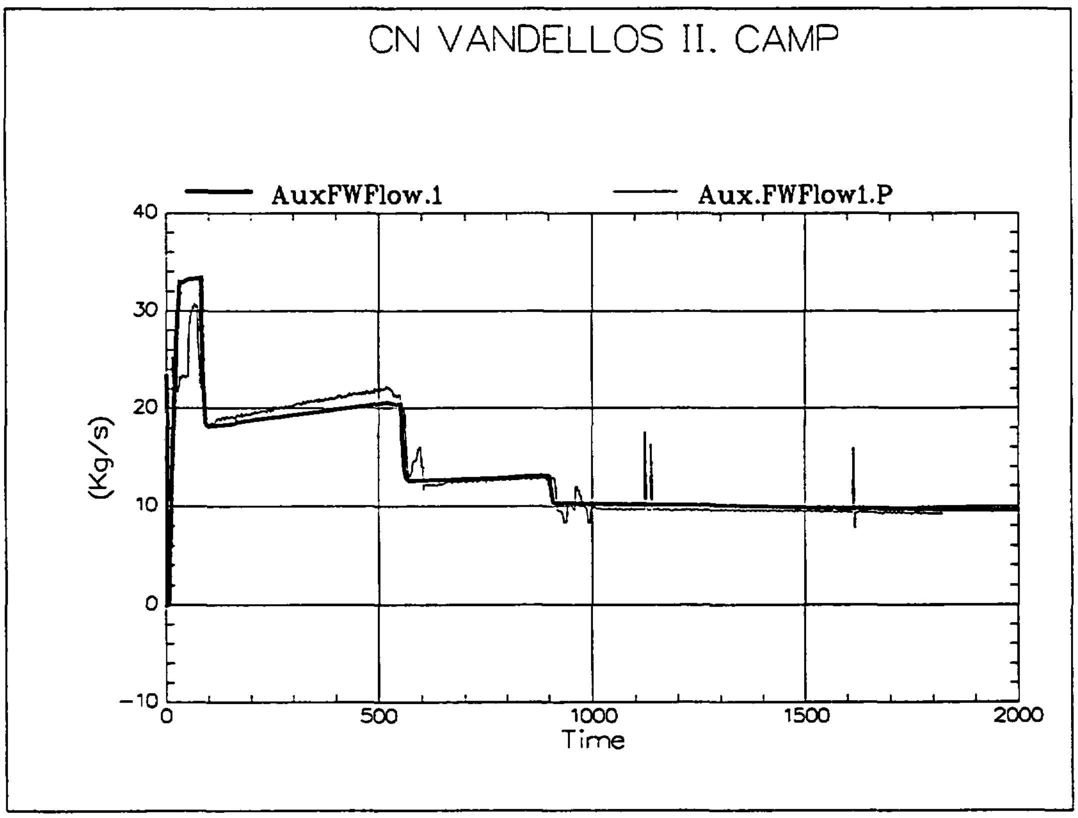


Figure 32. Auxiliary Feedwater Flow Loop 1

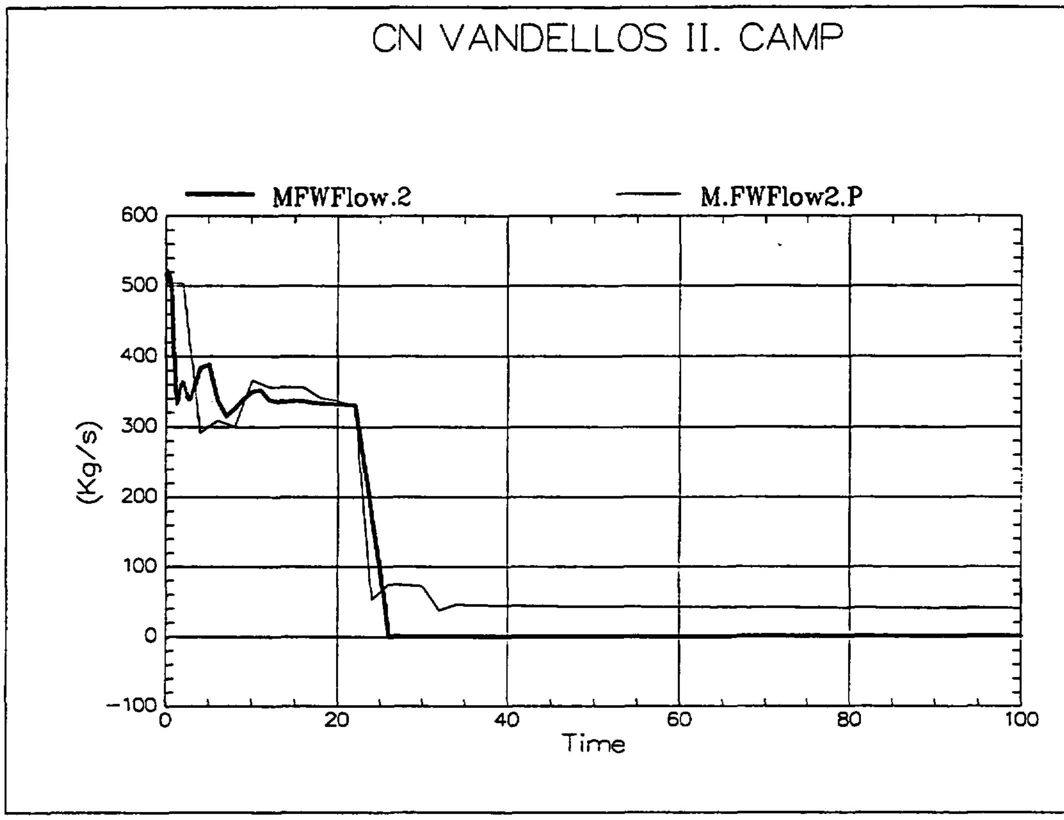


Figure 33. Main Feedwater Flow Loop 2

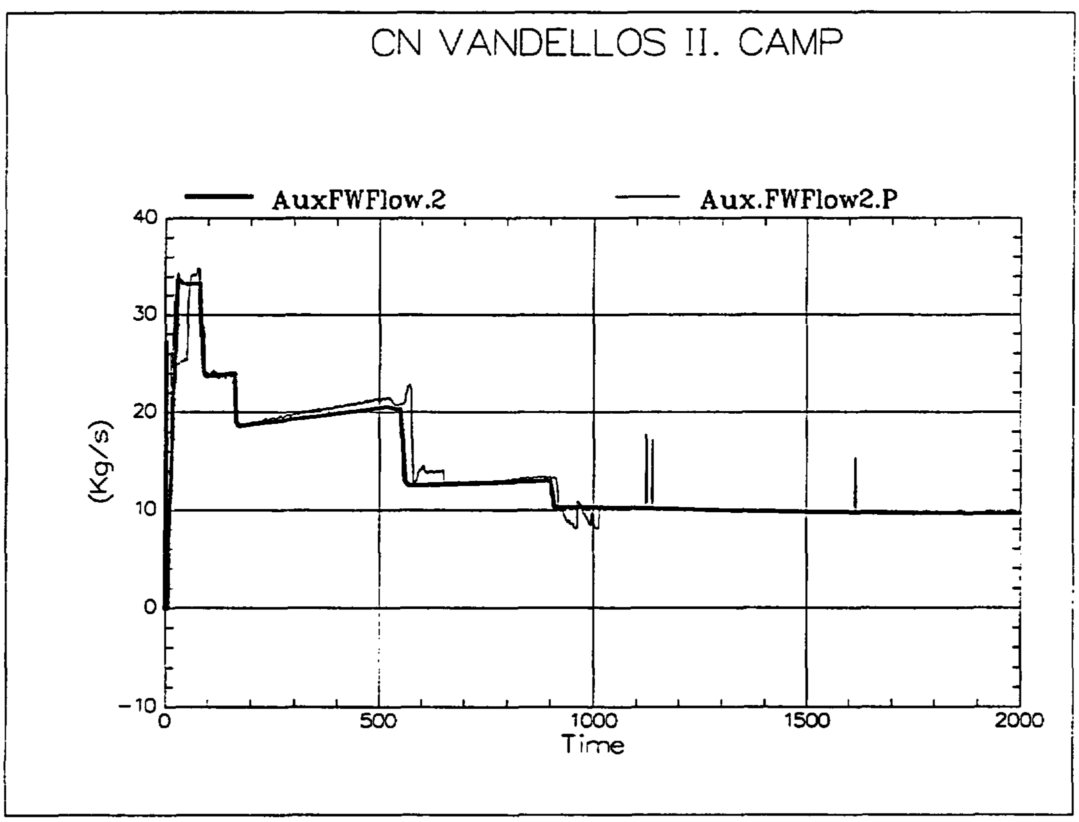


Figure 34. Auxiliary Feedwater Flow Loop 2

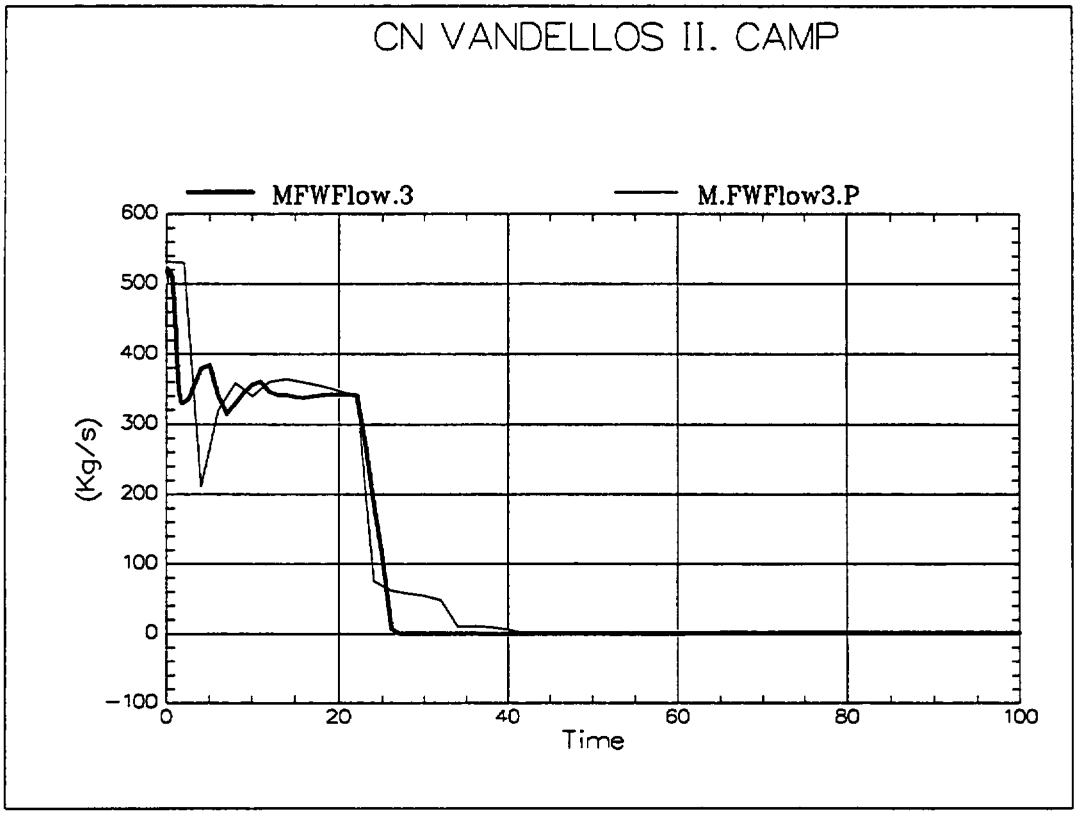


Figure 35. Main Feedwater Flow Loop 3

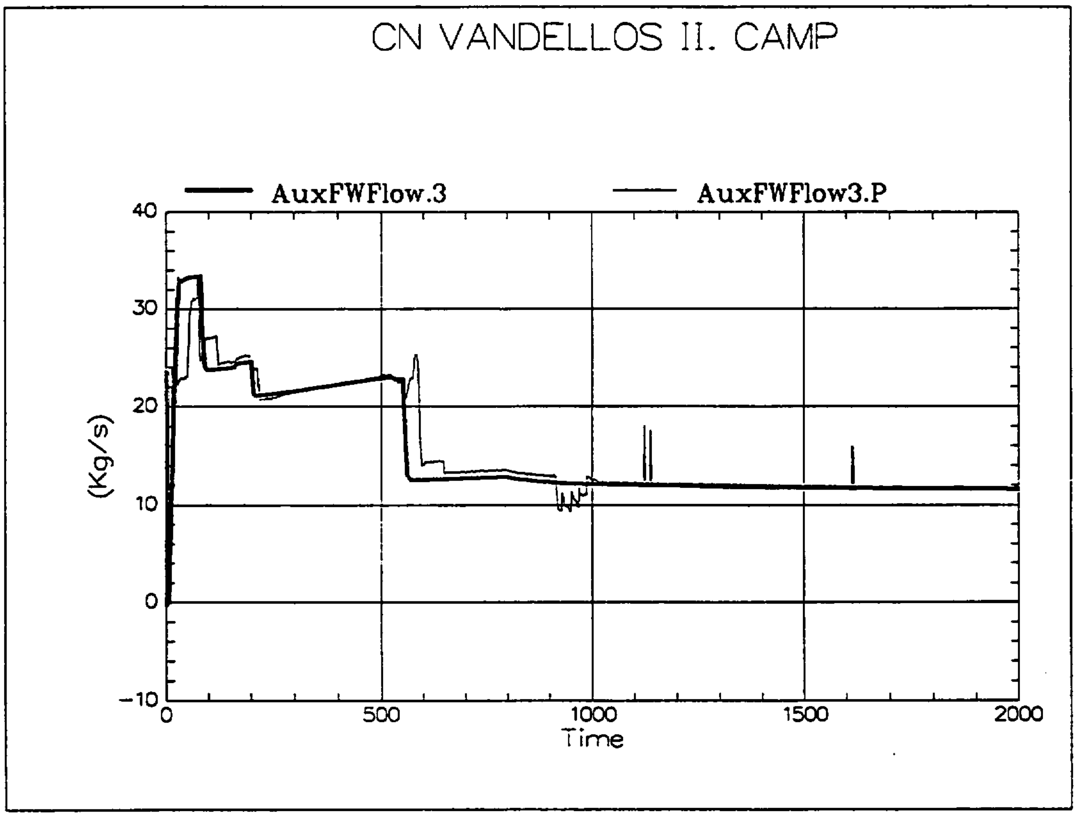


Figure 36. Auxiliary Feedwater Flow Loop 3

4.3. Run Statistics

The calculation has required the following CPU Time:

Computer	Pentium II-266MHz PC
Operating System	Windows NT
Transient time	2000 s
CPU Time	2207 s
C (Total number of actives volumes)	390
$\frac{CPU \times 1000}{C \times dT}$	.28295
CPU time / Transient Time	1.1035

5. COMPARISON BETWEEN RELAP5/MOD2 AND RELAP5/MOD3.2

5.1. RELAP5/mod3.2 instability.

We have detected that there are cases in which a node with a two phase mixture presents flow regime oscillations between "slug" and "annular-mist" regimes, causing pressure and void fraction oscillation that can affect level stability in steam generators.

Transition between these two regimes is done in RELAP within a void fraction span of 0.05 below the calculated limit. In this region, coefficients, such as interfacial heat transfer coefficient or interfacial friction coefficient, are calculated according with the expression (/1/ vol4. pg. 4A-24):

$$C = (C_{slug})^{Fslug} * (C_{anm})^{Fanm}$$

where

C_{slug} and C_{anm} are the coefficients for pure slug and annular-mist regimes

$$F_{anm} = \frac{(\alpha - (\alpha_{anm} - 0.05))}{0.05} \quad ; \quad F_{slug} = 1 - F_{anm} \quad when \quad (\alpha_{anm} - 0.05) \le \alpha \le \alpha_{anm}$$

We have checked that oscillations between these flow regimes can be considerably reduced if transition function is changed according with the expression:

$$F_{anm} = \sqrt{\frac{(\alpha - (\alpha_{anm} - 0.05))}{0.05}} \quad ; \quad F_{slug} = 1 - F_{anm} \quad when \quad (\alpha_{anm} - 0.05) \leq \alpha \leq \alpha_{anm}$$

This modification has been programmed in the code (*phantv* and *phantj* subroutines) used to perform calculations included in this report. Transitions between other flow regimes do not seem to show these oscillations, at least not so important, so we have decided not to modify those transitions.

In Figure 37 the effect of this modification on interfacial heat transfer coefficient is represented; we have assumed the values 1.e-4 W/m^3.K for slug regime and 0.5 for annular-mist (approximated values for vap.int.htc, obtained from Vandellòs model at full power steady state) and that transition occurs between 0.5 y 0.55 α_g.

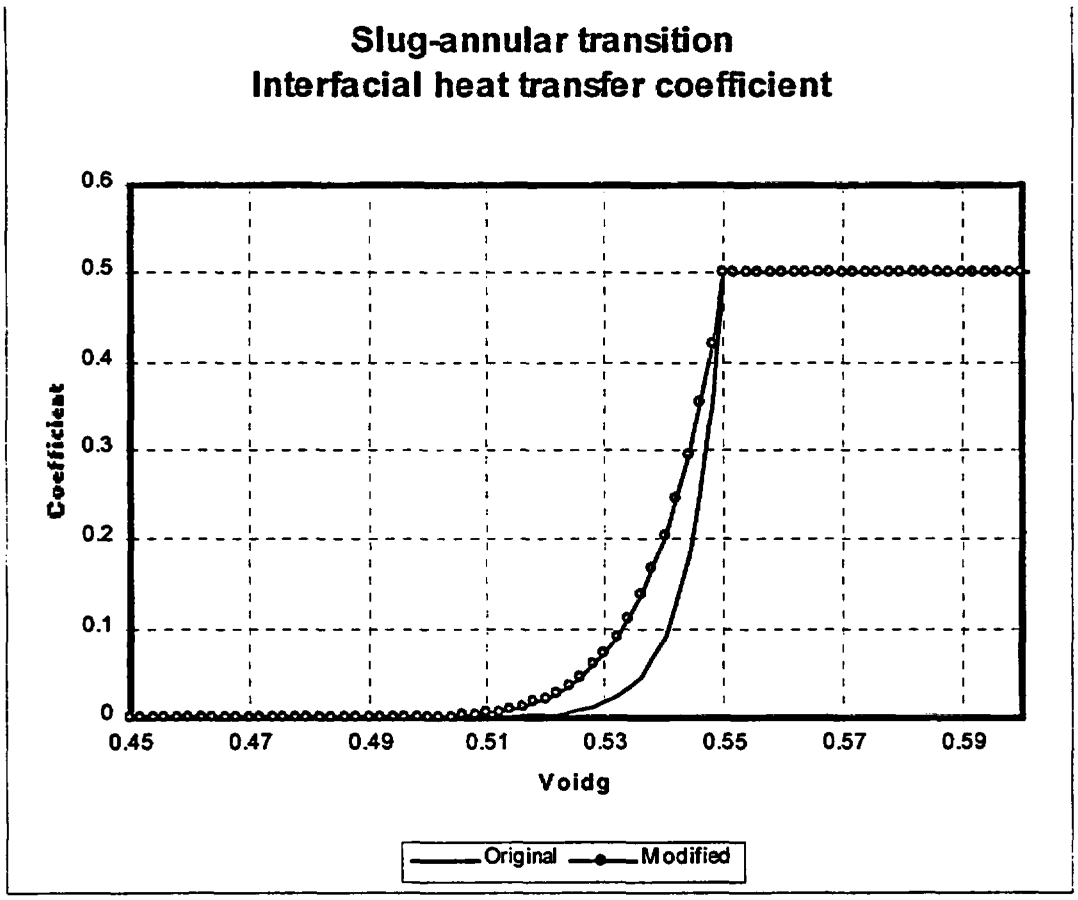


Figure 37. Modification of slug annular-mist transition

5.2. Steady State

An additional comparison between versions mod2.5 and mod3.2 of RELAP has been done, in order to do it, the models developed for such versions have been used.

Steady State is reached in both models after approximately 2000. seconds running a "null transient".

The main differences between the versions are shown in steam generators, that is, in two-phase flow. Results at nominal power are summarized in Table 3.

Table 3. Steady State Comparison.

	PLANT	*RELAP5/mod2.5*	*RELAP5/mod3.2*
Thermal Power (MW)	2775.	2775.	2775.
Primary Pressure (MPa)	15.5	15.5	15.5
Hot Leg Temperature (K)	599.8	599.7	599.3
Cold Leg Temperature (K)	564.8	565.0	565.2
Average Temperature (K)	582.3	582.3	582.2
Primary Flow (Kg/s)		13905.	14116
RCP Head (MPa)		.643	.623
Feedwater Mass Flow (Kg/s)		1561.	1561.
Steam Mass Flow (Kg/s)	1542.9	1542.9	1544.2
Secondary Pressure (MPa)	6.84	6.82	6.87
Recirculation Ratio	3.27 (*)	3.26	3.29
Liquid Mass per SG (Kg)	44100 (*)	37500.	40028.

(*) Design Values /5/

Vandellòs mod2.5 /3/ and mod3.2 /2/ models have been used to compare the behavior of steam generator model at different conditions, reducing load demand in 10%

steps, and waiting for the steady state to be reached before reducing load demand again (Figure 38). The most significant results are shown in the following figures.

In Figure 39 an example of the above-mentioned oscillations is shown. Steam generators level obtained with RELAP5 mod3.2 Vandellòs model, present such oscillations at time 4000-6000s corresponding to a turbine power of 70%.

Figure 40 shows the evolution of steam generator level with the modified code, where no level oscillations are observed.

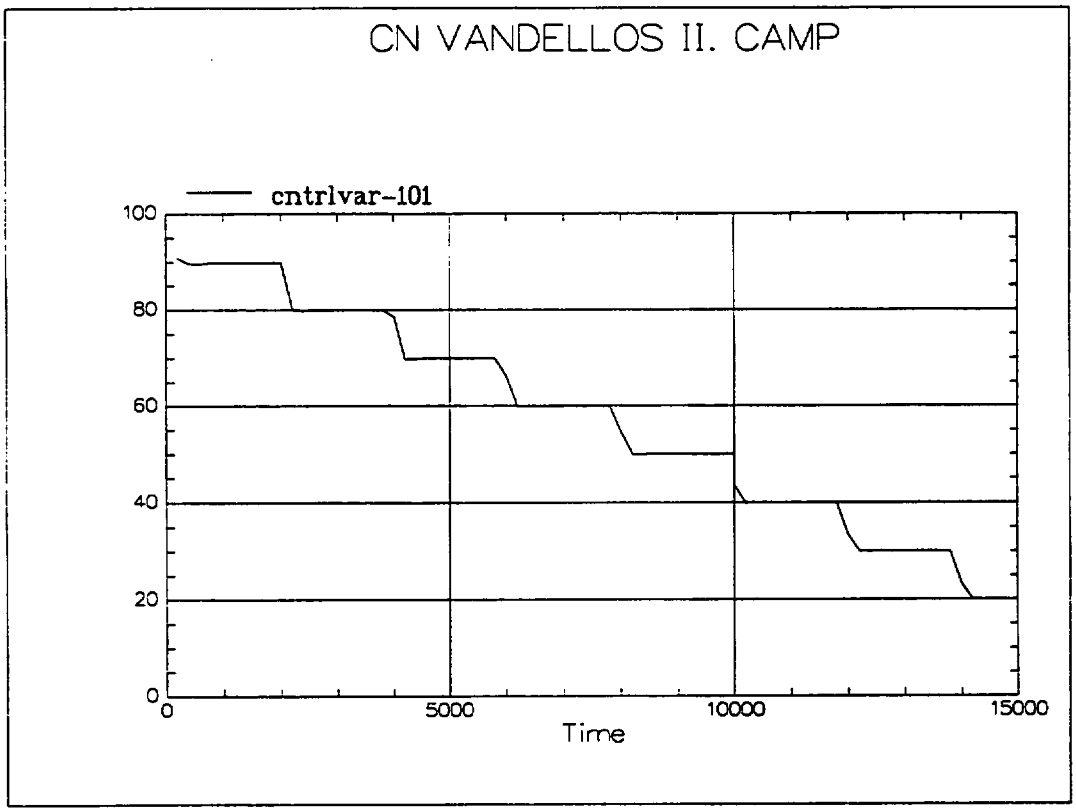


Figure 38. Load Steps. Turbine Power.

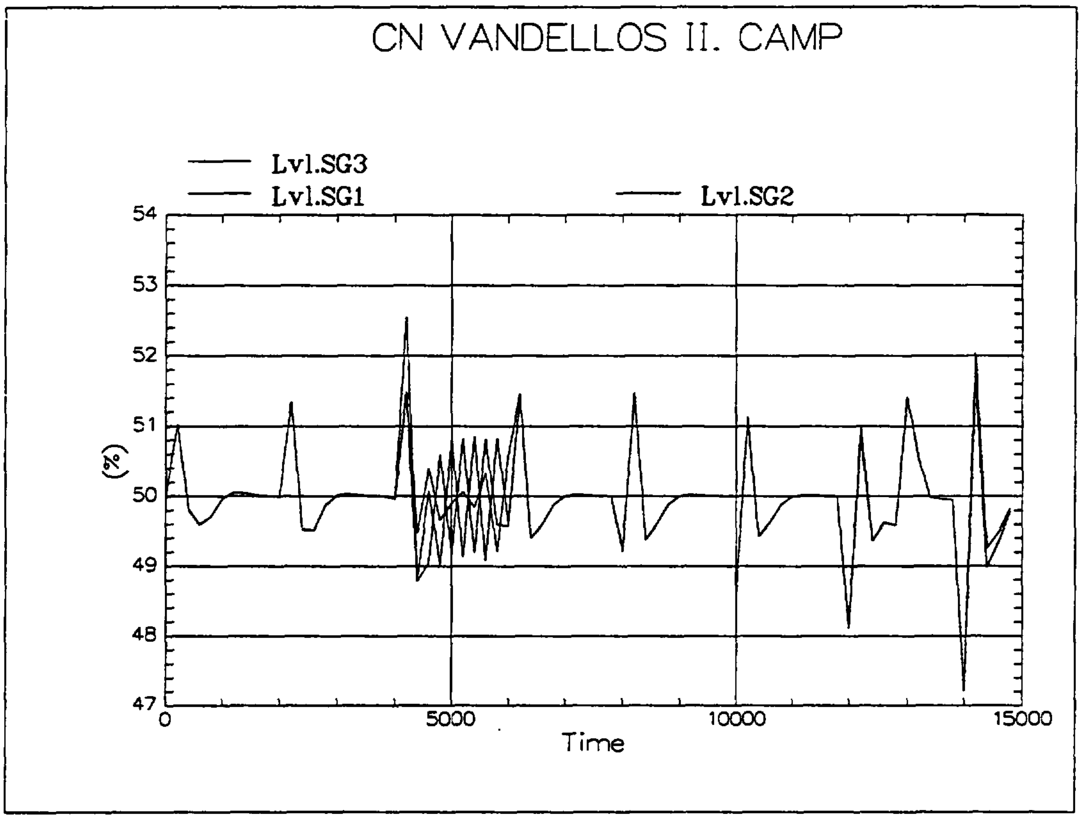


Figure 39. Steam generators level. Original Code

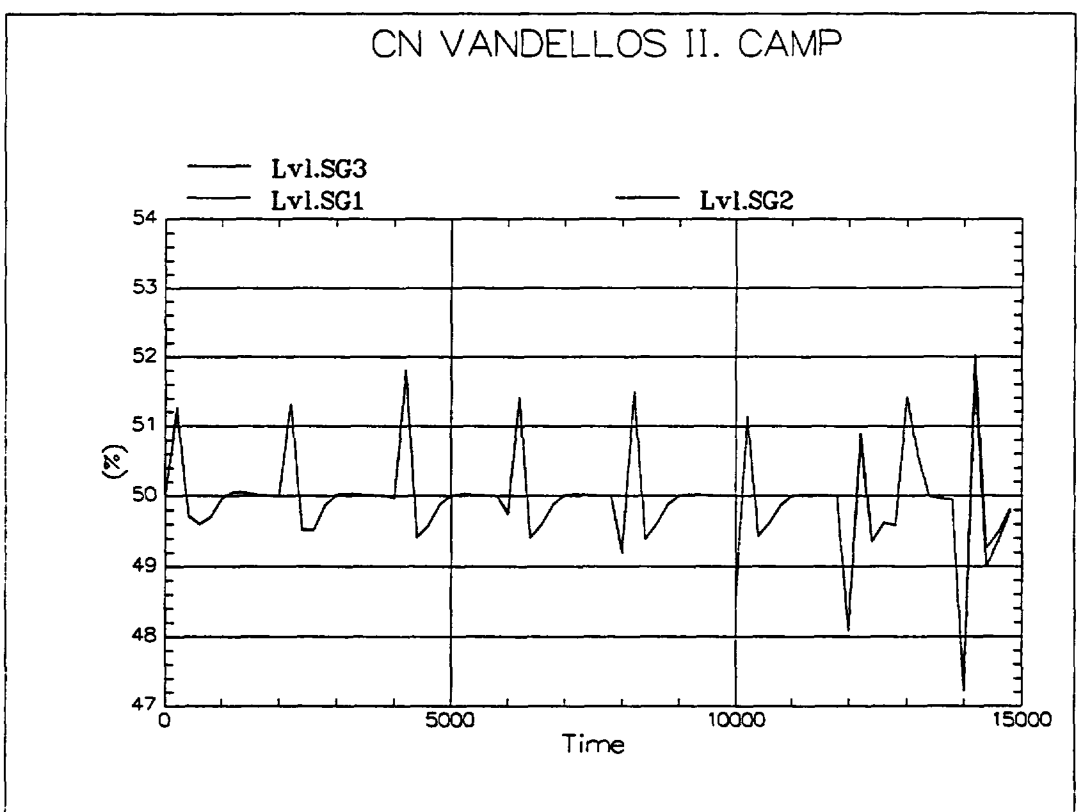


Figure 40. Steam generators level. Modified Code

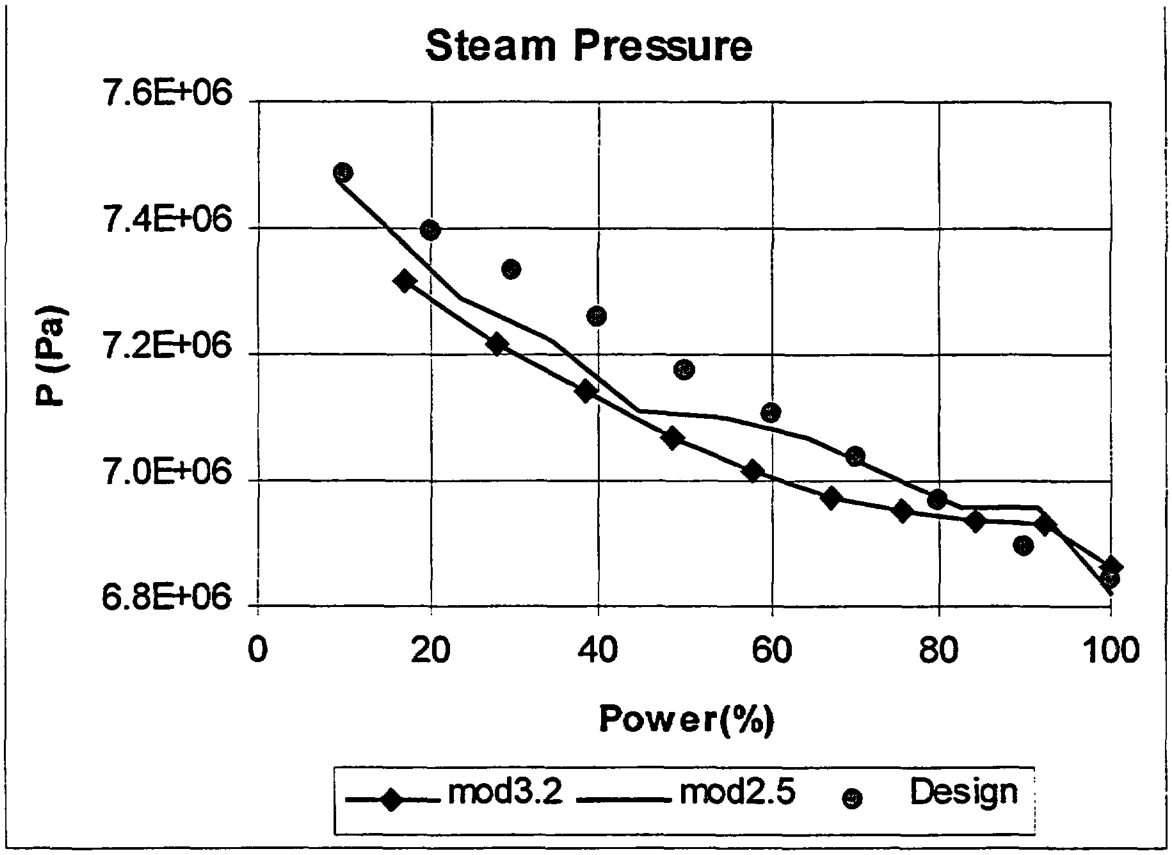


Figure 41. Steam Pressure vs. Heat Load

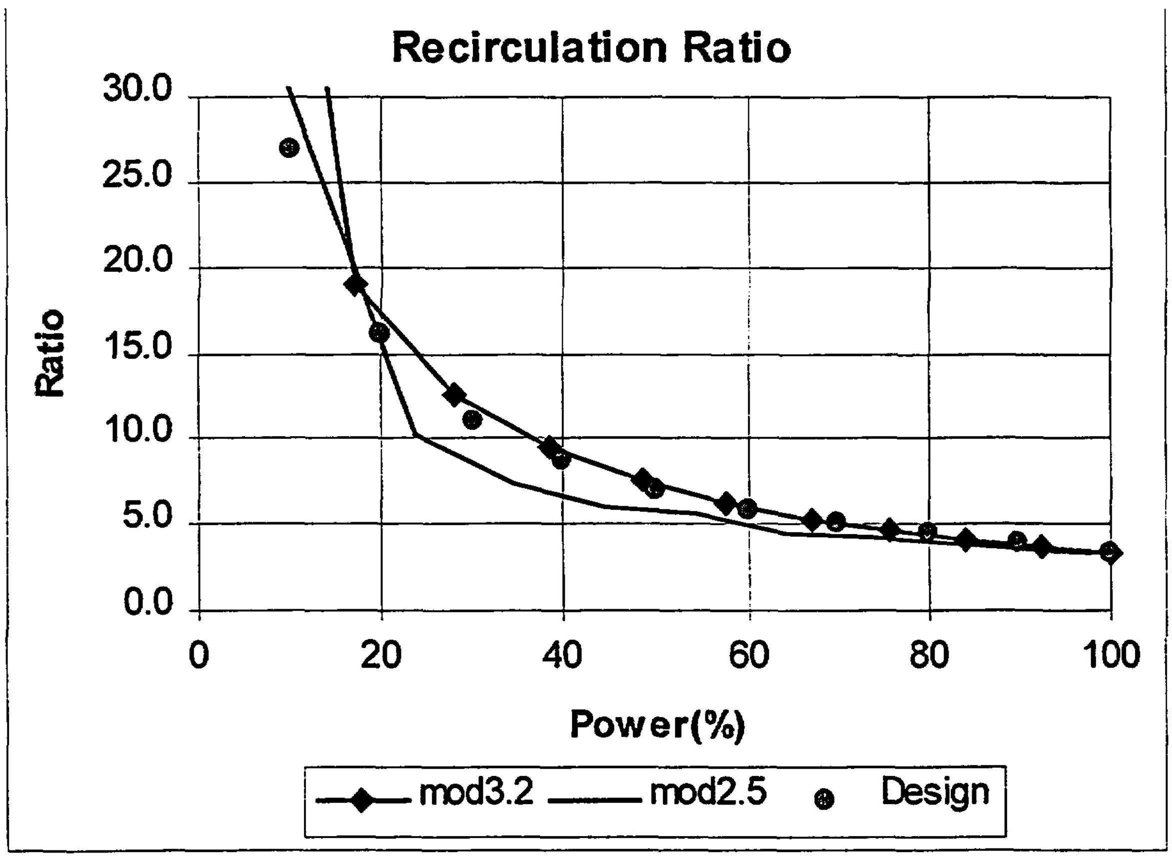


Figure 42. Recirculation Ratio vs. Heat Load

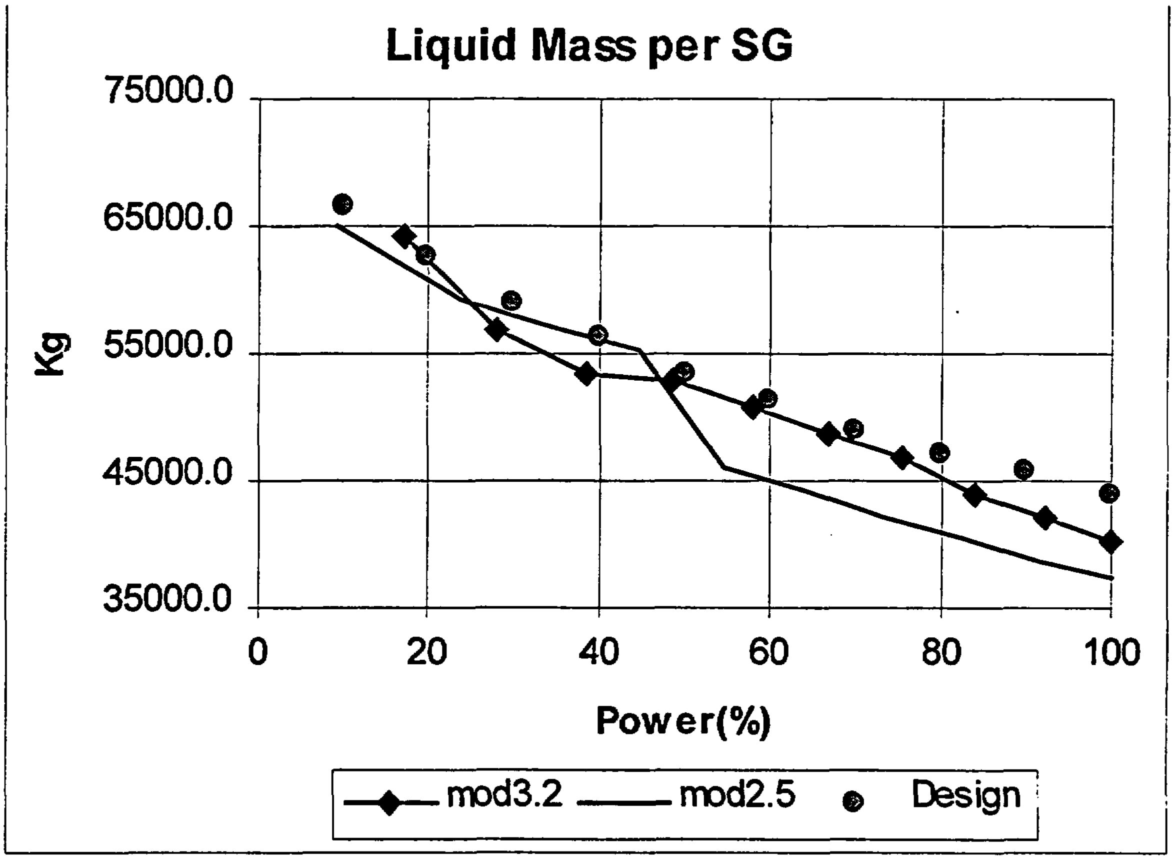


Figure 43. Liquid Mass vs. Heat Load

The comparison of the two versions (Figure 41, Figure 42 and Figure 43) shows that there are some differences in results related with two-phase flow. RELAP5/mod3.2 reproduces better the design values for steam generators/5/.

6. CONCLUSIONS

RELAP5/mod3.2 has improved two-phase models; so steam generators values are better reproduced with this version, using actual hydraulic diameters and material properties.

Some oscillations in slug annular-mist transition have been detected and corrected. The modified code is more stable when this flow regime transition occurs.

Vandellòs model for RELAP5/mod3.2 has shown to be a valuable tool to analyze Plant transients, including the one reported here, in which a wide variety of phenomena are involved: kinetics, natural circulation, forced circulation with only one pump, and secondary isolation. Results are much more accurate than those obtained with RELAP5/mod2.5 and the correspondent model.

The graphical Interface developed with NPA is a great tool that facilitates work both in engineering and instruction environment. Improvements incorporated in NPA make the graphical interface even more powerful and user friendly.

7. REFERENCES

/1/ "RELAP5/mod3.2 CODE MANUAL." The RELAP5 Code Development Team. NUREG/CR-5535

/2/ "Informe Final del proceso de validación del modelo de C.N. Vandellòs II para el código RELAP5/mod3.2." PMSA-CNV. Feb1998

/3/ "Modelación del Primario y sistemas asociados de la C.N. Vandellòs II con el código RELAP5/mod2.5". CNV. Feb. 1997.

/4/ "Informe Final de Seguridad" CNV II

/5/ "Model F steam generator Thermal hydraulic data report". January 7, 1981. Westinghouse Electric Corporation

/6/ "Precautions, limitations and setpoints" Rev.11. Westinghouse Energy System Europe.

/7/ "Diagramas lógicos". UTE (INITEC, INYPSA, E. AGRUPADOS)

/8/ "Diagramas de lazos" UTE (INITEC, INYPSA, E. AGRUPADOS)

/9/ "Diagramas de Tubería e Instrumentación" UTE (INITEC, INYPSA, E. AGRUPADOS)

/10/ "Isométricos de tuberías" UTE (INITEC, INYPSA, E. AGRUPADOS)

/11/ "Diagramas de proceso" UTE (INITEC, INYPSA, E. AGRUPADOS)

/12/ "Datos de planta obtenidos con el SAD". CNV II

/13/ "Balance del secundario". CNV II

/14/ "Informe migración a MOD3.2". PMSA

/15/ "Informe final de Validación del modelo de C.N. Vandellòs II para el código RELAP5 mod3.2" PMSA Feb.98

/16/ "Interactive Graphical Analyzer based on RELAP5/Mod3.2-NPA". PMSA, ANA, CNV II. Presented at Second CSNI Specialist Meeting on Simulators and Plant Analyzers. Finland, 1997.

/17/ "RELAP5/Mod3.2-NPA for Personal Computer". PMSA, ANA. Presented at Relap5 International Seminar. Texas, USA, May 1998.

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10. SUPPLEMENTARY NOTES

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11. ABSTRACT *(200 words or less)*

This report is an assessment calculation with RELAP5/MOD3.2 - NPA3.4 against a transient that took place in Vandellos II Nuclear Power Plant on December 2, 1991. This work is part of the Spanish contribution to the Code Assessment and Maintenance Program (CAMP). Vandellos II is a member of UNIDAD ELECTRICA, S.A. (UNESA).. Vandellos II is a 2775 Mwt three loop Westinghouse PWR owned by ENDESA, SA (72%) and IBERDROLA (28%); it is on the Mediterranean coast, near Tarragona Spain). The commercial operation began in 1988. The simulation has been running on a Pentium II 266MHz PC under Windows NT. This version has been tested and results are exactly the same as those obtained with a DECStation 500/200.

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

RELAP5/MOD3.2
PWR
Vandellos II

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