PWR Pressurizer Discharge Piping System On-Site Testing

M. Lasne, G. Anglaret
Framatome, Tour Fiat Cedex 16, F-92084 Paris la Défense, France

SUMMARY

Pilot operated relief valves (PORV) and spring-loaded safety valves (SV) are protected against leakage by a water seal.

When a valve pops open, this water seal is pushed into the discharge piping and produces substantial transient loads on piping supports (snubbers,guides...) lasting some hundred milliseconds.

Until 1982, no qualified code was available to modelize flashing and discharge and FRAMATOME has experienced failures on discharge line supports during hot functional tests. In 1979, an in-plant discharge test was scheduled in order to improve piping support behaviour and condensation efficiency in the pressure relief tank (PRT), and also to qualify thermohydraulic computer codes.

Twelve steam discharge tests were conducted in November 1981 with and without water seal through PORV or SV. During all the tests, the SV was assisted with a pneumatic ram. PORV and SV were opened separately or sequentially. The piping system had been previously excited in six different points with an unbalanced shaker in order to determine dynamic characteristics (natural frequencies, mode shapes and damping values) helpfull to adjust a mechanical model. Tri-axial accelerations were measured in ten points for each location of the shaker. Mechanical tests were run before the hot functional tests, discharge tests extended hot functional tests by eleven days.

A total of 132 channels were installed from the pressurizer nozzle, down to the PRT, and recorded on a fast digital acquisition system (120 channels) and on two analog recorders. Instrumentation included valve lift (4), static pressure sensors in the piping (12) and in the PRT (4), fluid thermo-couples in the piping (4) and in the PRT (7), accelerometers (26) and displacement sensors (7) on the piping, strain gages (19) on snubber rods to measure loads, welded strain gages (21) on piping and drag discs (2) to see the water seal passing. Ultra sonic sensors (8), combined with pipe wall thermo-couples (8) were used to estimate water seal volume and temperature. In addition, 5 parameters were recorded in the control-room. Pressure and fluid temperature were measured in SV chamber. Strain gages on class 1 piping and some accelerometers were also used to monitor shaker force level during mechanical tests.

Only one (pressure) sensor failed during the tests.

No problem appeared in PRT, where pressure stayed above 1 bar. After extensive checking of anchor steel plates, supports fairly behaved during all the discharge tests :

no plate displacement and no snubber failure, even if hydraulic snubbers were highly overloaded (1:4), particularly on 6" RV discharge piping. Expert evaluation showed no damage. Load level is closely dependent on water seal temperature and initial downstream piping temperature. These results are confirmed by calculations run with RELAP 5 MODE 1 CYCLE 18 by EPRI. On French PWR units, water seal will be reheated by insulation upstream of RV, and RV openings will be slightly shifted to separate transients in piping.

1 - INTRODUCTION

Past and present design of FRAMATOME PWR systems includes the installation of safety valves and relief valves which permit the discharge of steam from the pressurizer to the pressurizer relief tank (PRT) through discharge piping system. (see fig.6)

It has been found that certain spring-loaded safety and relief valves have a tendancy to leak when subjected to high pressure steam next to the valve seat. The valve leakage is thus limited by designing the system with a small volume of water, between the valve seat and the high pressure steam. The water seal is obtained by letting the steam condense in the portion of piping upsteam of the valve, by removing the thermal insulation.

At the other end, steam is discharged into the water contained initially by the PRT through a horizontal immersed quencher provided with a great number of small holes. The pipe between the valves and the quencher is initially filled with nitrogen (1) which is taken from the PRT nitrogen cover.

The opening of a valve causes the water seal to be pushed into the discharged piping by the pressurizer steam pressure; the nitrogen filling the pipe is subjected to pressure waves and pushes the water slug contained by the PRT quencher.

This discharge produces rapid pressure pulses in the discharge piping which result in quite substantial transient loads which can be reduced to forces applied along the axis of each pipe straight run. These loads would produce a large pipe whipping should the pipe not be adequately supported.

Water seal expulsion pluration depends on valve stem lift dynamics which can vary according to water-stem interaction. Pilot operated relief valves (PORV) are not very sensitive to this interaction and open relatively slow : .2 second about, whereas safety valves(SV) may chatter. So, to disconnect the evaluation of piping behaviour under hydrodynamic loads of SV chattering it was decided to assist the SV with a pneumatic ram so that it opens for sure and neatly in less than 40 milliseconds.

The experimental approach of this phenomenon is not easy because of its short transient nature : for example, a valve discharge transient is completed in less than 300 ms. Care must be awarded to the choice of sensor frequency responses, strengh, reliability as well as of cables and recorders.

The analytical approach is made difficult by the behaviour of the water seal : where does it flash, how much of it flashes, how does it break up ?

Considering these difficulties, a first test program was conducted in 1978 on BUGEY 3 in order to evaluate support loads due to PORV opening (1, 2, 3 valves operated at the same time). This test gave data that lead to several support design fixes on the plants in operation and under construction, and permitted to design more properly the next projects.

However it was insufficient to obtain a good data base and qualify a thermo-hydraulic analytical model that would have permitted to compute the loads generated by the steam discharge in other configurations, i.e. other piping diameters and routing, discharge through the safety valves, etc.

It was thus decided to perform a new test on a 900 MWe french plant, with the partial sponsoring of EdF (2) and EPRI (3).

The objectives of the test described hereunder are the following :

- characterize the mechanical response of the discharge piping to validate a mechanical model
- open one, two or several valves among the following : one SV and three PORV, at a time or sequentially and measure :
  . discharge piping transient response
  . support loads
  . water seal velocity
  . water and steam condition

Preparation of the test started beginning of 1980, the mechanical vibration test was conducted in september 1981, the discharge test was carried out in november 1981, on CHINON B1, during the reactor hot functional tests, and thermohydraulic and mechanical analyses of the discharge piping were conducted in the first half of 1982.

(1) Nitrogen is allowed from the PRT to the discharge piping through a small hole existing in the 12" pipe vertical run in the PRT.
(2) Electricité de France, SEPTEN, Tour EdF, PARIS LA DEFENCE, FRANCE
(3) Electric Power Research Institute, PALO ALTO, CA, U.S.A.

2 - INSTRUMENTATION (see table 4)

Objectives

The instrumentation should permit to :

- measure system initial thermohydraulic conditions
- monitor the valves stem displacements
- measure the piping mechanical response to hydraulic transient loads
- measure the fluid transient conditions in the piping system
- monitor some typical pressurizer fluid conditions
- determine the location, velocity and thermohydraulic state of the water seals during their travel to the PRT.
- measure the hydraulic parameters in the PRT

Sensors have been distributed from the top (pressurizer) to the bottom (PRT) of the discharge system, with the following principles :

- measure loads on all snubbers with strain gages sticked to the rods; eliminate bending strains.
- avoid instrumentation on sophisticated supports such as braced steel guides, trunnions supporting the header, which would lead to difficulties in the interpretation
- make sure that the frequency bandwidth of each channel is broad enough to track the dynamic nature of the transient
- make sure that the measurement is not impaired by the sensor environment (fluid, support movement, outside ambient temperature or radiation, etc)
- limit total number of dynamic parameters to 120, maximum number permitted by the digital data acquisition system, 12 quasi static parameters being recorded separately.

3 - QUALIFICATION OF INSTRUMENTATION DEVICES - PRELEMINARY TESTS

Instrumentation included mechanical and thermo-hydraulic sensors which were to be qualified for operating conditions. Sensors behaviour is closely related to mounting devices, for which specific studies and qualification are required. The main goal was to qualify fast response instrumentation devices with high temperature conditions. Qualification requirements and main results are summarized in TABLE 1.

For thermocouples, conclusions of test results are the following :

- for a constant diameter (1.5 mm) and protusion (3 mm), response time decreases from insulated head (0.57 s), to head to ground (0.15 s) and to unprotected head (0.056 s).
- for a given mounting type, response time decreases with diameter.
- insulating material (alumine or magnesie) does not change results.
- there is no significant decrease of response time for protusion over 3 mm.

The smallest response time has been found for a 0.5 mm diameter with unprotected head and a 2 mm protusion : it was 0.06 s at 63 %. But it appeared to be too weak and a 1.5 mm diameter sensor was chosen.

The GOULD pressure sensor has been selected by preliminary tests in which the quasi static thermal shift of ten different sensors was measured. GOULD sensor has a thermal shift smaller than 4.5 % of the measurement range at 180°C.

The sensor is mounted on a small tubing (FIGURE 2) which significantly reduces thermal shock on sensor. Thermal shock effect is an apparent negative pressure, occuring after the pressure transient.

The static comparison between welded and sticked strain gages pointed out a small shift (< 7%) in compression which may be due to a buckling of the tinsel.

For accelerometers, the main problem was to avoid saturation on amplifier with high magnitude high frequency shocks. Electric filter was not considered because sensor capacity varies significantly with temperature and changes cutting frequency. A rubber mechanical filter (FIGURE 3) was qualified and mounted on a rod equipped with fins.

Drag discs were designed and qualified by the supplier MEASUREMENTS INCORPORATED. They were supposed to have a natural frequency above 500 Hz and to measure a momentum flux between : 5×10^4 kg/ms^2 and 7.5×10^6 kg/ms^2.

Ultra-sonic barriers were used to detect water seal level and to measure water seal velocity during valve opening. A water seal running in front of an ultrasonic transmitter receiver unit induces a transmission echo whenever water is present in the pipe. A permanent sampling of two synchronous ultrasonic barriers as illustrated on FIGURE 4 allows the measurement of the water seal velocity by analyzing the difference in phase between channels 1 and 2. This system device was tested on site and on INDIRA test loop during preliminary discharge tests.

Preliminary tests were run on different plants (SAINT-LAURENT 2, TRICASTIN 3 and 4) and on INDIRA test loop in CHATOU, where a full size discharge system was installed, similar to on-site upstream and first downstream pipes. A number of discharge tests where run and every sensors, amplifiers and data acquisition system were tested.

4 - DATA ACQUISITION SYSTEM (DAS) AND DATA PROCESSING

The data acquisition system consists of :

- 1 FOURIER HEWLETT PACKARD 5451 C analyzer
- 1 Analog to Digital Converter and Multiplexer 120 channels, 100 kHz, monitored by the computer
- 24 sample-and-hold units
- 1 time base
- 3 output peripheral devices :
  - . 50 M-octet disc
  - . magnetic tape reader
  - . plotter

Figure 5 shows a schematic description of the DAS. The DAS has been used for acquisition and processing during discharge test, and for process the data of mechanical tests.

4.1 - Preliminary tests - Modal analysis

During preliminary tests, excitation force and piping accelerations are recorded on an analog magnetic tape located in the containment. They are filtered with a low-pass filter to avoid aliasing during Fourier process. Two tachometer signals are taken. The 1 pulse/rev. is used to give the phase reference (external trigerring signal) and to calculate the rotating frequency, via an RPM counter. The 64 pulse/rev. is used as external sampling signal, so that one obtains after an acquisition of 64 samples of a signal, a fast Fourier transform amplitude and phase information on the 32 first orders.In most cases, only the first order is of direct interest.

After the test, the data are multiplexed and processed on the HP computer to obtain transfer functions and modal parameters (natural frequencies, damping values and mode shapes).

4.2 - Discharge tests

It has been found that 24 channels have to be defined up to 200 Hz and 96 up to 100 Hz So 24 channels were sampled at 1000 Hz and sampled and held, while 96 were sampled at 500 Hz. Therefore the total multiplexer sample-rate was set to 72 kHz.

Multiplexed data are stored on the 50 M-octet disc and may be processed just after the test. A number of display programs may be used, like zoom, full scale display...

5 - MECHANICAL TESTS

As with any non-rigid pipe support system, however, the structural response of the CHINON B1 piping prevented direct comparison between the calculated hydrodynamic loads and the measured support loads. Therefore, it was decided to conduct mechanical tests in order to obtain modal parameters of the piping system (natural frequencies, mode shapes and modal damping values). These parameters were to be used by ANCO (1) to qualify a mechanical model with EASE 2 structural analysis code. Afterwards, calculated hydrodynamic loads were entered as input boundary conditions to obtain the calculated support loads for comparison with data.

Mechanical tests were run by LMS (2) and conducted by FRAMATOME. An unbalance exciter with rotating masses (max. force 12000 lbs at 50 Hz) was fitted to the pipe, delivering a frequency squared dependant force from 3 Hz to 100 Hz, measured with six load cells. Fifty measurement points were selected, distributed over the complex system (FIGURE 6). In order to be able to excite the complete structure, six excitations points were selected. The system was excited successively in one of these points and the frequency responses were measured between the exciting point and a limited number of measurement points related to that excitation point. For each excitation point, a number of reference points (related to other excitation points) are measured too. The frequency responses in the reference points provide a necessary link between the modal parameters, related to the different excitation

(1) ANCO Engineers, Incorporated, 9937 Jefferson Boulevard CULVER CITY, CA 90230, USA
(2) LEUVEN MEASUREMENT AND SYSTEMS, Naamse Steenweg 400, 3030 HEVERLEE, BELGIUM

points.

A typical frequency response function is shown in FIGURE 7. The resolution is 1 Hz. The approach in this test was to approximate each measured frequency response function by the most general expression for a linear model assuming general viscous damping.

$$\frac{X_i}{F_j} = \sum_{k=1}^{n} \frac{U_{ijk} + jV_{ijk}}{-\delta_k + j(\omega-\nu_k)} + \frac{U_{ijk} - jV_{ijk}}{-\delta_k + j(\omega+\nu_k)}$$

where X_i = displacement in point i (freq. domain)

F_j = force in point j (freq. domain)

n = number of degrees in freedom in considered frequency domain

ν_k = k^{th} modal damped natural frequency (rad/s)

δ_k = k^{th} modal damping value (rad/s)

ξ_k = $\frac{-\delta_k}{\nu_k}$ = damping ratio (%)

$U_{ijk} + jV_{ijk}$ = complex modal displacement

ω = pulsation

27 different modes are identified between 3 Hz and 100 Hz. Table 2 shows the calculated resonance frequencies and damping ratios.

All modal displacements were rescaled to bring them back to one excitation point.

Excitation point 5 was chosen for this purpose :

$$A_{i5k} = A_{imk} \cdot \frac{A_{r5k}}{A_{rmk}}$$

A_{i5k} = complex modal displacement in point i, with excitation in point 5 mode k.

A_{imk} = complex modal displacement in point i, with excitation in point m mode k.

A_{r5k} = complex modal displacement in the reference point r, with excitation in point 5 and m.
point r makes the link between different excitation in point 5 and m.

A_{rmk} = complex modal displacement in the point r, with excitation in point m, mode k

On one hand, the exciter force had to be high enough to make the snubbers operate and obtain loads on supports close to discharge loads; on the other hand, it had to be limited in order to maintain stress intensity below stainless steel endurance limit on class 1 piping.

Therefore a maximum force level was predicted by a previous calculation, assuming a damping ratio of 2 %. During the tests, a first low level and fast sweep sine test was run to estimate damping value. For all the tests, surveillance parameters were recorded : 3 accelerations on SV and 3 strain-gages bridges on class 1 piping, 1 measuring bending and torque. Response spectra were computed by HP system after each test and determined following excitation level, by comparison to pre-calculation results.

6 - DISCHARGE TESTS - DESCRIPTION AND MAIN RESULTS

Twelve steam discharge tests were conducted in November 1981, with and without water seal, through PORV or SV. During all the tests, the SV was assisted during valve opening with a pneumatic ram. PORV and SV were opened separately or sequentially. Tests conditions are summarized in TABLE 3. We have tried to obtain different water seal initial temperature condition : more or less hot (FIGURE 8). Discharge duration varied from 10 s to 60 s in order to test the efficiency of condensation in PRT; for transient tracking, one second would have been sufficient.

Typical pressure wave downstream a PORV occuring during a water seal discharge is shown on FIGURE 9. FIGURE 10 shows axial load on snubber during test 5. Two different transients occur, spaced out with 120 ms which is the delay between the two PORV opening.

After the second transient, the piping oscillates on snubbers during 0.7 s. An equivalent reduced damping coefficient may be estimated from the fuel vibration by means of the logaritmic decrements.

$$\beta = \frac{1}{2\pi} \ln \frac{A_o}{A_n}$$

In this case, the approximate valve is β = 35 %, which is quite higher than values used currently when analyzing pipelines subjected to seismic motion (1 to 3 %)

7 - INSPECTION

After completion of the mechanical tests, it was necessary to make sure that class 1 piping had not been damaged. Dye penetrant and gamma-ray inspections at all critical piping sections were conducted and results of gamma-ray were compared to reference documents : no damage was observed.

After discharge tests, an overall inspection covered class 1 piping, snubbers, support plates, support attachments to piping, SV and PORV tested. Results presented in TABLE 5 show that the pressurizer discharge system remained undamaged; one snubber was damaged by high magnitude load but still operating.

8 - QUALITATIVE INTERPRETATION OF TEST RESULTS

The overall pressurizer discharge system behaved finely during the seven days of testing, with no apparent damage to any part of the system.

Loads on supports

Results of tests conducted for EPRI by COMBUSTION ENGINEERING in Hartford, Connecticut on the same safety valve with the same water seal, with a single outlet 12" OD pipe, showed very high transient loads of the order of 1000 kN, in the second straight pipe run after the SV. This did not happen in CHINON due to the network character of the discharge piping : maximum loads recorded were 160 kN on the 6" pipe supports and .80 kN on the 12" common pipe supports, both due to PORVs discharges and not to the SV. In this way, the PORV loads are sizing.

However, the faulted condition load foreseen for the 900 MWe contract program was over passed on some snubbers (25000 N on the 6" vertical run and 12500N snubbers on the 12" expansion loop). Loads remained within the ASME maximum load calculated by the manufacturer : 2 times the load in faulted conditions.

The header is important to break down the water seal into parts and to split it.

Valve opening

The SV was leaking slightly after the first opening at reactor normal operating temperature.

Full valve stem displacements are obtained in 220ms for PORVs and 16 ms for the SV,the effective opening being obtained in a somewhat shorter time for the PORVs.

The 2 PORVs which were operated at the same instant always opened with a shift of about 120 ms so that the two water seals never travelled together in the common 6" piping; however they met at the 6" to 12" junction.

Water seal temperature

Loads on supports depend very much on the volume and temperature distribution of the water seal. A partial or hot water seal (temperature above 260°C which is the saturation temperature at the maximum pressure measured immediately downstream of the valves, 4.5 MPa) generates smaller loads.

Support plate attachements to walls

Most plates were fixed with expansible bolts. Before the preliminary mechanical vibration tests, a campaign was undertaken in order to check the efficiency of these fixations and many bolts were retightened.

During the mechanical tests and later during the discharge tests no plate displacement was observed - the plate contours were marked onto the concrete - and this good behaviour contributed very much to the test success.

Piping

Measured dynamic absolute piping displacements were smaller than 4 mm and strain gages showed very small stresses in every discharge test.

This qualifies the piping support principle of restraining axial movement of each straight run in its axis if possible, or as near the axis as possible (after an elbow).

Snubbers

All snubbers used, both mechanical and hydraulic type, behaved well i.e. blocked during the discharges and restrained the piping displacement.

Pressure relief tank

The steam condensation efficiency of the PRT has been greater than expected : during the tests, final pressure remained below 1 bar gage, whatever may be the steam mass flow rate and the discharge duration.

9 - INTERPRETATION OF TEST RESULTS BY ANALYSIS

One interpretation has been conducted by EPRI, in several steps :

- prepare a structural model of the piping system
- validate this model with the preliminary mechanical vibration tests
- use thermohydraulic computer programs to modelize the discharge system
- compute hydraulic parameters and hydraulic forces generated by the water seal and steam discharges
- adjust calculated to measured fluid conditions
- apply these calculated hydraulic forces to the validated structural model
- compare the calculated and measured support loads
- interprete discrepancies and corrections to apply, if necessary

Four tests among the twelve were selected for interpretation (1) with RELAP 5/MOD 1 computer program for the hydraulic part of the work.

Tests 3, 4, 8, 11(see TABLE 3) were selected for the evaluation; they represent a PORV and a SV opening, with and without a cold water seal.

With many refinements in the models used which we cannot develop here - especially distributing the loop seal water in the downstream piping as an initial condition - the comparison is as follows :

- pressures(see FIGURE11) are in good agreement for spikes and steady state, with a slight offset.
- momentum flux : calculated and measured maximum values and timing differ significantly. There may be a multidimensional flow regime effect and there is also an excitation of the first mode of the drag disc beam.
- support loads show an overestimation of the amplitude though the phase is good for the first cycle. Damping seems to have been grossly under estimated or the assumption of a distributed damping is not correct for the model studied. Indeed, when a straight pipe run is excited and vibrates along its axis on two snubbers, connected pipe segments are subjected to bending which induces few damping whereas the two snubbers along the axis induce much damping.

10 - CONCLUSION

For the discharge of steam with or without water seal into the discharge piping system the tests performed on CHINON B1 showed or confirmed the following points :

- small loads upstream of the valves
- high loads downstream of the valves, these loads being minimized by the piping network (the header especially), a hot water seal, time space between valve openings and being increased in the long PORV 6" downstream piping
- expansible bolts can withstand high loads when properly installed or retightened
- supporting each straight pipe run in its axis is a good procedure
- good condensation efficiency of the PRT

Though discharge piping supports can be designed to withstand higher loads it seems to us preferable, especially for an existing installation and if feasable, to :

- try to avoid cold water seals (by keeping their temperature above saturation temperature at maximum downstream pressure during the discharge)
- phase out value openings (1 second for ex.)
- design a piping which breaks down and splits the water seal as close as possible to the valves
- support the piping straight runs very carefully, as close as possible to their axis
- use snubbers which have a large plastic deformation capacity beyond their maximum design load.

(1) by Intermountain Technologies Inc. Idaho Falls, Idaho U.S.A.

TABLE 1 - QUALIFICATION OF INSTRUMENTATION DEVICES

MEASUREMENT	TECHNICAL PROBLEMS	TECHNICAL SOLUTION	QUALIFICATION
TEMPERATURE (1)	- Fast response sensor between 200 and 350°C - Mechanical resistance to water seal discharge	Chromel-alumel thermocouple with head to groune. Ø = 1.5 mm, protusion = 2 mm (see fig. 1) response time = 0.15 s at 63 %	- 10 m/s flow rate water loop with hot thermal shocks. - on test loop (INDIRA)
PRESSURE (2)	- Fast response sensor (200 Hz) submitted to a thermal shock (200°C) and to a pressure transient (50 bar) in the same time	Thin film strain gage transducer (GOULD) mounted inside a Helmoltz resonator (see fig. 2) 1 - Bandwidth = 1-1000 Hz 2 - No thermal effect during pressure transient 3 - Low sensitivity to acceleration	1 - shaking test with mounting device ($f \leq 4000$ Hz) 2 - Thermal shock test with mounting device ($\theta \leq 80$°C) 3 - Shaker test of sensor in two directions (20 g - 500 Hz) - on test loop (INDIRA)
STRAIN (3)	- Fast response sensor (100 Hz) submitted to high temperature (350°C)	Welded strain gages (VISHAY-MICROMESURE)	Static and dynamic comparison to sticked strain gages.
ACCELERATION (4)	- Measure an acceleration below 20 g - 100 Hz on a hot piping (300°C) submitted to high magnitude, high frequency acceleration	Sensor (ENDEVCO) sticked on a 4 mm thick rubber disc, protected against temperature by a finned rod (see fig. 3) - Bandwidth = 3 - 3000 Hz - Resonance # 1500 Hz in axial direction - Damping = 20 %	- Shaking test with mounting device between 100 and 5000 Hz - on test loop (INDIRA)
MASS FLOW RATE (5)	- Measure a mass flow rate between 5×10^4 kg/ms^2 and 7.5×10^6 kg/ms^2 at 70 bars and 260°C - Natural frequency > 500 Hz	- Two drag discs in two different section, with target on the axis of the piping - natural frequency = 437 Hz on a rigid mounting	- Hydrostatic leak test - Static hanging weight qualification test - Steady state low flow qualification test (water at ambient in reverse and forward flow) - on test loop (INDIRA)
WATER SEAL (6)	- Detect water seal length before valve opening - Measure water seal velocity during valve opening - Operate at 350°C	- 4 ultrasonic transmitter receiver units (fig. 4)	- On test loop (INDIRA) - On site (TRICASTIN 4)
SNUBBER LOAD (7)	- Lateral displacement at piping attachment induces bending	- 2 axial strain gages sticked to snubber rod on a diameter and Wheatstone bridge	- negative : (SAINT LAURENT 2) - positive : on test loop (INDIRA)

(1) 4 sensors in piping and 7 in PRT
(2) 12 sensors in piping and 4 in PRT
(3) 21 on piping
(4) 26 sensors on piping
(5) 2 locations on piping
(6) 4 units combining US sensors and pipe wall thermocouples
(7) 19 sensors

TABLE 3 - TEST LIST AND CONDITIONS

N° (2)	Date	Sequence	Primary system Pressure (BAR)	Discharge duration (S)	Water Seal	Comments
1	11/12/81	Relief Valve 08 VP	163	55	5 Liters	Calibration, RV leaking before test
2	11/13/81	" " 08 VP	164	55	5 liters	Test
3	11/13/81	" " 08 VP	163,5	10	6 liters	Test
4	11/14/81	" " 08 VP	163,8	10	Steam	Test
5	11/14/81	RV 08 then 09 and 10 VP	163	20	08 : 6 liters 09 : 10 " (1) 10 : 10 " (1)	Test
9	11/15/81	Safety valve 13 VP	163,8	10	≥ 27 liters	Calibration, SV leaking after test
10	11/15/81	" " 13 VP	163,8	10	20 liters	Test
14	11/16/81	RV 08 then 09 and 10 VP then SV 13 VP	154	15	08 : 6 liters 09 : 10 " (1) 10 : 10 " (1) 13 : 23 "	Calibration
8	11/16/81	Safety valve 13 VP	164	30	≥ 27 liters	Test
15	11/17/81	RV 08 then 09 and 10 VP then 13 VP	164	15	08 : ≥ 8,5 liters 09 : 10 " (1) 10 : 10 " (1) 13 : ≥ 27 "	Test
11	11/18/81	Safety Valve 13 VP	164	30	Steam	Test
12	11/18/81	RV 08 then SV 13 VP	151	20	08 : 7 liters 13 : 27 "	Test

(1) estimated value, no measurement
(2) identification of the test ; does not always fit with test procedure number.

MODE	RES. FREQ. (Hz)	DAMPING RATIO (%)
1	5.4	7.3
2	7.7	18.2
3	11.7	21.3
4	12.3	1.8
5	15.0	1.6
6	16.5	1.9
7	18.2	2.1
8	21.3	4.3
9	24.7	10.9
10	28.9	1.8
11	34.0	2.0
12	37.0	5.5
13	39.2	2.8
14	41.7	2.6
15	46.7	1.8
16	49.3	3.8
17	52.9	10.1
18	57.0	6.3
19	60.1	3.8
20	64.3	2.1
21	68.4	2.5
22	71.0	3.0
23	78.5	2.0
24	81.2	3.0
25	87.0	3.0
26	90.9	7.0
27	93.0	1.6

Table 2 : Resonance Frequencies and Damping Ratios identified on Pressurizer System

TABLE 4 - INSTRUMENTATION

	Number of Channels	
	Dynamic	Quasi static
Fluid temperature	12	
Pipe wall temperature		8
Static fluid pressure	15	
Total fluid pressure	1	
Fluid mass and velocity	6	4
Support stress	19	
Pipe wall stress	21	
Acceleration	26	
Pipe displacement	7	
Valve stem displacement	4	
Drag disc	2	
Thermocouple cold and hot weld for compensation	2	
Measurements on the pressurizer from the control room	5	
TOTAL	120	12

TABLE 5

MATERIAL	INSPECTION	DURING TESTS	AFTER MECHANICAL TESTS	AFTER DISCHARGE TEST	RESULTS
Class 1 piping	- gamma ray / - dye penetrant } on critical welding	no	yes	yes	nothing to report
Support attachment to piping	dye penetrant	no	no	yes	N.T.R.
Support plates	1 - visual inspection 2 - retightening of expansible bolts	yes	yes	yes	1 - no plate displacement - preloading decreased
Snubbers	1 - visual inspection 2 - dimensional " 3 - quasi-static and dynamic tests	no	no	yes	1 - NTR 2 - one snubber damaged but still operating 3 - NTR
Safety Valve	visual inspection of internals	no	no	yes	grinding of seat and flap was requested.

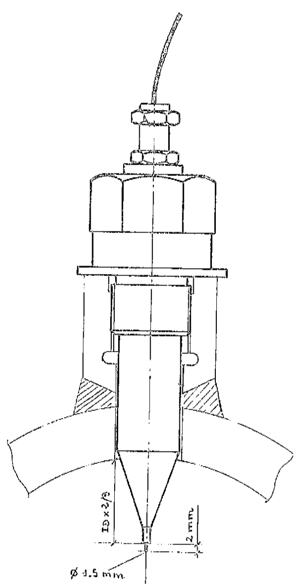


FIGURE 1 : TEMPERATURE PROBE

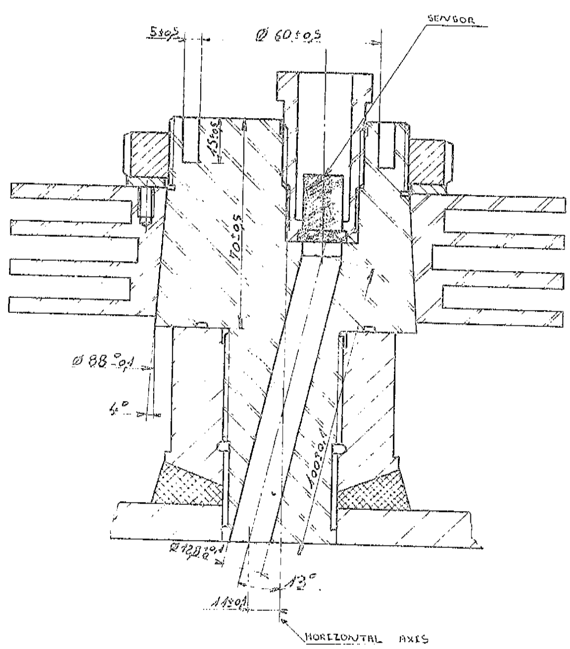


FIGURE 2 : PRESSURE PROBE

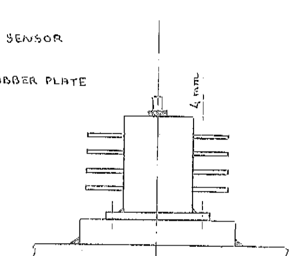


FIGURE 3 : ACCELERATION PROBE

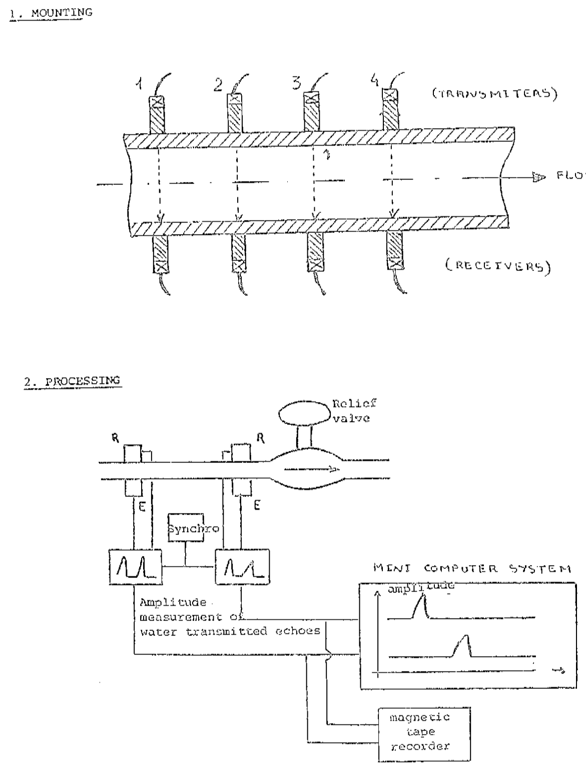
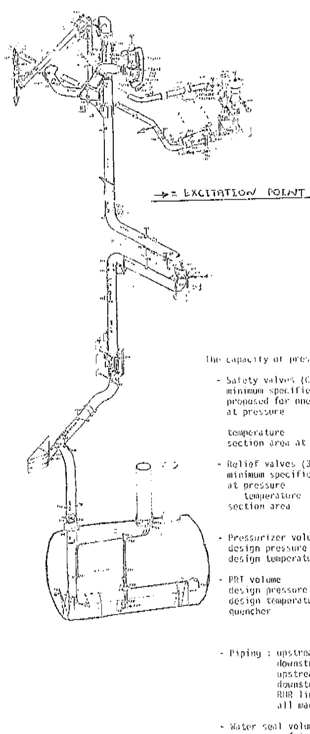


FIGURE 4 : ULTRA SONIC SYSTEM



The capacity of pressurizer discharge valves is :

- Safety valves (CROSBY 6M6)
  - minimum specified flow rate : 400 t/h for 3 valves (steam)
  - proposed for one valve : 177 t/h
  - at pressure : 179,2 bar absolute
    3 % accumulation included
  - temperature : 356°C
  - section area at nozzle : 23,3 cm^2
- Relief valves (3" FISHER barrel type)
  - minimum specified flow rate : 95 t/h (steam)
  - at pressure : 162 bar absolute
  - temperature : 348°C
  - section area : 33 holes 5/16 inch. about 1/2 inc. long
- Pressurizer volume : 40 m^2 approxi:
  - design pressure : 162 bar absolute
  - design temperature : 348°C
- PRT volume : 37 m^3 (25,5 m^3 water)
  - design pressure : 7 bar rel.
  - design temperature : 100°C
  - quencher : 12" OD 902 holes Ø 13 plus 21 holes Ø 13 at downstream end
- Piping : upstream safety valve : 6" OD Sch 160
  - downstream " " : 12" OD Sch 80 S
  - upstream relief valves : 6" OD & 3" OD Sch 160
  - downstream " " : 3" OD & 6" OD Sch 160
  - RHR line 50 m long : 6" OD Sch 10 S
  - all made of 304 L SS
- Water seal volume
  - upstream safety valve : 30 litres approx.
  - upstream relief valve : 10 litres approx.
- Approximate volume between safety and relief valves and the PRT : 3 m^3
  - RHR line 6" OD : 1 m^3
- Primary system total volume : 283 m^3

FIGURE 6 : PRESSURIZER DISCHARGE PIPING SYSTEM

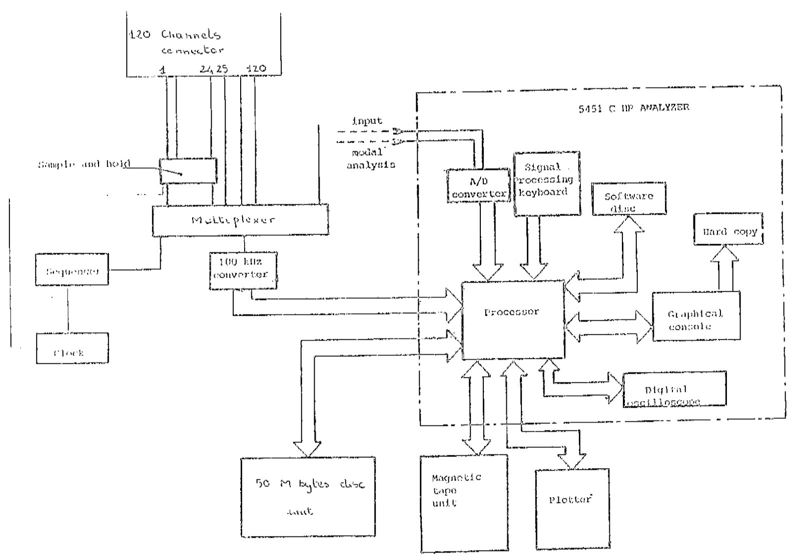


FIGURE 5 : DATA ACQUISITION SYSTEM SCHEMATIC DESCRIPTION

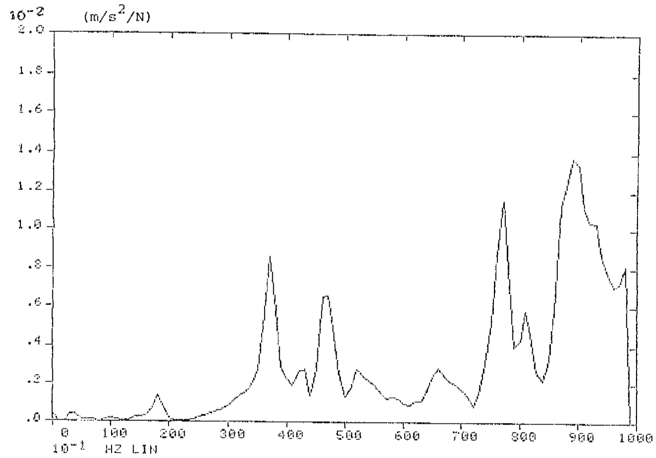


FIGURE 7 : TYPICAL FREQUENCY RESPONSE

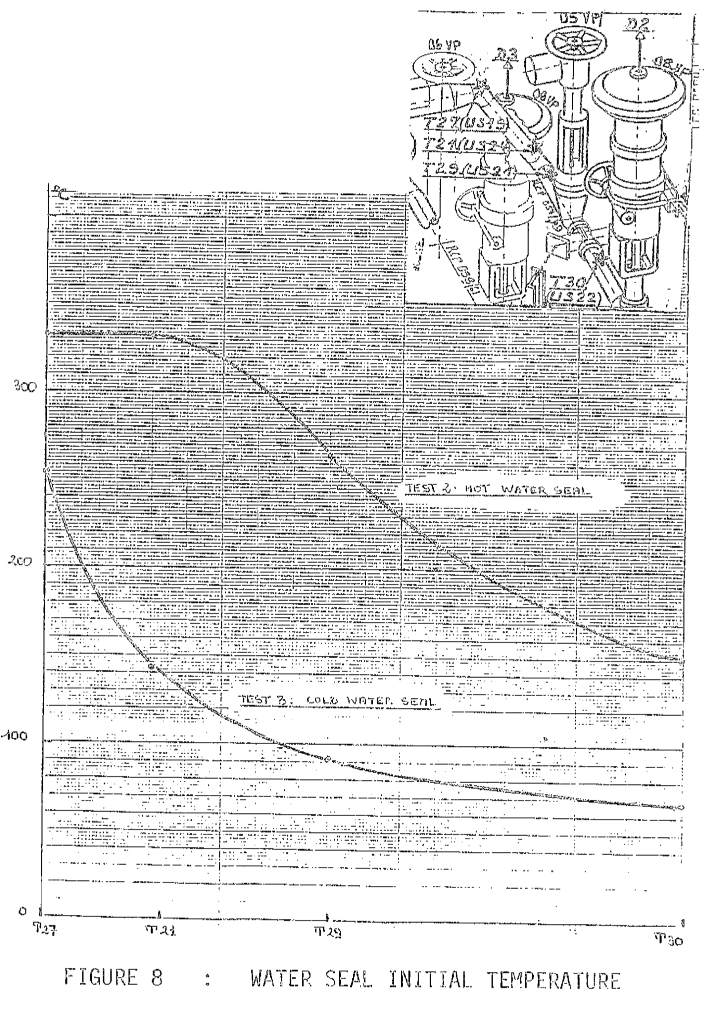


FIGURE 8 : WATER SEAL INITIAL TEMPERATURE

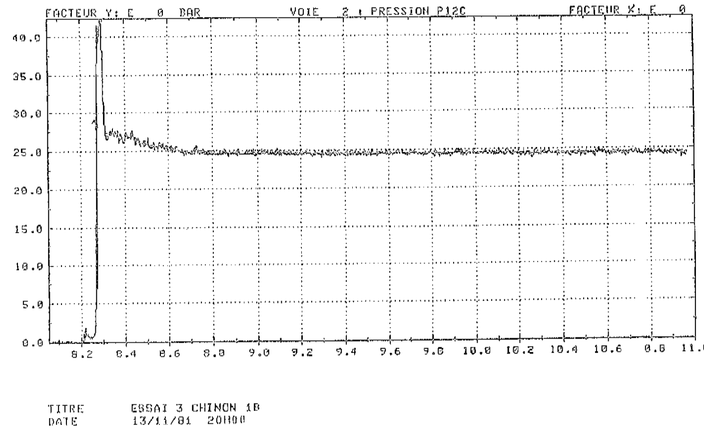


FIGURE 9 : PRESSURE WAVE IN PORV WATER SEAL DISCHARGE

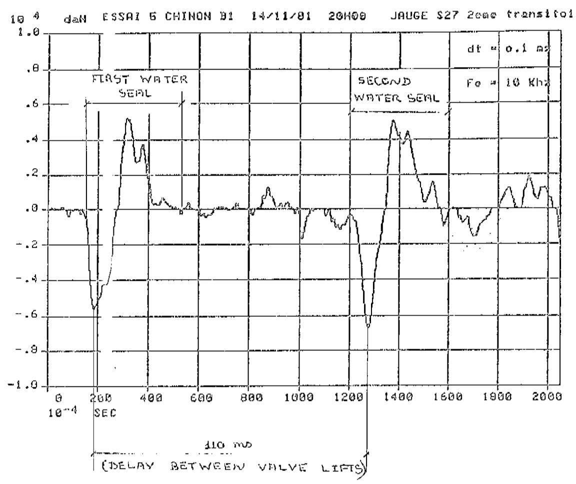


FIGURE 10 : AXIAL LOAD ON SNUBBER

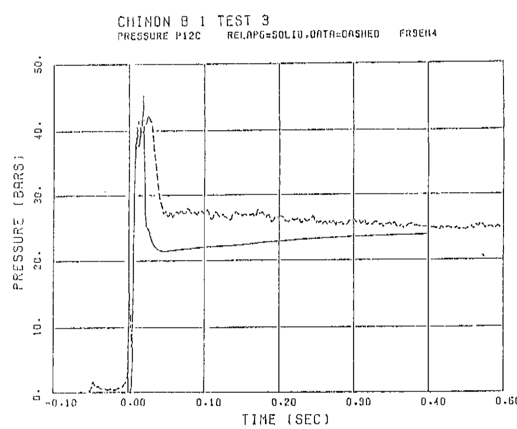


FIGURE 11 : COMPARISON BETWEEN CALCULATED AND MEASURED PRESSURE WAVE - TEST 3

F 2/7*