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ICSP-AL-BOUT-R

International Agreement Report

Application of Full Power Blackout for C. N. Almaraz with RELAP5/MOD2

Prepared by
A. L. Lechas

C. N. Almaraz I y II
c/Claudio Coello, 123
28006 - Madrid, Spain

Office of Nuclear Regulatory Research
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)

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NOTICE

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ABSTRACT.-

The analysis group of Almaraz Nuclear Power Plant has developed a model of the plant with RELAP 5 / MOD. 2 / 36:04. This model is the result of the work-experience on the code RELAP 5 / MOD. 1 / that was the standar code during the period 1.984/1.989. Different solutions were adopted in the network to adecuate the model to RELAP 5 MOD. 2 Computer Code.

This transient was selected for ICAP because it presents an experience with the same transient calculated with RELAP 5 / MOD. 1 / CY 29 computer code. The comparison between both analysis will be interesting.

EXECUTIVE SUMMARY.-

Almaraz Nuclear Power Plant are two units P.W.R. designed by Westinghouse. Commercial operation started in April 1.981 the Unit I and in September 1.983 the Unit II.

Almaraz Nuclear Power Plant has a nominal reactor power of 2696 MWt and three loops (each). Steam generators are typical U-tubes model D-3 with preheater designed by Westinghouse. Reactor coolant pumps are type single stage, centrifugal model W-11011-A1 (93-D) designed also by Westinghouse.

The total electrical power output is 930 MWe.

Almaraz nuclear power plant received the computer code Relap 5 / Mod. 2 / 36:04 through the ICAP project. In exchange Almaraz Nuclear Power Plant should send to ICAP the results analysis selected for that purpose two transients.

The first one is the blackout from 100% rated power to be described in this report.

The Almaraz nuclear power plant model, with Relap 5 / Mod. 2 / 36:04, consists of 210 control volumes, 220 junctions, 37 heat structures and 189 control variables.

All calculations have been carried out on a computer C.D.C. Cyber 180/830. The C.P.U. time versus real time event was 22.6.

ICAP PROJECT

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F O R E W O R D

This report has been prepared by Central Nuclear de Almaraz in the framework of the ICAP-UNESA Project.

The report represents one of the 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 Regulatory Commission (USNRC) in the form of Spanish contribution to the International Code Assessment and Applications Program (ICAP) of the USNRC 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:

- Unidad Eléctrica (UNESA)
- Unión Iberoamericana de Tecnología Eléctrica (UITESA)
- Empresa Nacional del Uranio (ENUSA)
- TECNATOM
- Empresarios Agrupados
- LOFT-ESPAÑA

The program is executed by 12 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.

1. INTRODUCTION

Within the framework of the Spanish contribution to the I.C.A.P. project, which is promoted by the Spanish Nuclear Safety Council (Consejo de Seguridad Nuclear) and in which participation by the Electrical Sector is led by U.N.E.S.A., the different nuclear power plants, electrical utilities and engineering companies mainly dedicated to development of Nuclear Energy were invited to collaborate.

In this respect CENTRAL NUCLEAR DE ALMARAZ is one organization in Spain dedicated to the nuclear-based generation of electrical energy. The company's two 930 MWe units are one of the main contributions to the country's installed electrical power.

Almaraz Nuclear Power Plant began to perform calculations using the Relap 5 Mod. 1 calculation Code in 1984, with a dual application: on the one hand, due to the need for a Best Estimate Calculation Code for the calculation of accidents and transients, and on the other for the training of operations personnel, an area in which the code has been widely used since 1984.

With respect to thermohydraulics, versions 19, 21, 25 and 29 of the above-mentioned Relap 5 mode 1 code have been used, the model utilized being variable depending on the transient to be calculated, but generally equipped with 210 control volumes.

Mode 2 of the Relap 5 calculation code was installed in the Almaraz NPP computer in April 1988, this initiating knowledge of the code and attempts to acquire the experience necessary for future replacement of Relap 5 Mode 1 C and 29, although at present the standard calculation code at Almaraz continues to be mode 1.

On the basis of the above, the first complete calculation of an accident was undertaken. Our organization decided to dedicate this initial experience to normal blackout (loss of offsite power, Loop), as this sequence presents a series of highly important characteristics that may be summed up in the following two areas:

- Experience accumulated in previous analysis using Relap 5 Mode 1.

- The possibility of comparing results with an actual event that occurred at Almaraz NPP in December 1981.

2. PLANT AND TRANSIENT DESCRIPTION

2.1 PLANT DESCRIPTION

C.N. Almaraz I and II is a PWR nuclear power plant designed by Westinghouse of the USA. The plant is owned by a consortium of four spanish utilities: COMPAÑIA SEVILLANA DE ELECTRICIDAD, S.A.; HIDROELECTRICA ESPAÑOLA, S.A.; IBERDUERO, S.A. and UNION ELECTRICA-FENOSA, S.A.

Comertial operation started in April 1.981 the Unit I and in September 1.983 the Unit II.

C.N. Almaraz I and II has a nominal reactor power of 2.686 MW (thermal) each. The core contains 157 fuel elements, each one with 17x17 standard fuel rods. Steam generators are three, one per loop, the model is D-3 designed by Westinghouse, with typical U-tubes and preheater.

The rated generator electrical output is 930 MW. Reactor coolant pumps are type single stage, centrifugal, model W-11011-A1 (93-D) designed also by Westinghouse.

The unit modeled was the Unit I, the difference between Unit I and Unit II is located in the vessel upflow versus downflow.

A more complete description is given in Table I.

2.2 TRANSIENT DESCRIPTION

This transient is a normal Blackout (loss of external electrical power) at full power. It is a calculation of a very similar event that took place on December 31, 1981, and classified as not Programmed, but is not possible to make a detailed comparison because in the nuclear power plant, at this date, there was not very sophisticated computer data acquisiton system, as there is now.

This transient was characterized by a loss of forced primary coolant flow. The condenser is not available because the condensate pumps trip and there is not vacuum at the condenser.

The turbine valves close and the pressure increases at the secondary side.

After 8 seconds the main feedwater is tripped and the auxiliary feedwater started, 60 seconds after Blackout signal.

The rising pressure and temperature in the secondary side result in a corresponding temperature and pressure increase on the primary side.

The pressurizer level increases to 7.9 meters with a maximum 7.5 seconds after the Blackout signal. The water level in the steam generators drops to a minimum of about 11 m after that.

The residual heat was calculated by the Relap 5 computer code and the results were very close to the curve contained in A.N.S. 5.1.

The pressurizer spray was not taken into account due to the fact that the results of the different analysis showed that the contribution to the transient results is negligible.

The parameters of the reactor coolant pump were apported by Westinghouse included the pump homologous curves.

3. MODEL DESCRIPTION

During the nodalization process, previous experiences with the Relap 5 Mod. 1 computer code and the results obtained by different users were taken into consideration along, with EG&G remarks with respect to optimization of RELAP 5.

The plant was modeled by two loops: the first one (the double loop) containing the pressurizer, and the second one, one single loop. This model was prepared for asimetrics calculations due to one single failure, for instance a failure in one steam generator. The model with three loops does not have special contributions.

3.1 Primary System

3.1.1. Hot and Cold Legs Nodalization

The final configuration (see Figure 1) for nodalization of the hot legs was accomplished by means of 3 components which divided each of the legs into 5 control volumes.

As regards correct simulation of the hydrodynamic model, the above-mentioned control volumes were affected by their corresponding hydraulic diameter (diameter of one single leg).

The first component corresponding to the reactor vessel outlet nozzle was nodalized by means of a branch with a control volume. The reason for nodalizing the nozzle by means of a branch is that it is in this control volume that the high pressure safety injection is connected (percentage injected into the hot leg).

The straight section of the hot leg was nodalized by means of a pipe with 3 control volumes connected to the curved section of the hot leg by means of a branch with a single control volume.

The steam generator inlet chambers were nodalized by means of a single volume (SNGLVOL). This volume is in fact a double volume for twin loops, attaining its real magnitude as a single volume for the case of the single loop.

The steam generator tubes were nodalized by means of a pipe with 8 control volumes - four risers and four letdowns, (see figure 2).

Heat transfer from the primary to the secondary side was accomplished by means of heat plates simulating the entire tube surface with respect to heat transfer.

Heat transfer in relation to the tube support plate was represented by means of two heat plates simulating heat generation across this component.

The steam generator outlet chambers were represented by a single volume having the same geodesic head as the actual steam generator inlet chamber. This was represented by a single volume (SNGLVOL).

The section of the cold leg located between the outlet of the steam generator and the main coolant pump was nodalized by a single component (PIPE), which was divided into 5 control volumes.

The first three of these five control volumes sloped downwards, the fourth being horizontal and the fifth ascending.

The final control volume was connected to the main coolant pump - nodalized by the component pump. The pump curves were incorporated into the input data without using the Westinghouse pump curves included in RELAP 5 and the input date were aported also by Westinghouse.

The pump outlets were connected to the cold legs, each of which was nodalized by means of 3 components, 2 pipes and 1 branch, representing 5 control volumes.

The objective underlying the incorporation of the branch was to connect the high and low pressure emergency core cooling systems and the accumulators (see Figure 3).

3.1.2. Reactor vessel nodalization

The core, downcomer and bypass reflector were divided by means of volumes having the same length and geodesic head.

No heat structures were considered in the upper and lower areas of the core (influence of springs and plugs) (Figure 4).

The heat structures (fuel rods) corresponding to the active part of the core are simulated by including the heat source (UO_2) and the properties of UO_2, fuel-to-cladding gap and zircaloy for heat transfer to the coolant.

The collection zone for water coming from the inlet nozzles is represented by a single control volume which has the same geodesic head as the zone for distribution of water to the outlet nozzles forming part of the upper plenum.

The downcomer inlet zone is also represented by a single control volume. This volume has the same length and geodesic head as the core outlet zone (lower parts of the upper plenum).

The downcomer itself is represented by 2 control volumes having the same length and geodesic head as the adjacent areas of the core and bypass reflector, which are also represented by 2 control volumes.

The lower plenum is represented by one control volume. (BRANCH with four JUNCTIONS).

The upper plenum is divided into 5 control volumes. The core water collection zone was divided into different control volumes due to the fact that, otherwise, we would have two interconnected volumes, one excessively large and the other excessively small, for which reason the results corresponding to this control volume would be insufficiently reliable.

The mass transfer through the guides columms upper internals was not taken into account.

In order to achieve complete homogenization of the fluid, a control volume (branch 223 and 224) has been derived from the upper part of the upper plenum, which is also connected to the single a double, outlet nozzles.

The reactor vessel head has been divided into 2 control volumes in order to assure a coherent configuration with respect to the dimensions of the adjacent volumes.

3.1.2.1. Hot fuel rod condition considerations

In order to calculate heat loads for any of the fuel rods, a truncated cosine distribution based on an integral value of 177 W/cm was used.

In order to account for the maximum load conditions of a centrally located rod, a heating structure was calculated for this rod with a maximum heat coefficient of 410 W/cm axially orientated from the intermediate zone.

3.1.2.2. Reactor shutdown process conditions

The reactor may be conditionally controlled by the model by means of control logic processes.

This control may be time-dependent or depend on system variables. These variables may be assumed to be instantaneous or delayed by means of disconnection process result logic connections, depending on the complex system conditions to which they refer (model auto-control).

All questions (trips) may be applied in the reversible or irreversible mode. These possibilities are to be applied depending on the plant operational mode and the problem to be dealt with.

3.2. Secondary System

3.2.1. Steam generator secondary side nodalization

The steam generators were nodalized taking into account their different fundamental parts, (see figure 2).

These working zones include fundamentally the following:

- Rise chamber
- Downcomer annulus
- Separators
- Steam generator head
- Auxiliary components

3.2.1.1. Rise chamber

This chamber was nodalized by means of a component (pipe) divided into 6 control volumes.

The first four control volumes - as from the tube support plate - have the same geodesic head as the control volumes corresponding to the primary tubes.

The fifth control volume runs from the end of the tube bundle to the inlet of the 12 risers (tubes channelling the mixture of steam and water to the steam separators). This fifth volume has the same geodesic head as the first zone of the downcomer annulus.

The sixth control volume corresponds to the 12 risers channelling the mixture to the separators. These risers have been nodalized by means of a single control volume (the sixth) to which has been assigned the hydraulic diameter corresponding to each of the 12 tubes.

3.2.1.2 Downcomer annulus

The downcomer annulus has been nodalized by means of the component "ANNULUS", which has been divided into 5 control volumes and whose geometric characteristics have been commented on above.

3.2.1.3 Separators

The model D-3 steam generator installed at Almaraz NPP has 12 steam separators, and corresponding steam dryers, located in the steam generator head.

The new separator model (SEPARATOR) incorporated in RELAP 5 Mod. 2 contemplates inlet of a mixture of water plus steam, which is divided at the outlet and sent in two directions: upwards, in the case of steam with a small portion of water, and downwards, in the case of water with steam.

In this respect, the volume adopted for this component is indifferent and does not represent the real conditions of the model D-3 steam generator, steam separators and dryers; however, the results achieved accurately represent the path followed by the fluid.

The way in which the separator is incorporated into the RELAP 5 model does not correspond to the real geodesic situation. This is due to the fact that experience suggests that the most appropriate form of nodalization is that observed in Figure 2.

3.2.1.4 Steam generator head

The steam generator heads have been nodalized by means of two components - one volume (SNGLVOL) and one branch (BRANCH) -, dividing this area into 2 control volumes connected to the steam generator via the separator (SEPARATOR).

The upper part of the steam generator head is connected to the main steam line and auxiliary components.

3.2.1.5 Main steam line

The main steam lines corresponding to each of the 3 steam generators installed at Almaraz NPP are not of the same length; consequently, the steam path is different in each of these lines.

The value used is the average length of loops 2 and 3 up to the steam header, this fictitious length being subsequently nodalized as a twin loop.

The single loop has been nodalized using the exact length of loop 1.

With respect to this nodalization, four different parts should be distinguished:

a) Nodalization from the steam generator head to containment, nodalized by means of a "PIPE".

b) Nodalization from containment to the steam isolation valve. This zone has been nodalized by means of a "BRANCH" in which are applied the steam isolation valve, the relief valve and the 5 safety valves, all of which have been jointly nodalized by means of a single "VALVE".

   Both the relief and steam isolation valves have been nodalized with the components called "VALVE".

c) Nodalization from the steam isolation valve to the steam header. This zone has been nodalized by means of a "PIPE".

d) The four 24-inch steam lines channelling the steam to the high pressure turbine have been nodalized by means of a control volume to which has been assigned the corresponding hydraulic diameter.

This nodalization makes it possible to correctly assembly the high steam line differential pressure trip.

3.2.1.6 Steam header

The steam header has been nodalized by means of a branch with 2 inputs, one for the twin loop steam line and the other for the single loop.

The 24-inch line has been joined to the steam header; as has been pointed out above, this line is also connected to the turbine by means of the control and shutdown valves and the turbine bypass valves leading to the condenser.

3.2.1.7 Auxiliary components

The steam generator auxiliary components may be subdivided into the feedwater system protection systems and turbine.

A detailed description of each is given below.

3.2.1.7.1 Feedwater systems

Basically, Almaraz NPP possesses a main feedwater system and an emergency (or auxiliary) feedwater system.

The main feedwater system has two steam turbine-driven pumps for the three steam generators. In order to save computer time, the feedwater simulated at the inlet of each steam generator is 2/3 capacity of each pump, taking into consideration the losses experienced in the feedwater line from the pump to the inlet to the steam generator.

Consequently, and with respect to main feedwater, we have a hypothetical pump feeding each steam generator. This pump is determined by the hypothetical real pump curves at the inlet to each steam generator.

Injection by this hypothetical pump is given depending on steam generator level, injecting rated flow (497.6 kg/s) at rated level (12.5 m) from the tube sheet.

The table containing the hypothetical pump curve is given by a time-dependent junction (TMDPJUN), and is governed by a trip aimed at interrupting feedwater flow whenever the event should make this necessary.

Fluid inlet conditions are given by a time-dependent volume (TMDPVOL) giving the exact pressure and temperature at the inlet to the steam generator.

Emergency cooling injection (auxiliary feedwater) has been performed analogously to the above. This injection is provided by 2 motor-driven pumps and 1 turbine-driven pump. With respect to these pumps, and given their different characteristics, the methodology used is analogous to the above, the result being the overall joint characteristics at the steam generator inlet.

Pipe losses have been taken into account in the curve for the pumps. A time-dependent junction (TMDPJUN) has been calculated (characteristics of the assumed assembly at the steam generator inlet), along with a time-dependent volume (TMDPVOL) (for inlet conditions). (See Figure 2.)

3.2.1.7.2 Protection systems

The safety and relief valves have been simulated by means of their corresponding assemblies (VALVE), and the hypothetical atmospheric steam dump by means of a time-dependent constant volume (TMDPVOL), which gives us the pressure and temperature conditions outside containment.

Likewise, steam generator shutdown due to dumping of steam to the condenser has been simulated, represented by a time-dependent volume (TMDPVOL), along with the actuation valve which was represented by the component (VALVE).

3.2.1.7.3 Turbine

Downstream of the four 24-inch lines branching off from the steam header is the turbine with its upstream located control and shutdown valves.

Only the shutdown valve has been represented nodalized by its component, VALVE. The connection is direct to the turbine, which is represented by a time-dependent volume (TMDPVOL) including turbine conditions.

3.3. Pressurizer and surge line nodalization

The pressurizer model nodalized is highly simplified. Computer system limitations have been a determining factor in this aspect; however, the model meets the requirements perfectly.

3.3.1. Pressurizer nodalization

Nodalization of the pressurizer was carried out using three components: two components BRANCHES and one component PIPE.

The two BRANCHES represent the upper and lower heads of the pressurizer. The lower head (BRANCH 510) is joined to the lower cylindrical end of the pressurizer, on one side (junction 2), and on the other to the surge line (junction 1).

The upper head (BRANCH 530) is joined to the upper part of the cylindrical shell of the pressurizer.

The cylindrical part of the pressurizer was represented by means of a "PIPE" with 5 control volumes.

The pressurizer has been provided with heat structures relating to heat transfer across its walls.

3.3.2 Surge line nodalization

The surge line was nodalized by means of a PIPE component with 4 control volumes, connection to the twin loop hot let being accomplished by means of a junction (SNGLJUN).

3.3.3 Spray System

The spray has not been taken into account because the RCPs were stopped at the begining of the transient.

3.4 Controls

The calculation code RELAP 5 Mod. 2 offers enormous possibilities with respect to plant controls. It is common practice, when studying an accident or transient, to determine beforehand when the trip will occur and the causes for this trip.

In order to accomplish a real model, all reactor trips were included as well as all causes possibly leading to safety injection.

This fact is of great use as there are events for which the cause of reactor trip may not be strictly determined. Evidently, this is not particularly important from the point of view of transient analysis, but very important as regards operation.

The safety and relief valves have been nodalized and provided with opening or closing controls.

Also incorporated are the logics for auxiliary feedwater start-up and main feedwater isolation. This was accomplished on the basis of the same requirements governing the previous trip, i.e. incorporating all the causes that might give rise to these trips.

Tripping of the main coolant pumps have been taken into account; likewise, the model incorporates all causes of turbine trip. The only trips not included are those due to electrical causes such as, for example, low frequency or low voltage trips.

All controls referring to safety injection, actuation valves, etc. have been incorporated in the problem.

Almaraz NPP has also been provided in this nodalized mode with controls in those places in which this has been considered appropriate, both for control in the strictest sense - such as in the case of the pressurizer or the steam generators - and for refuelling water storage tank level. The core and upper plenum have also been provided with controls, although in this case it is naturally only possible to speak of level in the case of a loss of coolant accident.

3.4.1 Incorporation of reactor trip

As has been pointed out above, all reactor trips have been incorporated. These trips are as follows:

- Nuclear overpower trip

- Primary high average temperature trip
- Low pressurizer pressure trip
- High pressurizer pressure trip
- High pressurizer level trip
- Low primary coolant flow trip
- Low steam generator level trip
- Safety injection trip

All of the above causes for trip have been incorporated in the Almaraz NPP model.

These trips have been incorporated with non-exclusive logic; in other words, if one occurs, the reactor trips; but on the other hand, it is possible to see at which moment in time the other trips would be produced, although as can be logically supposed no actuation is possible as the order would have been given previously.

As is already known, reactor trip implies direct tripping of the turbine, interruption of the main feedwater flow, and actuation of the auxiliary feedwater to the steam generators (due to tripping of the main feedwater turbine-driven pump).

All the above has been appropriately incorporated in order to simulate real actuation in Almaraz NPP. Following generation of the trip signal, the control and shutdown banks would be inserted (a scram occurs), the main coolant pumps would trip (in the case of blackout), and the sequence of events described above would occur.

3.4.2 Incorporation of safety injection trips

The trips giving rise to safety injection incorporated are as follows:

- Low-low pressurizer pressure
- High steam line differential pressure
- High mass flow in the main steam lines coincident with low steam line pressure
- High mass flow in the main steam lines coincident with low average primary temperature
- Safety injection actuation on high containment pressure has not been contemplated

As described above, for reactor trips safety injection can be initiated if any of the above-mentioned events occur. As has been pointed out, if safety injection occurs without reactor trip, this trip will take place on safety injection initiation.

3.4.3 Incorporation of auxiliary feedwater flow initiation for steam generators

The auxiliary feedwater system to the steam generators may actuate under normal operating conditions or as a result of accidents or transients.

The possible causes for auxiliary feedwater system start-up and shutdown are as follows:

- Safety injection
- Main feedwater pump trip
- Low steam generator level
- Normal operation from 0 to 30% power

The code has been provided with all logics and controls necessary for simulation of all these possibilities.

Consequently, the Almaraz NPP model using RELAP 5 Mod. 2 code, would copy plant operation in the automatic mode.

3.5 Valves

In the calculation for blackout special attention has been given to modelling the safety and relief valves, both those of the steam generators and the pressurizer, as a series of problems have been encountered which will be described below.

The version 004, Cy 36 of the Relap 5 Mod. 2 computer code - which is currently the version used for Almaraz NPP - does not accurately calculate the critical discharge flow. The calculated flow is much higher than the real value. There are techniques that can be used to correct this defect. The first of these being the experience of certain laboratories with respect to mass flow from the valve closure position to valve open position, assuming the steam to be a compressible gas, and calculating the critical discharge flow for the valve area, assuming isoentropic evolution of the fluid via the break. These data could be incorporated in a time-dependent junction, and then, by inserting a valve opening and closing, can be governed and the critical discharge flow can be controlled (see Figure 5^a).

Optimization could be accomplished by incorporating an opening trip in the time-dependent junction and then assuming zero mass flow on closure trip. (See nodalization figure.)

3.5.1 Steam generator secondary valves

The steam generator secondary side valves have been nodalized by the specific component "VALVE". The relief valves can be set from the control room, the setpoint established for operation with respect to station blackout being the value corresponding to operation at 100% power, which is the value that the operators usually have inserted. Opening pressure is 76.9×10^5 Nw/m^2, closing pressure is 68.276×10^5 Nw/m^2, and which flow is 52.08 kg/s.

The safety valves actuate against the force applied by a spring on the basis of static pressure. Closing pressure will be identical to opening pressure, but when the valve is open the dynamic pressure term will be other than zero. Consequently, the static closure pressure will be lower. These calculations have been carried out and have given the following results:

First safety valve:

Opening pressure	80.55×10^5 Nw/m^2
Closing pressure	74.21×10^5 Nw/m^2
Maximum discharge flow	41.19 kg/s

Second safety valve:

Opening pressure	81.93×10^5 Nw/m^2
Closing pressure	75.28×10^5 Nw/m^2
Maximum discharge flow	41.89 kg/s

Third safety valve:

Opening pressure	83.00×10^5 Nw/m^2
Closing pressure	76.2×10^5 Nw/m^2
Maximum discharge flow	42.41 kg/s

Fourth safety valve:

Opening pressure	83.7×10^5 Nw/m^2
Closing pressure	76.76×10^5 Nw/m^2
Maximum discharge flow	42.75 kg/s

Fifth safety valve:

Opening pressure	84.28×10^5 Nw/m^2
Closing pressure	77.24×10^5 Nw/m^2
Maximum discharge flow	43.08 kg/s

Nodalization of the loop is different inasmuch as the mass flow in the model loop (which is double) is clearly double.

3.5.2 Pressurizer safety and relief valves

The pressurizer safety and relief valves are located circumferentially on the same parallel, i.e. parallel 44° 13' from the pole.

These valves are off-set 66° one from the other (see Figure 6[a]).

The nozzles of both the safety and the relief valves have a diameter of 6 inches.

According to the final safety analysis:

There are 3 safety valves and 2 relief valves discharging to a common header.

As can be appreciated in Figure 7[a], the different safety valves form a loop in order to assure the hydraulic seal and maintain forces of reaction on the nozzles located downstream.

Let us look at each of the systems in more detail.

Table II shows all the pressurizer setpoints in great detail. For this particular accident, it is extremely important that the discharge of both the pressurizer safety and relief valves is correctly modelled, as on the basis of the discharged mass it is possible to evaluate if the pressurizer relief tank rupture disc has broken, and if there is a discharge to the containment atmosphere, which should

certainly not be the case but, however, should be demonstrated. What is expected of the calculation performed is that the relief valve opens for a very short time, or not at all, although it is not expected that there should be any discharge across the safety valves.

As regards the relief valves, the configuration for Almaraz NPP is that shown in Figure 8.

There are 2 relief valves, their relief capacity being:

(At 165 kg/cm^2)

95254 kg/h ==> 26.5 kg/s each

with the fluid being saturated steam.

There are 3 safety valves, their maximum capacity being:

172364 kg/h ==> 47.88 kg/s each

Consequently, the relief valves have a fictitious capacity of 52.92 kg/s.

The 3 safety valves have a fictitious capacity of 143.636 kg/s

The opening pressure in Nw/m^2 would be as follows:

$$P_A = 171.2 \ Nw/m^2$$

and the closing pressure will be

$$P_c = 170.2 \ Nw/m^2$$

In this respect we believe that it would be more than acceptable to have both opening and closing occurring at the same pressure, which would imply a saving on control volumes.

In this case, the definitive nodalization would be as shown in Figure 9.

The conditions in the pressurizer relief tank could be incorporated, although this aspect is of little importance due to the short transient period to be calculated.

Relief valve opening pressure is $162.03 \times 10^5 \ Nw/m^2$ and the closing pressure is $160.92 \times 10^5 \ Nw/m^2$

3.5.2.1 Pressurizer valve hysterisis curves

In order to provide a real evolution for mass flow across the pressurizer safety and relief valves, curves have been defined to show the typical evolution of mass flow on valve opening. This evolution does not correspond to any real event observed at Almaraz NPP, as no experience is available with the above mentioned valves, but has been based on the experiences of the RESEARCH PROJECT V102-9 for September 1981, which gave rise to the document "FLOW VISUALIZATION TESTS AND ANALYSIS OF SAFETY AND PRESSURE RELIEF VALVES", which was prepared by EPRI. This document includes experiences with safety and relief valves analogous to those installed at Almaraz NPP.

The above mentioned hysterisis curves have been calculated by extrapolating the results of the above mentioned document, and are represented in Figs. 10 and 11. As can be appreciated, on both curves the pressure increase following opening to the outlet mass flow is very small as at this moment the velocity is still very low. Subsequently, and as velocity increases, mass flow increases up to the critical discharge flow value. As can be seen in Figs. 10 and 11, this evaluation corresponds only to opening, as closure is considered to be instantaneous because of the spring.

3.6 Positive and Negative Moderator Temperature Coefficient Considerations

It has been considered appropriate to carry out the calculation using two different moderator temperature coefficients. The first of these is for the initial Almaraz 1 cycle which corresponded to a negative moderator temperature coefficient, the second calculation corresponding to cycle 5 of Almaraz 1, which gave a slightly positive reactivity coefficient at the beginning of life.

As in previous cases, the calculations carried out are divided into two parts. One zone is that given by the Fuel Designer for cycle 5, which is shown in Figure 12. Figure 13 shows the corresponding calculations and conversion from degrees centigrades to degrees Kelvin, while Figure 14 shows the definitive form used as input to the code, with reactivity in dollars depending on the density of the moderator as requested by the code.

Following performance of these calculations it was concluded that repetition would be unnecessary as the moderator temperature coefficient is only very slightly positive, and the calculations would be, in a sense, repetitive.

3.7 Emergency Core Cooling System

The emergency core cooling system installed in Almaraz NPP is made up as indicated in Figure 15. This figure, which is self-explanatory, shows the system connected to the emergency bus.

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 stable state was obtained with the "steady-state" option of RELAP 5/MOD 2 code from the input data.

Particular conditions could be defined for this purpose having a stabilizing effect on the sequence of the steady-state calculation, like a TMDPVOL at the head pressurizer or other techniques to acelerate the Steady State calculation. Those techniques have not been used in this case.

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.

A stable condition for the model has been reached after 186.45 seconds of calculation. RELAP 5/MOD 2 code stops the steady state calculation once the stability has been accepted by its internal checking procedure. The main results of the calculated values versus operating values are represented in Table V. We have some discrepancies with regard to the heat transfer coefficient in the Steam Generator (Secondary Side), the mass inventory and the isentropic coefficient in valves discharges. Justification of discrepancies are included in the references 20 and 21.

5. TRANSIENT CALCULATION

5.1 Event Sequence

The sequence of events occurring during blackout can be seen in Table III and associated text, and requires no further explanation.

5.2 Evolution of Reactivity During the Simulated Period

On the basis of the hypothesis developed previously, attempts have been made to carry out these calculations using both positive and negative moderator reactivity coefficient. The positive coefficient hypothesis had been calculated for cycle 5 of Almaraz I. On the basis of the results - which showed a very small difference - it was decided not to perform both calculations, as the results would necessarily have been very similar.

Figure 17 shows the evolution of core reactivity. For study, this curve can be divided into two parts. The first arises as a result of the insertion of negative reactivity due to insertion of the control and shutdown banks. The second corresponds to reactivity insertion as a result of variation of the moderator density (cooldown).

5.3 Nuclear Power (Evolution throughout the transient)

As regards nuclear power during evolution of a blackout event, total nuclear power has been represented. Graph 18 shows total reactor power.

The above-mentioned figure shows the delay in the low primary mass flow signal as well as the lag between the electrical signal and the mechanical signal. As can be appreciated in the graph, initiation of rod drop occurs 2.3 seconds into the accident.

5.4 Evolution of System Pressure

Pressure is transmitted throughout the entire circuit at the speed of sound. Figures 19 and 20 show the evolution of the pressure on the primary and secondary sides of both steam generators. This evolution is as follows: as a result of the normal blackout (LOOP) and closure of the turbine shutdown valves there is a pressure increase on the secondary side resulting from the fact that the dynamic pressure term in the equation showing quantity of movement is transformed into static pressure, with the additional aggravation that the turbine bypass to the condenser is not available.

Consequently, the pressure increases up to the setpoint of the safety and relief valves, which are the valves opening in the case of Almaraz Nuclear Power Plant for this accident. Once a certain quantity of steam has been dumped the safety valves begin to close while the relief valves open in order to maintain the corresponding setpoint pressure, which is somewhat higher than the zero load pressure. This evolution can be seen in Figures 19 and 20. As regards primary pressure, the evolution is reflected in Figure 19 which shows a pressure increase at the beginning of the transient, and a subsequent decrease.

Let us now analyze the reason for this increase. When blackout occurs there is a temperature increase in the hot channels because of the fuel, this being due to the fact that the trip of the three main pumps causes a rapid increase in fluid temperature in the core. This, in turn, applies a reduction in the fluid density, for which reason the pressurizer level increases, compressing the bubble and increasing pressure. This also causes steam to be condensed into liquid; however, the pressure increase is faster, and eventually exceeds the relief valve setpoint, the valve opening for 6.2 seconds, and then closing. The valve does not re-open throughout the entire transient. Figure 21 shows a detail of the evolution of pressurizer pressure and how this parameter exceeds the relief valve setpoint. It should be pointed out that in this figure the units are not kg/cm^2 but the international Nw/m^2. Figure 22 shows mass flow across the pressurizer relief valve, along with the corresponding setpoint and valve opening. Subsequently, primary pressure decreases with reactor shutdown and rod insertion. When the primary pressure decreases the third phenomenon occurring in this evolution takes place, this being the way in which primary pressure follows secondary pressure.

This is due to the fact that the secondary side pressure is high and prevents faster cooldown of the primary, the secondary side pressure thus leading the primary pressure. There is a fourth phenomenon, i.e. shutdown of the main coolant pumps, which makes residual heat removal more difficult. Consequently, during the second part of the transient the core must be cooled by natural circulation.

Having said the above, it would be advisable to present a systematic synopsis of the phenomena occurring, and the reasons.

From 0 ---> 6 seconds <u>Pressure increase</u>	Because of shutdown of the main coolant pumps, the core temperature increases, this implying a reduction in density, an increase in level and pressure, and opening of the relief valve
From 6 ---> 12 seconds <u>Rapid pressure decrease</u>	The control rods are fully inserted and the reactor cools down as a result of the lack of fission events, the density increases and pressure decreases; there is a drop in pressurizer level
From 12 ---> 74 seconds <u>Gradual pressure reduction</u>	The main pumps are coasting down but are still pumping some 800 kg/s; primary pressure follows secondary pressure
From 74 ---> 100 seconds <u>Even more gradual pressure decrease</u>	Mass flow is decreasing; the process of heat transfer to the secondary is masked by the low coolant flow. The pressure decreases more gradually

Figure 23 shows the evolution of the pressure in the secondary lines reflecting the increase in pressure due to closure of the turbine shutdown valves and the non-availability of the turbine bypass system to the condenser. Subsequently, the safety and relief valves open, the pressure decreases, and 60 seconds after blackout auxiliary feedwater flow is initiated to the steam generators. As this is cold water, the overall density increases and the pressure drop is more rapid, subsequently stabilizing during the steaming process. If feedwater is colder, the complete shutdown process will be completed sometime earlier.

5.5 Evolution of System Temperature

The phenomenon of secondary primary temperature leading or following - which has been studied in the previous paragraph - can be observed in Figures 24 and 25, which show all the phenomena described above. The temperature on the secondary side follows pressure, as we are working under saturation conditions. The figure also shows valve opening, the ingress of auxiliary feedwater to the steam generators (second 60), and the events described above.

The phenomena occurring in the primary have been described above and are reflected in Figure 26. This figure shows the increase in temperature in the channel as a result of the pumps tripping, and the subsequent availability of less mass coolant flow. Subsequently, on reactor trip, the coolant cools down and the temperature in the active core channels decreases. Also represented is the evolution of the temperature in the upper primary side zone of the steam generator tube (see Figure 24). It can be seen that the temperature peak for this parameter lags behind the peak value in the core (see Figure 26), this being a result of the fact that the temperature related information is carried by the fluid itself. As can be observed, in this zone we have no secondary lead as the peak value occurs before the peak temperature on the secondary side. Consequently, Figure 26 shows that this is a primary side phenomenon.

It is also interesting to show as from what moment these lead phenomena occur. Close observation of Figure 24 shows how there is a temperature decrease on injection of auxiliary feedwater. This temperature decrease is also felt by the primary, although the core is practically unaffected by the phenomenon (see Figure 26) as the information is carried by the fluid itself and the quantity of this fluid decreases less because of the main coolant pump trip.

5.6 Evolution of Mass Flow

The evolution of mass flow during the transient has been represented by three figures. The first of these figures corresponds to the evolution in the hot leg; the second shows the evolution in the cold leg, and the third corresponds to the speed of the main pumps and shows the evolution for pump shutdown.

Figure 27 shows the evolution of mass flow in the hot leg. As can be seen in this figure, 100 seconds after blackout the mass flow reaches a value of 582 kg/s.

Figure 28 shows the evolution of the mass flow in the cold leg, the value in this case being the same.

Figure 29 shows the evolution of the speed of the pumps, which go from 153 rad/s - the normal operation speed - to 20 rad/s 100 seconds into the transient. Stabilization would be achieved when natural circulation occurs under stable conditions. In this respect, it should be remembered that natural circulation, according to calculations carried out by C.N. Almaraz and corroborated by Westinghouse, is approximately 200 kg/s.

5.7 Level Behaviour and Opening of Pressurizer Valves

Point 5.4 has already provided sufficient information on the phenomena occurring in the primary circuit with respect to pressure and its interaction with level. This point will include a description of the processes taking place. As a result of station blackout, the main coolant pumps trip, the circuit instantly feels the effects of the loss of mass flow. As a result of this event, the fluid in the core heats up. The process of temperature increase is one of reduction of density, i.e. the volume that before was X will now be X+Y; in other words, there is expansion. This expansion is felt by the entire circuit, in which the pressurizer acts as an expansion chamber.

Consequently, pressurizer level increases. This increase in level causes the bubble in the pressurizer to contract, increasing pressure and consequently the saturation temperature limit, which gives rise to condensation. Subsequently, due to insertion of the control and shutdown banks, the core begins to cooldown. For both this reason and because of the steam generators (refer to point 5.4), the primary fluid contracts and steam generator level decreases with time into the transient (see Figure 30).

The pressure described above eventually exceeds the relief valve setpoint, producing valve opening at the mass flow forecasted by Westinghouse. Relief valve opening occurs 1.8 seconds after station blackout, the valves then closing 8 seconds into the event.

5.8 Evolution of Mass Flow in the Secondary

Three graphs have been used to represent the evolution of the mass flow in different areas of the secondary side, in the steam generator. This evolution can be seen in graphs 31, 32 and 33.

Figure 31 shows the interruption of main feedwater supply to the steam generator. As can be seen, the loops start with different mass flows but the shut-off time is the same. Evolution of steam flow can also be seen in the figure 32. Given the closure of the shutdown valves and the non-availability of the turbine bypass to the condenser, there is a pressure increase which increases the saturation temperature limit, this meaning a reduction in the generation of steam. Subsequently, the relief valves open and the mass steam flow increases as a result of the reduction in pressure, and consequently saturation temperature limit. Opening of the safety valves can also be seen in the evolution of the mass steam flow. As can be seen, closure of these valves causes steam flow to fall to zero; also shown is the subsequent repeated opening and closing of the steam generator relief valves. Initial supply of auxiliary feedwater to the steam generators can be observed at second 60 into the transient in both graphs, (see figure 33).

5.9 Evolution of Steam Generator Level

Figures 34 and 35 show the evolution of the level versus transient time. As a result of the pressure increase experienced by the steam generator secondary side, for the reasons already pointed out above, level collapses as a result of pressure increase, shut-off of the auxiliary feedwater also contributing to this effect. Opening of the steam generator safety and relief valves causes the slope of the level curve to change because of the depressurization caused by opening of these valves. After second 20, level continues to drop because main feedwater flow has been cut off and the valves continue to release steam to the atmosphere. Apart from this, pressure in the steam generator is still very high and the level attempts to find an equilibrium position. At second 60 into the transient, auxiliary feedwater injection into the steam generators begins, consequently, level is recuperated and attempts to achieve an equilibrium value corresponding to the pressure determined by the steam generator.

6. RUN STATISTICS

Figure 16 shows the time taken by the computer versus the real time corresponding to the transient. This calculation was carried out using a CDC cyber 830 computer which Almaraz NPP has installed in his Headquarter Central Office at Madrid. The operating system used is the NOS, Release 2.5. The editor is the "FULL SCREEN EDITOR". As can be observed, the relationship existing between the CPU time and real transient time is in the ratio 3098/100; in other words, a time of 30.9 : 1. Although this calculation time is not excessive, it can be observed that it is still far from attaining a simulation time, i.e. a ratio of 1 : 1.

In table IV a typical run statistics has been summarized for blackout analysis. 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 C.P.U. time.

7. CONCLUSIONS

The study of the behaviour of Almaraz NPP in response to station blackout does not show any increase in fuel temperature, with only the cladding being somewhat affected by the heat-up in the primary system.

As regards the steam generators, the relief valves and 3 safety valves per steam generator open.

Therefore, if any event of these characteristics were to occur the plant could be re-started without any need for revision.

Consequently, the plant is capable of withstanding an accident of these characteristics without sustaining any damage.

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TABLE I

Number of Loops	3
Core	
Number of Assemblies	157
Rod Array	17 x 17
Rod OD, cm.	0.95
Number or grids	8R
Active Fuel Length, cm.	365.76
Number of control rods, FL	48
Steam Generator	
Model	D3-1
Shell design pressure, Nw/m^2	82.74×10^5
Reactor coolant pump	
Model	93D
Pump motor, hp	7000
<u>Thermal Design Paramters</u>	
NSSS power, MWt	2696
Reactor power, MWT	2686
Thermal Design Flow, Loop m^3/s	5.93
Reactor Coolant Pressure, Nw/m^2	155.139×10^5
Reactor Coolant Temperature, °K	
Core outlet	601.
Vessel outlet	599.6
Core average	583.
Vessel average	582
Vessel/core inlet	564.4
Steam generator outlet	564.3
Steam Generator	
Steam Temperature, °K	556
Steam Pressure, Nw/m^2	68.05×10^5
Steam Flow, Tm/hr total	5379.5
Feed Temperature, °K	496.8
Moisture, % max	.25
Zero Load Temperature, °K	564.9
<u>Hydraulic Design Paramters</u>	
Best Estimate Flow, m^3/s	6.17
Mechanical Design Flow, m^3/s	6.43
Pump design Point Flow, m^3/s/head (mts)	5.93/86.25

TABLE I (Cont. 1°)

THERMAL AND HYDRAULIC DATA

General

Total core power	2686 MWt
Number of loops	3
Best estimate flow per loop	6,17 m^3/seg
Mechanical design flow per loop	6,43 m^3/seg
Thermal design flow per loop	5,93 m^3/seg
Design core bypass flow	4.5%
Design vessel and core inlet temp./enthalpy	564.4°K/1291.6 KJ/Kgr
System pressure	155.139 x 10^5 Nw/m^2
Best estimate vessel pressure drop based on thermal/best estimate flow	2.826 x 10^5/Nw/m^2
Best estimate core pressure drop based on thermal/best estimate flow	1.613 x 10^5 Nw/m^2

4. FLUID SYSTEMS DATA*

4.1. RCS Geometry and Hydraulic Data

4.1.1. Reactor vessel

4.1.1.1. Volumes

1. Core fuel region	15.07 m^3
2. Upper plenum	26.06 m^3
3. Downcomer	
3.1 above nozzle bottom	4.24 m^3
3.2 below nozzle bottom + barrel baffle volume	18.05 m^3
4. Lower plenum	24.748 m^3
5. Upper head	12.82 m^3
6. Inlet nozzle (incl. cold leg piping)	3.038 m^3
6. Outlet nozzle (incl. hot leg piping)	2.8316 m^3

TABLE I (Cont. 2°)

Pressure Losses

Operating conditions:

Pressure = 155.130 x 10^5 Nw/m^2
Inlet temperature = 564.4°K
Flow = 5.93 m^3/s/loop

Region	Pressure drop (Nw/m^2)
inlet nozzle	0.5254 x 10^5
barrel - vessel annulus	0.04 x 10^5
lower plenum	0.35579 x 10^5
support plate	0.05516 x 10^5
diffuser plate	0.00
core	1.3976 x 10^5
outlet nozzle	0.1303 x 10^5
plenum	0.03034 x 10^5

Hot Leg

Segment from reactor vessel to S.G. inlet

- weight of steel in contact with primary water:	138783,84 Nw
- height (difference from cold leg):	1.3 m
- length:	5.514 m
- flow area:	0.426 m^2
- hydraulic diameter	0.737 m
- volume (including outlet nozzle)	2.831 m^3
- steady state pressure losses K:	35.3 x 10^{-6} $m/(m^3/hr)^2$

TABLE I (Cont. 3°)

Cross Over leg

Segment from S.G. out let to pump inlet

- weight of steel in contact with primary water:	74849.86 Nw
- height (difference from cold leg):	0.314 m
- length:	3.83 m
- flow area:	0.4867 m^2
- hydraulic diameter:	0.787 m
- volume:	3.36 m^3
- steady state pressure losses K:	64.5×10^{-10} $m/(m^3/hr)^2$

Cold Leg

Segment from reactor coolant pump outlet to reactor vessel inlet

- weight and area of steel in contact with primary water:	128917,73 Nw
- height (difference from cold leg):	0. m
- length:	6.925 m
- flow area:	0.383 m^2
- hydraulic diameter:	0.6979 m
- volume (including inlet nozzle)	3.0389 m^3
- steady state pressure losses K:	35.3×10^{-10} $m/(m^3/hr)^2$

TABLE I (Cont. 4°)

4.1.5. Pressurizer Surge Line

- area of steel in contact with primary water:	0.064 m^2
- height (difference from cold leg)	0. m
- length:	17.06 m
- flow area:	0.64 m^2
- hydraulic diameter:	0.284 m
- volume:	1.217 m^3
- equivalent length	147.9
- steady state pressure losses delta P at max. surge line flow	4.1577×10^5 Nw/m^2

4.1.6. Pressurizer Data

39,6 m^3 pressurizer general assembly
Pressurizer as built
Pressurizer

a. Number of relief valves:	2
b. Relief valve rated flowrate (each):	95.253 Tm/hr
c. Relief valve rated pressure:	$162.03 \times 10^5 Nw/m^2$
d. Number of safety valves	3

e. Safety valve rated flowrate when fully opened (each)	172.352 Tm/hr
f. Safety valve rated pressure	172.378×10^5 Nw/m^2
g. Number of spray valves	2
h. Spray valve capacity (fully open)	0.022 m^3/seg/valve
i. Heaters capacity	
ON/OFF	1023 kW
Proportional	377 kW

Steam Generator Volumes

- Inlet plenums including nozzles	4.332 m^3
- Tubes	17.78 m^3
- Outlet plenums including nozzles	4.332 m^3

2 Loop Flowrate Data

Active loop flow	6.27 m^3/seg
Inactive loop flow	1.38 m^3/seg

CVCS and Charging System Data

Maximum possible flowrate to RCS at power	0.0104 m^3/seg
Maximum possible flowrate to RCS at refueling	0.018 m^3/seg
Minimum RCS water volume for RHR operation	91.746 m^3
Maximum letdown flow	0.0076 m^3/seg

TABLE I (Cont. 6°)

Safety Injection System Data

Accumulator

a. Total volume:	41.059 m^3
b. Water volume (LOCA)	27.6 m^3
c. Gas pressure (LOCA)	41.37×10^5 Nw/m^2
(design)	48.26×10^5 Nw/m^2
d. Minimum boron concentration (SLB)	2000 ppm
e. Temperature (SLB)	310.7°K
f. Equivalent length/diameter	132 m
g. Line volume from accumulator to check valve nearest RCS	0.996 m^3
h. Line volume from check valve to Reactor Vessel	0.215 m^3
i. Point of entry to reactor coolant system:	cold leg
j. Line characteristics	
hydraulic diameter	0.2667 m
area	0.05586 m^3

Safety Injection System

a. Startup time of safety injection pumps; time from start to full speed	12 sec
b. Diesel generator starting and sequences loading delay time	12 sec
c. Boron injection volume	
• from cold-leg SI pump to boron injection tank	0.566 m^3
• from boron injection tank to a header where flow branches and is fed to each cold-leg connection	0.7928 m^3
• from the header to cold-leg connections (total of all lines)	0.00566 m^3

TABLE I (Cont. 7°)

d. Boron concentration in BIT	20000 ppm
e. BIT enthalpy (min)	111,6 KJ/Kgr
f. Boron concentration in RWST	2000 ppm
g. RWST temperature (LOCA)	273.6°K
RWST temperature (design)	338.5°K

Secondary side

A. Minimum water level in shell side of the SG required to completely cover the tubes, from tube sheet	8,43 m

B. Water and Steam masses

100 % power case - normal water level
at Tsec : 556.8°K
Steam mass 3920 Kgr
Water mass 42936.8 Kgr
Total mass 46857.6 Kgr

50% power case -
at Tsec : 562.4°K
Steam mass 4562.2 Kgr
Water mass 37379. Kgr
Total mass 41942. Kgr

0% power case -
at Psec : 76.329×10^5 Nw/m^2
Steam mass 4318 Kgr
Water mass 44597.8 Kgr
Total mass 48916.5 Kgr

TABLE I (Cont. 8°)

Water level is 12.49 m above tubesheet

Preheater Data

A. Preheat heat transfer surface

- surface area of tubes in parallel-flow region	170 m^2
- surface area of tubes in inlet region	156.3 m^2
- surface area of tubes in counter flow region	312.6 m^2
- surface area of tubes in cold leg boiling region	156.3 m^2

B. Heat transfer resistance

- associated with preheater primary - side film resistance, m^2 °K/KW	0.029971
- prehetater secondary - side film resistance, m^2 °K/KW	0.07052
- preheater fouling factor, m^2 °K/KW	0.01763
- overall preheater heat transfer resistance, m^2 °K/KW	0.1918

C. Total volume of steam and water in preheater — 7.518 m^3

TABLE I (Cont. 9°)

Steam Generator Data

1. Heat Transferred - MWt - 898.66
2. Heat Transfer load - MWt - 897.8
3. Primary flow rate - m^3/s - 5.93
4. Primary Flow Rate - Kgr/seg - 4.423
5. Coolant Inlet Temp. - °K = 599.6
6. Coolant Outlet Temp. - °K = 564.3
7. Average Coolant Temp. - °K = 582
8. Primary Operating Pressure - x 10^5 Nw/m^2 - 155.139
9. Feedwater Temperature - °K = 497
10. Steam Flow Rate - Kgr/seg - 496
11. Steam Pressure - x 10^5 Nw/m^2 - 68.05
12. Steam Temperature - °K = 556
13. Primary Pressure Drop - x 10^5 Nw/m^2 - 2.208
14. Circulation Ratio = 2.31
15. Total Heat Transfer Surface - m^2 = 4459.3
16. Preheat Heat Transfer Surface - m^2 = 841
17. Number Counterflow Passes = 4
18. Number Parallel Flow Passes = 3
19. O.D. & Wall of Tubes - cm = 3/4 x 0.1092
20. Tube Material - Inconel 600
21. Number of U-tubes - 4674
22. Tube Pitch - cm = 2.6987
23. Primary Volume - m^3 = 26.47
24. Secondary Volume - m^3 = 168.4
25. Primary Design Pressure - x 10^5 Nw/m^2 = 171.343
26. Secondary Design Pressure - x 10^5 Nw/m^2 = 81.707
27. Number Tube Supports = 8
28. Circulation Hole Diameter - cm = 1.27
29. Average Tube Length - m = 17.039
30. Maximum Tube Length - m = 19.29
31. Tube Straight Length - m = 7.528
32. Minimum Bend Radius - cm = 5.715
33. Maximum Bend Radius - cm = 153.255
34. Weight of Tubes - Nw = 427916.8
35. Weight Tube Plate Forging - Nw = 404786.2
36. Weight Channel Casting - Nw = 267781.6
37. Weight Elliptical Head - Nw = 182376.2
38. Weight Stub Barrel - Nw = 161024.8
39. Weight Lower Shell - Nw = 419910.
40. Weight Transition Cone - Nw = 183710.6
41. Weight Upper Shell - Nw = 591610.
42. Weight Misc. Internals - Nw = 493305
43. Total Dry Weight - Nw = 3020327

TABLE II

PROJECT REACTOR COOLANT SYSTEM PRESSURE SETPOINTS
(10^5 Nw/m^2)

Project pressure	171.2
Operation pressure	155.131
Safety valves	171.2
Power operated relief valves	
Pressurizer spray valves (begin to open)	155.72
Pressurizer spray valves (completely open)	159.1
High pressure trip	164.3
High pressure alarm	160.9
Low pressure trip (typical but variable)	130.
Low pressure alarm (interlocked with pressurizer relief valve)	150.5
Hydrostatic test pressure	214.0
Backup heaters connected	152.29
Proportional heaters (begin to operate)	155.0
Proportional heaters (total operation)	152.97

TABLE III

EVENT SEQUENCE FOR LOSS OF ALL OFF-SITE POWER AT 100% POWER OPERATION

EVENT	VALUE
1) Blackout signal (main pump shutdown)	0.025 sec.
2) Pressurizer relief valve opening	1.8 sec.
3) Reactor trip signal On low mass flow in the primary	2 sec.
4) Control rod fully inserted	4.125 sec.
5) Steam generator relief valve open	4.2 sec.
6) High pressurizer pressure signal (without effect)	6.125 sec.
7) Pressurizer relief valve closure	8 sec.
8) Main feedwater (cut off)	8 sec.
9) Auxiliary feedwater (turbine-driver pump start-up)	60.025 sec.

TABLE IV

RUN STATISTICS

CASE	BLACKOUT
COMPUTER	CYBER 180/830
CPU TIME (S)	3098
REACTOR TIME	100
C (TOTAL NUMBER OF ACTIVES VOLUMES IN THE MODEL)	173
DT (TOTAL NUMBER OF TIME STEPS)	1136
(CPU $X10^3$) / (CXDT)	15.76
CPU TIME / REACTOR TIME	30.98

TABLE V

Steady state results at 100% power

Variable	Units	Almaraz Nuclear Power Plant	RELAP 5/MOD.2 (calculated)
Reactor power	(Mw)	2686	2686
RCS average temperature	(K)	308.4	308
Pressurizer level	(%)	56	55
Pressurizer pressure	(MPa)	15.14	15.73
RCS mass flow rate (per loop)	(Kg/s)	4423	4425
Reactor coolant pump speed	(RAD/s)	153.4	153.1
Steam generator pressure	(MPa)	6.805	6.79
Steam generator circulation rate	(-)	2.1	2.8
Steam generator collapsed liquid level	(m)	12.491	12.697
Steam flow rate	(Kg/s)	496	477
Feedwater temperature	(K)	497	497 (INPUT DATA)

PROYECTO ICAP (ICAP PROYECT)

RAMA CALIENTE (HOT LEG)

LONGITUD (LENGTH)

AREA (FLOW AREA)

DIAMETRO HIDRAULICO

(HYDRAULIC DIAMETER)

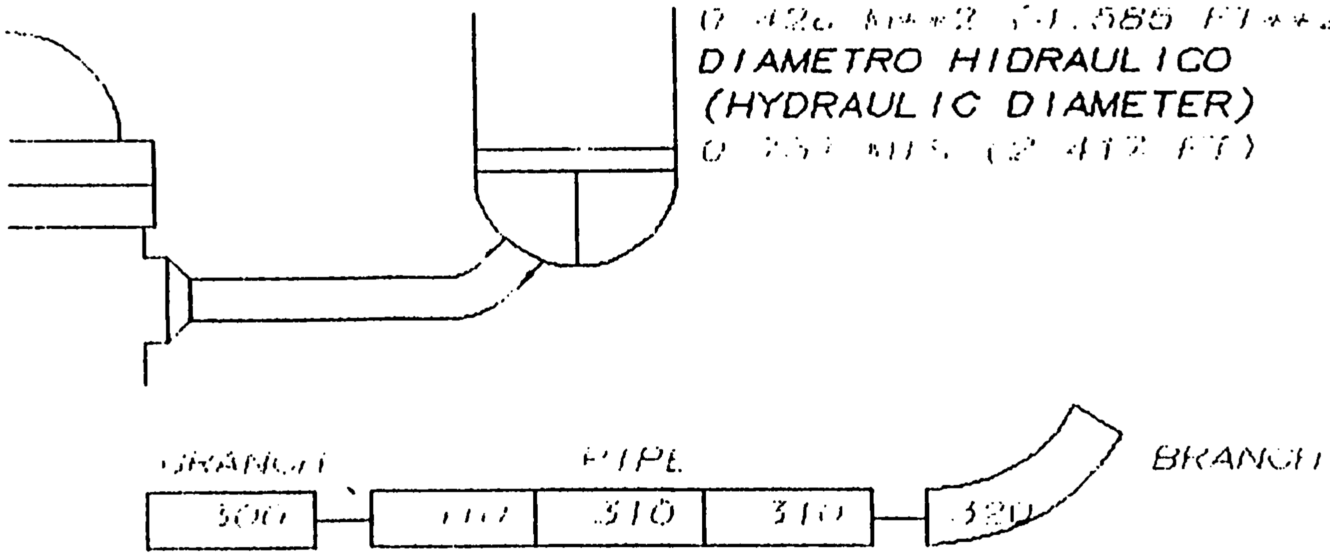


FIGURE 1º

PROYECTO ICAP (ICAP PROYECT)

[illegible]

GENERADOR DE VAPOR

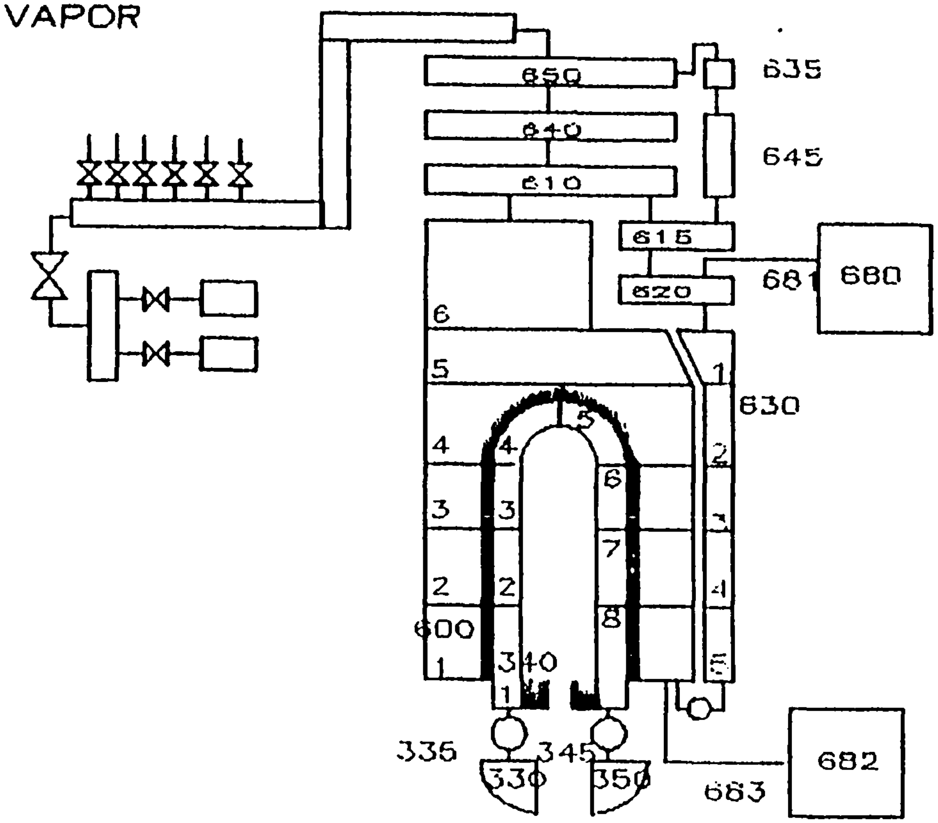


FIGURE 2º

PROYECTO ICAP (ICAP PROYECT)

RED DE TRABAJO (NETWORK)

RAMA FRIA (COLD LEG)

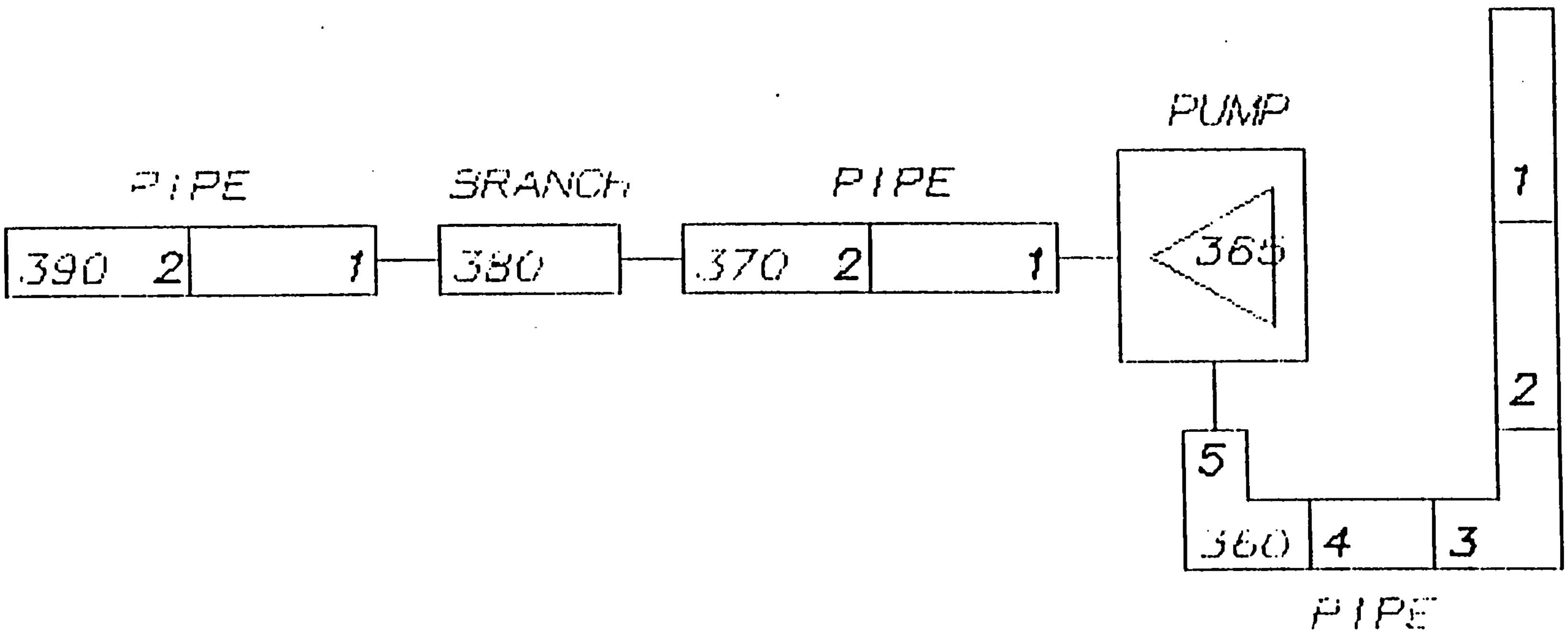


FIGURE 3

PROYECTO ICAP (ICAP PROYECT)

[illegible]

VASIJA DEL REACTOR

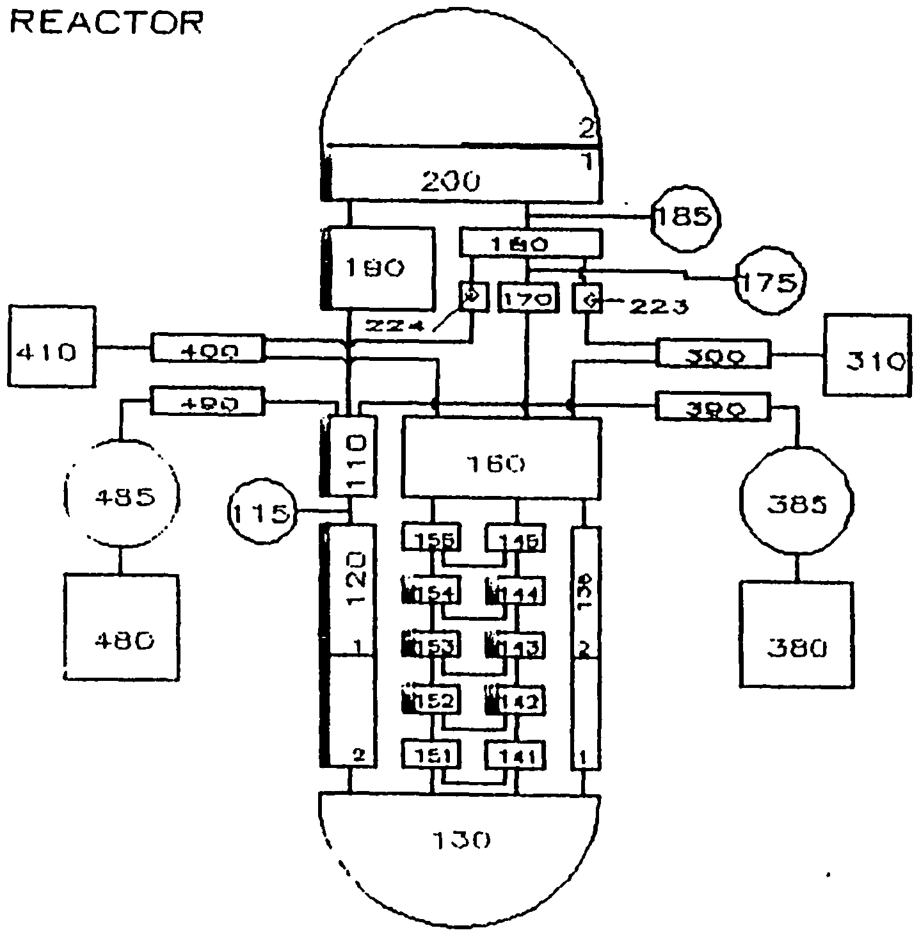


FIGURE 4º

54

PROYECTO ICAP (ICAP PROYECT)

RED DE TRABAJO (NETWORKS)

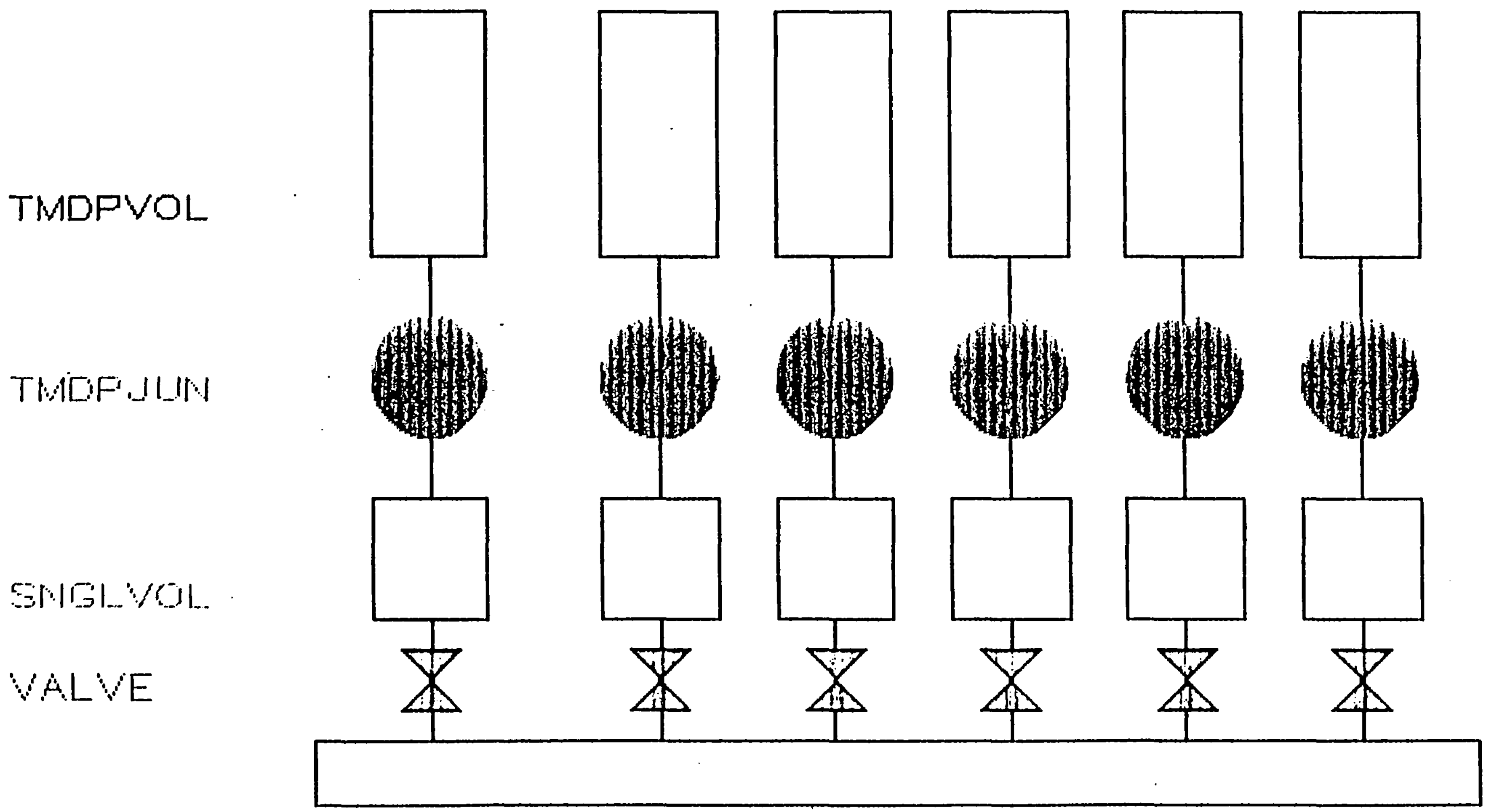


FIGURE 5

PROYECTO ICAP (ICAP PROYECT)
SAFETY AND RELIEF VALVES

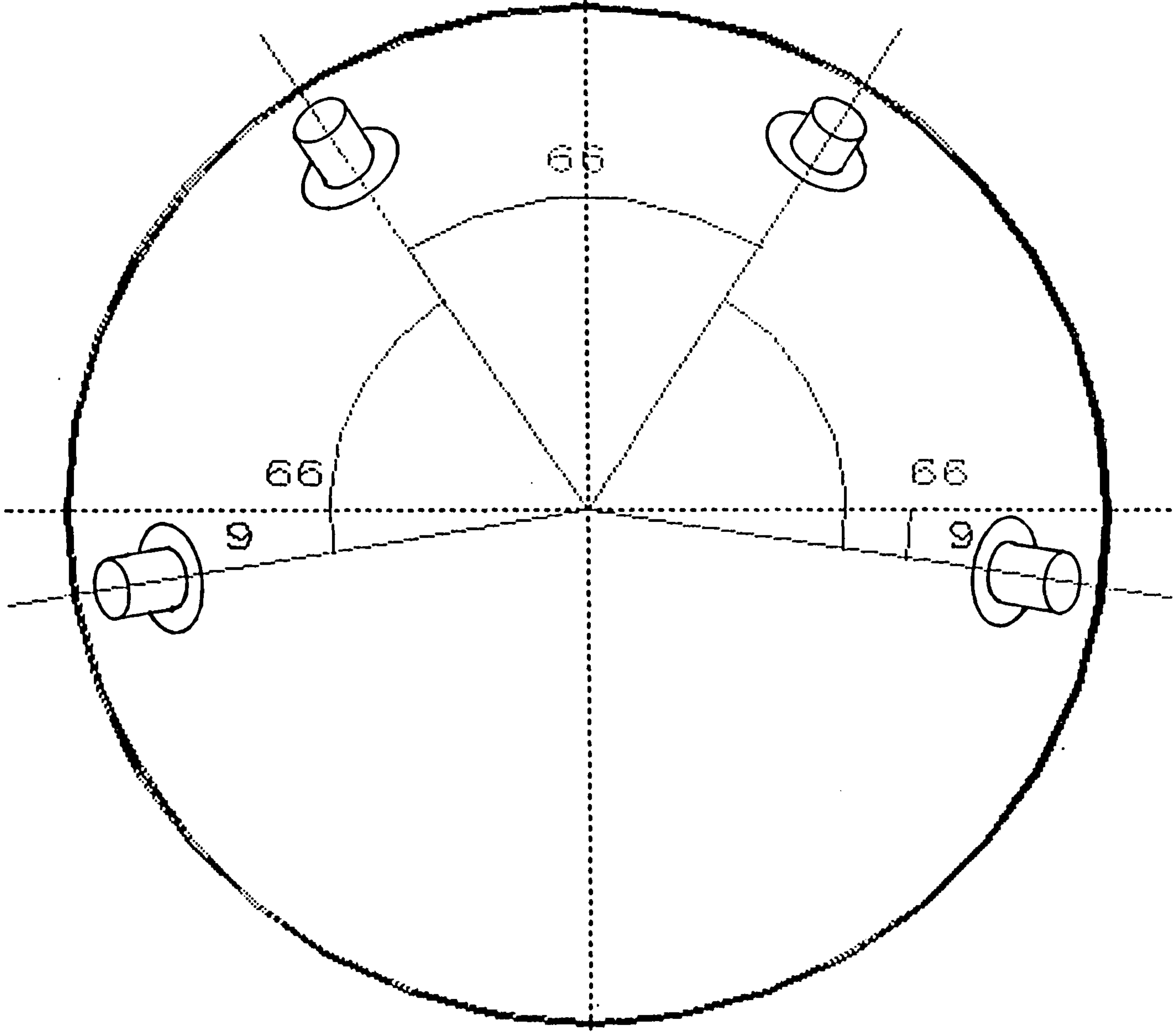
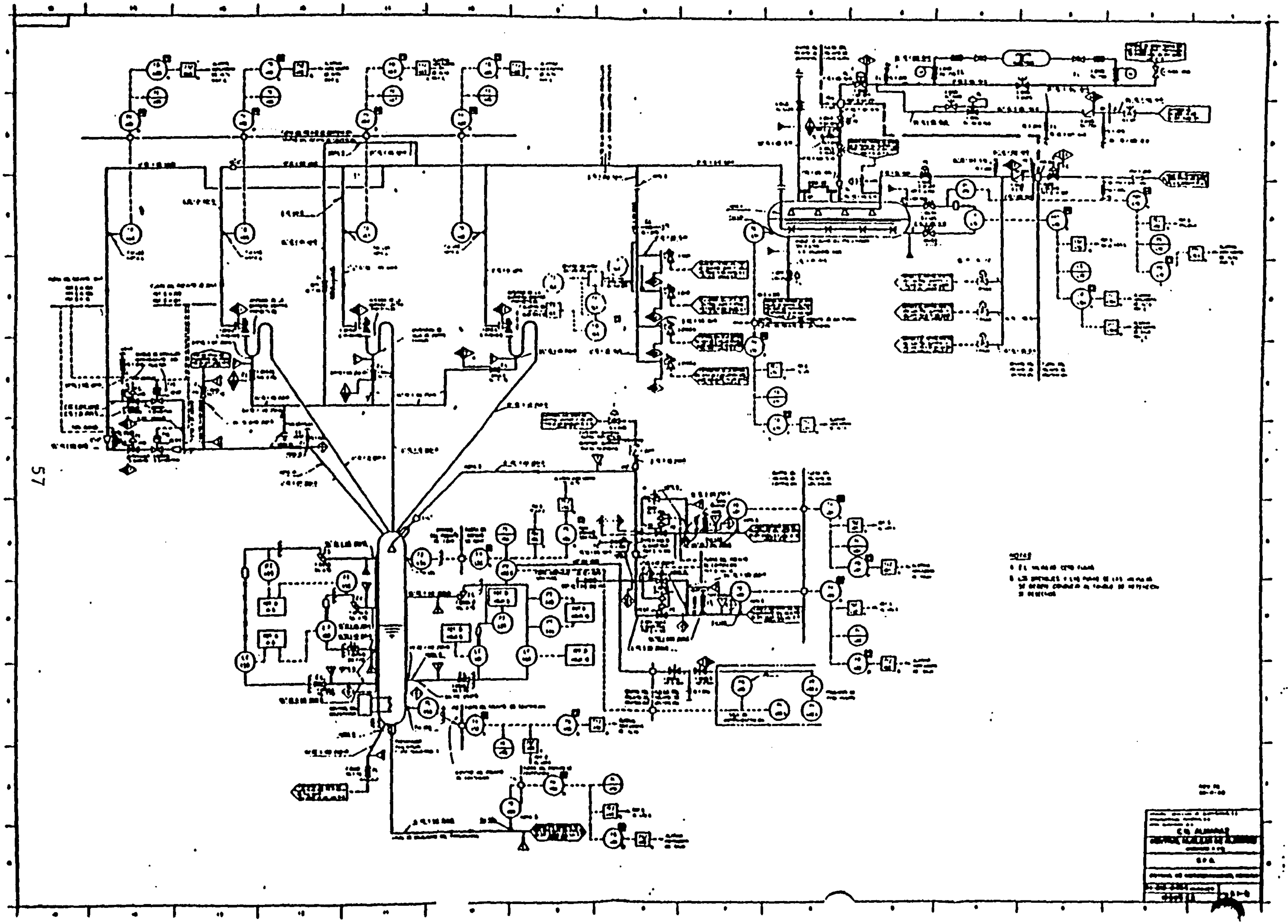
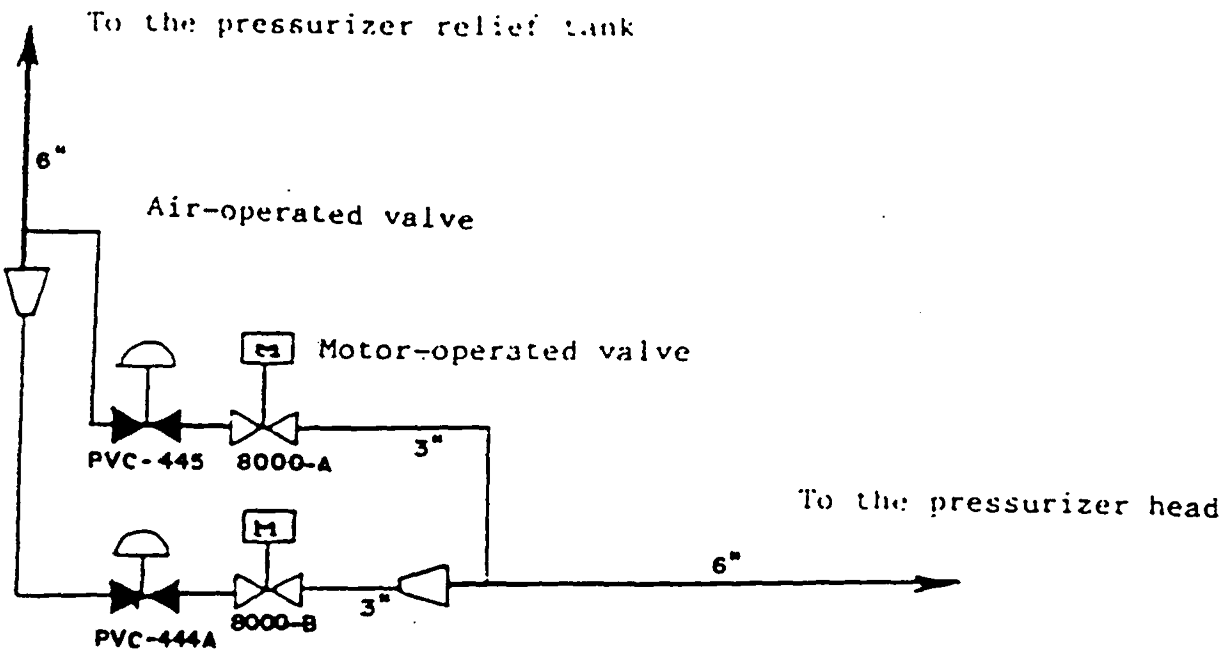


FIGURE 6





To the pressurizer relief tank
6"
Air-operated valve
Motor-operated valve
PVC-445
8000-A
3"
To the pressurizer head
6"
PVC-444A
8000-B
3"

FIGURE-8

PROYECTO ICAP (ICAP PROYECT)

SAFETY AND RELIEF VALVES

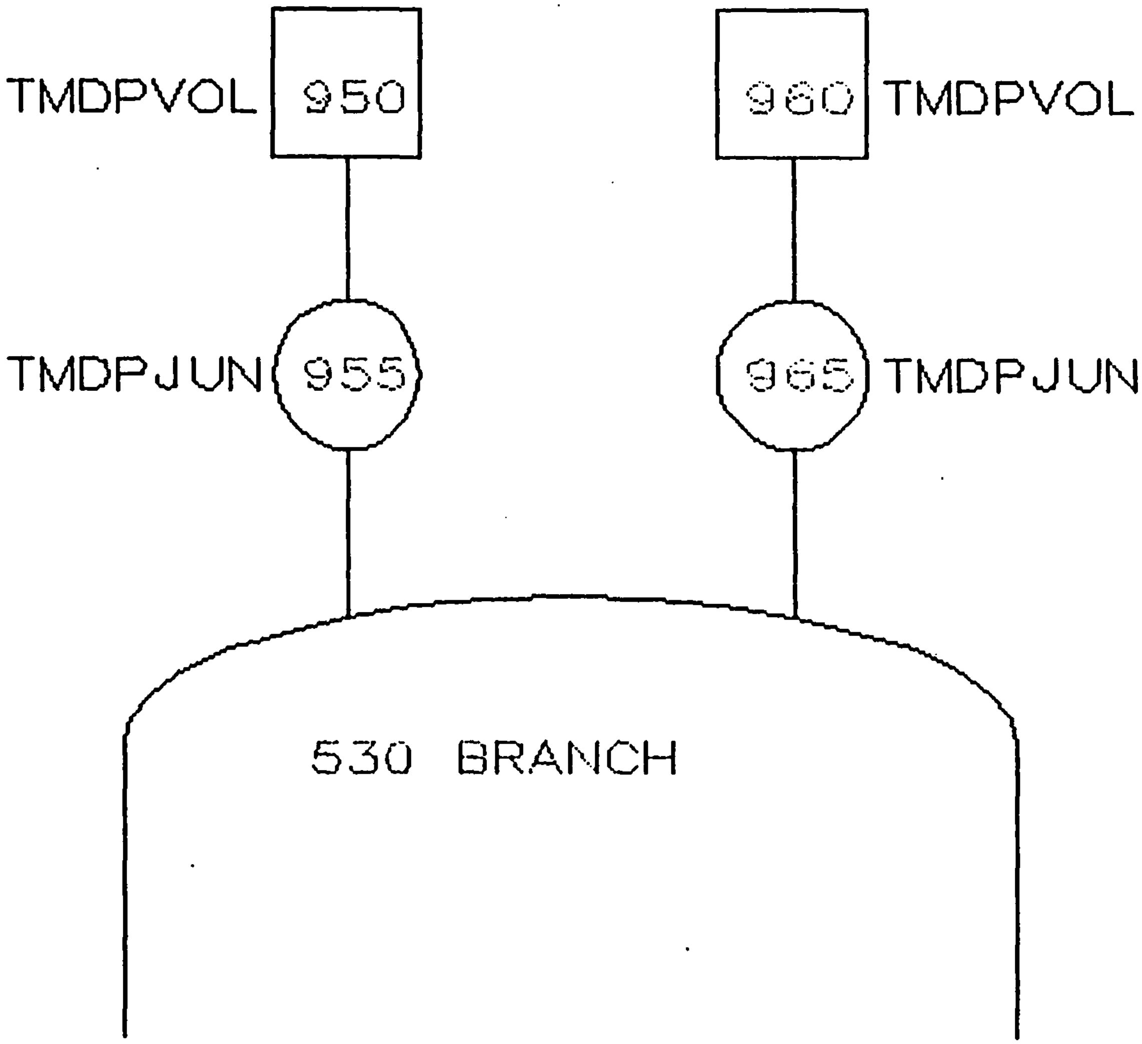


FIGURE 9

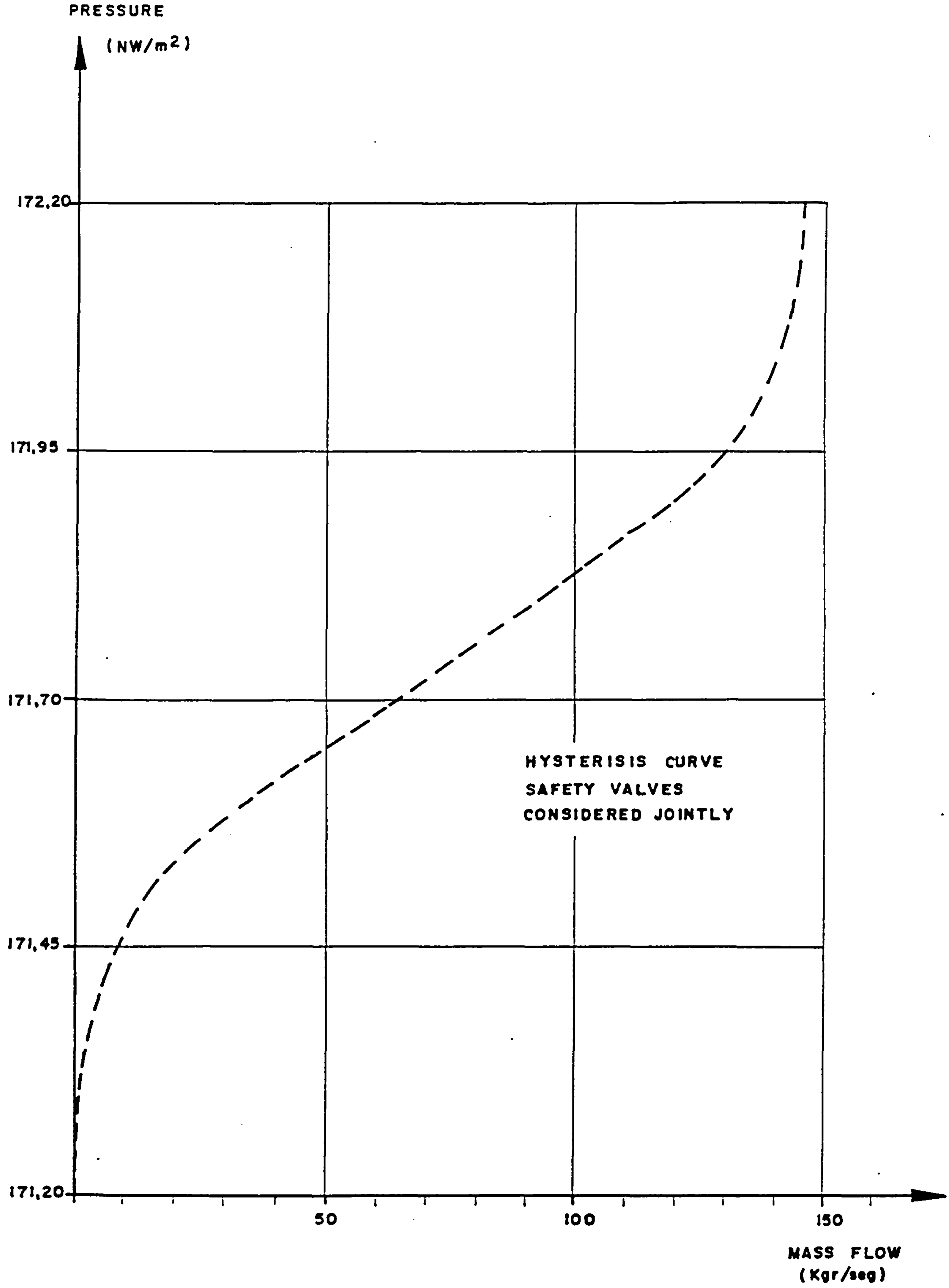

PRESSURE
(NW/m2)
172,20
171,95
171,70
171,45
171,20
50
100
150
MASS FLOW
(Kgr/seg)
HYSTERISIS CURVE
SAFETY VALVES
CONSIDERED JOINTLY

FIGURA-10

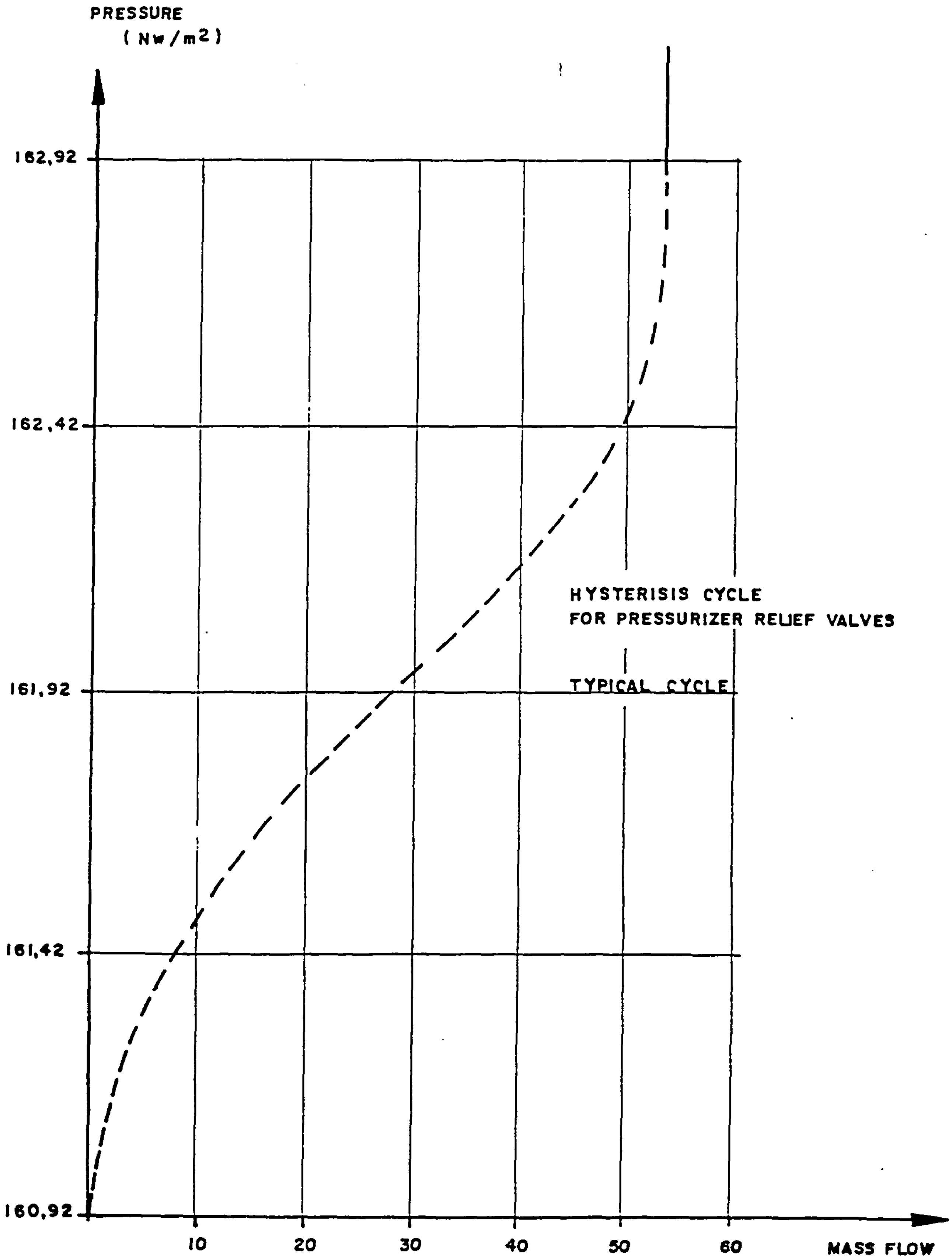
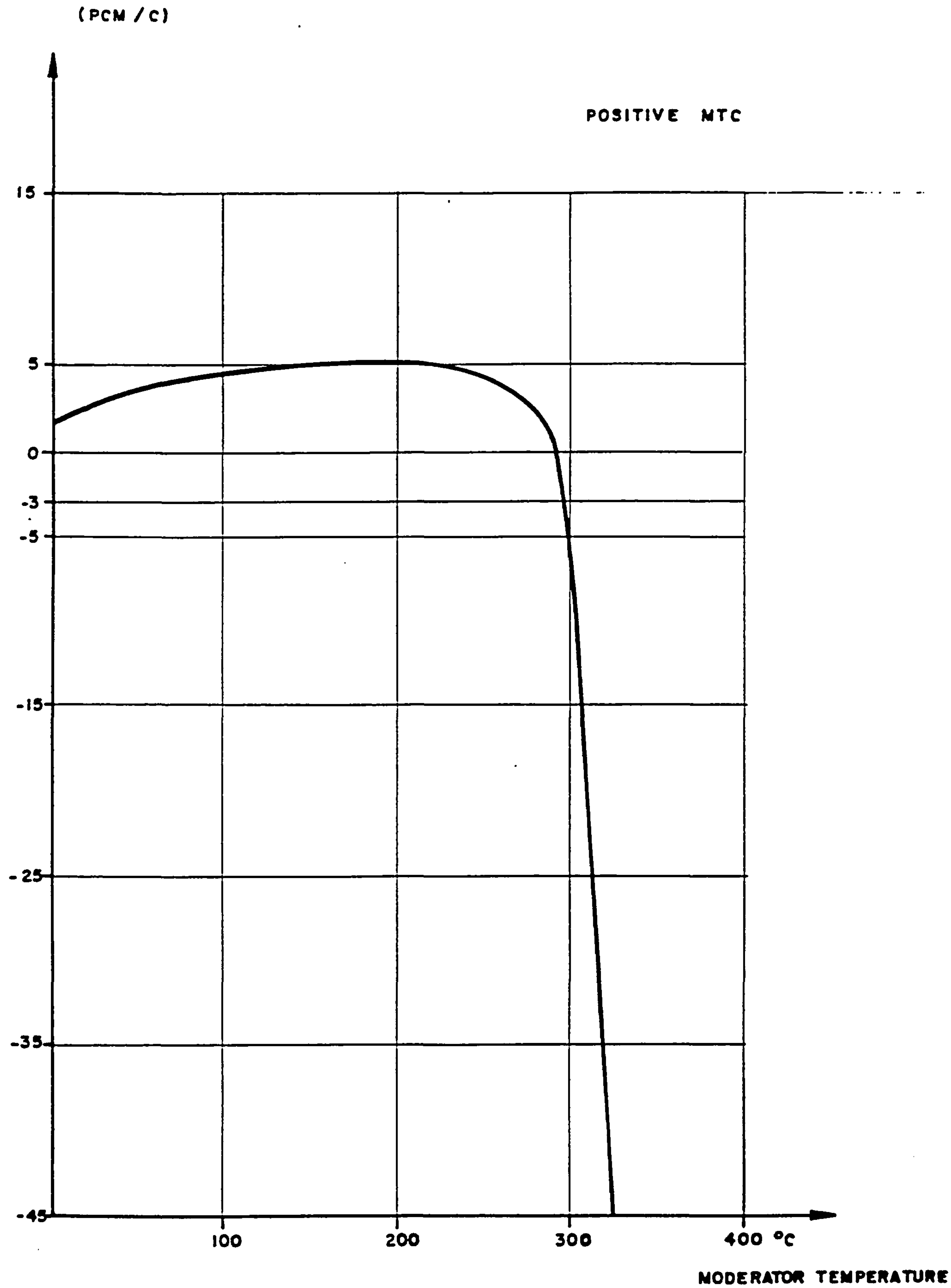

PRESSURE
(Nw/m2)
162,92
162,42
161,92
161,42
160,92
10
20
30
40
50
60
MASS FLOW
HYSTERISIS CYCLE
FOR PRESSURIZER RELIEF VALVES
TYPICAL CYCLE

FIGURE - 11



(PCM / C)
POSITIVE MTC
15
5
0
-3
-5
-15
-25
-35
-45
100
200
300
400 °C
MODERATOR TEMPERATURE

FIGURE-12

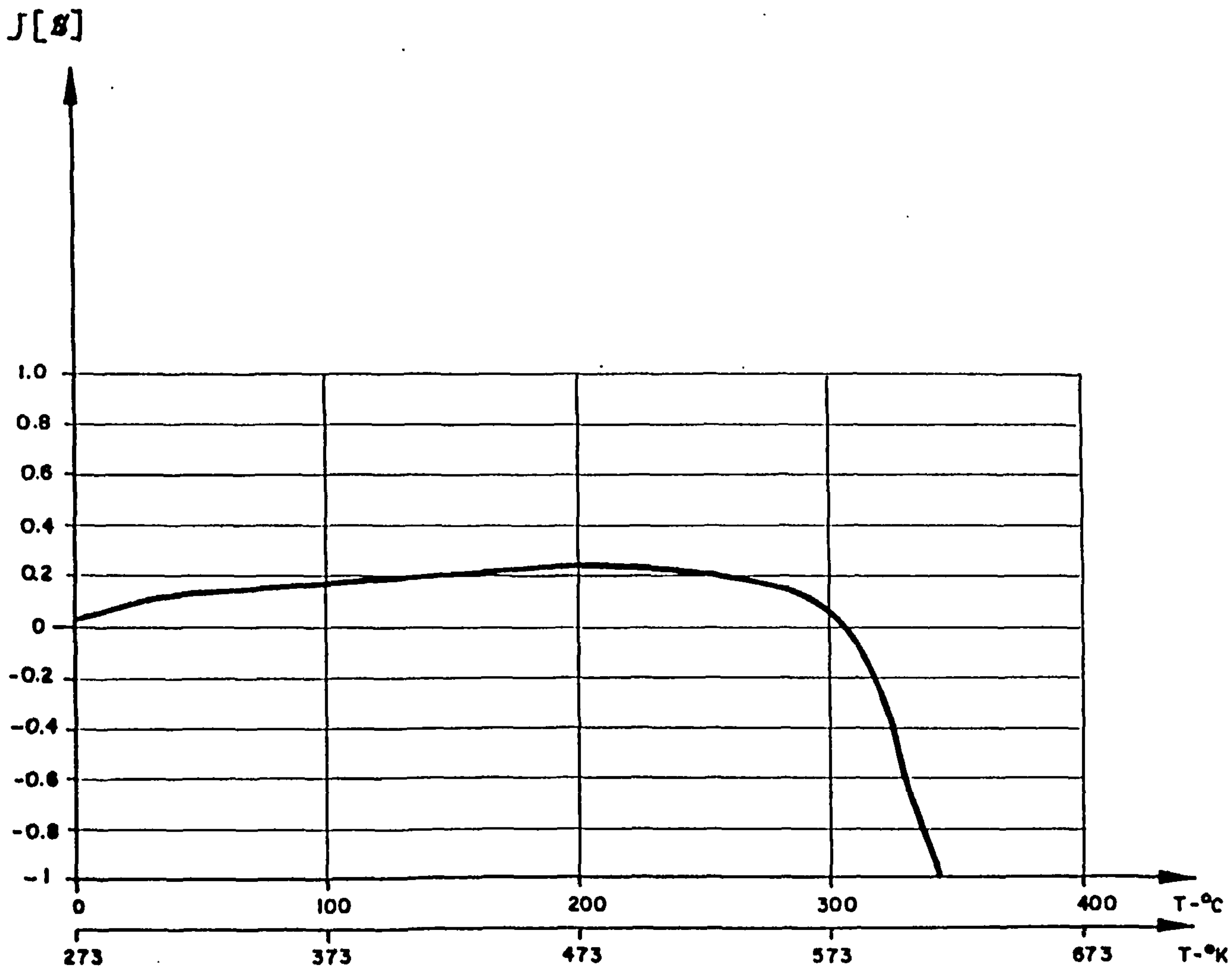

J[%]
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
100
200
300
400
T-°C
273
373
473
573
673
T-°K

FIGURE - 13

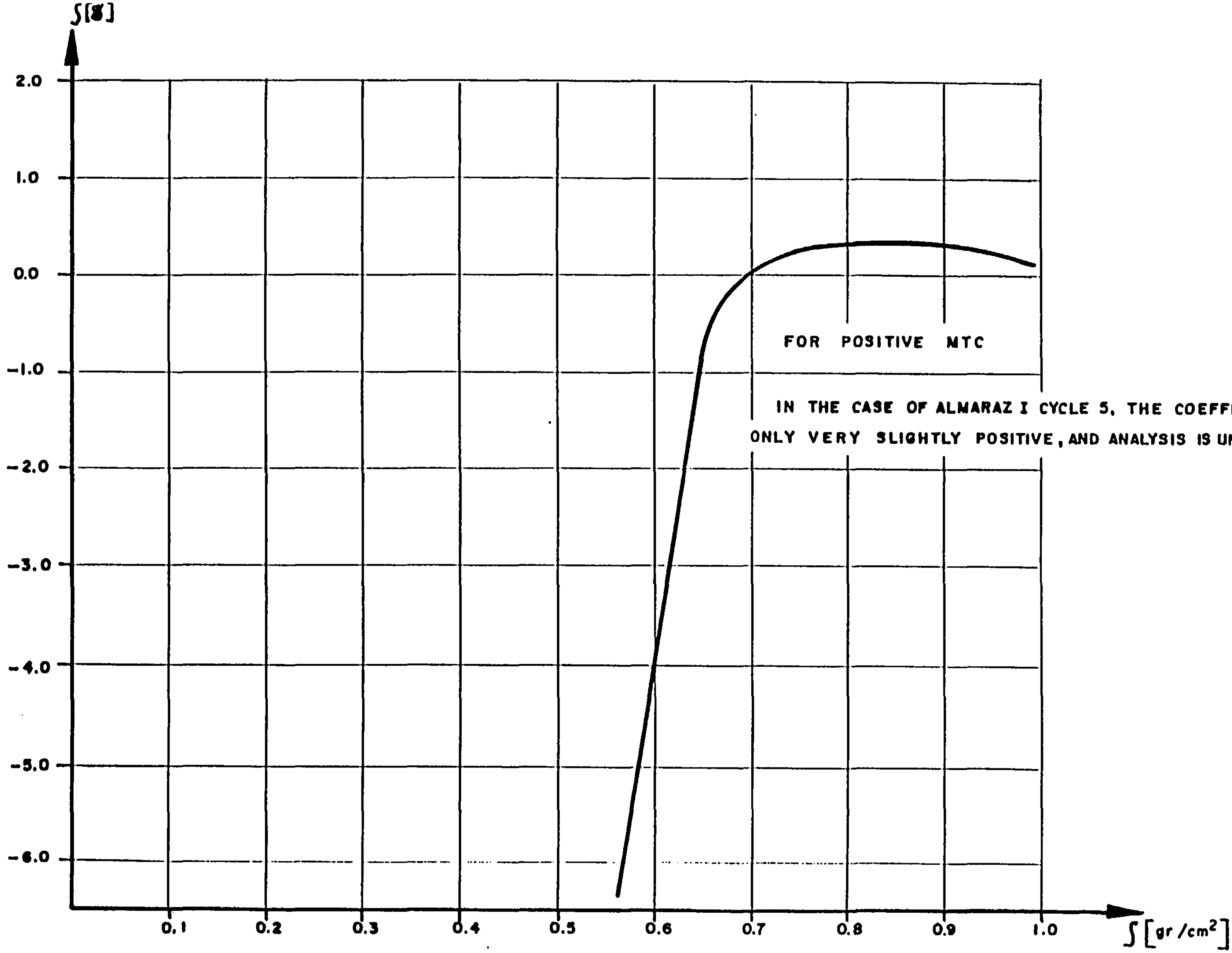
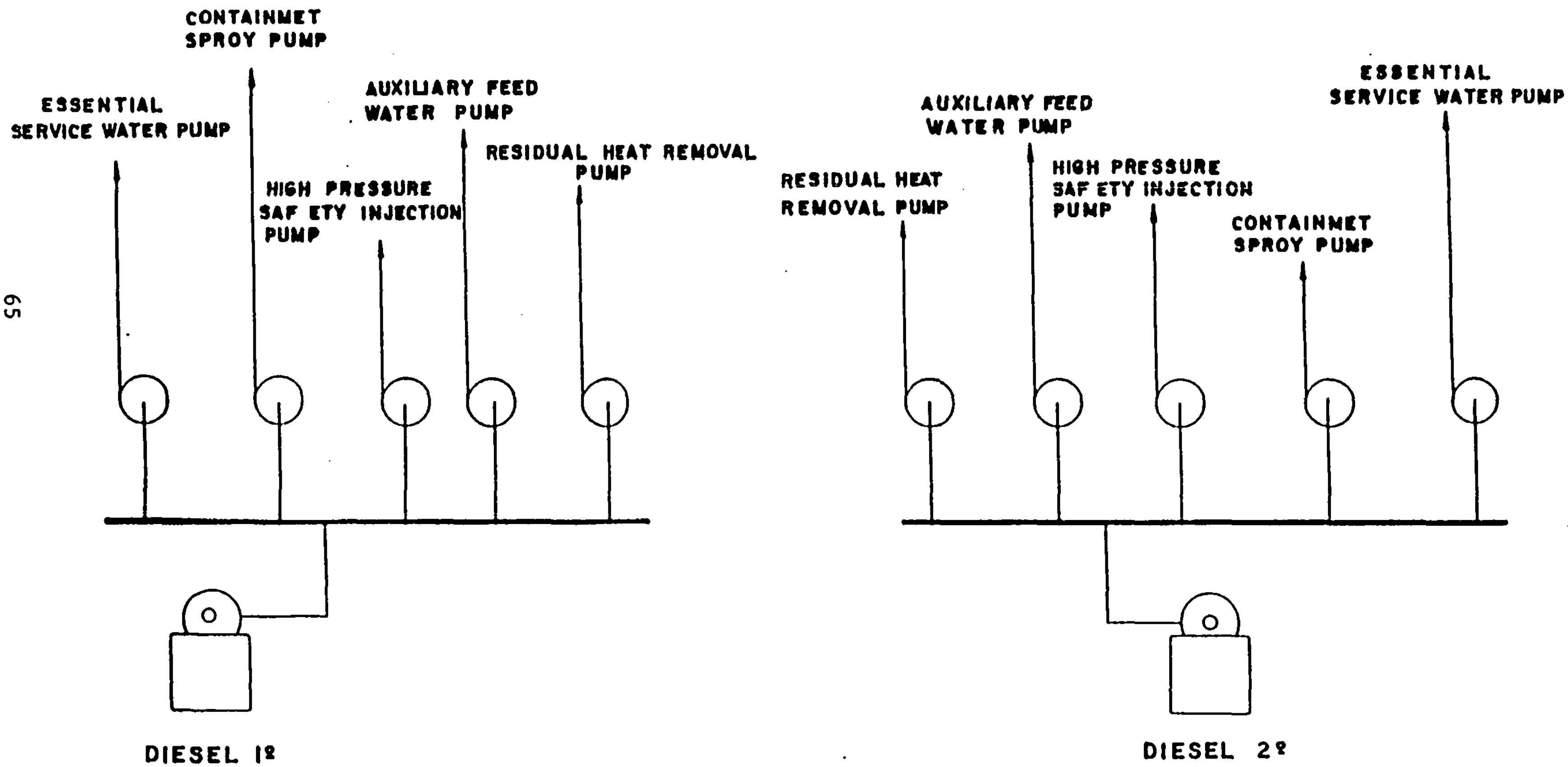

2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
ʃ [gr/cm²]
FOR POSITIVE MTC
IN THE CASE OF ALMARAZ I CYCLE 5, THE COEFFICIENT IS
ONLY VERY SLIGHTLY POSITIVE, AND ANALYSIS IS UNNECESSARY

FIGURE-14

ALMARAZ NUCLEAR POWER PLANT



65

FIGURE - 15

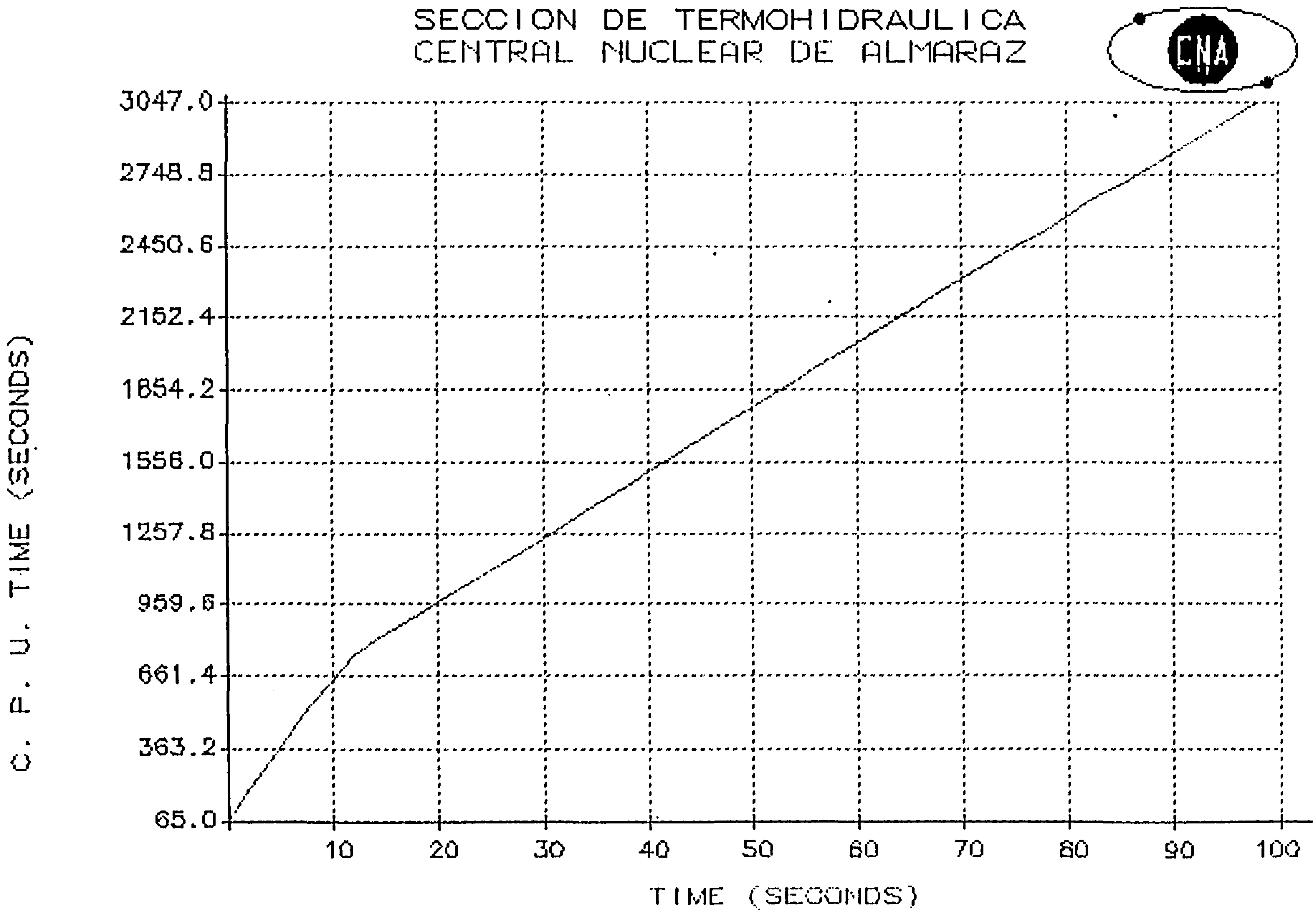

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
3047.0
2748.8
2450.6
2152.4
1854.2
1556.0
1257.8
959.6
661.4
363.2
65.0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)
C. P. U. TIME (SECONDS)

FIGURE 16

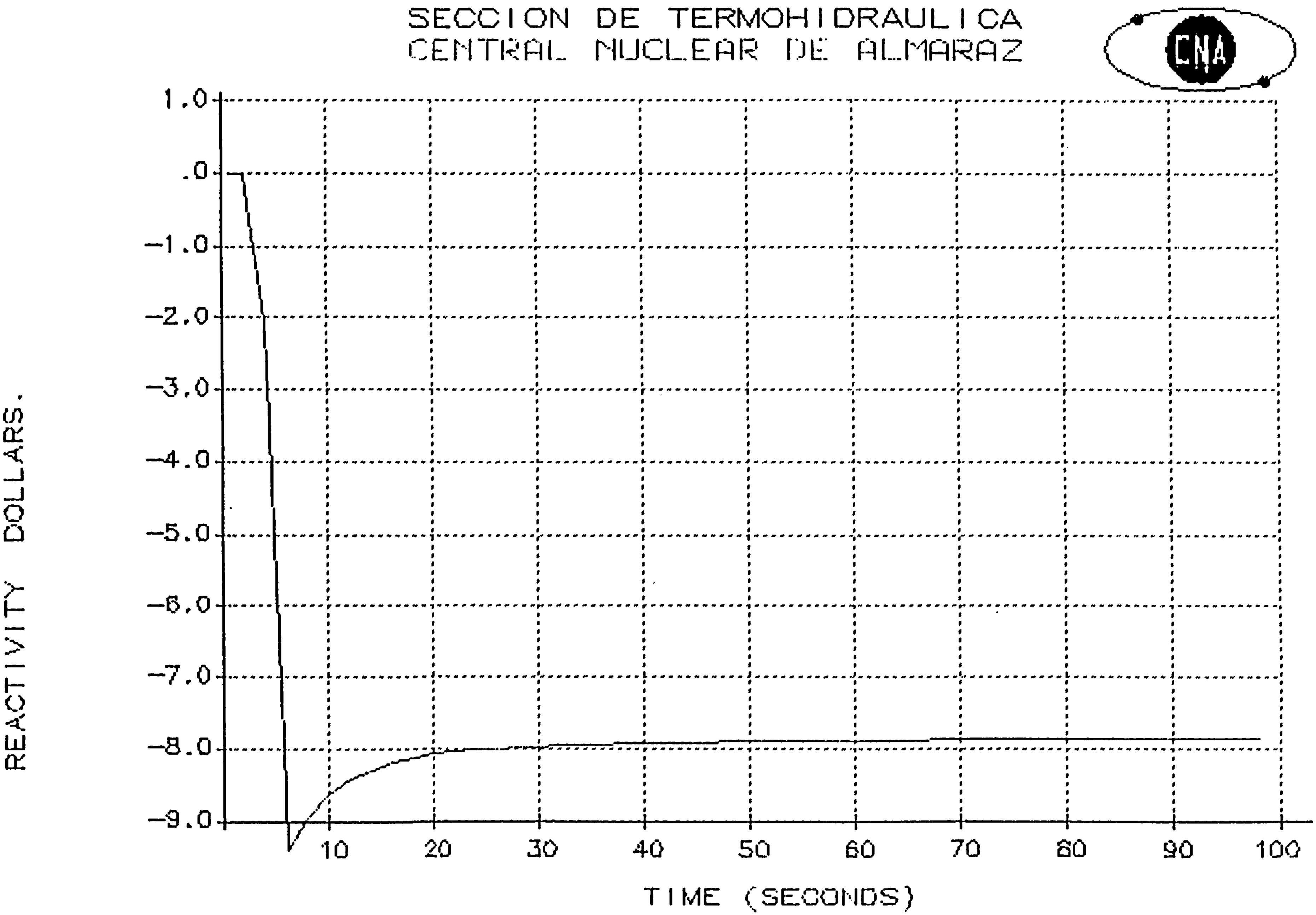

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
1.0
.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
-9.0
REACTIVITY DOLLARS.
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)

FIGURE 17

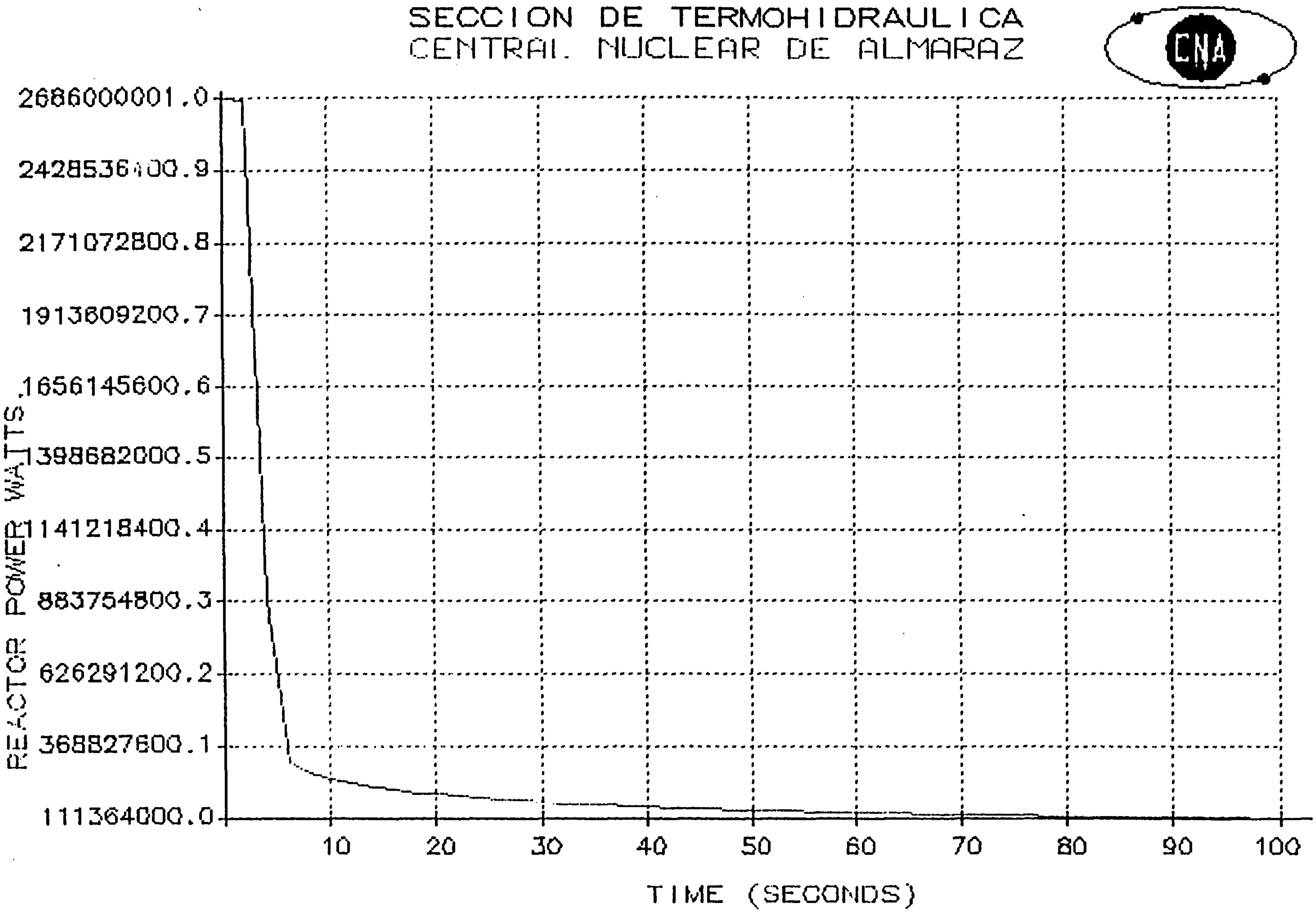

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
REACTOR POWER WATTS
2686000001.0
2428536400.9
2171072800.8
1913609200.7
1656145600.6
1398682000.5
1141218400.4
883754800.3
626291200.2
368827600.1
111364000.0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)

FIGURE 18

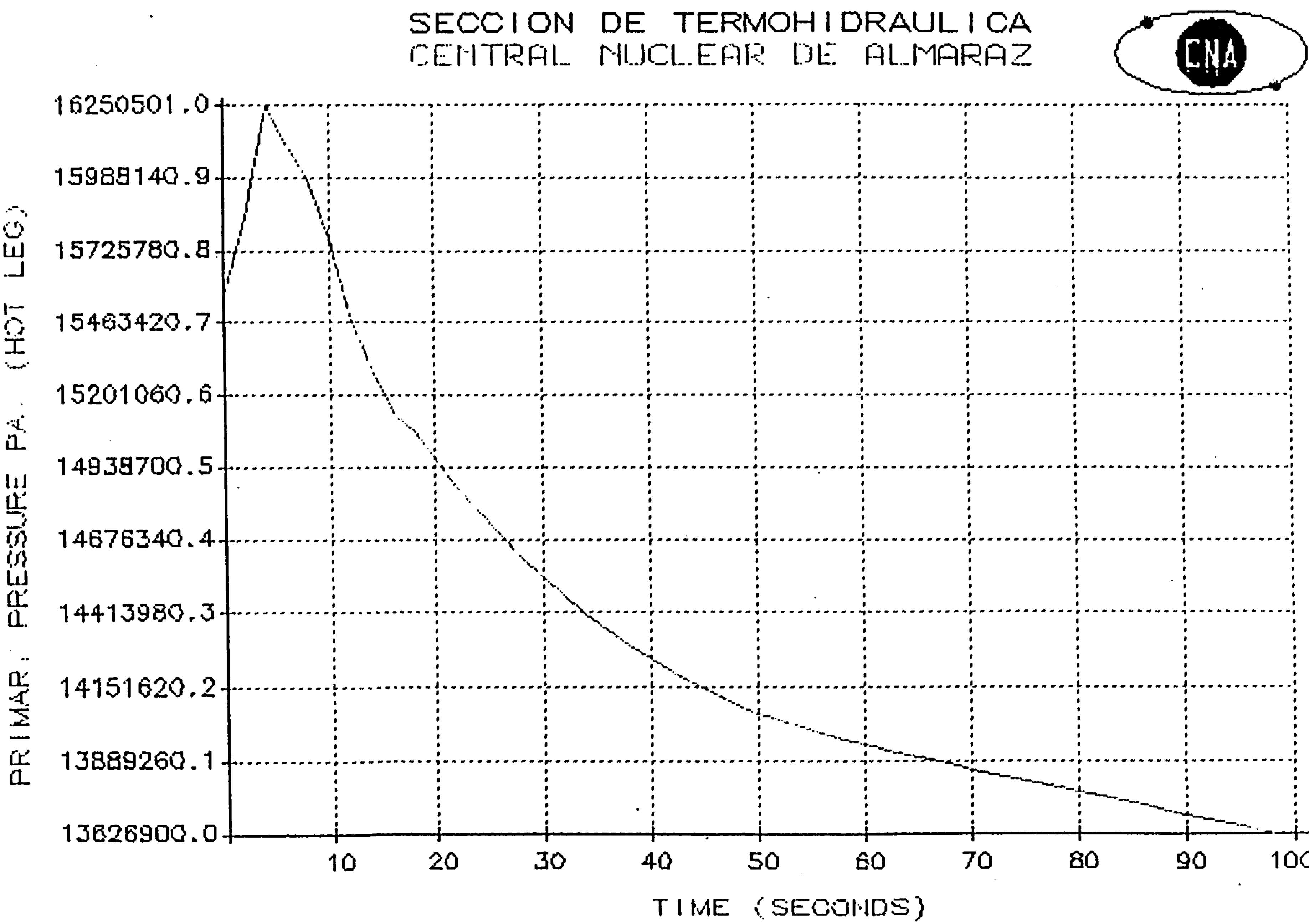

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
PRIMAR. PRESSURE PA. (HOT LEG)
16250501.0
15988140.9
15725780.8
15463420.7
15201060.6
14938700.5
14676340.4
14413980.3
14151620.2
13889260.1
13626900.0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)

FIGURE 19

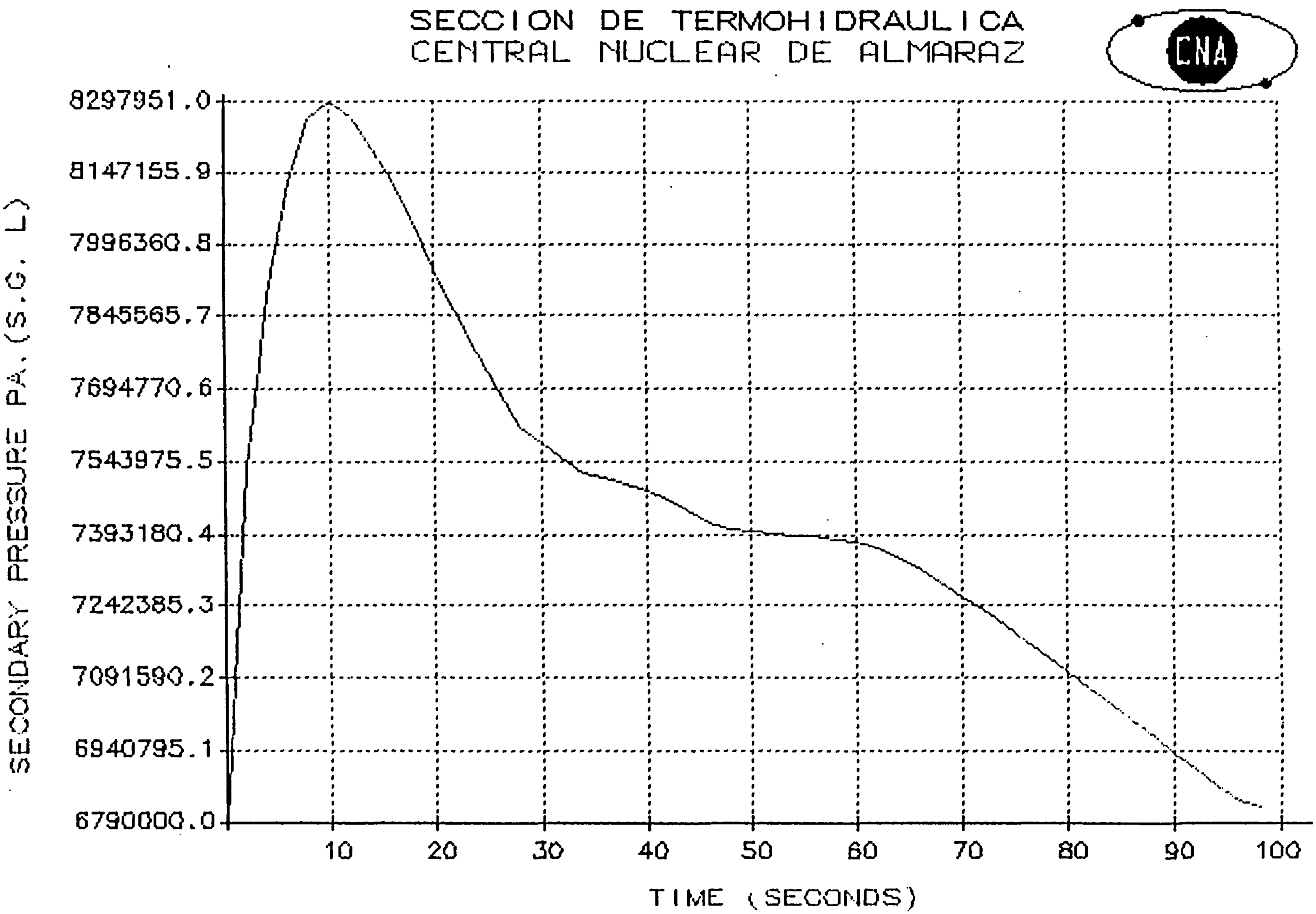

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
8297951.0
8147155.9
7996360.8
7845565.7
7694770.6
7543975.5
7393180.4
7242385.3
7091590.2
6940795.1
6790000.0
SECONDARY PRESSURE PA. (S.G. L)
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)

FIGURE 20

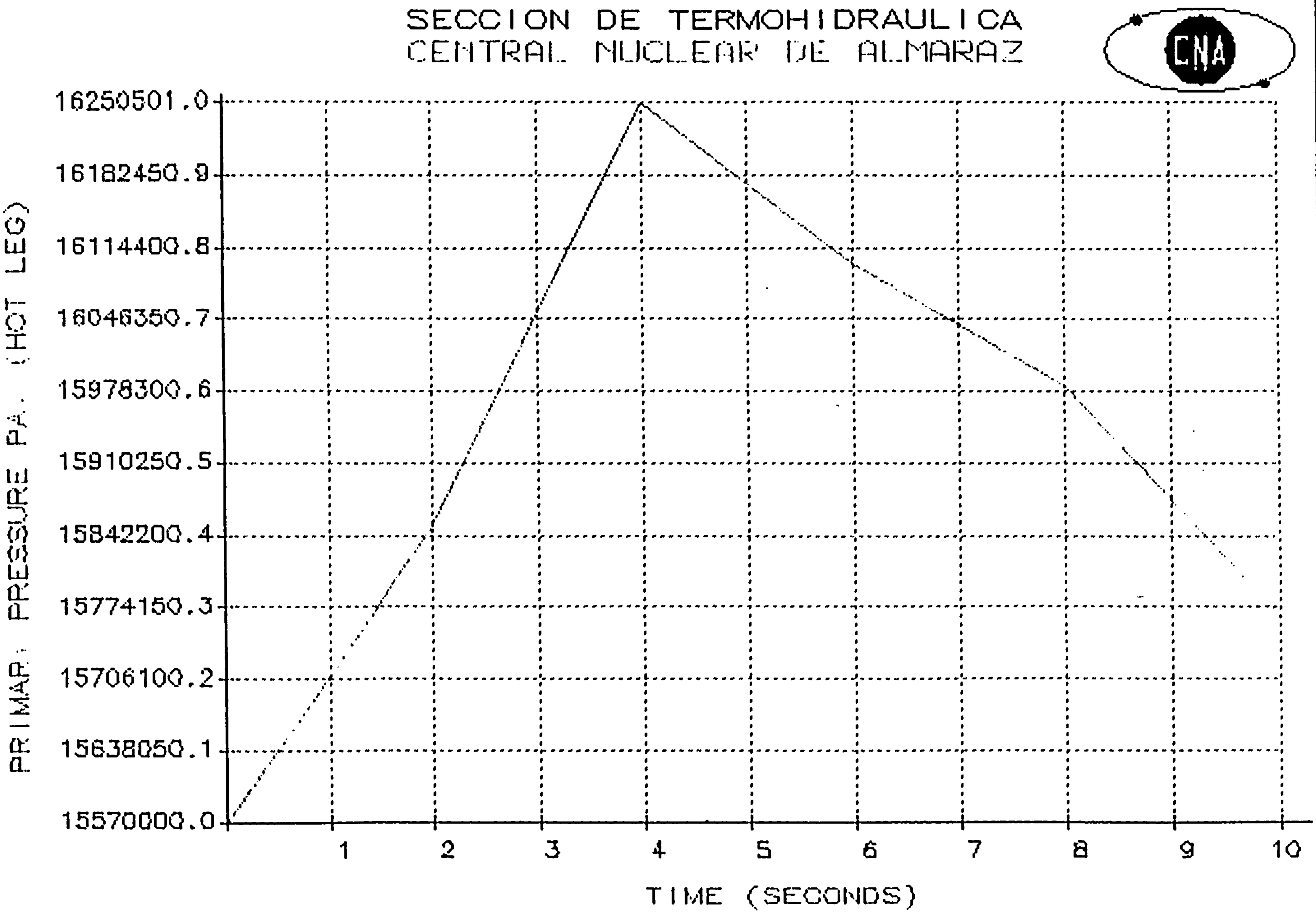

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
PRIMAR. PRESSURE PA. (HOT LEG)
16250501.0
16182450.9
16114400.8
16046350.7
15978300.6
15910250.5
15842200.4
15774150.3
15706100.2
15638050.1
15570000.0
1
2
3
4
5
6
7
8
9
10
TIME (SECONDS)

FIGURE 21

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ

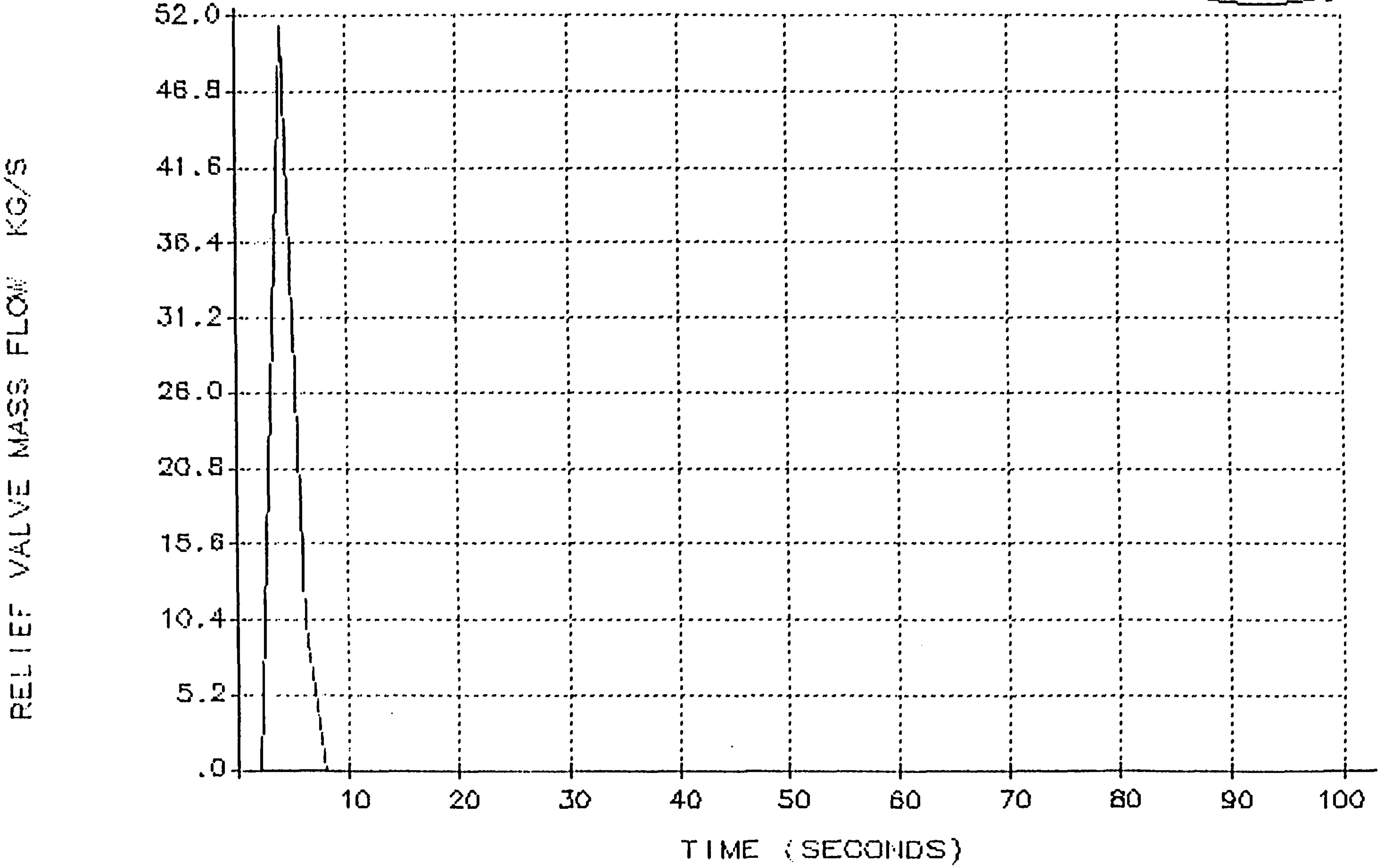


FIGURE 22

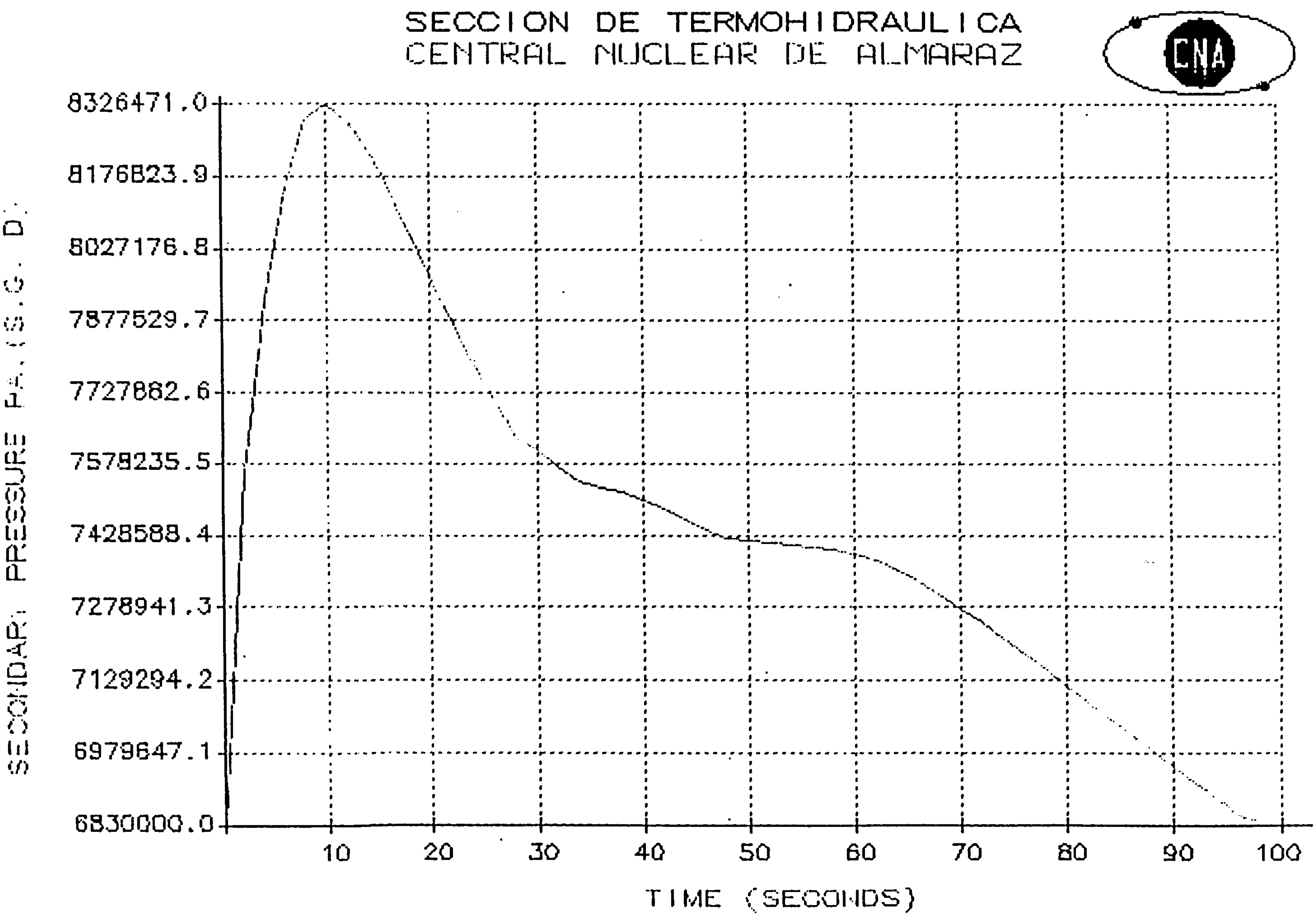

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
8326471.0
8176823.9
8027176.8
7877529.7
7727882.6
7578235.5
7428588.4
7278941.3
7129294.2
6979647.1
6830000.0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)
SECONDARY PRESSURE PA. (S.G. D)

FIGURE 23

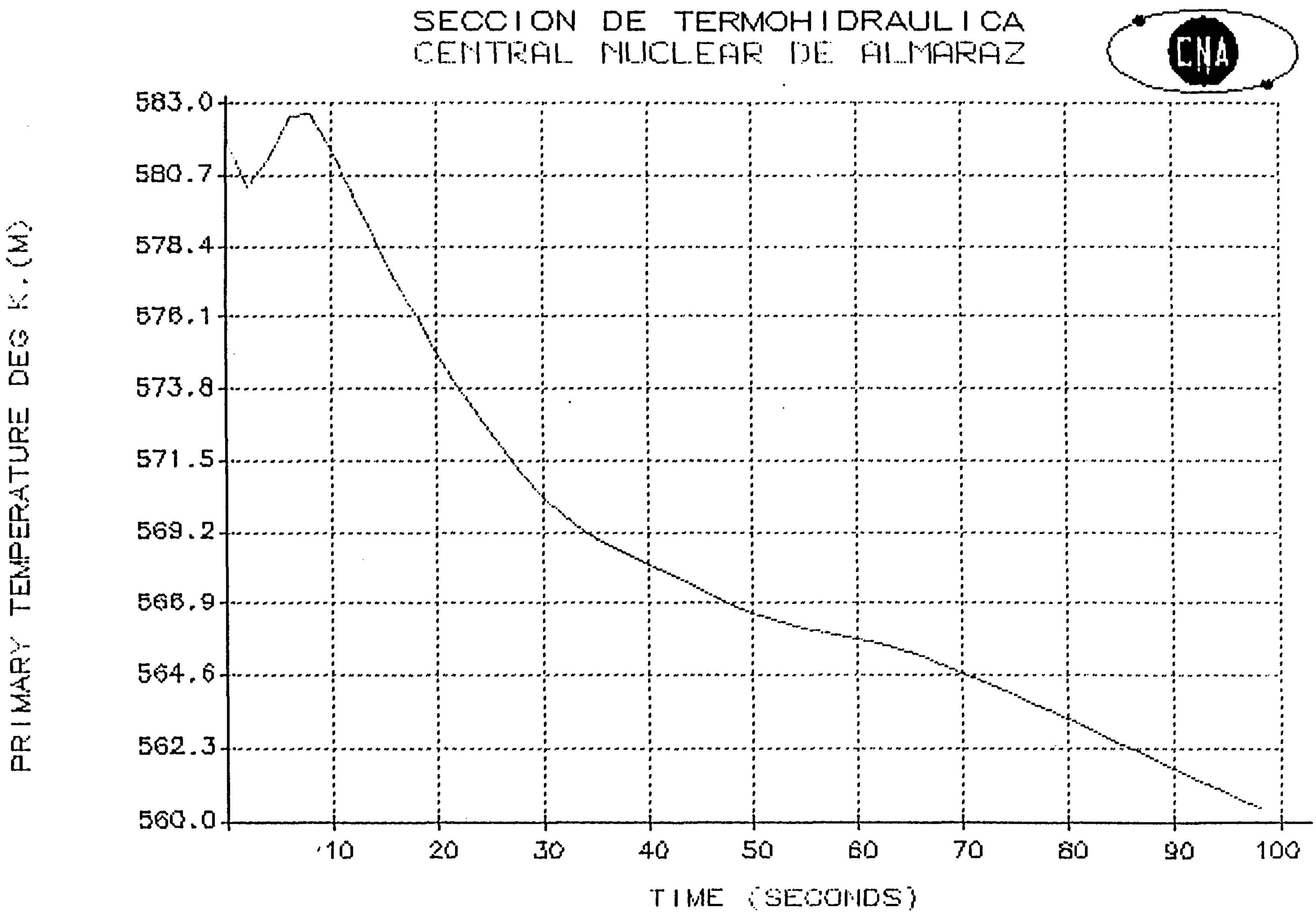

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
PRIMARY TEMPERATURE DEG K.(M)
583.0
580.7
578.4
576.1
573.8
571.5
569.2
566.9
564.6
562.3
560.0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)

FIGURE 24

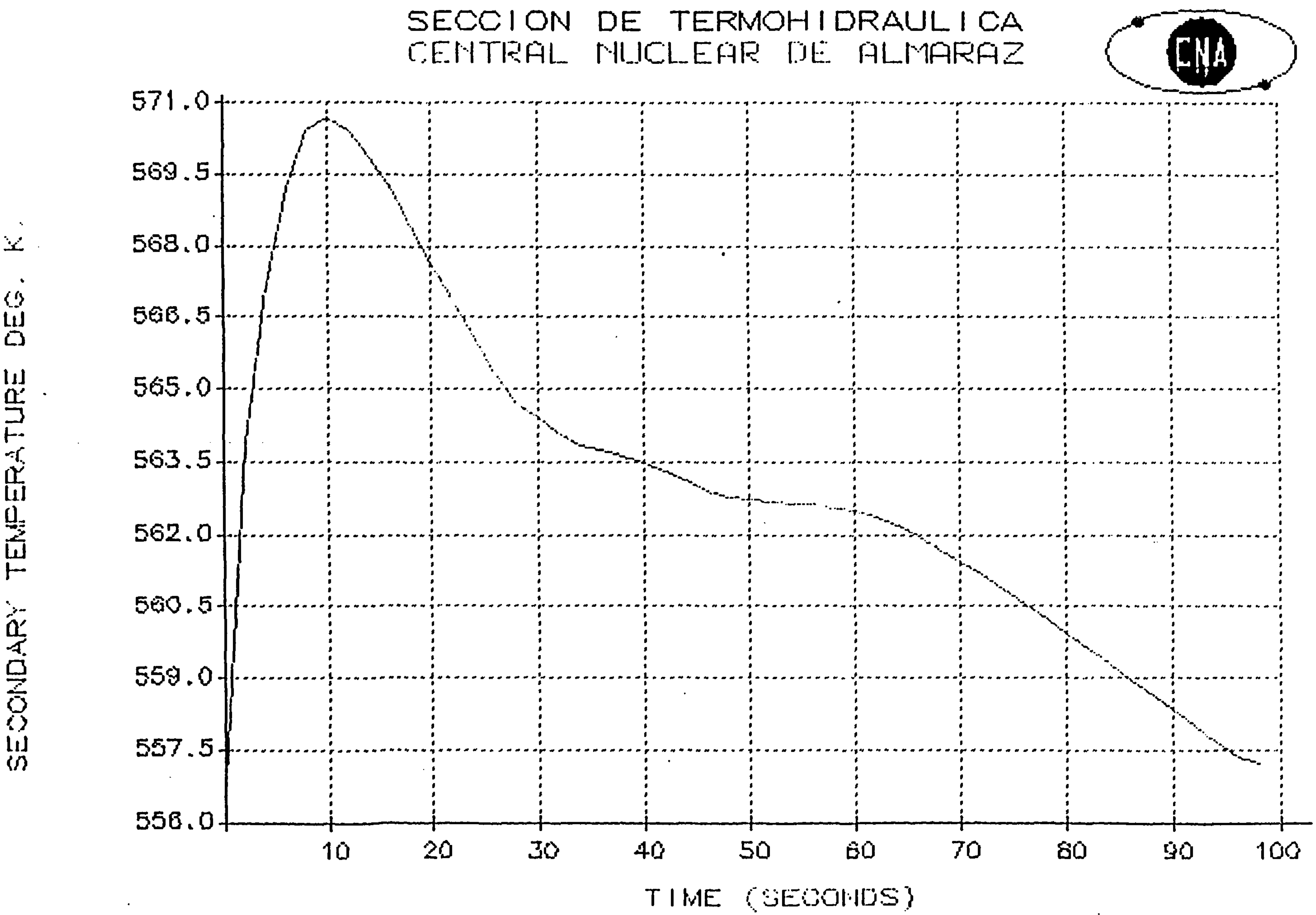

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
SECONDARY TEMPERATURE DEG. K.
571.0
569.5
568.0
566.5
565.0
563.5
562.0
560.5
559.0
557.5
556.0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)

FIGURE 25

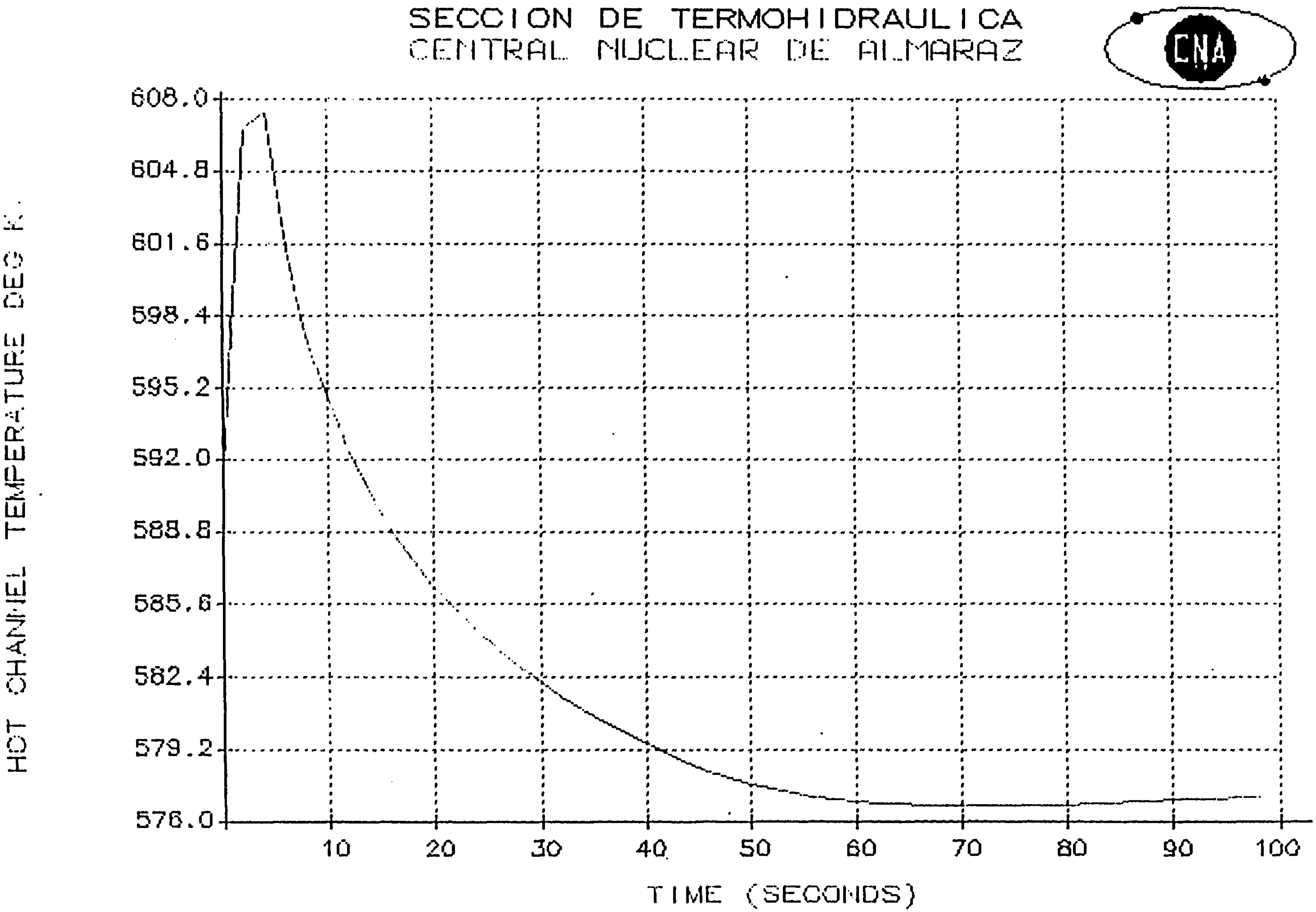

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
HOT CHANNEL TEMPERATURE DEG K.
608.0
604.8
601.6
598.4
595.2
592.0
588.8
585.6
582.4
579.2
576.0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)

FIGURE 26

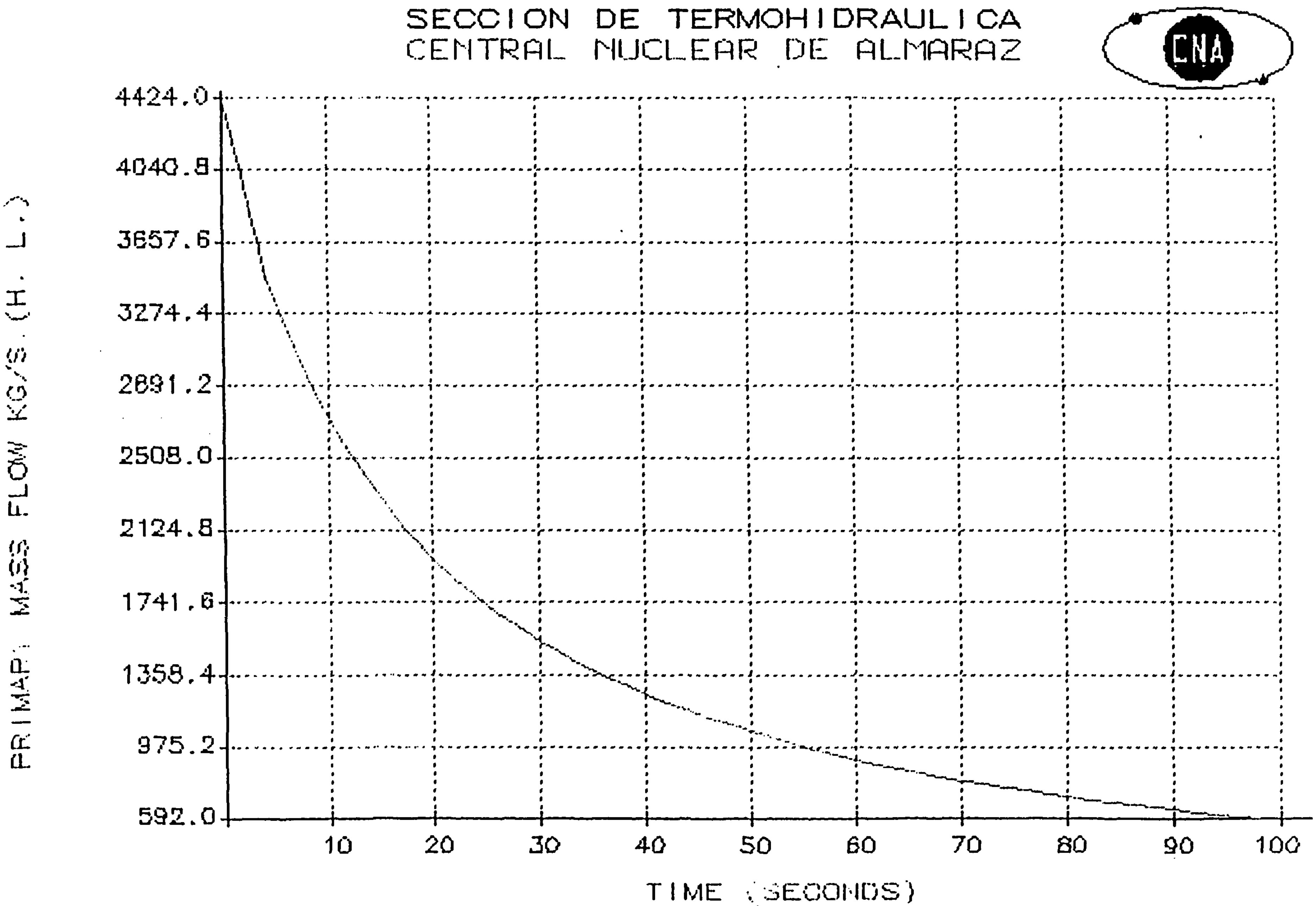

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
PRIMAP: MASS FLOW KG/S (H. L.)
4424.0
4040.8
3657.6
3274.4
2891.2
2508.0
2124.8
1741.6
1358.4
975.2
592.0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)

FIGURE 27

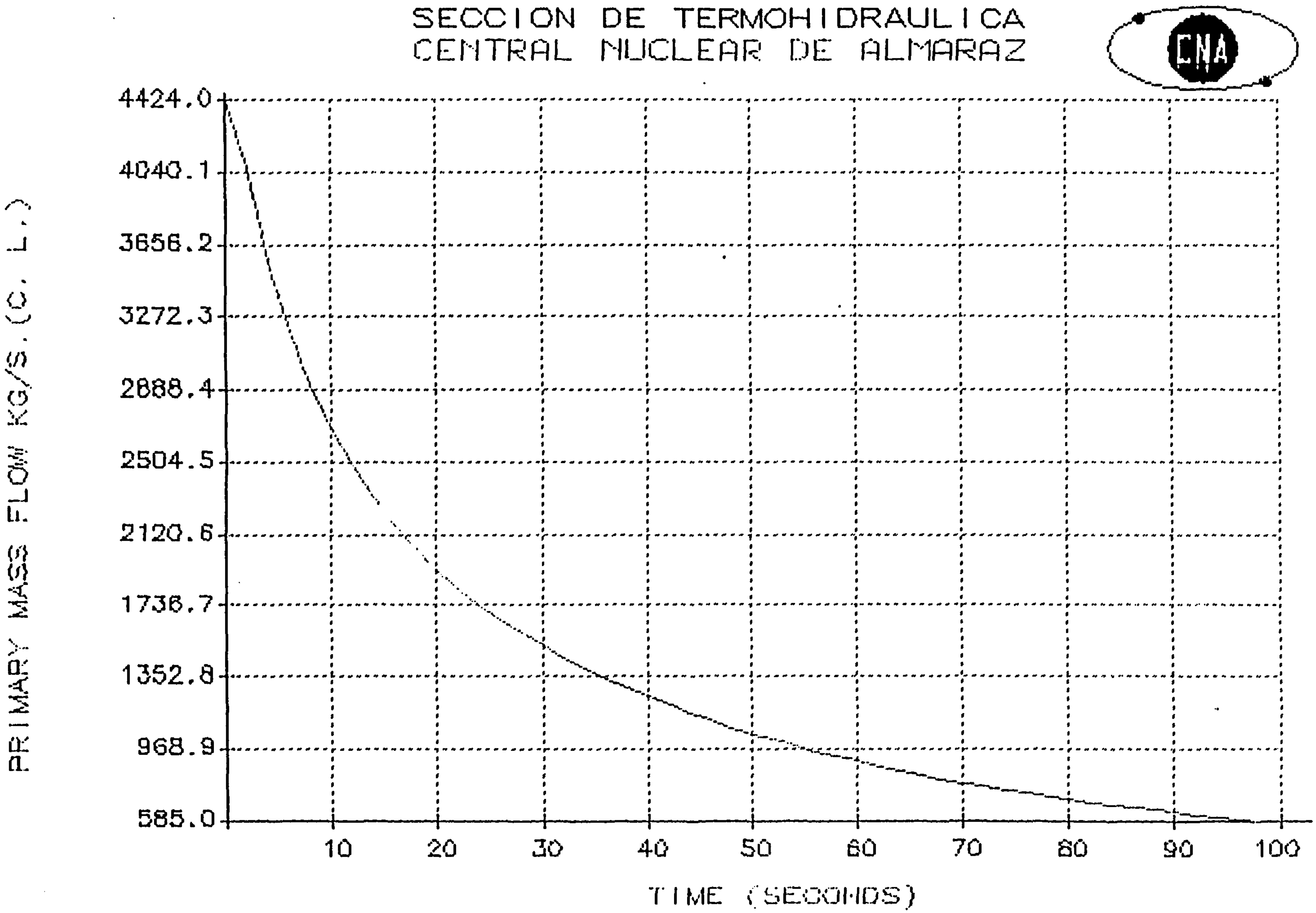

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
PRIMARY MASS FLOW KG/S. (C. L.)
4424.0
4040.1
3656.2
3272.3
2888.4
2504.5
2120.6
1736.7
1352.8
968.9
585.0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)

FIGURE 28

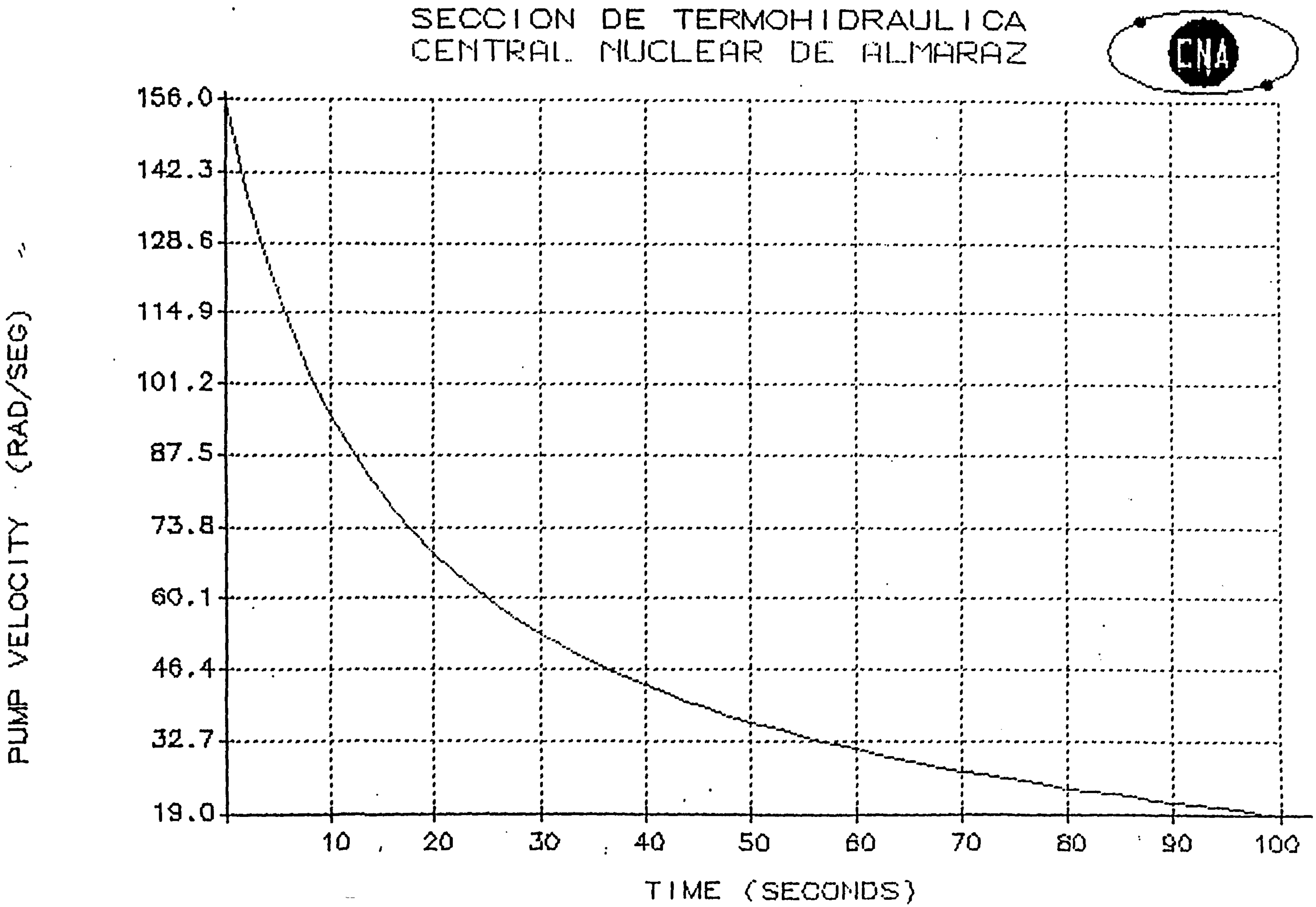
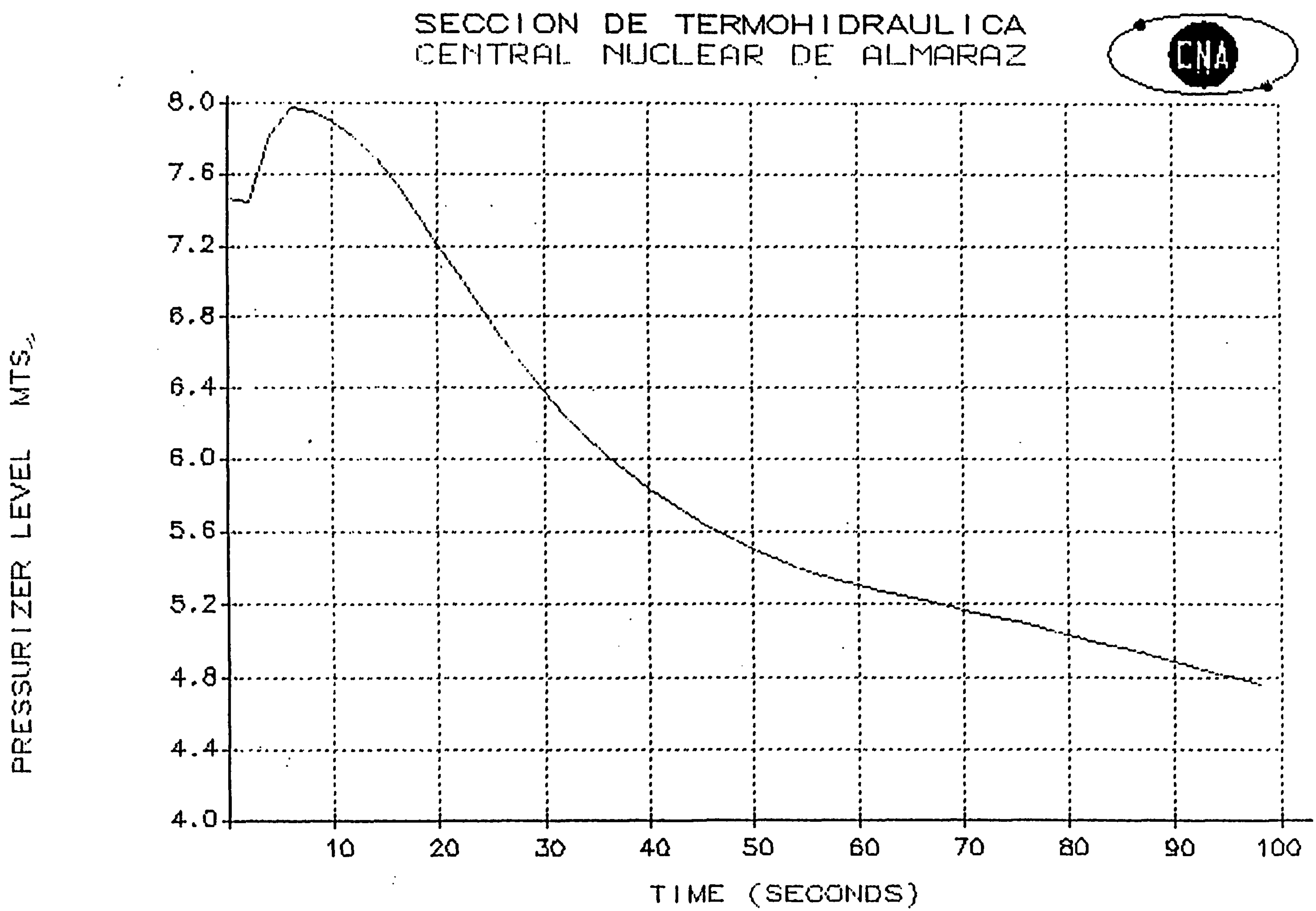

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
PUMP VELOCITY (RAD/SEG)
156.0
142.3
128.6
114.9
101.2
87.5
73.8
60.1
46.4
32.7
19.0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)

FIGURE 29



SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
PRESSURIZER LEVEL MTS.
8.0
7.6
7.2
6.8
6.4
6.0
5.6
5.2
4.8
4.4
4.0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)

FIGURE 30

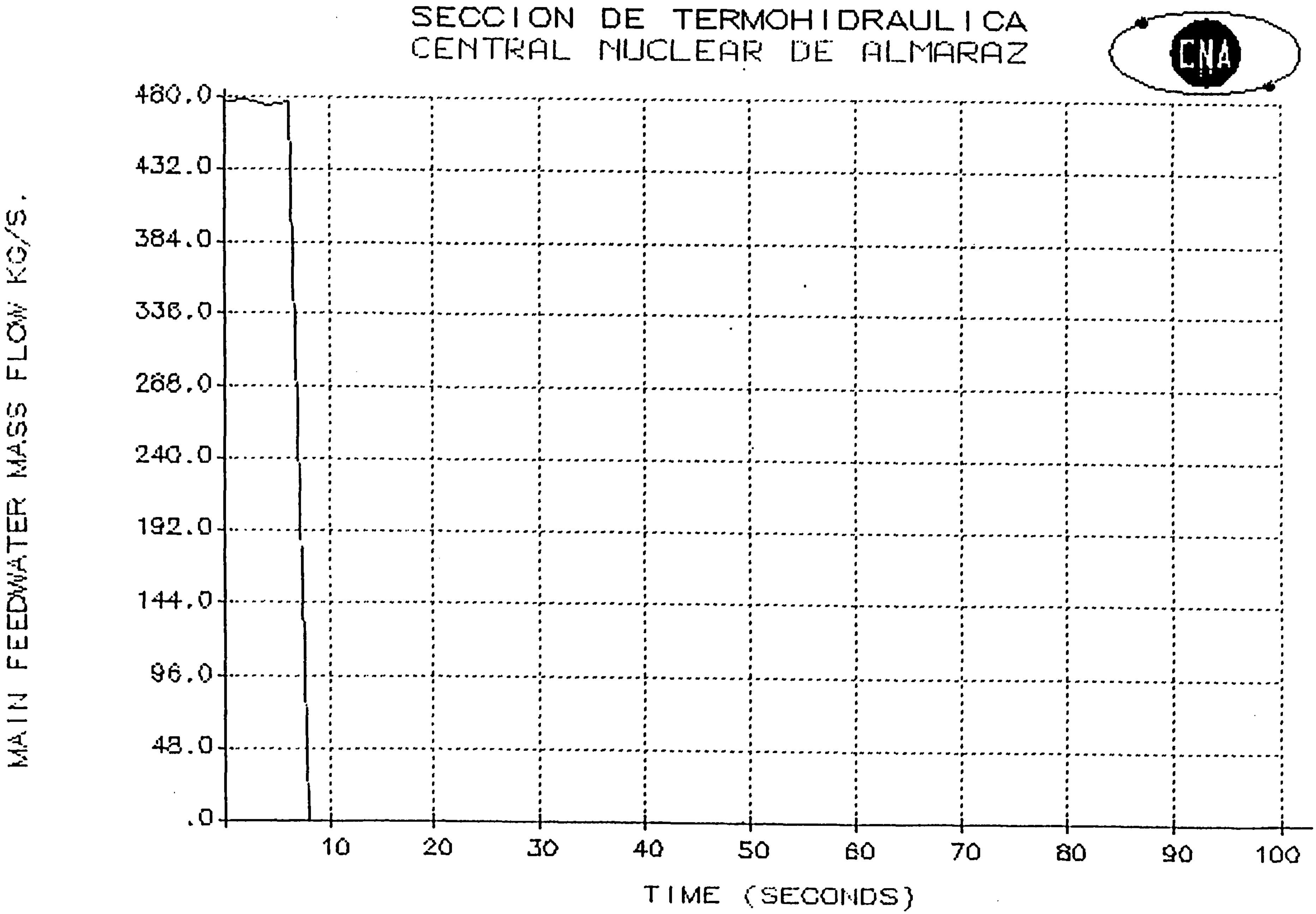
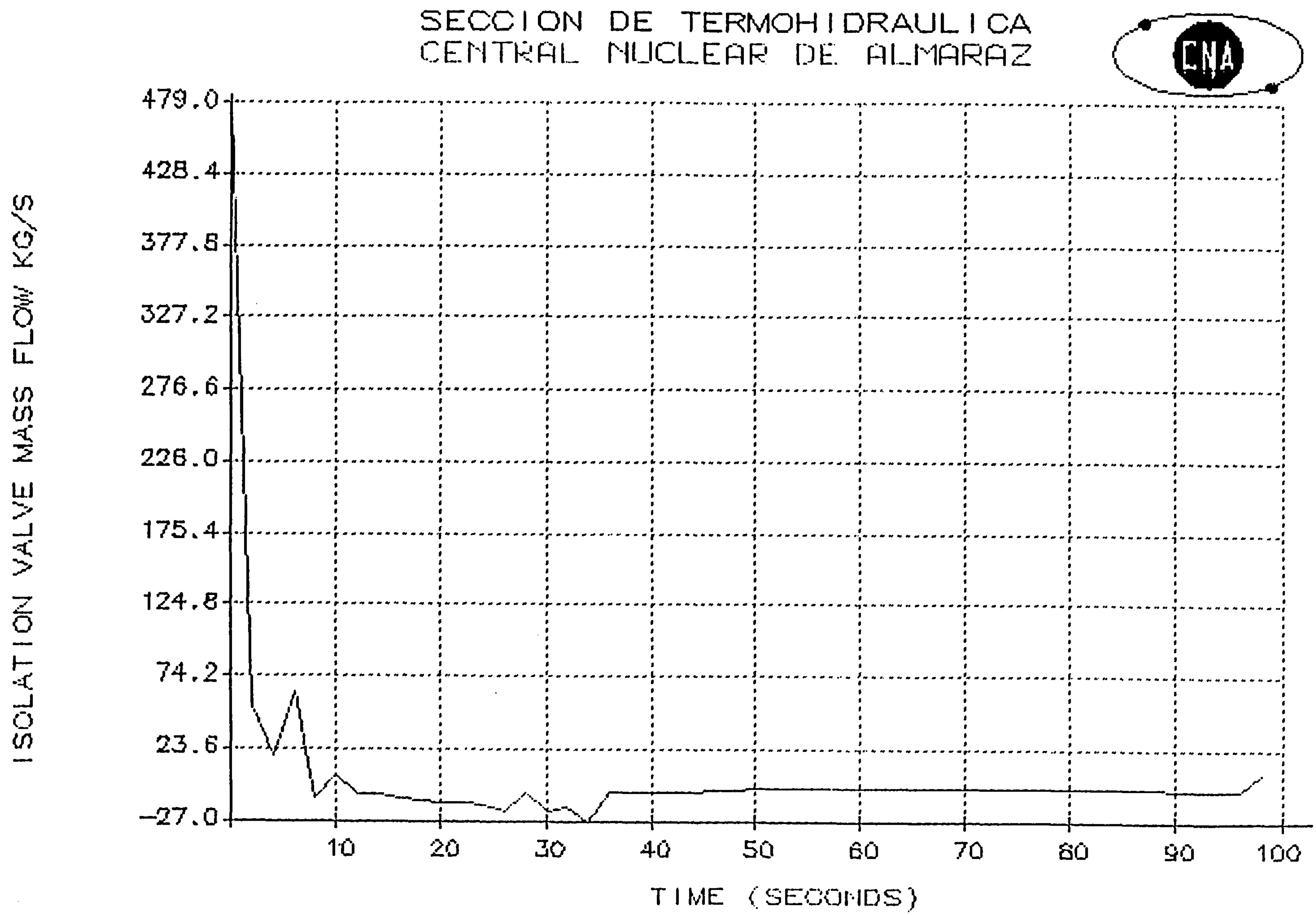

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
MAIN FEEDWATER MASS FLOW KG/S.
480.0
432.0
384.0
336.0
288.0
240.0
192.0
144.0
96.0
48.0
.0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)

FIGURE 31



SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
ISOLATION VALVE MASS FLOW KG/S
479.0
428.4
377.8
327.2
276.6
226.0
175.4
124.8
74.2
23.6
-27.0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)

FIGURE 32

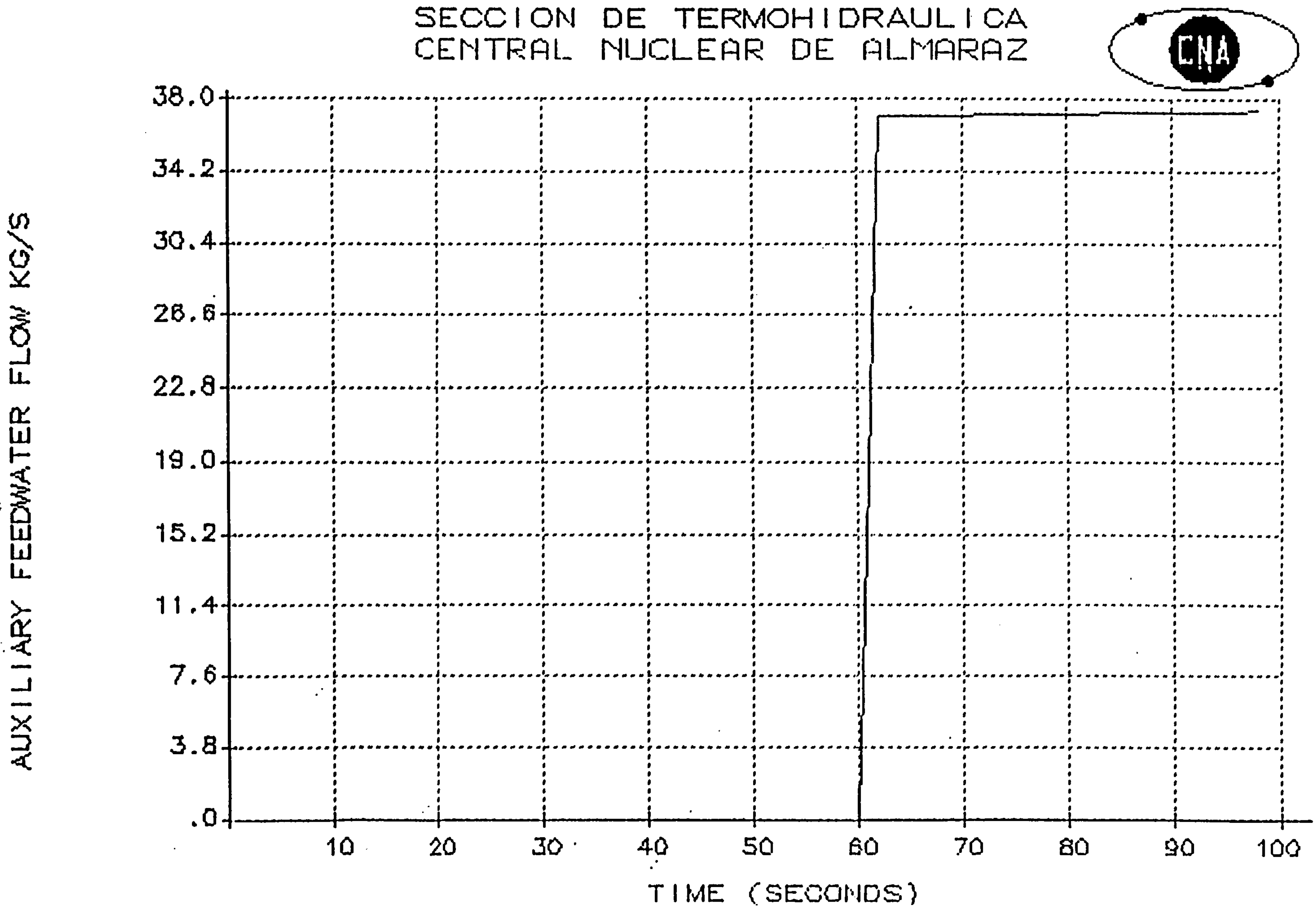

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
AUXILIARY FEEDWATER FLOW KG/S
38.0
34.2
30.4
26.6
22.8
19.0
15.2
11.4
7.6
3.8
.0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)

FIGURE 33

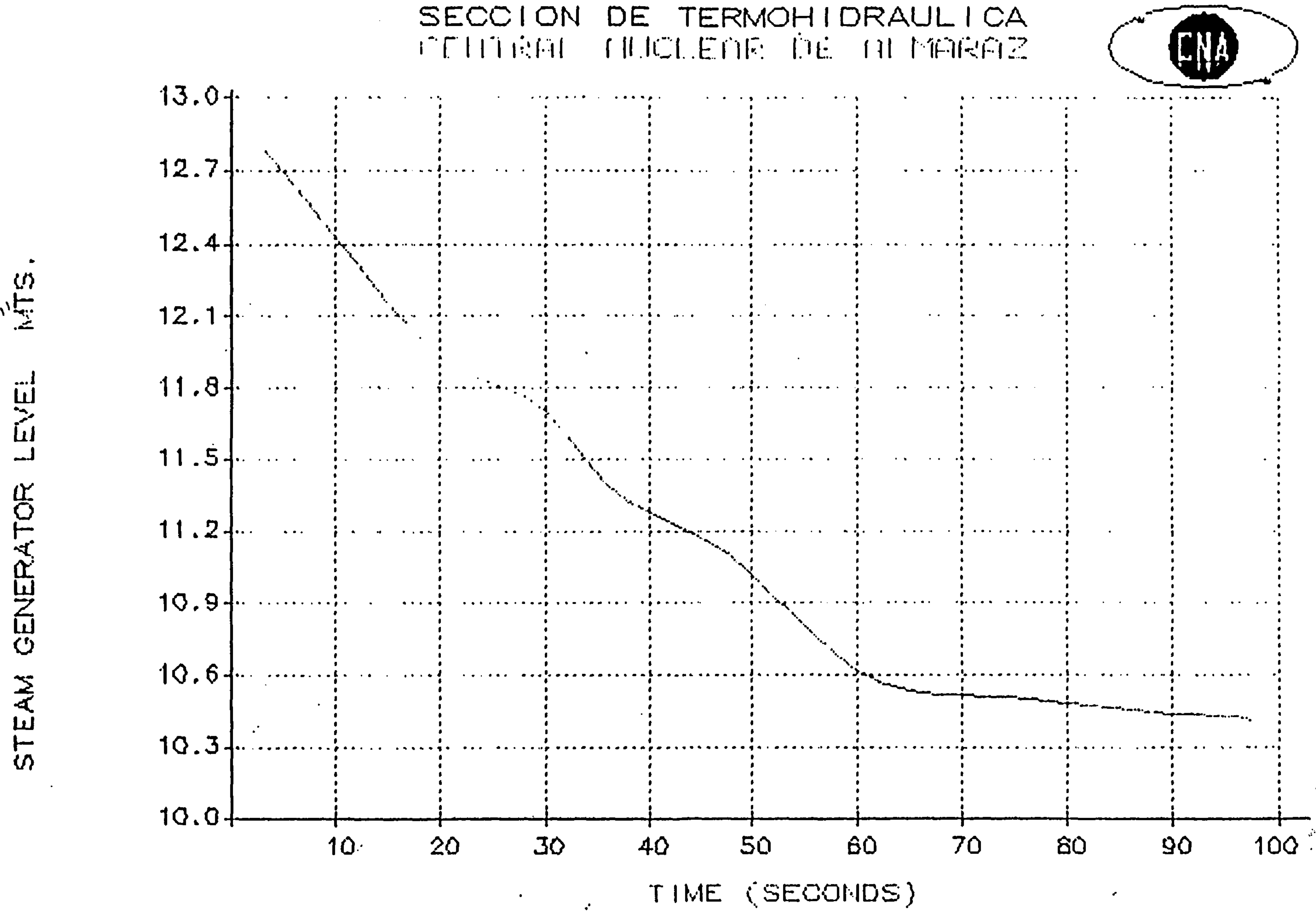
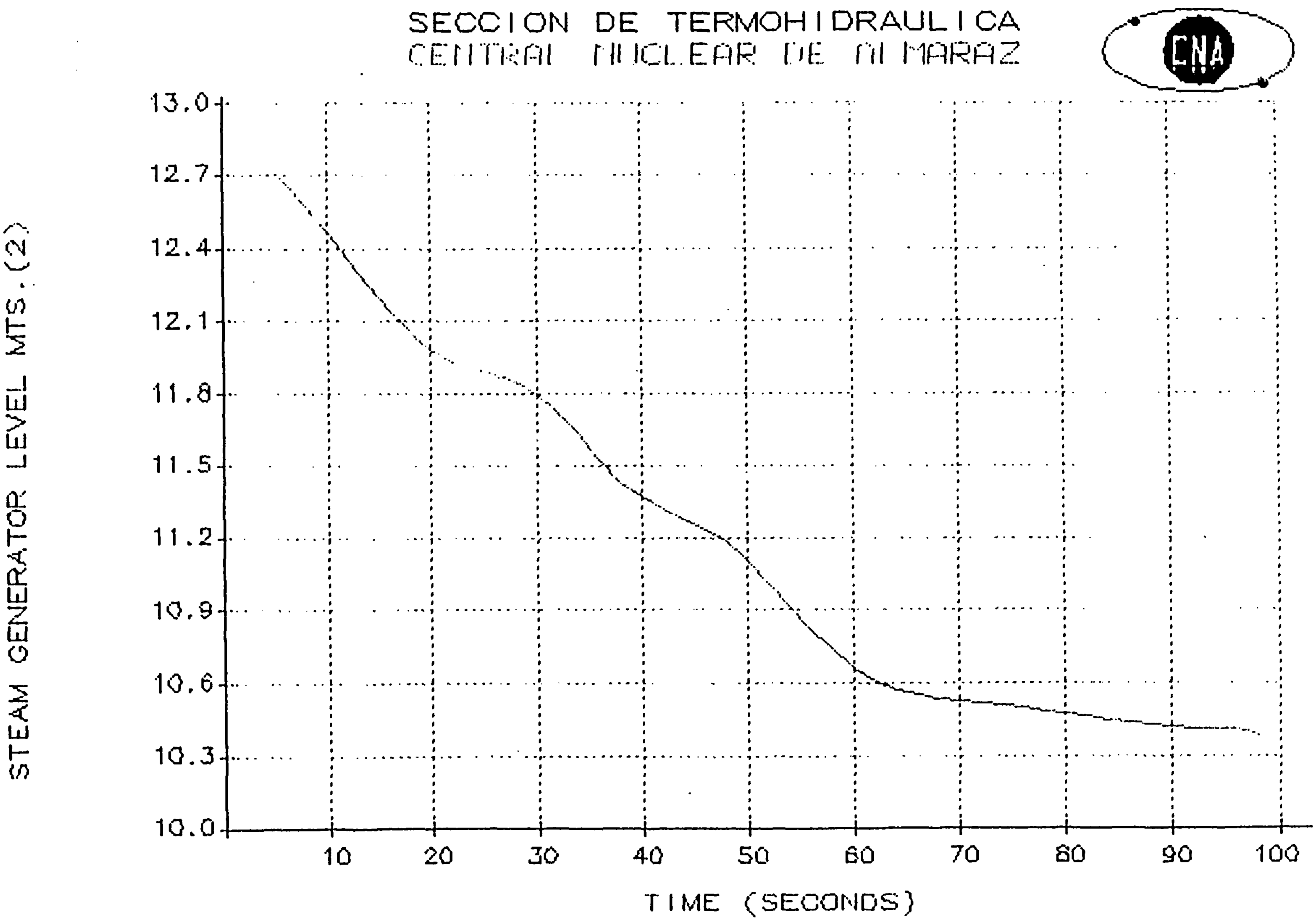

SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
STEAM GENERATOR LEVEL MTS.
13.0
12.7
12.4
12.1
11.8
11.5
11.2
10.9
10.6
10.3
10.0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)

FIGURE 34


SECCION DE TERMOHIDRAULICA
CENTRAL NUCLEAR DE ALMARAZ
CNA
STEAM GENERATOR LEVEL MTS. (2)
13.0
12.7
12.4
12.1
11.8
11.5
11.2
10.9
10.6
10.3
10.0
10
20
30
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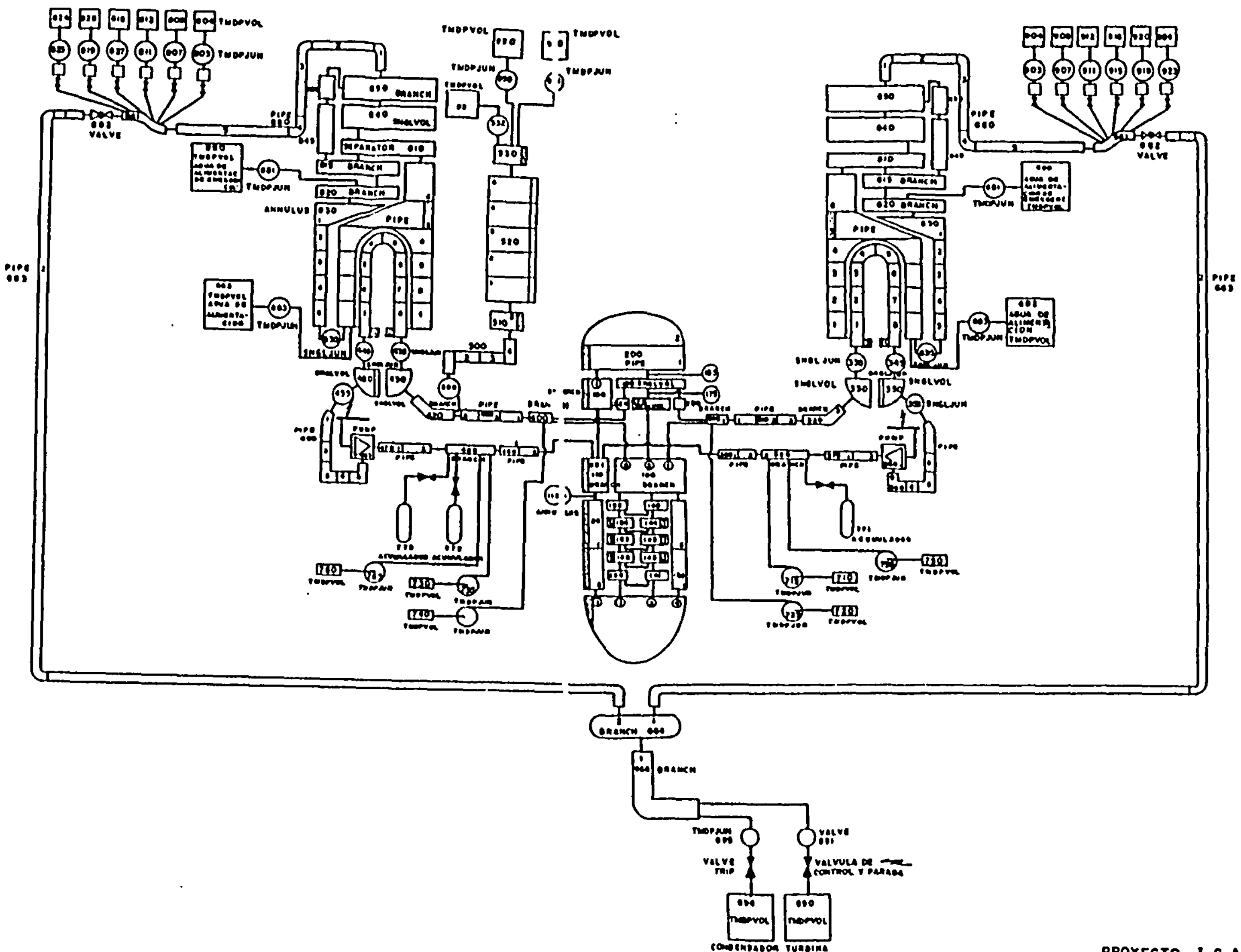
50
60
70
80
90
100
TIME (SECONDS)

FIGURE 35



PROYECTO I.C.A.P.

BLACKOUT

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28006 – Madrid, Spain

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11. ABSTRACT (200 words or less)
The analysis group of Almaraz Nuclear Power Plant has developed a model of the plant with RELAP5/MOD2/36.04. This model is the result of the work-experience on the code RELAP5/MOD1 that was the standard code during the period 1984/1989. Different solutions were adopted in the network to adequate the model to RELAP5/MOD2 Computer Code. This transient was selected for ICAP because it presents an experience with the same transient calculated with RELAP5/MOD1/CY 29 Computer Code. The comparison between both analysis will be interesting.

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