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International Agreement Report

Assessment of TRAC-PF1/MOD1 Against an Inadvertent Steam Line Isolation Valve Closure in the Ringhals 2 Power Plant

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Office of Nuclear Regulatory Research
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Prepared as part of
The Agreement on Research Participation and Technical Exchange
under the International Thermal-Hydraulic Code Assessment
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FOREWORD

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

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

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

- Unidad Eléctrica (UNESA)
- Unión Iberoamericana de Tecnología Eléctrica (UITESA)
- Empresa Nacional del Uranio (ENUSA)
- TECNATOM
- 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.

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Project BIV-770355

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Swedish State Power Board
Swedish Nuclear Power Inspectorate

ICAP
ASSESSMENT OF TRAC-PF1/MOD1 AGAINST AN INADVERTENT STEAM LINE ISOLATION VALVE CLOSURE IN THE RINGHALS 2 POWER PLANT

Abstract

A steam line isolation valve closure transient in a three loop Westinghouse PWR has been simulated with the frozen version of TRAC-PF1/MOD1 computer code. The results reveal the capability of the code to quantitatively predict the different pertinent phenomena. For accurate predictions of the system response it was realized that careful nodalization of the steam generator dome region and outlet nozzle was required as well as of the pressurizer walls and spray nozzle. The amount of initially stored energy in the fuel had an essential impact on the after scram short-term prediction. Proper control system behaviour was of major concern. Difficulties in adequate control system operation were encountered when large timestep sizes were used.

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Approved by Eric Wellstrand

NP121 AH

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Executive summary

A TRAC-PF1/MOD1 simulation has been conducted to assess the capability of the code to predict a steam line isolation valve closure transient.

The measured data was obtained from an inadvertent steam line isolation valve closure at about 80 per cent power in the Ringhals 2 power plant. Ringhals 2 is a Westinghouse PWR with three loops and two turbines of Stal-Laval design. The nominal power is 2 440 MW thermal and 800 MW electrical. It is equipped with three Westinghouse steam generators of the 51 series without feedwater preheat. Because of problems with the U-tubes about 11.6 % of the tubes are plugged. Consequently power is restricted to 80 per cent of rated power.

Following the isolation valve closure in one steam line a steam flow increase and pressure decrease were experienced in the other two steam lines. A closure signal for the two intact steam lines isolation valves was then initiated on high steam line flow concurrent with low steam pressure. This resulted in activation of safety injection (SI), isolation of main feedwater as well as initiation of auxiliary feedwater. A scram signal for the reactor was obtained and also isolation of letdown and charging. After a few seconds the steam dump valves opened and dumping started. These valves were later closed but prior to this time the effective steam dumping was decreased because of the closure of the isolation valves.

In the TRAC-simulation a two loops representation was used so that the asymmetric behaviour between the faulty loop and the two intact loops could be treated. A neutron point kinetics was used to model the core with reactivity feedback.

The complete model comprised 96 components (295 cells).

The boundary conditions were either taken directly from the recordings of the plant computer or were inferred from these. The following conditions were used:

- The flow area vs time for the steam line isolation valves
- The flow area vs time for the turbine valves
- The flow area vs time for the steam dump valves

- The feedwater flow and temperatures
- Scram reactivity vs time
- The auxiliary feedwater flow and temperature vs time
- Decay heat
- High head safety injection flow vs time

The pressurizer control system was modeled in detail and so was the trip logic for the scram.

The result of the simulation revealed the importance of proper modeling of steam generator internals especially in the expected two-phase region as well as the modeling of pressurizer walls and spray nozzle in order to reasonably predict the condensation phenomena. It was also found that adequate reproduction of the core initial stored energy was essential for the after scram short-term prediction. Accurate modeling of valves' characteristics and operation sequences was of major concern as was a faithful reproduction of control system behaviour. Proper modelling of the signal processing devices in the plant was also found to be important.

From the run statistics it was found that a 60 s transient used 305 timesteps ranging from 0.01 to 1.1 s. This required 3 353 CPU-seconds on a CDC Cyber 180-835 computer. For running 300 s including two restarts 5 379 CPU-seconds were used for 465 timesteps.

It was observed that when using large timesteps the control blocks experienced severe oscillations, especially those with short time constants. A feedback on the timestep size with respect to control system performance and design is desirable.

1 Introduction

The International Thermal-Hydraulic Code Assessment and Application Program (ICAP) is being conducted by several countries and coordinated by the USNRC. The goal of ICAP is to make quantitative statements regarding the accuracy of the current state-of-the-art thermal-hydraulic computer programs developed under the auspices of the USNRC.

Sweden's contribution to ICAP relates both to TRAC-PWR (Ref 1) and RELAP5 (Ref 2). The assessment calculations of TRAC have earlier been carried out as a joint effort between the Swedish State Power Board (SSPB) and Studsvik AB whereas the RELAP5 calculations have been conducted by Studsvik for the Swedish Nuclear Power Inspectorate (SKI).

Quite recently a Swedish group was formed for coordination of Swedish efforts within ICAP. This group has representatives from SSPB, SKI and Studsvik and has emphasized the importance of using plant transients for assessment purposes. Accordingly the Swedish future efforts will basically concentrate on analyzing plant transients with the TRAC-PF1 code. The assessment matrix is shown in Table 1.

Table 1

ICAP Assessment Matrix - Sweden

Code	Facility	Type	Description
TRAC-PF1	Ringhals 4	Integral, full scale	Full load rejection
TRAC-PF1	Ringhals 2	Integral, full scale	Inadvertent steam line isolation valve closure in one loop
TRAC-PF1	Ringhals 4	Integral, full scale	Symmetric loss of feedwater
TRAC-PF1	SPEC	Integral, small scale	Symmetric loss of feedwater

The Spanish contribution to ICAP is mainly focused on the investigation of the applicability of state-of-the-art codes like TRAC and RELAP5 in the area of transient analysis. The common objectives of the Swedish and Spanish ICAP organizations have resulted in the present analysis as a joint effort between the Consejo de Seguridad Nuclear, Swedish Nuclear Power Inspectorate, Swedish State Power Board and Studsvik.

In this report the results of an assessment of TRAC-PF1/MOD1 against a steam line isolation valve closure are presented. The ability of TRAC to simulate this transient is assessed by comparison to measured data from an inadvertent valve closure occurence at about 80 per cent power in the Ringhals 2 power plant.

This report is organized as follows: Section 2 describes briefly the Ringhals 2 power plant and the transient which originated from the steam line isolation valve closure in one of the loops. In section 3 the TRAC model used to simulate the transient is described and section 4 is a review of the procedure used to obtain the specified steady state. Section 5 presents the results from the simulation as well as performance of the TRAC-code. Also some run statistics are given. Conclusions are presented in section 6.

2 Plant and transient description

The Ringhals 2 power plant is located on the Swedish west coast and is one of four plants on the same site. All the plants are operated by the SSPB. Ringhals 2 is a three-loop, two turbine PWR of Westinghouse Stal-Laval design with ASEA electrical generators. The nominal thermal power is 2 440 MW and the electrical net output is 800 MW. Ringhals 2 is equipped with three Westinghouse steam generators (model 51) of the vertical U-tube design without any feedwater preheater section. The feedwater is fed directly to a distributor device located in the top section of the downcomer.

Because of problems with the U-tubes in the steam generators about 11.6 % of the tubes have been plugged. Consequently, the core power has been lowered to about 80 % of nominal and primary temperatures have been decreased accordingly.

The transient was initiated by an interruption of power to the electrical coil in the magnetic pilot valve of the steam line isolation valve in loop 3. The isolation valve closed and the steam flow decreased by one third quite rapidly. This resulted in a rapid pressure decrease in the two other steam lines and a corresponding steam flow increase. The steam flow in loops 1 and 2 rapidly increased to the trip setpoint for high steam line flow and thus one condition of two for initiation of safety injection (SI) was obtained. The other condition was low steam pressure. The actual pressure never reached the low steam pressure setpoint; however, the control signal has a lead-lag compensation with a pronounced lead influence and this signal was passed the setpoint value very soon into the transient. Thus, the condition of high steam flow along with low steam pressure was obtained which, according to the logic of the plant safety system, corresponds to an indication of a steam line break downstream of the isolation valves. This resluted in a closure signal for the two intact steam line isolation valves, activation of SI, isolation of main feedwater, scram signal generation, and termination of letdown and charging flows. The auxiliary feedwater flow was automatically activated.

Because of the isolation of the steam generators the circulation flow on the secondary side ceased and a stagnant condition occurred. The steam generators downcomer level quickly decreased. The core decay heat and the stored energy in the structures on the primary side caused the secondary side pressure to slowly increase.

On the primary side the pressurizer spray kept the primary pressure within specified limits during the first part of the transient. However, due to a continued SI-flow the pressurizer level increased continuously and at about 18 minutes after scram the pressurizer was filled with water and a rapid pressure increase occurred. This caused some blow off to the pressurizer relief tank but the rupture disks on this tank remained intact.

The secondary side pressure continued to increase; at about 40 minutes after scram it reached the setpoint for the first safety valve. The relief valves' setpoint had earlier been increased somewhat in order to prevent excess activity release. It could not be established whether these valves were activated. At about one hour after scram the steam line isolation valves were opened and the pressure was decreased.

The faulty equipment was replaced and after about 20 hours from scram the reactor was critical and after another 12 hours the 80 % power level was resumed.

Throughout the transient important plant signals were monitored and stored on the plant computer. Unfortunately the plant signal follower, which records the time sequence of trips and control signals, was not functioning properly and thus no true sequence of events could be established. Instead, important parameters needed for simulation of the transient, such as closing time for steam line isolation valve and the time points when they started to close, had to be inferred from timeplots of relevant signals.

3 Code and model description

The simulation of the transient was made with version 14.0 of the TRAC-PF1/MOD1 computer code (Ref 1) with an additional update to provide proper functioning of the restart capability of the core component. The program was run on a CDC Cyber 180-835 computer under the NOS 2.5 operating system with no SCM and LCM partition of the memory. Instead the central processor primary memory was used together with an extended memory capability. TRAC was also locally modified to allow writing of signal variables and control block output on a separate file for later plotting with a separate program. Thus the EXCON and TRAP programs were not used for producing the graphics to this simulation.

In the simulation a two loops representation was used as shown in Figure 1. This was necessary in order to properly take into account the asymmetric transient behaviour of the loops. The faulty loop 3 of the plant was represented by one loop while the plants' loops 1 and 2 were merged into the other loop. Differences between loops 1 and 2 were considered to produce effects of secondary order during the transient. The level of detail of the model is believed to be appropriate to make it suitable for simulation of most operational transients and small breaks. The intention has been to create a general model suitable for simulating most transients. Some of the auxiliary systems in the model were never activated during this transient.

3.1 Primary system nodalization

A one-dimensional representation of the vessel was used with the following bypasses included, Figure 1:

- upper plenum bypass (component 70)
- core and guide tubes bypass (component 50 side tube)

The whole vessel was comprised of seven components with a total of 22 cells. A lumped parameter model and adiabatic walls (no heat losses to the environment) were used for representing the vessel structure and internals. In order to avoid a dead end and thermal stratification in the upper head the tee side of component 70 was attached to the top cell. With this configuration a fill component with zeroflow (component 80) was connected to the very top of the upper head.

The reactor core, denoted by component 60, was divided into five vertical cells. The core was split into an average core and a hot rod. The axial heat flux shape and hot rod peaking factors were derived from incore measurements. The axial shape was preserved during the transient. Default point kinetics together with reactivity feedback were used to simulate the neutronic response of the fuel during the transient. The decay heat was calculated according to ANSI 5.1.

The pressurizer was modeled according to recommendations given in the TRAC User's Guide (Ref 3).

The bottom of the pressurizer was modeled by using a pipe component divided into four cells to assure proper draining and accurate pressure loss computation (component 400). The length of this component was specified to equal the length of the electrical heaters and the heater power was assumed to be deposited directly in the fluid. The main body of the pressurizer was modeled as a tee component number 410. Six cells were considered reasonable to simulate the pressure transients and level behaviour. The side tube at the very top of this component was used to model connections to the pressure relief and safety valves. The top hemisphere of the pressurizer was represented by a "prizer" component number 420. One feature of this component was to serve as a pressure boundary condition during the steady state calculations.

The spray flow was simulated by attaching a fill component to the upper end of the "prizer" component. The corresponding junction flow area was specified such that the liquid velocity was 4 m/s at a spray flow rate of 19.4 kg/s. This will activate the enhanced interfacial condensation model in the "prizer" component and thus allowed for adequate condensation of vapor when a reasonable spray flow was maintained.

The pressurizer walls were simulated by heat structures with four radial nodes. The heat losses to the environment were chosen so that they balanced the steady state heater power when a specified spray flow was maintained. The losses were then about 178 kW.

All the pressurizer valves were sized, as suggested in Ref 3, to their rated capacities under choked flow conditions. The pressurizer pressure control was modeled in detail and tested separately before implementation in the models' control system. Although the level control was modeled it was bypassed for this specific transient.

The piping of the RCS loops was represented by pipe and tee components including a lumped parameter heat structure representation of the pipe walls. No heat losses to the environment were assumed. All relevant connections to auxiliary and safety systems were included in order to make the TRAC-model complete and applicable to a variety of transients. For this transient only the high pressure safety injection (HPSI) in the cold legs was activated.

The "accum" component was used to model the accumulator. A check valve controlled by the pressure difference separated the accumulator component from the rest of the primary system.

The nodalization of the primary side (steam generator U-tubes excluded) comprised 52 components and 128 cells (fills and breaks included). The primary side of each steam generator included 12 cells of which 10 were interacting with the secondary side and the remaining two cells represented the inlet and outlet plenum respectively.

3.2 Secondary system nodalization

The steam generators were modeled in detail for the purpose of generality. Each steam generator was comprised of a number of components where the "stgen" component (enclosed by dashed lines in Figure 1) included the primary side of the U-tube bundle and the secondary side riser and separator parts. The steam separation was accomplished by means of tee components number 140 and 340. The original intention was to make use of the carry-over and carry-under functions included in the "sept" component (TRAC-separator component). However, as these functions were not fully known, especially for varying operational conditions, it was decided to use the ideal separator capability included in tee components. Thus, complete water separation was assumed in the upper junction of components 140 and 340 with water drainage to the downcomer through the tee component side pipe.

The downcomer was nodalized so as to permit adequate tracing of the level as well as correct placement of level pressure taps and the feedwater inlet. Also pure geometrical considerations like area changes were included when the downcomer noding was set up.

The steam generator level measurement, represented by a differential pressure between the indicated downcomer pressure taps in Figure 1, was explicitly modeled in order to estimate dynamic contributions from downcomer flow.

The feedwater header was represented by an arbitrarily sized tee component. However, as this component was extended in the horizontal plane the flow area was made rather small in order to assure quite high flow velocities. This was done as a measure to prevent expected difficulties at low feed water flow when the downcomer level resides below the feedwater inlet. Unrealistic stratification in the feedwater header can occur under this condition and force the calculation to proceed with unnecessary small time steps.

The steam lines up to the header configuration (components 701 and 702) were assumed to be completely symmetrical. Although the steam lines in the plant are somewhat asymmetrical this approach was chosen in order to facilitate future applications of the model to other transients without the need for renodalization of the steam lines. The total volume and the average length of the steam lines were retained.

The steam flow was measured by means of a differential pressure between the steam dome pressure tap and a tap in the relief and safety valve header. In order to avoid disturbances from the flow restrictor device located in steam dome outlet (junctions 501 and 601) the noding in the very first part of the steam lines was made somewhat more dense than elsewhere. This is according to recommendations in Ref 3.

Downstream the steam line header device the steam flow was divided into two streams - one for each turbine. The line for each turbine was further split into two flow paths - one containing the turbine valve and the other containing the dump valve. Time dependent characteristics of these valves were given as boundary conditions.

The characteristics and sizing of the relief and safety valves as well as the dump valves were analyzed and set up prior to implementation in the model. For the relief and safety valves the sizing was accomplished by tuning the valve flow area under choked flow conditions until the specified capacity was obtained. The turbine valves were set up somewhat differently. The choking plane was assumed not to occur in the valve junction but in the next downstream junction. This was judged to more closely simulate the real case where choking occurs in the turbine nozzles rather than in the turbine valves.

The secondary side of each steam generator comprised 9 components ("stgen" counts as one component) and 37 cells (fills included) whereas the complete steam line made up 26 components and 69 cells (breaks included). Thus the complete plant model comprised 96 components and 295 cells where also the primary side of each steam generator is included.

3.3 Control system and trip logic modeling

In order to make the calculation fully dependent on only the initial event, that is the closure of the steam line isolation valve in the single loop (MSIV3 in Figure 1), extensive use of the TRAC-PF1/MOD1 capability of modeling the control and protection system was made. The following systems were modeled:

- Pressurizer pressure control
- Steam line break protection logic which subsequently activated:
  - Reactor trip
  - Feedwater isolation
  - Startup of auxiliary feedwater, motorpumps, turbinepumps
  - Turbine trip
  - Steam dump deblocking and dump valve opening
  - Isolation of the double loop steam generator
  - HPSI

The main feedwater control was not explicitly modeled. Instead the measured feedwater flow was given as a trip controlled tabulated boundary condition where the time trip point was determinded by reviewing pertinent measured signals.

The diagram of the pressurizer pressure and level control is shown in Figure 2. This system was separately tested. It was found during the calculations that unphysical oscillations in the output of the PI-controller occurred regularly. By replacing the PI-controller by the equivalent set of control blocks this problem was eliminated. Apparently, due to the explicitness of the control block numerics, the efficiency of the control system depends upon timestep size, particularly if the rate of change of the variable being controlled is large. A feedback on the timestep depending on the performance of the control blocks would have alleviated the problem.

The steam line break protection logic is shown in Figure 3. High steam line flow coincident with low steam line pressure in the double loop will trigger the reactor trip, safety injection etc. All the trips were affected by pure delays simulating the time span between the time point when the logic signal became true and the time when the corresponding action started. All trips were latched to avoid the return to initial trip state during the course of the transient.

The auxiliary feedwater flow was obtained by the fill components 962 and 964. The flow was directly taken as the output from some control blocks that were set up to account for the flows from both the motor driven and turbine driven pumps. The rate of change in flow as well as the asymmetric flow distribution to the single and double loop steam generator respectively was included. The activation of the turbine driven pumps was triggered by low level in single loop steam generator.

For the calculation a total of three passes through the control parameters evaluation was specified in order to advance signal variables, control blocks and associated trips to corresponding conditions at each time point.

4 Steady state calculation

Prior to the transient simulation the TRAC model was adjusted to replicate the plant stationary pre-test conditions. This was done by means of a step-wise procedure whereby the major components were separately brought to a specified steady state condition before joining them together.

Initially the vessel assembly was run and adjusted to attain the correct bypass flows and pressure drop. The absolute massflow was obtained from a heat balance at given core power (80.7 % of nominal power) and the pressure from plant data. The next step was to add the primary piping and pressurizer with the hot leg and loop seal directly joined (no steam generators). The pressure drop over the steam generator primary side was introduced as an additional form loss coefficient between the hot leg and the cold leg. The core power was deactivated and the cold leg temperature was assumed to prevail throughout the primary system. The pump speed was controlled to maintain the target mass flow and form loss coefficients were adjusted to obtain the desired overall primary side pressure drop and distribution.

The measured steam flows and corresponding feedwater flows were found not to balance during the pre-transient phase indicating that some of the flows were miscalibrated. A heat balance for the steam generator revealed that the steam flows were somewhat erroneously recorded. Thus, for the TRAC steady state the steam flows were assumed to directly match the feedwater flows.

The steam lines were adjusted to attain specified pressure drop distribution at specified steam flows. Since the steam dome pressure was not measured directly, it had to be inferred from the measured steam line pressure and the manufacturer's stated pressure drop across the flow restrictor located in the steam dome outlet. Once the dome pressure was known the steam generator steady state could be addressed.

Key parameters in the steam generator steady state adjustments were the primary inlet and outlet temperatures, the steam generator dome pressure, the feedwater and steam flow, mass distribution, circulation flow and downcomer liquid level. In order to attain the primary to secondary heat transfer the U-tubes heat transfer area was increased by 32.6 % after allowances were made for current tube plugging (assumed equal in all three steam generators). This relative increase in heat transfer area was the same as found in earlier steam generator analyses at full power (Ref 4). Also the downcomer pressure drop coefficient governing the circulation was preserved from what was found in Ref 4. The circulation thus obtained seemed to be in fairly good agreement to what could be inferred from information in Ref 5. The level in the downcomer was attained by adjusting the liquid content in the upper part of the downcomer.

The final step was to bring together the primary and secondary side systems and run a steady state for the complete model. This was run for 200 seconds with a maximum timestep of 1.0 second. No special problems were encountered in this calculation and the result from the steady state analysis is found in Table 2. Relevant statistics for the steady state calculations are:

CPU-time/problem time = 0.066

CPU-time/cell and timestep = 2.4 ms

5 Data comparison

The simulation was made using a single and a double loop representation, the double loop being a scaled-up representation of the single loop. The measured thermal-hydraulic data were obtained for each loop, thus an averaging procedure had to be applied in order to provide data for the double loop. The averaged parameters for the double loop were:

- Cold leg temperatures
- Hot leg temperatures
- Mass flows
- Secondary side pressures
- Steam flows
- Feedwater flows and temperatures
- Steam generator levels

During steady state the averaging was applied to all three loops to make them apriori completely symmetrical.

5.1 Boundary conditions used in the simulation

The main heat source during the transient was the core power and decay heat. The default kinetic parameters were used. The decay heat was simulated according to the ANSI-curve assuming equilibrium conditions. The rod insertion following the reactor trip signal was specified as a ramp with 1.8 s duration with a best estimate value for the reactivity worth of the control rod banks (ρ = -0.0888).

The speed of the reactor coolant pumps was assumed to remain constant throughout the transient.

The HPSI flow was made dependent on the back-pressure according to plant design data, also the rate of change and temperature (300 K) were considered.

The pressurizer control was fully modeled using the rated values for the proportional and back-up heaters. The spray flow was taken from the double loop cold leg and ranged from its trickle flow to its maximum rated value. For simplicity a constant spray water temperature (552.8 K) was assumed corresponding to the steady state cold leg temperature. This temperature was only slightly changed during the transient thus justifying this assumption. The pressurizer heat losses accounted for about 144 kW on the average during the transient.

The feedwater flow was carefully modeled. The main feedwater flow was tabulated from recorded data as a function of time and was introduced as trip controlled tables in the fill components 961 and 963. The time functions are shown in Figure 4. The auxiliary feedwater flow was provided by two motordriven pumps and one turbinedriven pump. From the motorpumps 50 % of the total flow was delivered to the single loop steam generator while the other 50 % was fed to the double loop steam generator (asymmetric distribution). Once the turbinedriven pump was activated its flow was delivered equally to the three steam generators. Also the rate of change in flow was considered in order to simulate the acceleration of the pumps. The auxiliary feedwater flow and temperature were taken from previous plant test data.

The steam line isolation valves' (components 502 and 602) characteristics (valve flow area vs time) were also tabulated as a function of time. A piecewise linear function was deduced from steam flow and pressure measurements and is shown in Figure 5. The closing time was derived in Ref 6.

The characteristics of the turbine stop valves were assumed to be linear. The closing time was specified to 0.4 s. During the first half of this time span the valves were assumed to remain fully open while a linear closure was applied for the latter 0.2 s.

The steam dump actuation was derived from the steam dump demand signal which was converted into an estimated delayed flow area vs time function. After the scram and closure of the turbine valves the so-called trip mode of the steam dump control system was activated thus deblocking 50 % of the available dump capacity. However, due to delayed response of the dump control system only about half of this dump capacity was used as is shown in Figure 6.

5.2 Results from the simulation

Because of problems encountered with the plant signal follower no real sequence of events was recorded and actual timing of trips etc had to be inferred from the time plots of different signals. As the plotted signals were inherently affected by processing delays and filtering as well as (in some cases) low scanning frequency there were considerable uncertainties in the so deduced sequence of events and a meaningful comparison with the calculated one was immaterial. For that reason only the calculated sequence of events is given in Table 3.

After four seconds of steady state calculation in transient mode the single loop steam line isolation valve (component 602) started to close according to a flow area vs time function deduced from the actual plant recordings. Following its closure the pressure in the single loop steam line started to increase, Figure 7, and the steam flow to decrease, Figure 8. The flow decrease resulted in a rapid reduction of the main feed-water flow (specified as a boundary condition), Figure 4. Due to this steam and feedwater flow decrease the internal circulation was reduced and the downcomer level experienced a substantial reduction, Figure 9, as the level was balanced out with the riser liquid content.

The single loop steam generator pressure, level, and flow behaviour were well reproduced in the calculation. In order to account for the plant signal processing the TRAC calculated signals were filtered by means of a first order lag function with 0.5 s time constant. The downcomer level was calculated from the differential pressure between the pressure tap cells. The algorithm used for this purpose did not take into account the steam contribution in the ΔP thus somewhat overestimating the liquid level as the ΔP decreased with a final steady error when ΔP corresponded to vapor column only, Figure 9.

Figure 9 also shows the downcomer collapsed liquid level with respect to the tube plate. When this level decreased below the location for the narrow range lower pressure tap at about 16 s there was still a continuous decrease in the narrow range level. This was caused by some flow redistributions in the upper part of the downcomer during the course to a zero circulation condition which occurred when the collapsed level had stabilized at about 22 s.

Following the closure of the single loop isolation valve the steam flow in the double loop steam line increased (measured as a differential pressure between the steam dome and the safety and relief valve header) and the steam pressure decreased. Due to the increased steam flow the main feedwater flow increased, Figure 4. It was observed that the calculated transient pressure decrease in the double loop steam line prior to the reactor and turbine trip was slightly overestimated, Figure 10. This is believed to be caused by the omission of most of the structual materials in the secondary side of steam generator model. The only structure included apart from the tube bundle was the dome internals. However, because of the vapor environment the heat transfer from the dome internals during this phase of the transient was very moderate despite of the fairly big heat tranfer area. Structures like the wrapper, tube support plates etc located in a two-phase surrounding would have contributed to the vaporization during the pressure decrease and would thus have helped to maintain the secondary side pressure.

The pressure drop across the flow restrictor located in the steam generator outlet was calculated according to the TRAC automatic form-loss computation. From Figure 10 it seems that this pressure drop was quite high (about 0.15 MPa during steady state). However, due to the big flow area difference between the steam dome and steam line the major part of this pressure drop was caused by the convective terms in the momentum equation (recoverable losses) and only about 7 per cent was the head loss across the restrictor. Also the convective terms were the main reason for the different pressure time derivative between the dome and the steam line. A more dense noding in the dome region might have resulted in a less pronounced pressure decrease during the phase when the steam flow accelerated.

The steam line break trip as implemented in the model was triggered by concurrent high steam line flow and low steam line pressure in the double loop. The pressure signal was lead-lag compensated with a predominant lead function. In the real transient there was no indication of the moment the isolation valve started to close. Instead the moment at which the flow definitely started to decrease was used as a reference point. In doing so the trip condition was met after 3 seconds from this moment while in the TRAC calculations it occurred after 3.1 seconds. Scanning frequency and calculation timestep can easily account for the difference.

When the trip signal occurred the reactor was scrammed, Figure 11, with a reactivity insertion of -8.88 per cent ramped over 1.8 seconds. This approximation was considered to have only minor implication for the calculation although it is desirable to use the more realistic S-shape scram curve if possible. Usually the decay heat and to some degree the important delayed neutrons population become the most important heat source. Care should be taken in interpreting Figure 11 as once the reactor was scrammed the output from the PRM-detectors was not highly accurate, especially when realizing that the basic heat source then was from γ-decay.

Simultaneously with the reactor trip, the turbine valves were closed thus stopping the steam flow, Figure 12. As a consequence the pressure quickly built up in the steam line, Figure 10. At 10.73 s the double loop steam line isolation valve started to close being fully closed 4.4 s later. According to the dump demand signal an activation of partial dumping was imposed between 11.76 and 33.76 s into the transient. However, the open dump valves did not relief the pressure in the steam generators because the upstream located isolation valves were closed at this time.

From the flow measurement there was no firm evidence of the quick closure of the turbine valves and the subsequent opening of dump valves, Figure 12. However, it is believed that these details were hidden in the filtering process of the measured flow signal. The smoother behaviour of the measured flow may be due to the measuring system having a larger lag than the 0.5 s value used in the TRAC control systems' calculation of steam line flow.

Following the reactor trip the average temperature on the primary side decreased, thus causing a drop in the pressurizer level and pressure, Figures 13 and 14. The simulation's exaggeration of this drop may be due to overestimating primary to secondary heat transfer and underestimating the stored energy in the fuel. The heat sink during the time period of interest was the double loop steam generator. The heat transfer area was scaled up by a factor of 1.32 in order to match steady state performance. This scaling was the same as used for 100 per cent power. As the circulation on the secondary side decreased when the downcomer and riser levels balanced, Figure 15, a stagnant condition prevailed. At such a zero flow situation one would expect that a smaller scaling of the heat transfer area would be more adequate. Thus a gradual change of the scaling with respect to circulation flow would probably have produced a more realistic heat transfer. Consequently a constant scaling factor may have resulted in a overpredicting primary to secondary heat transfer thus causing an underprediction of the pressurizer level.

The TRAC baseline calculation used a too-high value of gap conductance for the fuel rods. In the simulation a value of 17 kW/m^2K was used. Thus the available stored energy in the fuel was underestimated.

The TRAC calculation was subsequently rerun with a modified gap conductance value of 6.5 kW/m^2K. The results from this simulation are indicated in Figures 13 and 14 and were in better agreement with measurement. With this lower gap conductance more energy was stored within the fuel during the steady state (the average fuel temperature increased by about 100 K) which during the transient was transferred to the coolant thereby increasing the coolant average temperature. The impact on the secondary side was very minor although a small improvement of the pressure response was observed.

As a result of the steam line break signal the HPSI was initiated with a fixed delay of 2.0 s and a constant rate of change of 1.626 kg/s^2 up to the best estimate flow value depending on the RCS back pressure, Figures 16 and 17. Throughout the rest of the transient the HPSI flow became the most important contribution to the pressurizer level and pressure increase. As observed in Figure 13 the rate of level change is overpredicted indicating an overestimation of the HPSI flow.

The transient was also calculated up to 300 s in order to investigate the code performance for mild transients. In Figure 18 the pressurizer level response is shown for these 300 s. From this figure it is even more clear that the HPSI flow was somewhat overpredicted. Also in Figure 18 is shown the pressurizer collapsed level revieling a lower increase than the level from ΔP. The explanation could be found in the algorithm used to obtain the level from the ΔP. It was set up to model the plant measurement device with no explicit density (temperature) compensation. During the pressurizer outsurge period the density remained about constant. The liquid volume reduction in the pressurizer was about 4.8 m^3, a volume much bigger than the surge line volume.

Then during the later insurge water from the hot leg entered the pressurizer. The hot leg temperature was now lower and consequently the assumption of constant liquid density was not fully appropriate. It was also worth noticing that due to the high subcooling of the insurge water no vapor was produced by the back-up heaters.

The long term plot of the pressurizer pressure is given in Figure 19. Following the pressure recovery the pressurizer control program initiated the spray at about 125 s, Figure 20, and as a result there was a stabilization of the pressure which was favourably calculated in comparison to measurement.

5.3 Code performance

In this kind of fairly mild transient no problem with the thermal-hydraulic calculation was encountered. Instead the control system performance became a source of difficulty.

Due to the explicitness of the control system processing it was clear that the control performance would be sensitive to the calculational timestep, thus becoming the limiting factor for the soundness of the simulation.

During the 300 s transient no limitation of the timestep was imposed from the input and TRAC was allowed to use as big a timestep as the solution method permitted. In this calculation the size of the timestep ranged from 0.01 to 3.83 s. A representation of the general behaviour of the controllers is given by the pressurizer spray flow in Figure 20. At about 200 s an instability developed (time step size = 1.5 s). This was later recovered because of the feedback of the spray flow to the thermal hydraulics which caused a reduction of the timestep. As expected, control systems with smaller time constants were more prone to unstable behaviour. One example is given in Figure 21 showing the filtering of the pressurizer pressure in order to simulate the data processing of the plant. In this case a first order lag function with 0.5 s time constant was used. All the filtering was later removed from the 300 s calculation.

It is apparent that unless a restrictive timestep is imposed problems with the control systems may arise. It is also desirable to implement an internal limitation on the timestep as function of the performance of the control systems. Another possible approach is to allow for some degree of implicitness by closing the thermal-hydraulic and control loops during the convergence calculations.

The first 60 s simulation was executed without any restarts. This 60 s required 304 timesteps ranging from 0.01 to 1.1 s without externally imposed timestep limitation. 3 353 CPU-s were needed on the CDC Cyber 170-835. The 300 s simulation was run with two restarts and made use of 465 timesteps totally. The total CPU-time was 5 379 s.

6 Conclusions

An assessment of TRAC-PF1/MOD1 version 14.0 against an inadvertent steam line isolation valve closure in loop 3 of Ringhals 2 PWR power plant was conducted. Extensive use of results from Ringhals 2 data aquisition system was made to derive the initial conditions and also some of the necessary boundary conditions.

The results from the TRAC simulation were compared to measured data. This comparison revealed some discrepancies for important plant parameters of which the following is a summary:

a) the pressurizer level and pressure decrease following the reactor scram were too pronounced

b) the pressurizer level and pressure increase rate following the HPSI injection were slightly overestimated

c) thermal stratification of the pressurizer liquid during the insurge period was overestimated; consequently, the level prediction based on ΔP was distorted

d) secondary side double loop (scaled up reproduction of the single loop) pressure showed a faster than observed decrease prior to reactor scram and an earlier pressure increase after scram

e) the steam generator liquid level calculated from a ΔP-algorithm revealed a nonzero level although the collapsed level was below the lower pressure tap location

Discrepancy a) was explained in terms of overestimated primary to secondary heat transfer and underprediction of core initial stored energy. A more realistic value for the fuel gap conductance helped considerably to alleviate the problem.

Discrepancy b) was mostly due to the use of a best estimate value for the HPSI flow which was slightly overestimated. A somewhat excessive superheating of the vapor phase ($\sim$ 2.1 K) could account to some degree for the faster than observed pressure increase. Excessive superheat during insurge has also been reported in Ref 7. It is also worth noting that the pressure stabilisation because of the spray system was correctly predicted.

Discrepancy c) was a result from the TRAC incapability to reproduce thermal mixing phenomena. This caused a situation with highly heterogeneous liquid density distribution which distorted the performance of the pressurizer model.

The faster than observed decrease in secondary pressure as mentioned under item d) was believed to be a result of the omission of major heat structures on the secondary side especially in the two-phase region. These would have contributed to the vaporization during the depressurization phase thus reducing the depressurization rate. Uncertainty remains on the impact of heat transfer area scaling following a sudden power change.

The observed earlier pressure increase was a result of uncertainty in timing of the boundary conditions applied in order to reproduce the trip sequence of turbine valves closure and opening of the steam dump valves.

Item e) was caused by an oversimplified ΔP-algorithm ignoring the vapor contribution in the ΔP. The liquid level calculated from the ΔP was then somewhat overestimated with a final steady error when ΔP corresponded to a vapor column only.

The code robustness was limited by the control system performance. It was observed that the use of large timesteps caused unstable operation of several control blocks, especially those with short time constants. A built in limitation of the timestep size with respect to control system performance and design would be desirable. Presently one has to avoid if possible to make use of such control blocks that impose timestep limitations.

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7 PETERSEN, A C
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TABLE 2. RESULT OF STEADY-STATE ANALYSIS

PRIMARY SIDE

PARAMETER	MEASURED/SPECIFIED	CALCULATED
CORE POWER (MW)	1962.6 (80.7 %)	1962.6
FLOW LOOP 1+2 (KG/S)	--	9239.96
FLOW LOOP 3 (KG/S)	--	4617.81
RCP SPEED (RAD/S)	--	155.14
RCP HEAD (MPA)	--	0.537
T HOT LEG 1+2 (K)	579.40	579.69
T HOT LEG 3 (K)	579.40	579.69
T COLD LEG 1+2 (K)	552.80	553.03
T COLD LEG 3 (K)	552.80	553.03
DELTA-T (K)	26.6	26.79
PRZ PRESS. (MPA)	15.547	15.547
PRZ LEVEL (%)	34.55	34.06

TABLE 2. RESULT OF STEADY-STATE ANALYSIS (CONT.)

SECONDARY SIDE

PARAMETER	MEASURED/SPECIFIED	CALCULATED
PRESS. SG 1+2 (MPA)	--	5.162
PRESS. SG 3 (MPA)	--	5.162
LEVEL SG 1+2 (%)	43.67	42.84
LEVEL SG 3 (%)	43.67	42.91
CR-RATIO 1+2 (-)	--	5.69
CR-RATIO 3 (-)	--	5.69
FW FLOW 1+2 (KG/S)	680.0	680.0
FW FLOW 3 (KG/S)	340.0	340.0
FW TEMP. (K)	479.93	479.93
STEAM FLOW 1+2 (KG/S)	770.8	685.1
STEAM FLOW 3 (KG/S)	85.4	342.6
PRESS. STL 1+2 (MPA)	4.963	5.014
PRESS. STL 3 (MPA)	4.963	5.014
PRESS. HDR (MPA)	4.882	4.893
PRESS. HTV21 (MPA)	--	4.666
PRESS. HTV22 (MPA)	--	4.662

Table 3

TRAC sequence of events.

Event	Time (s)
Single loop steam line isolation valve starts to close	4.0
Valve fully closed	8.4
Steam line break signal activated	8.69
Turbine trip	9.03
Reactor trip	9.03
Feedwater isolation trip	10.73
Activation of auxiliary feedwater motor pumps	10.73
HPSI trip	10.73
Double loop steam line isolation valve starts to close	10.73
Pressurizer back-up heaters on	11.76
Steam dump valves start to open	11.76
Double loop steam line isolation valve fully closed	15.13
Steam dump valves fully closed	33.76

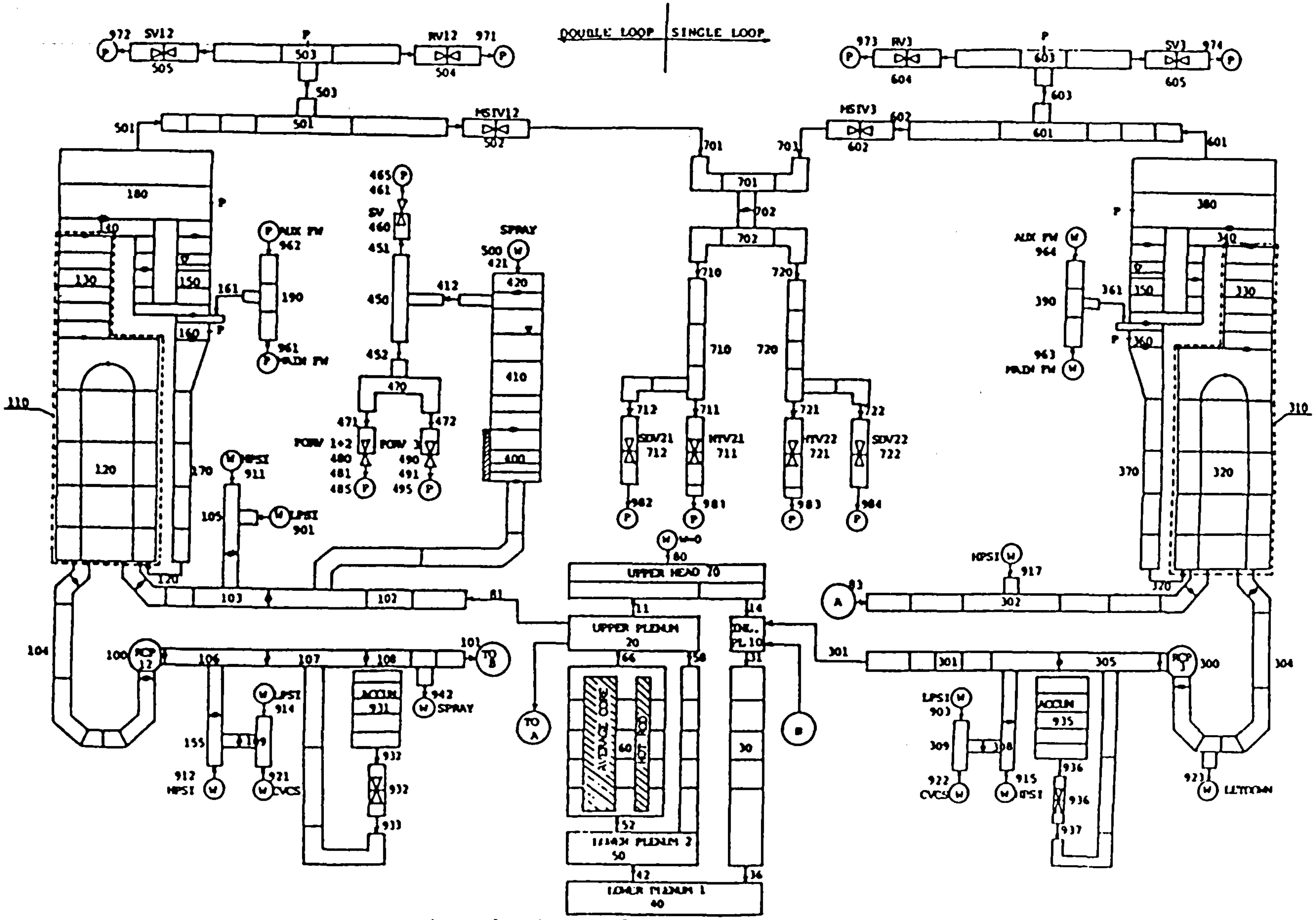

Figure 1. Ringhals 2 nodalization scheme.

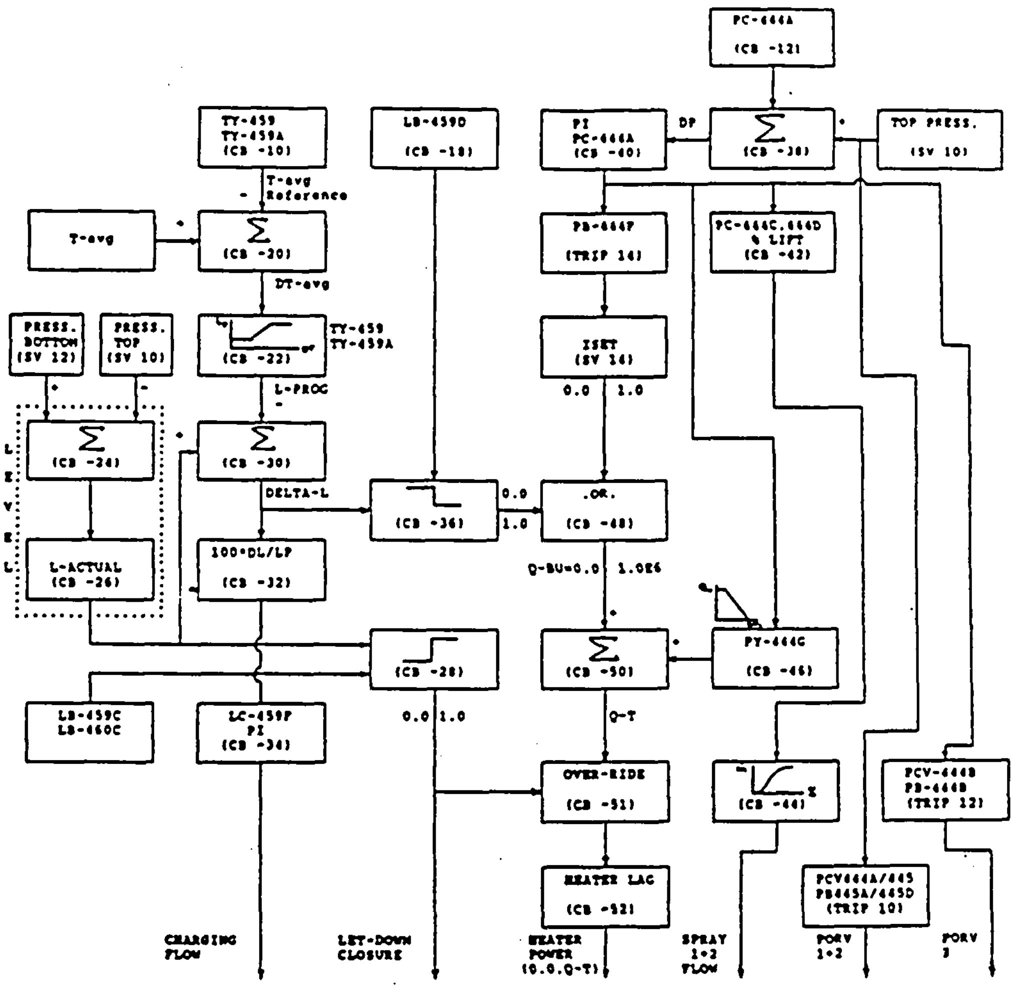

Figure 2. Pressurizer control.

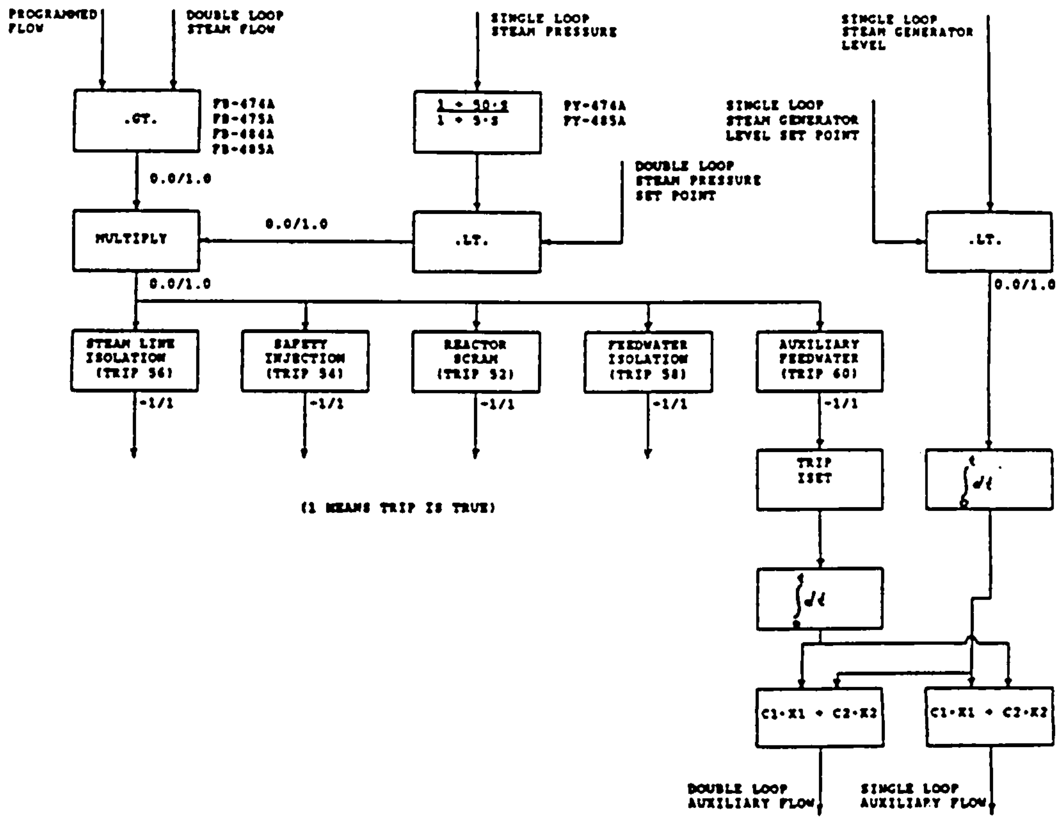

Figure 3. Trip logic.

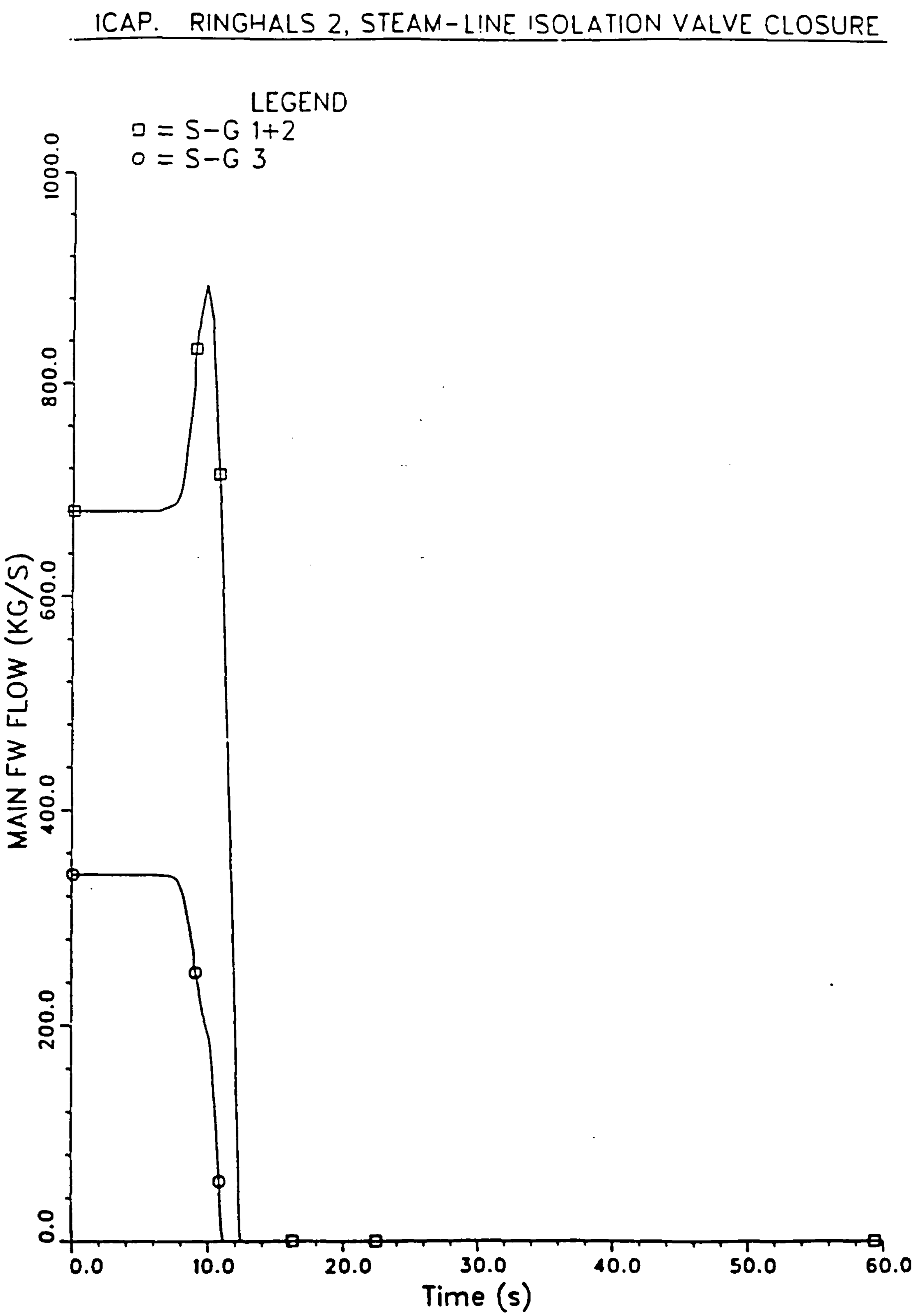

Figure 4. Main feedwater flow boundary condition.

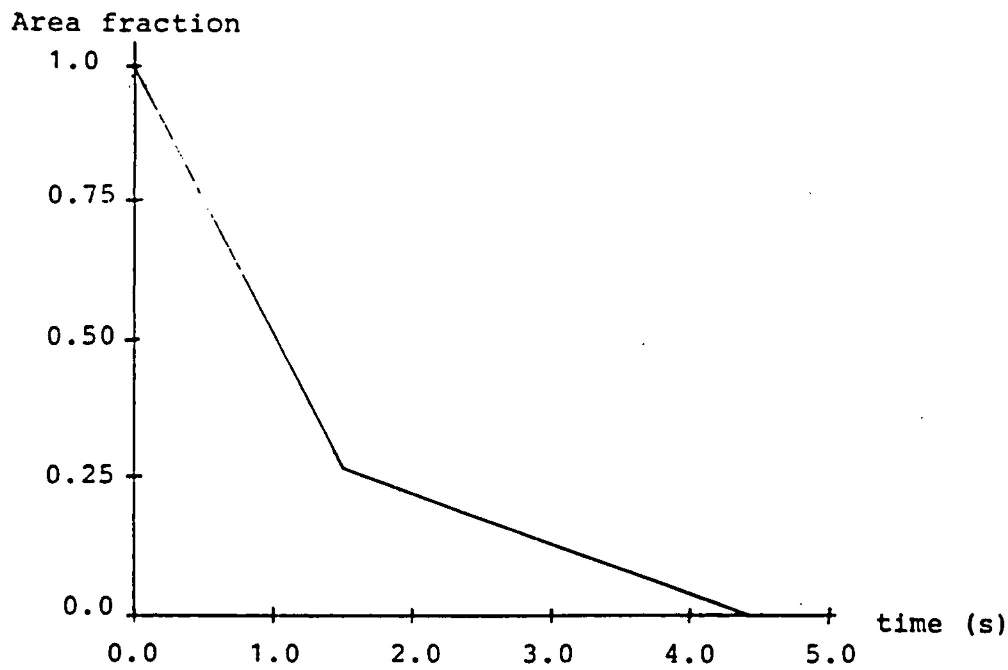

Figure 5. Isolation valve time characteristics

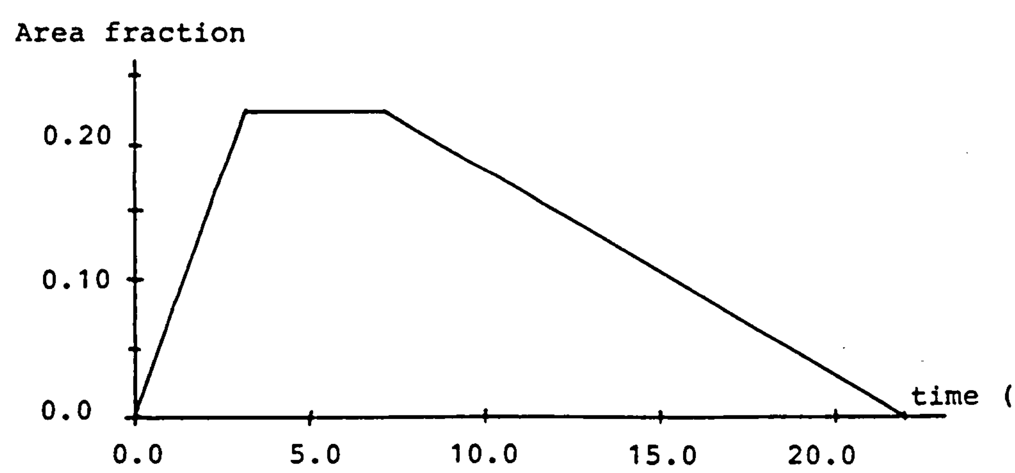

Figure 6. Steam dump valve time characteristics

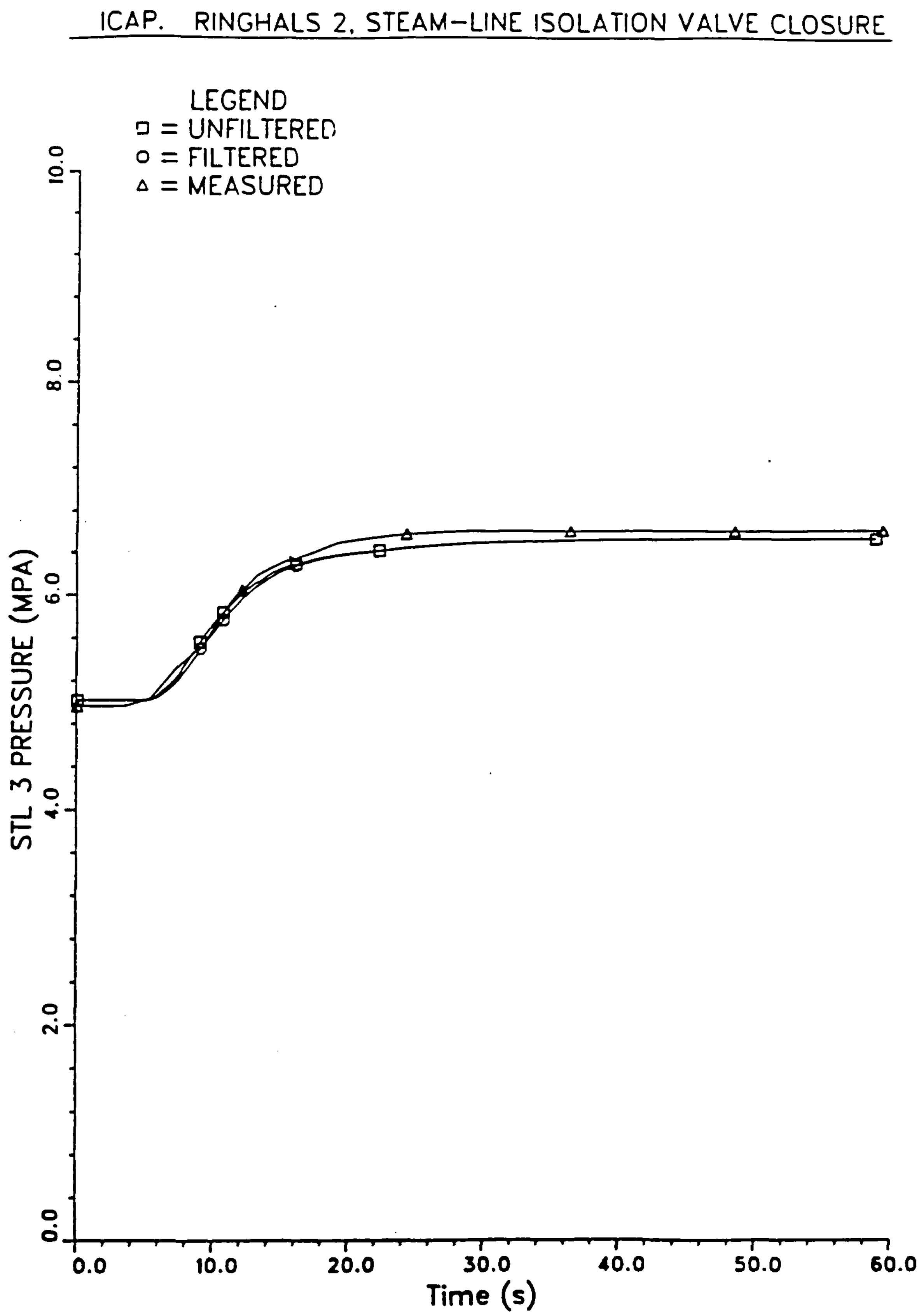

Figure 7. Single loop steam line pressure.

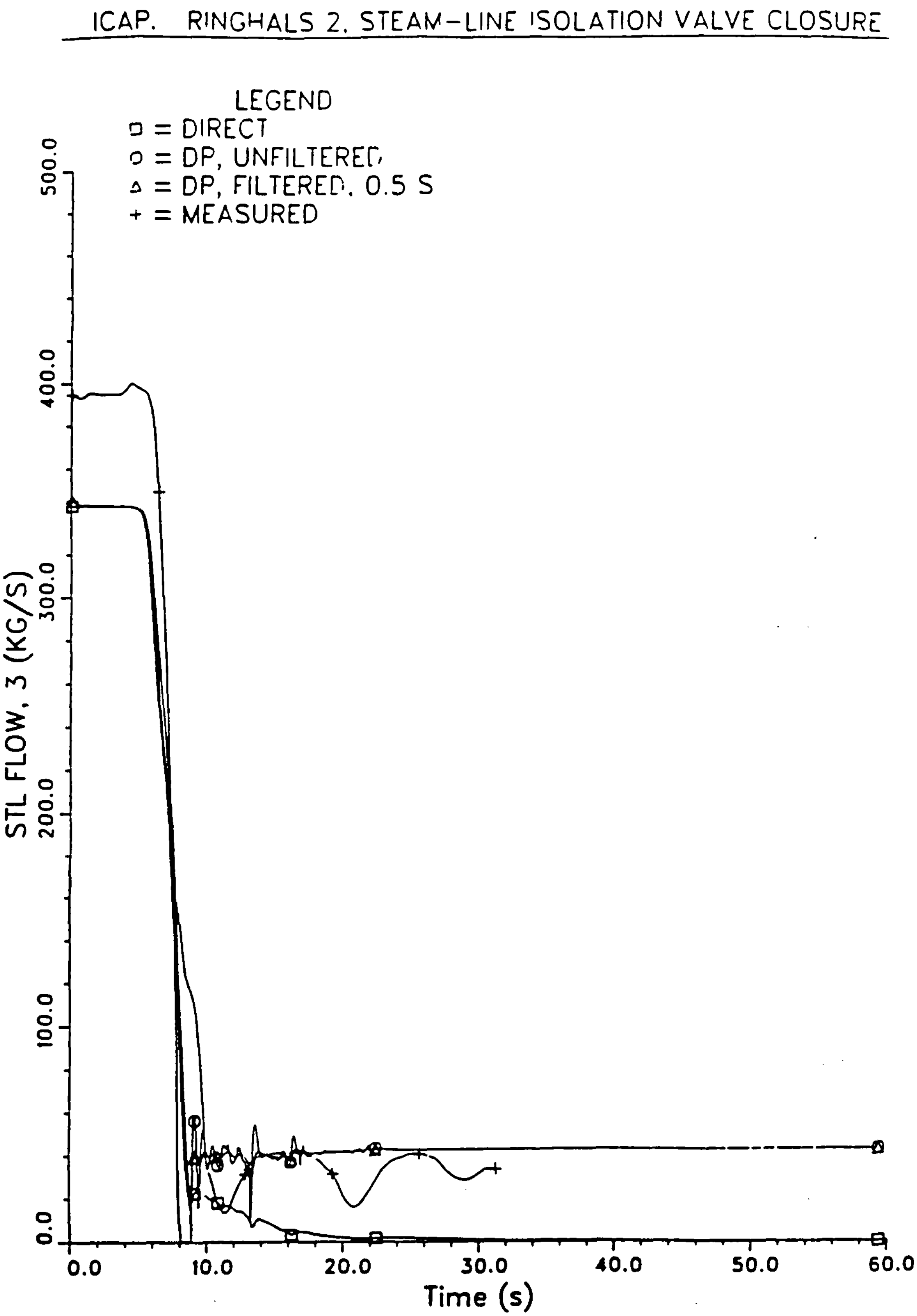

Figure 8. Single loop steam flow.

ICAP. RINGHALS 2, STEAM-LINE ISOLATION VALVE CLOSURE

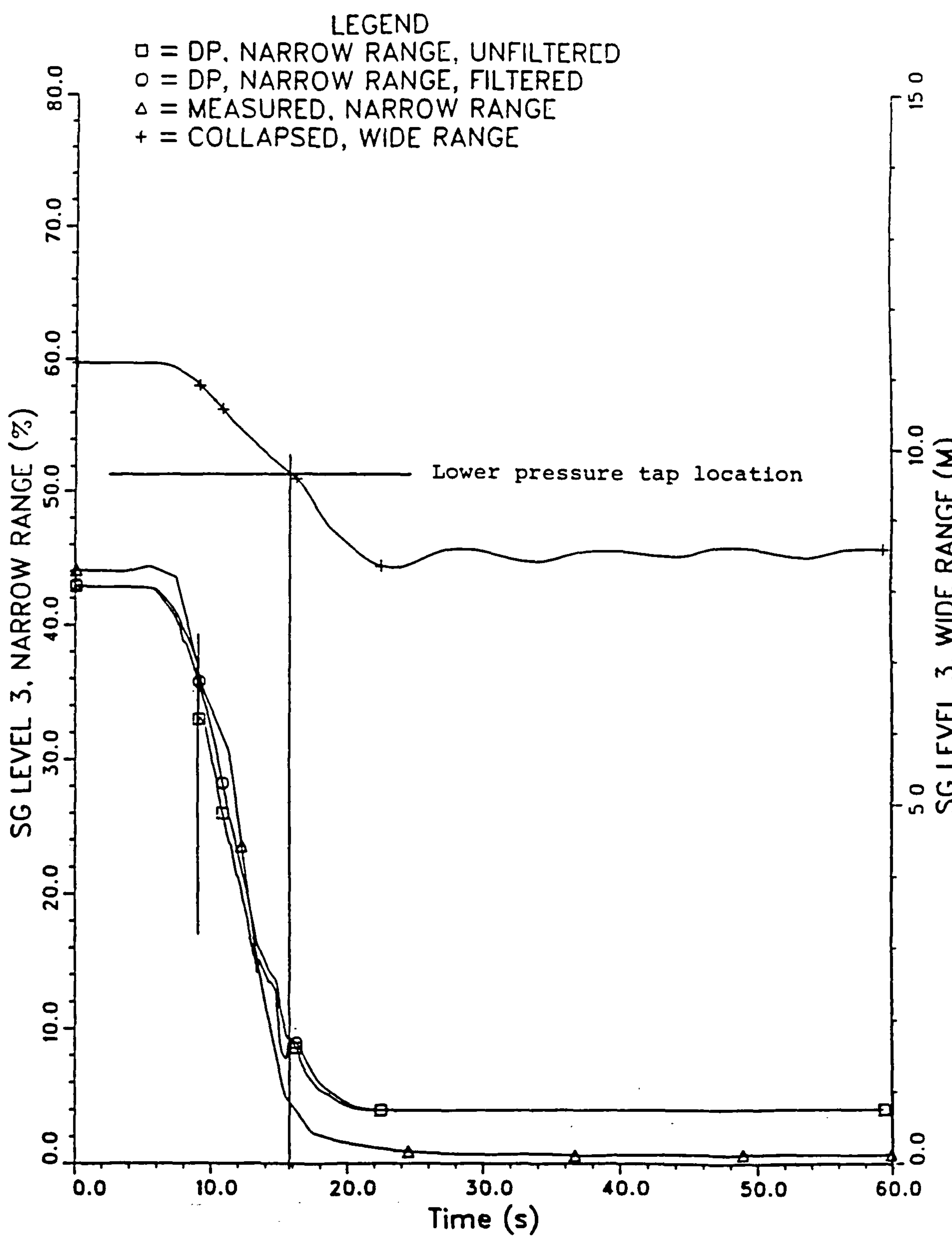

Figure 9. Single loop steam generator level.

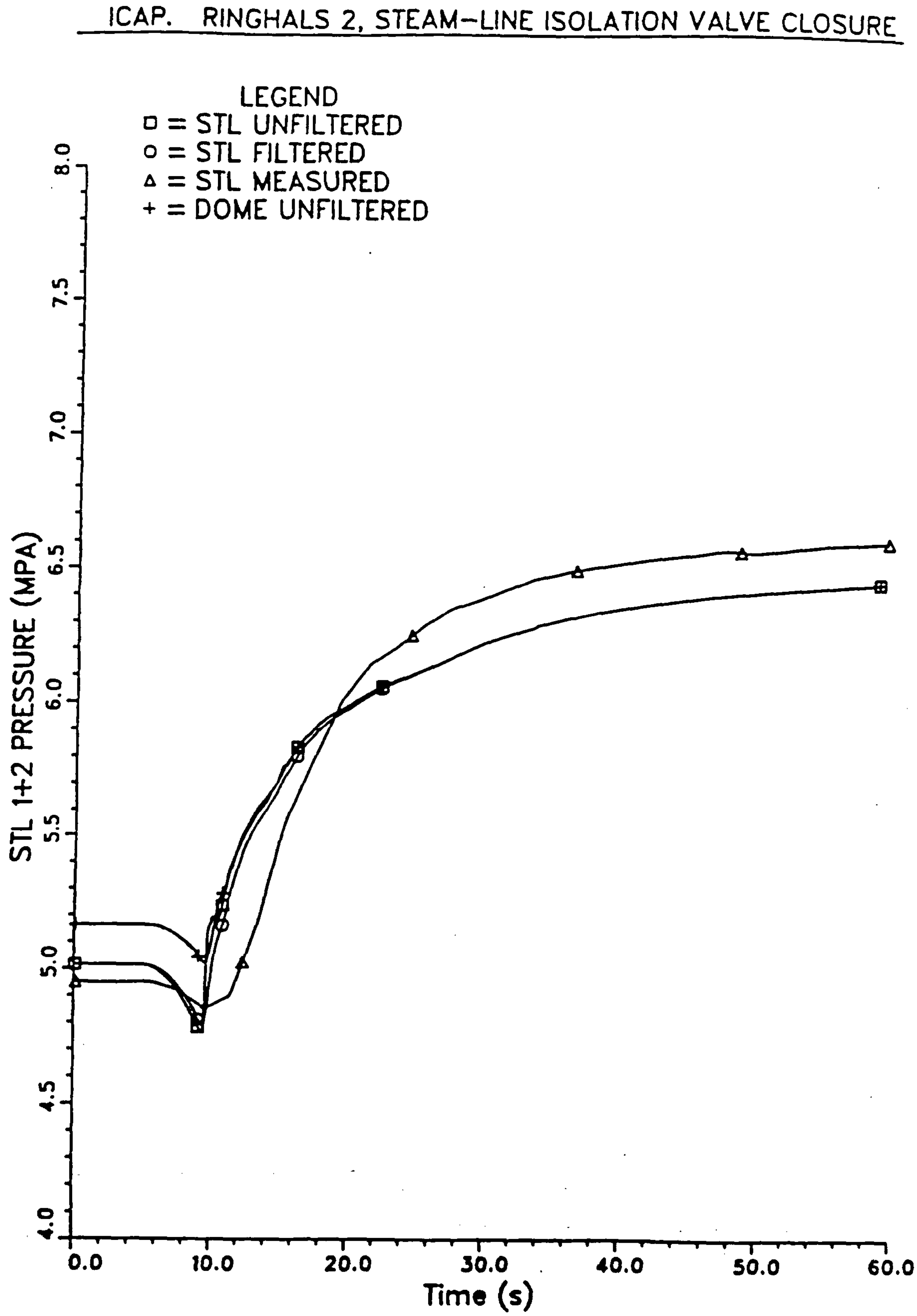

Figure 10. Double loop steam line pressure.

ICAP. RINGHALS 2. STEAM-LINE ISOLATION VALVE CLOSURE

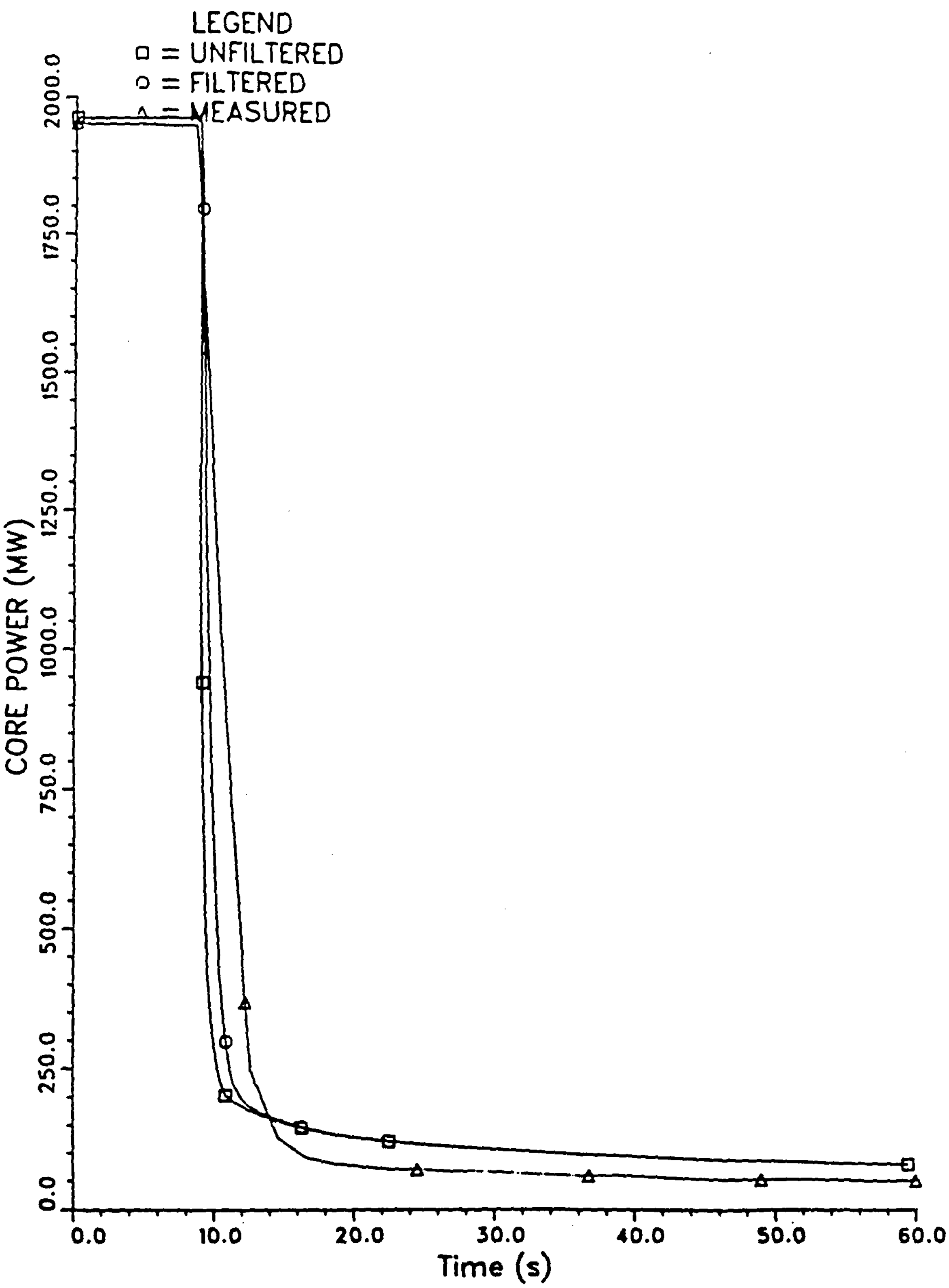

Figure 11. Core power.

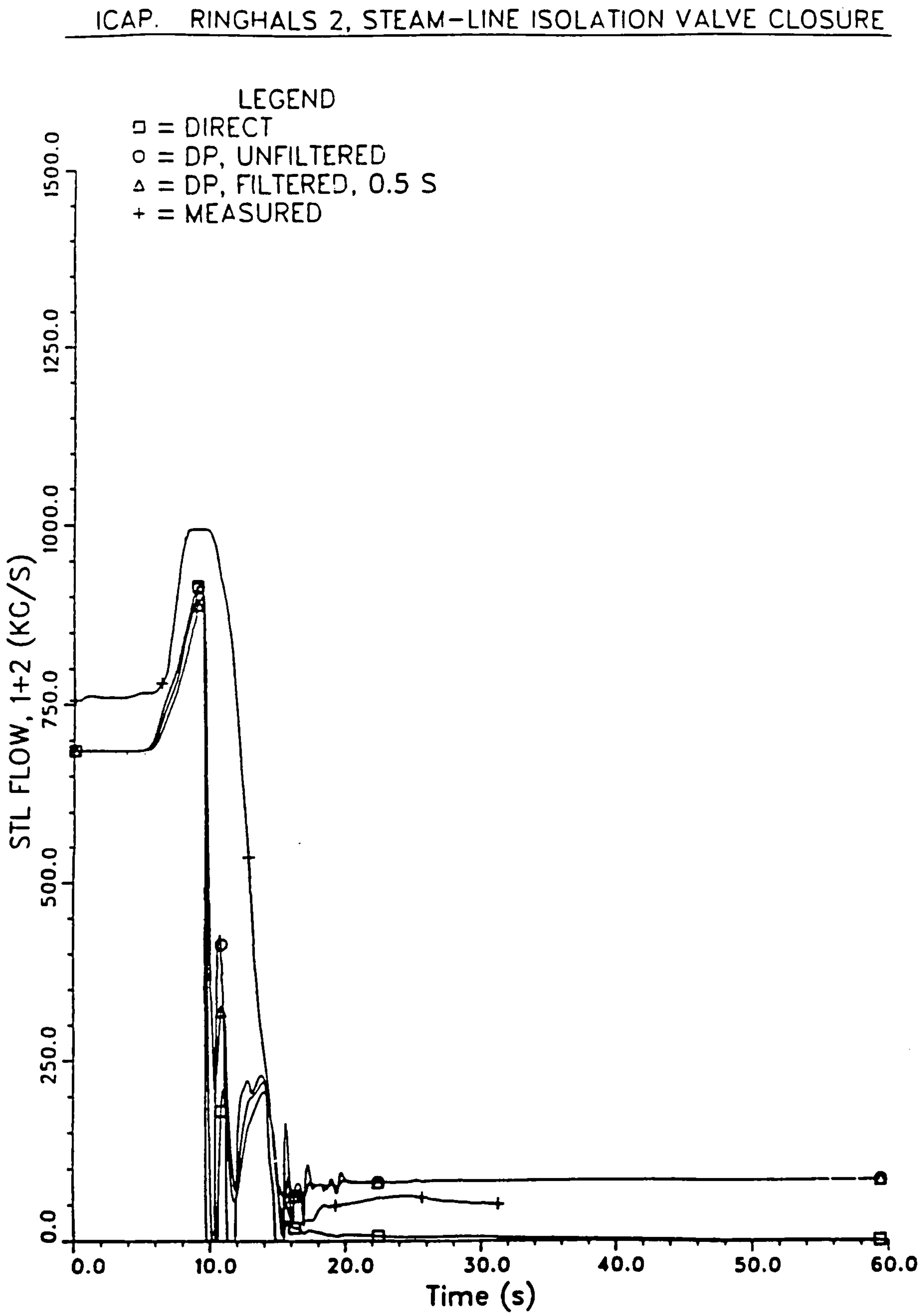

Figure 12. Double loop steam flow.

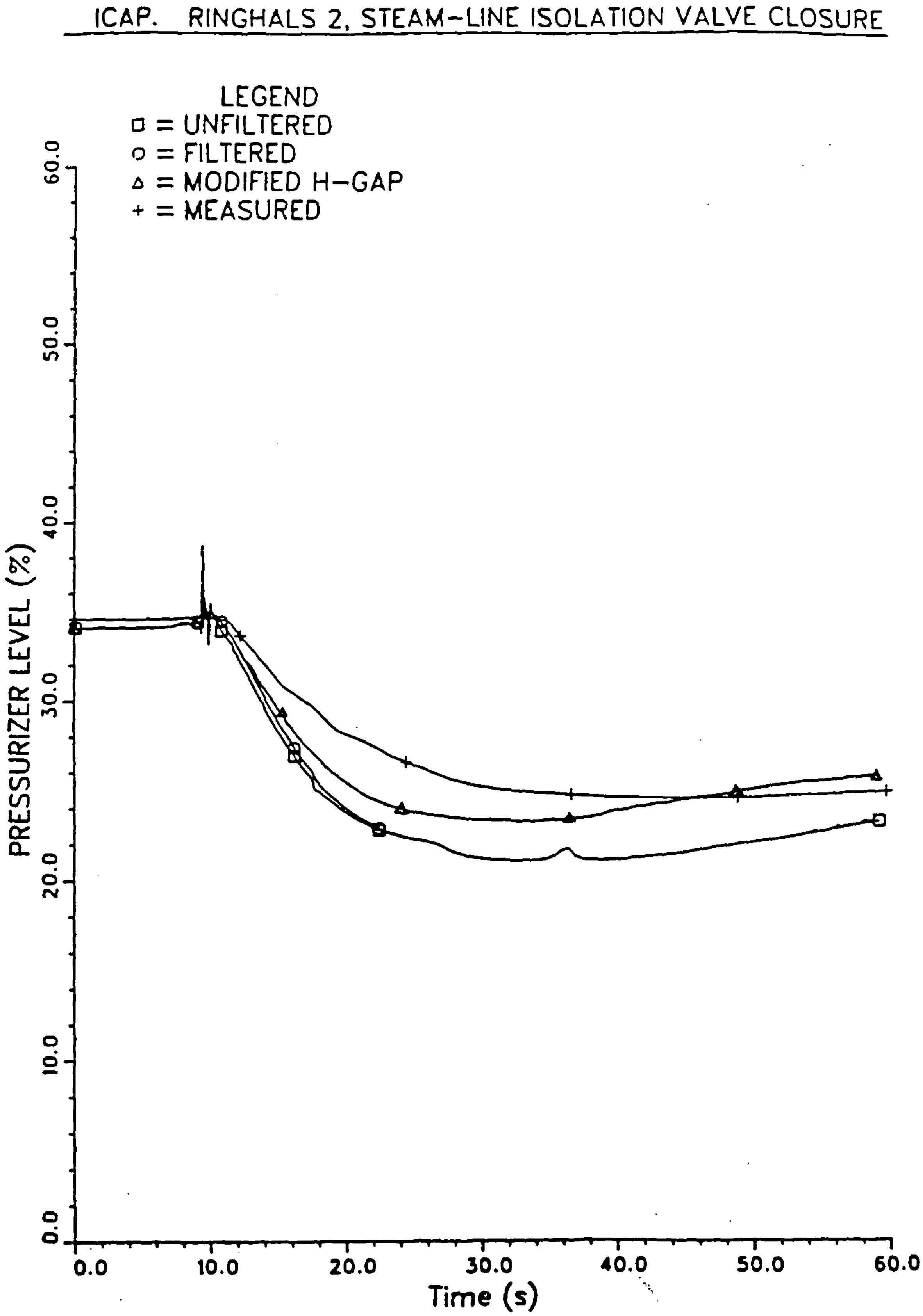

Figure 13. Pressurizer level.

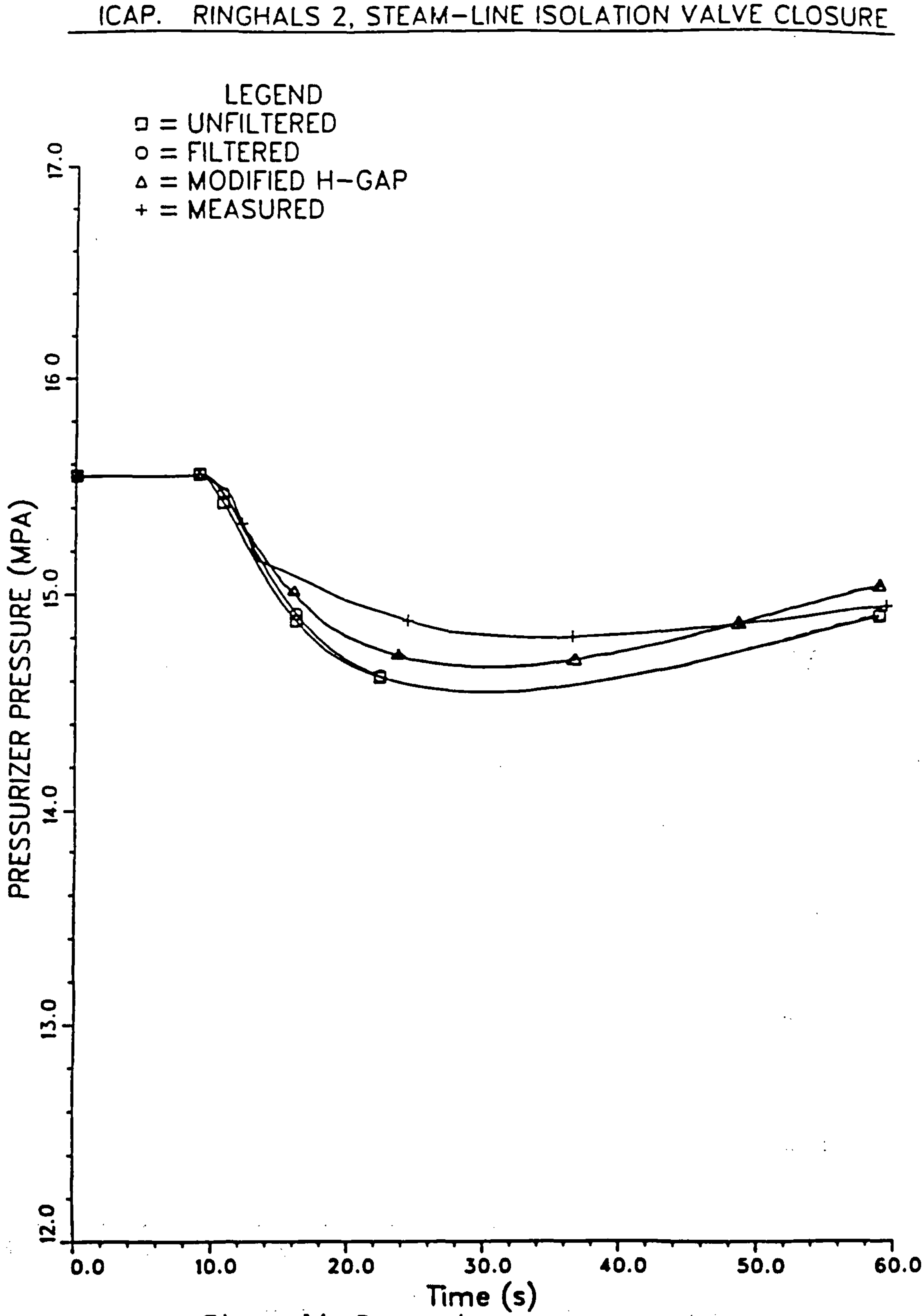

Figure 14. Pressurizer pressure.

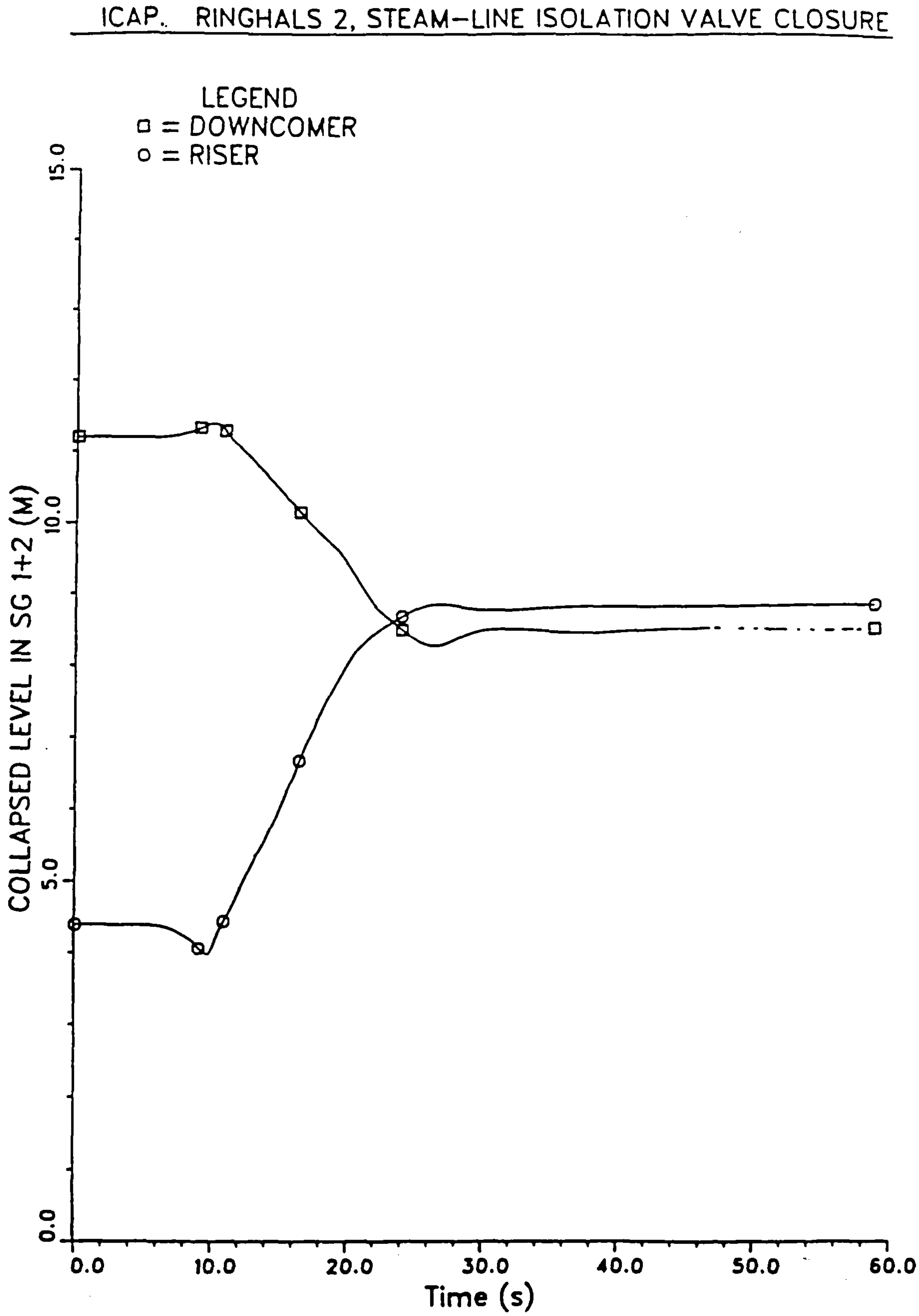

Figure 15. Double loop steam generator levels.

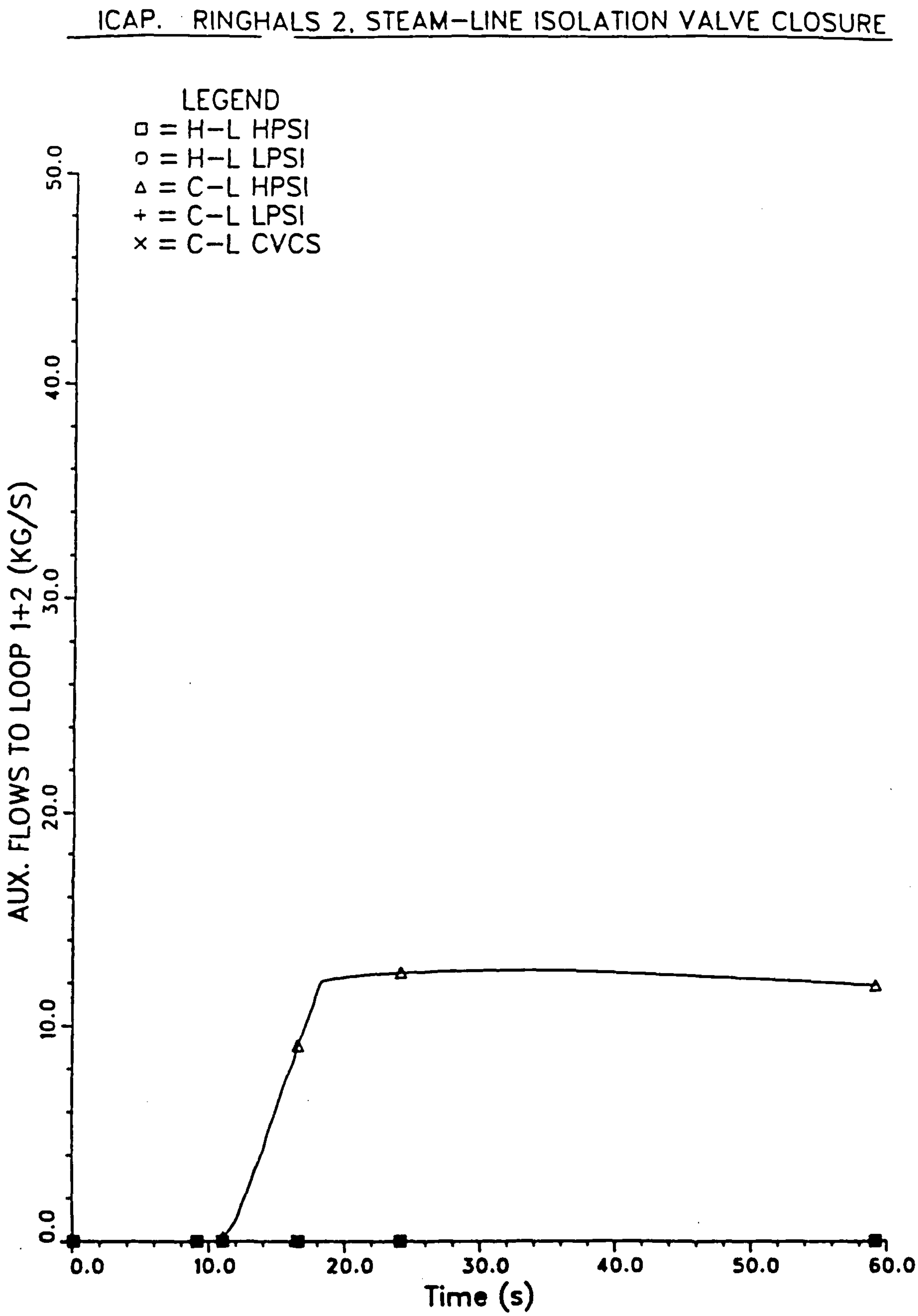

Figure 16. Double loop safety injection flow.

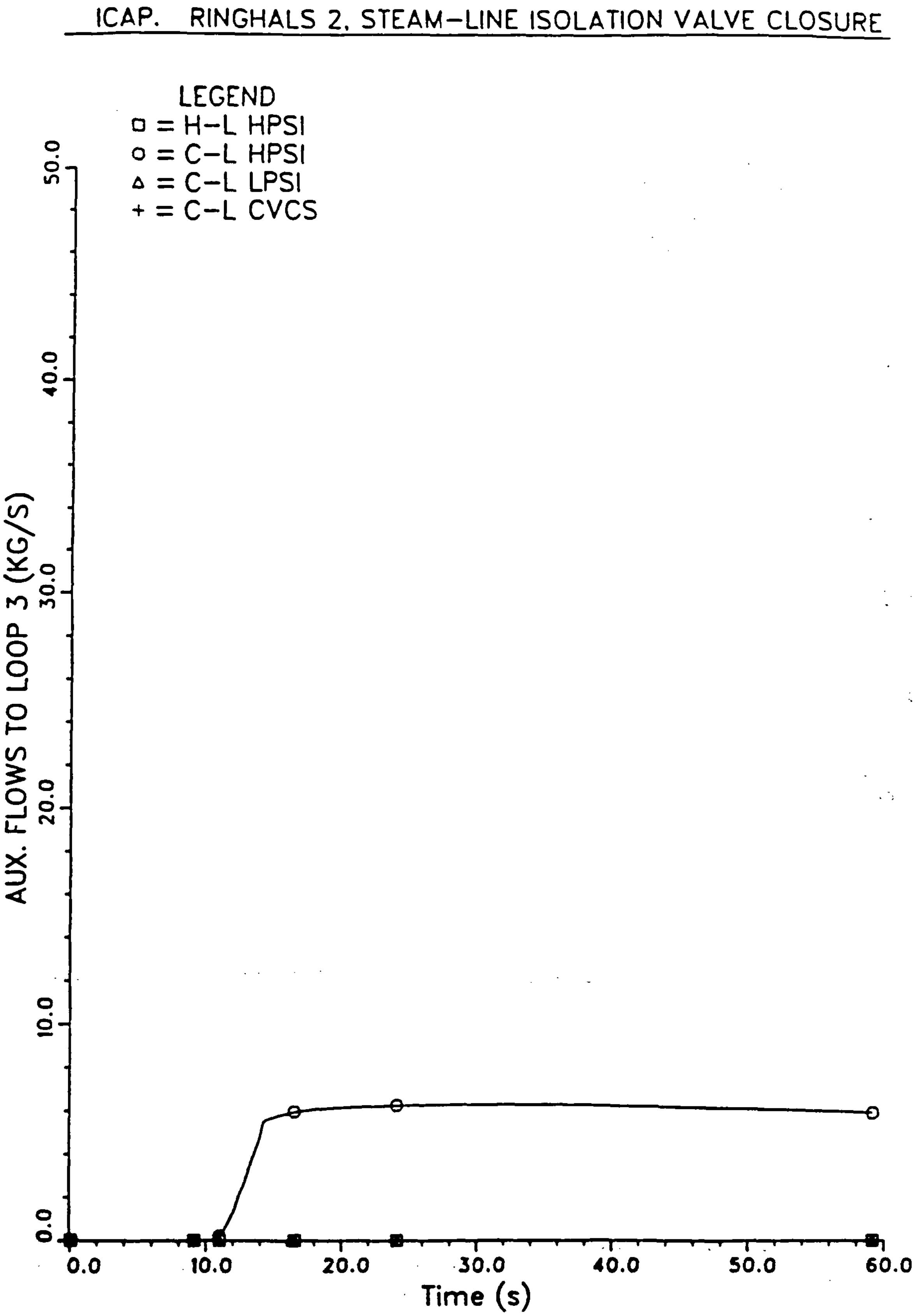

Figure 17. Single loop safety injection flow.

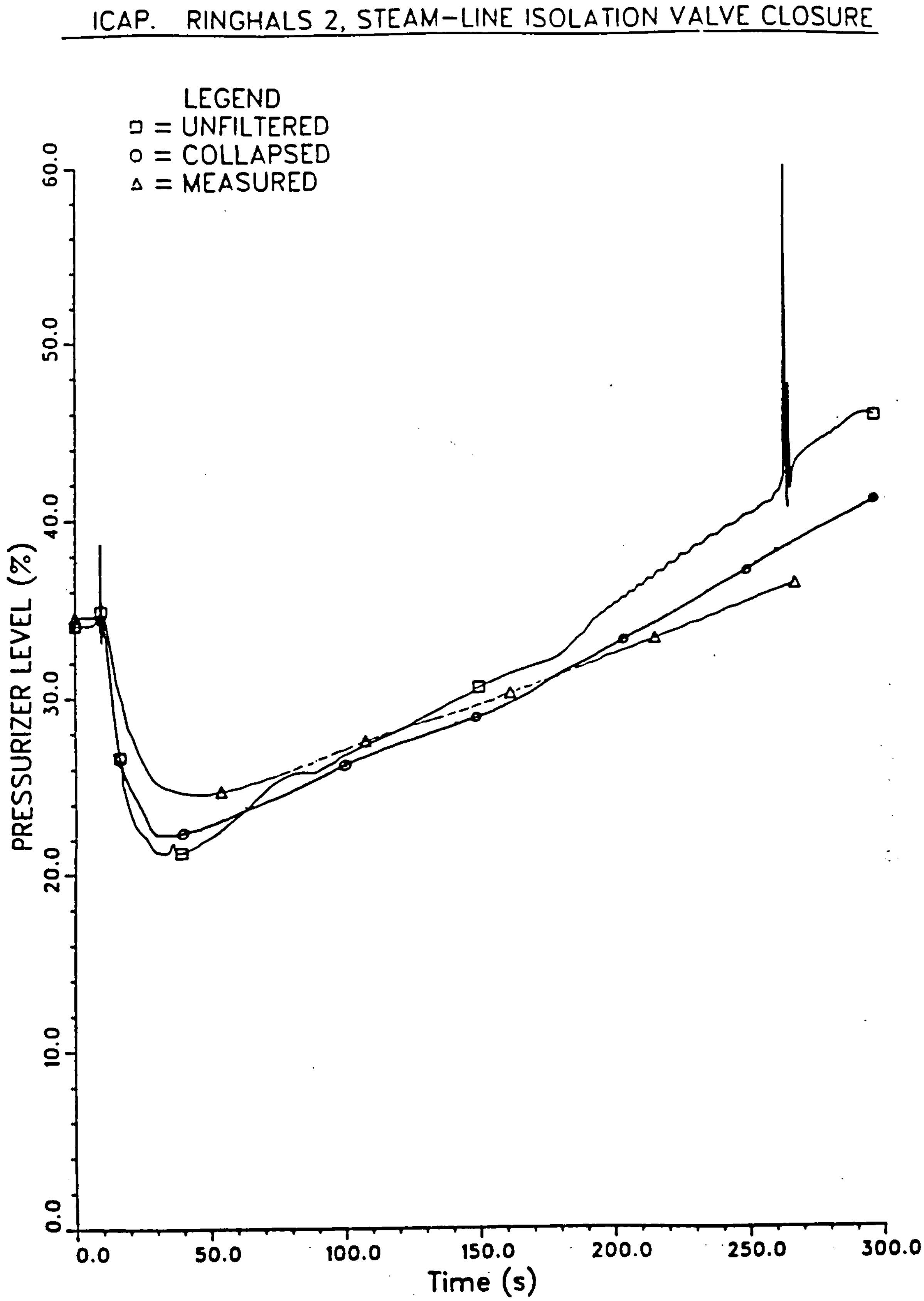

Figure 18. Pressurizer level, long term.

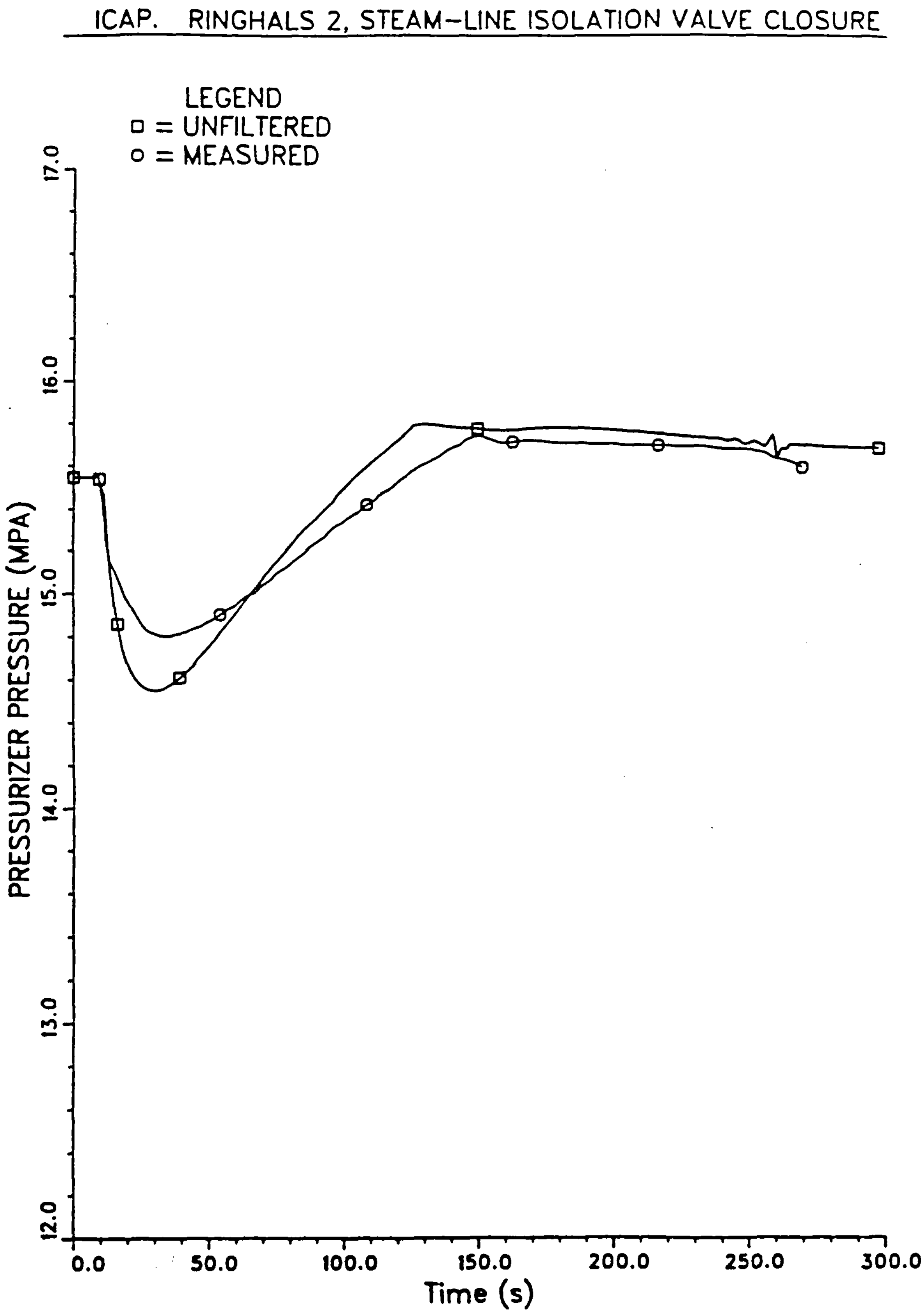

Figure 19. Pressurizer pressure, long term.

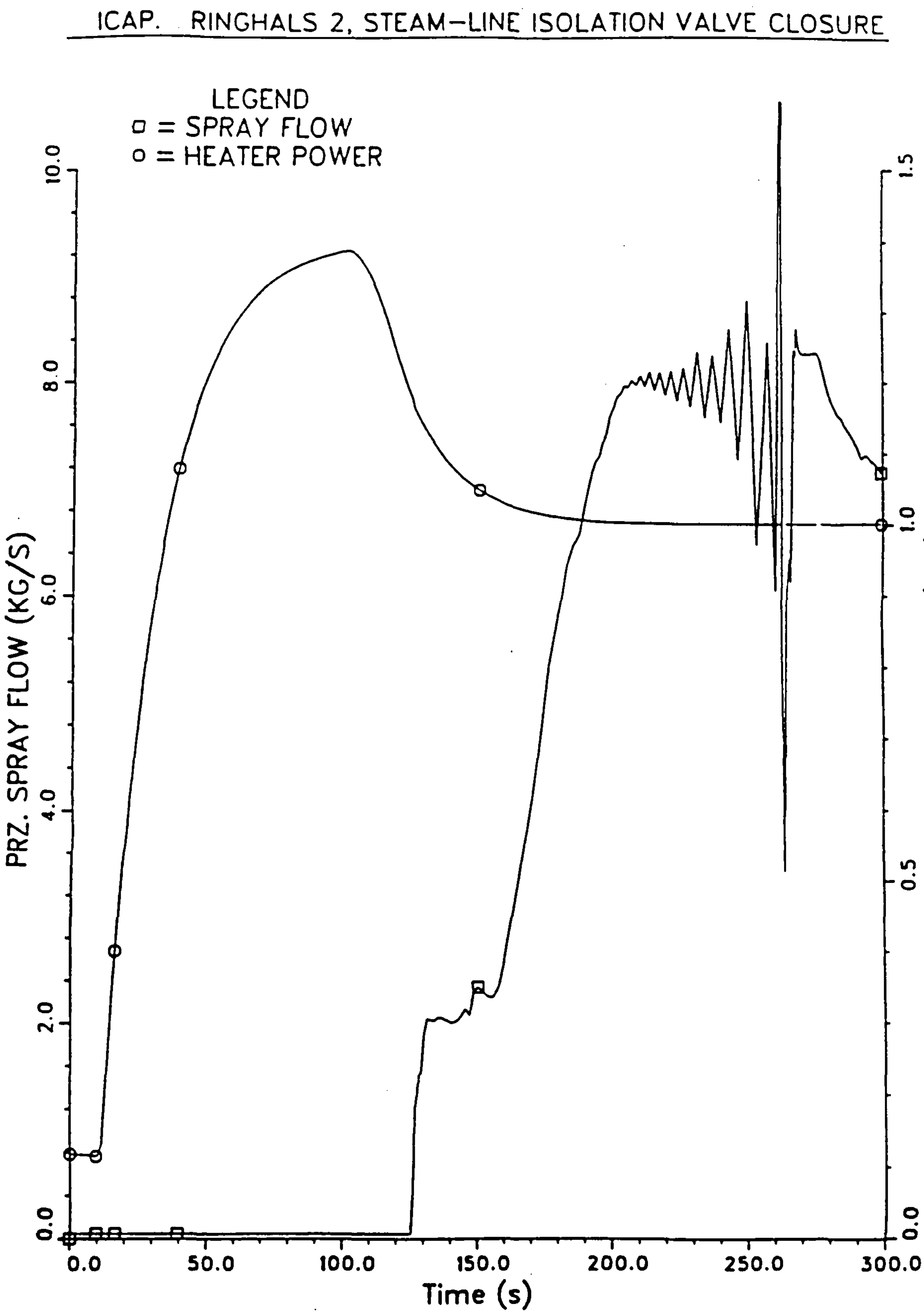

Figure 20. Pressurizer spray and heater power.

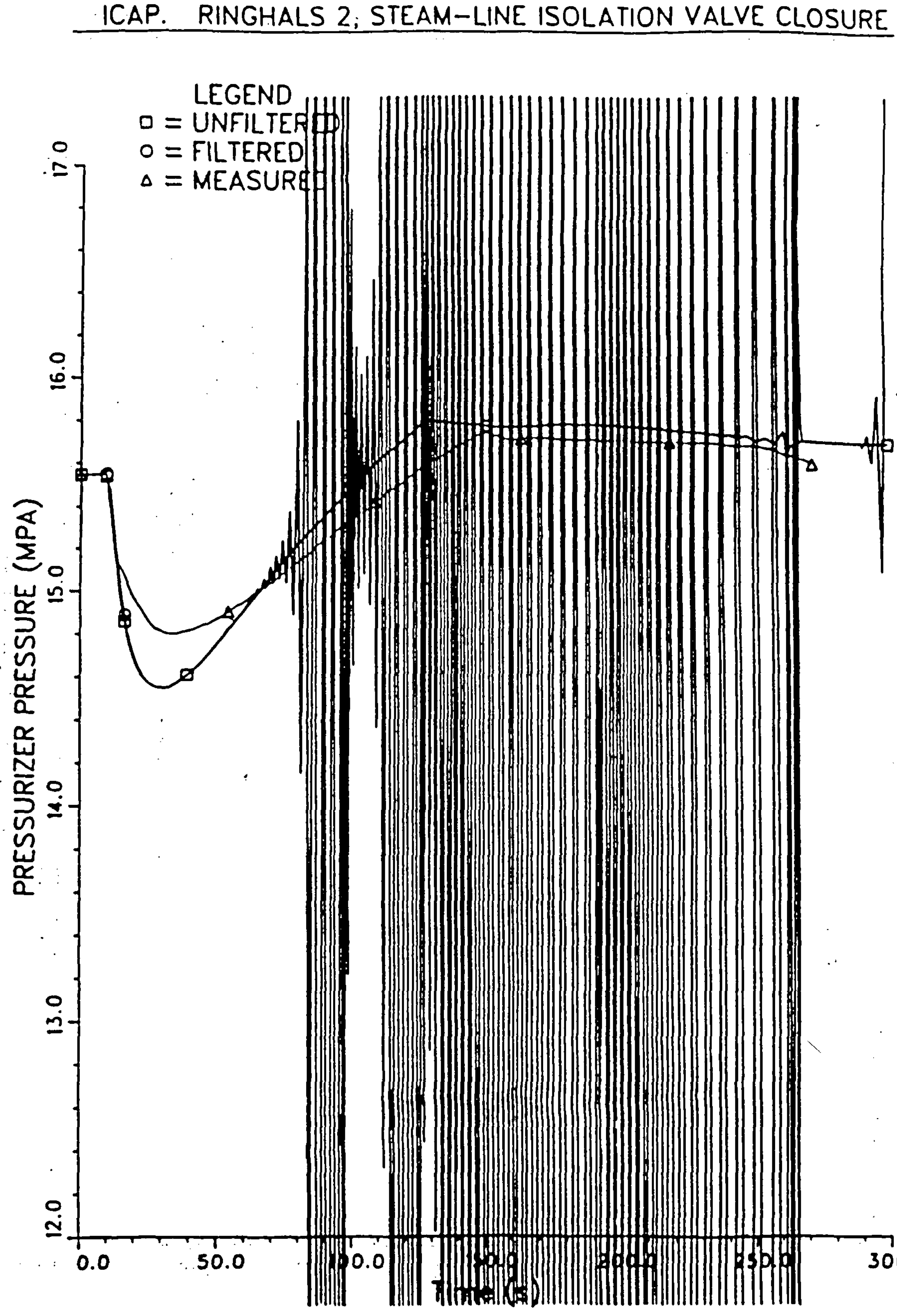

Figure 21. Control block behavior.

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11. ABSTRACT *(200 words or less)*

A TRAC-PF1/MOD1 simulation has been conducted to assess the capability of the code to predict a steam line isolation valve closure transient.

Extensive use of results from Ringhals 2 data acquisition system was made to drive the initial conditions and some of the necessary boundary conditions.

The results of the simulation revealed the importance of proper modeling of steam generator internals as well as the modeling of pressurizer walls and spray nozzles in order to reasonably predict the condensation phenomena.

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MARCH 1992