CSN2-103

Studsvik Arbetsrapport -Technical Note

Projektidentifikation — Project identification	Datum — Date	Rapport nr — Report No.
SKI B39/83-G.2.1/812/82	84-06-04	SD-84/43, NR-84/423

Titel och författare — Title and author

PRELIMINARY DATA COMPARISON REPORT FOR ISP17

An international containment standard problem based on the Marviken full scale experiment Blowdown No 18

Jan-Erik Marklund

ABSTRACT

In the November 1982 CSNI meeting it was decided that the test BD18 from the second series of Marviken full scale containment experiments would serve as a basis for an open international standard problem, ISP17, with STUDSVIK, Sweden as host organization.

The purpose of ISP17 is to get insight in best-estimate modelling capacities of present containment computer codes, primarily concerning

- Vent clearing transients
- Medium-time pressure suppression characteristica.

The present report contains brief information on the basis for the standard problem and a preliminary comparison and assessment of the six submitted results.

The vent clearing transients are quite well modelled by most submittals, while the pressure level development to a large extent depends on the assumptions made for air transfer to the wetwell.

The work has been financially supported by the Swedish Nuclear Power Inspectorate (SNPI).

LIST OF CONTENTS

1.   BACKGROUND AND SUMMARY

Four international containment standard problems
have already been carried out under the supervision
of CSNI/NEA working groups.

-          Two open (blind/open) standard problems
           (1, 2) based on experiments performed by
           Battelle Frankfurt at a 1:64 (volume
           scale) model of the BIBLIS-A reactor.

-          An open standard problem (3) based on an
           experiment in a small-scale (~2 m^3) two-
           compartment model at the Australian Lucas
           Heights Laboratories.

-          A blind standard problem (4) based on the
           full-scale HDR experiments, carried out
           during 82/83.

All of these experimental facilities simulate dry
containments.

In the February 1982 meeting (5) with the Contain-
ment Working Group of CSNI, interest was expressed
for a standard problem based on some experiment
in a BWR-type containment, i.e. with a pressure
suppression pool.

A proposal (6) made by Sweden for an open standard
problem based on some test of the altogether 25
Marviken full scale containment experiments (7, 8)
was approved as a potential candidate for ISP17 by
the CSNI Principal Working Group meeting in
October 1982.

After consultations with potential participants,
the test No 18 was chosen for the standard prob-
lem, and this was approved by the CSNI full meet-
ing in November 1982.

Specifications (9) for ISP17 were distributed in
June 1983 and a workshop (10) discussing these
specifications and other questions related to the
standard problem was held at Marviken on August 18,
1983.

The deadline for submittals was originally set to
December 31, 1983 but was later moved 2 months
ahead to February 29, 1984.

Submittals were obtained from four participants,
ECN (Energy research Centre, Netherlands), Univer-
sity of Pisa (Italy), VTT (Technical Research
Centre, Finland) and STUDSVIK (Sweden). Italy and
Sweden contributed with two different submittals,
so there were altogether six submitted results as
well as some parameter studies from Italy, Finland
and Sweden.

The codes used for the submittals were ARIANNA-1
(Italy), CONTEMPT-LT/26 (Italy), CONTEMPT-LT/28
(Finland), COPTA-7 (Sweden) and ZOCO-V (Nether-
lands).

ARIANNA-1 is the only dry containment code partici-
pating and as such could quite naturally produce
sensible results only for the time up to the vent
clearing, which occurred around 1.4 s after blow-
down start. Still this run was valuable, since
due to the many drywell nodes (17 compared to 4
and 1 for the other codes) it could give more
information on pressure differences and flow paths
etc than the other codes.

All the other codes contain wetwell models and
could therefore produce results for the whole blow-
down period. Two of these codes (COPTA and ZOCO)
allow subdivision of the drywell into a fairly large
(around 10) number of subcompartments, while the
two CONTEMPT versions do not have that possibility.

The evaluation of the results was split into two
different time-frames, short-time cases covering
the first 4.4 s (0 - 1.4 s for the ARIANNA-1 run)
and long-time cases covering the period 0 - 200 s
(0 - 75 s for the ZOCO-V run).

The short-time cases were further separated into
two groups, group A containing cases with subdiv-
ided drywell and group B with one-node drywell
modelling. This separation was made mainly to en-
sure readable comparison diagrams.

For the short-time cases the most important par-
ameters are the differential pressures, the vent
clearing transient and the pool swell phenonema.

The differential pressure between drywell and
wetwell as well as the vent clearing transient
are quite well modelled by most of the codes.

The differential pressures in the drywell are
also fairly well modelled by those codes allowing
this (ARIANNA-1, COPTA-7 and ZOCO-V).

Only two of the codes, COPTA-7 and ZOCO-V, contain
special pool swell models, that allow a fairly
correct modelling of the pool swell phenonema.

In the long-time cases, the parameter of largest
interest is the pressure build-up. This is influ-
enced by the mass transfer to the wetwell and by
heat soakage of the pool and into solid structures,
such as the concrete confinements and the great
number of metal structures in the containment.

The pressure levels after roughly 50 s are to a
large extent controlled by the total mass of air
transferred from the drywell to the wetwell through
the vent pipes. Different approaches were used by
the codes to model the air transfer. Most codes
were using knowledge of the measured air flow
rates. Only one of the submittals (ZOCO-V) tried
to avoid this by using a 4-compartment subdivision
of the drywell throughout the transient.

As a whole the success in the modelling was satis-
factory, and useful experiences were obtained.

Minor deficiencies in code behaviour were dis-
covered by some of the participants during the
runs and corrected code versions were created.

The present report contains first a brief summary
of the test conditions for the Marviken tests. Than
there are given summary data for the selected test
BD18. Finally the main part is devoted to descrip-
tions of the codes used and comparisons of the
submitted results as well as related parameter
studies. In appendices are given comments received
from the participants after the presentation of
draft comparison report.

2.   EXPERIMENTAL BASIS AND CHOICE OF TEST

The first series of 16 full scale containment re-
sponse tests (7) was carried out at Marviken,
Sweden, in 1973 - 74.

A second series of nine tests (8) was carried out
in 1976.

The measurement system had been significantly aug-
ment as compared with that of the previous test
series and allowed oscillations to be studied for
frequencies up to 100 Hz.

These experiments were carried out as a multi-
national project, as in the first series of tests.
The organizations represented were from Denmark,
the Federal Republic of Germany, Finland, France,
Japan, the Netherlands, Norway, Sweden and the
United States.

In the remaining part of this chapter will be given
a brief description of the common test conditions
for the second series of Marviken experiments, as
well as a motivation for the choice of blowdown 18
as the basis for ISP17.

2.1   Brief description of the test facility

The Marviken station (see Figure B.1) was originally
built to operate as a boiling heavy-water direct-
cycle reactor with natural circulation. The station
had been completed up to acceptance testing, inclu-
ding pre-operational light water tests.

The main parts of the facility are the pressure
vessel and the containment (see Figure B.2). Dis-
charge flow from the pressure vessel was fed into
the containment through a discharge pipe.

The containment consists of a drywell part, con-
nected with the wetwell through a vent system.

2.2   Test program for the Marviken II tests

In the second series of tests a total of 9 blow-
downs were performed starting with Blowdown 17 in
order to indicate the continuity with the first
series of 16 blowdown test. A presentation of the
main test parameters in the second series is given
in Table A.1.

In all tests the pressure vessel was filled with
280 - 290 tons of water which were heated and
pressurized to approximately 6 MPa.

In Blowdown 17 the water was heated to a nearly
homogeneous saturation temperature of 260°C while
in all the subsequent blowdowns a temperature
stratification was established with about 25°C
subcooling in the lower region and with saturation
temperature in the upper region. The reason for
establishing temperature stratification was to
prolong the period of subcooled single-phase
liquid flow into the containment and facilitate the
measurements of the discharge flow rate in the
early phase of the blowdowns.

2.2.1   Containment conditions

The changes that were made in the containment be-
tween the tests were largely confined to the vent
system and the wetwell as shown in Table A.1.

The first change, made after Blowdown 17, was the
blocking of twenty-nine vent pipes which reduced
the total vent pipe flow area from around 4 m^2 to
around 2 m^2. Before Blowdown 25, the last blowdown

run, a special arrangement was made, referred to
as the single cell, in which another vent pipe
was chosen to be open on the secondary side of the
partition wall.

The purpose of the single cell, consisting of a
vent pipe encircled by a pipe of larger diameter
(900 mm) was to permit comparisons of the press-
ure oscillations and pressure spikes for an iso-
lated vent pipe in a bounded single cell with those
in a multi-vent region.

The pool partition wall was installed between
Blowdowns 20 and 21 and divided the wetwell pool
into two regions, the primary region with 27 open
vent pipes and the secondary region with the
single vent pipe.

Before Blowdown 24 two of the four blowdown
channels were blocked in order to establish the
so-called detuning of the vent system.

Variations in the depth of the wetwell pool and
thereby in the pool mass and vent submergence
were made in Blowdowns 20 and 25.

The containment tightness was investigated by
means of air pressurization before the series of
tests was begun.

2.3   Instrumentation and data acquisition
         systems

A list of the data channels that comprise the
measurement system for the blowdown tests is given
in Table A.2. This list is not completely valid for
all tests as modifications were made between the
tests.

A lay-out of the measurement system is shown in
Figure B.3. The sensing elements were in most cases
located at the measurement positions in the press-
ure vessel of in the containment (cf Figures B.4,
B.5 and B.6). For some channels, mainly those meas-
uring pressure, the sensing elements were located
outside the containment with a connecting arrange-
ment to the measurement position.

2.3.1   Types of sensing elements and other equip-
ment

Pressure and differential pressure

Strain gauges were used to measure pressure and
differential pressure in the vessel.

Temperature

All temperatures were measured with thermocouples
of chromel-alumel type. They were shielded with
inconel, insulated with magnesium oxide and had an
insulated measuring junction. Three different di-
mensions, 0.5 mm, 1 mm and 2 mm in diameter, were
used so as to meet the different time-constant re-
quirements.

Mass flow

The items of measurement related to mass flow rate
were those of the pitot-static tubes, the radio-
active tracer method and the infrared light attenu-
ation technique.

The pitot-static tubes, installed in the main dis-
charge pipe, were merely aimed at measuring the
discharge flow rate in periods of subcooled liquid
flow.

The radioactive tracer method and the infrared
light attenuation technique were adopted to measure
vent flow related parameters in one of the four
blowdown channels.

Liquid level and phase boundary

The level probes installed in the vent pipes and
in the wetwell were of the spark plug type.

Measurements of the liquid level were also per-
formed with differential pressure channels.

Impact load

The impact targets above the wetwell water pool
exposed, in Blowdowns 17 - 20, flat and quadratic
surfaces of stain-less steel which were welded on
to horizontal rods that were fastened to vent
pipes. In the subsequent tests cylindrical targets
were also used.

The sensing elements were strain gauges and ac-
celerometers. The triaxial piezoresistive acceler-
ometers failed to work due to water leakage.

2.4   Data accuracy

The error limits of the data channels are deter-
mined in the form of maximum errors and probable
errors. The maximum error calculation applied to
the whole channel gives with high confidence the
limits of the systematic errors. The probable
error is defined as one standard deviation and
is a measure of the spread of data from identical
channels measuring the same quantity. Provided the
systematic errors are negligible the probability
that the data lie within the probable error limits
is generally 68 per cent.

The errors thus evaluated are presented in
Table A.3.

The error limits of the calculated data, referred
to as non-measured quantities, are more difficult
to deduce since in addition to considerations of
the accuracy of the basic data an assessment of
the calculational technique is required.

2.4.1   Discharge flow rate

The discharge flow rate is for most of the blow-
down periods determined from the DP-over-vessel
data with error limits of about ± 7 per cent. For
the more rapid transients the errors are larger
but are not likely to exceed ± 20 per cent.

2.4.2   Specific enthalpy

The uncertainty of the specific enthalpy of the
discharge flow is estimated at $^{+30}_{-10}$ kJ/kg which
is equivalent to $^{+3}_{-1}$ per cent.

2.4.3   Flow rate of air into the wetwell

During periods of relatively stabilized air flow
rate the error is estimated at 5 - 6 per cent but
larger errors exist for short periods.

2.4.4   Steam flow rate into the wetwell

Error limits of 10 - 15 per cent are estimated for
relatively stable flow rates while in periods of
strong flow variations the error limits may be as
large as 30 - 40 per cent.

2.4.5   Water flow rate into the wetwell

No reasonable accuracy can be claimed for the flow
rate of water into the wetwell pool.

2.4.6   Gas velocity in downcomers

The error limits of the velocity measured with the radiotracer method are ± 5 per cent.

2.4.7   The infrared absorption method

The evaluation of maximum error limits of the infrared measurements yielded the following results:

Velocity (determined for droplets)	± 5 per cent
Density of steam	normally < ± 10 - 12 per cent
Density of air	from about ± 10 per cent early in the blowdowns to the order of a factor of ten in the later part of the blowdowns
Concentration of liquid droplets	errors are too large for a meaningful evaluation of water flow rate

2.5   Choice of test for ISP17

In six of the blowdowns in the Marviken II tests most of the air in the drywell was transferred to the wetwell by a prepurging process before the main blowdown took place. It means that essentially no pool swell was encountered in these six experiments. Therefore one of the remaining three experiments BD17, BD18 and BD21 was preferred as basis for a standard problem.

In BD21 the pool was subdivided into two parts. BD17 and BD18 were relatively similar to each other. The main differences between them were

-       The flow area was larger in BD17 than in BD18.

-          The initial temperature profiles in the
           pressure vessel were different, giving
           BD18 a longer period of subcooled flow
           through the discharge pipe than BD17.

-          BD17 has been used by many code developers
           as a reference case.

With these points in mind, BD18 was finally chosen
to be the basis of the standard problem ISP17.

3.   BRIEF PRESENTATION OF THE SELECTED
          STANDARD PROBLEM

In this chapter we will first give a brief summary
of the data for the Marviken blowdown 18, focussing
on the data most important for the evaluation of
the standard problem, and then briefly relate the
requested computations for ISP17.

The standard problem covers only the thermal-
hydraulic part of the experiment, but not the dy-
namic part (oscillations). The reason is that gen-
eral containment codes normally are not capable of
handling the oscillatory phenomena correctly. For
such purpose special codes are used.

3.1   Basic data for Marviken Blowdown 18

The relevant data for Marviken Blowdown 18 are
described in a set of reports, of which the most
important are given in this report as Ref 11
through Ref 17. Below will be given a brief sum-
mary of the most important data for the ISP17
computations.

3.1.1   The containment

The Marviken containment is of the pressure-
suppression type, divided basically into two com-
partments, the drywell and the wetwell. The latter
did contain a condensation water pool, connected
to the drywell by a vent system (see Figure B.2).

The drywell, consisting of several subcompartments,
had a total active air volume of 1 972 m^3 in BD18
(see Table A.4). In this volume is included the air
in the open vent pipes, but not in the plugged vent
pipes. The air volume of the drywell openings is
also included.

The wetwell is located beneath the drywell. The
initial depth of the wetwell water pool in BD18
was 4.51 m, giving an initial active water volume
of 556 m³ and an initial air space volume of
1 583 m³. In the active water volume is included
5.6 m³ of water in the open vent pipes.

A schematic drawing of the containment is shown
in Figure B.7. A possible subdivision into a 5-node
model, used by two of the participants in ISP17,
is also indicated in that figure.

The active cross-sectional area of the wetwell
varies considerably for different distances above
the wetwell floor (see Figure B.8). For the pool
surface levels relevant for BD18, the variation
is between 45 m² and 119 m², being 108 m² for most
of the pool swell distance.

3.1.2   Vent system

The vent system consists of 4 steel pipes, with a
1.2 m inside diameter, which connect the lower dry-
well to a header located in the wetwell air space.
From this header a total of 58 vent pipes, around
5.5 m long (inside) and with a 0.3 m inside diam-
eter, lead vertically downwards into the wetwell
water pool. Thirty of the vent pipes were blocked
(see Figure 9) during BD18, leaving 28 active vent
pipes, i.e. totally 1.98 m² flow area. The initial
submergence depth was 2.81 m.

3.1.3   Drywell openings

The minimum flow areas for the drywell openings
are listed in Table A.5. When lumped together for
the 5-Room case in Figure B.7, the total flow
areas become as in Table A.6.

3.1.4   Heat conducting structures

The Marviken containment contains a vast amount of
structures that could conduct and absorb heat.
These structures are described in the test report
MXB-101 (Ref 11). A summary of the total surfaces
areas is given in Table A.7 and suggested values
for some heat soakage constants in Table A.8. Be-
low follows a brief discussion of possible model-
ling of these structures. A more detailed dis-
cussion is given in Ref 18.

A.   Aluminium

The aluminium present in the containment was very
thin, usually around 1 mm thick, and could there-
fore be represented by its total heat capacity.
The total amount in drywell was 1 969 kg, rep-
resenting a heat capacity of 1.76 MJ/K if C_p =
= 896 J/kg/K is used, see Table A.9. No aluminium
was present in the wetwell.

B.   Structures made of steel or concrete

The total steel content in the containment is
listed in Table A.10. Some of this is thin and
could probably be treated as an additional heat
capacity, while some is thicker and the heat con-
ductivity has to be considered.

The blowdown pipes and possibly the vent pipes are
the only structures that in any significant amount
could contribute to heat flow by conduction between
rooms. Most of the concrete walls have a thickness
of 0.5 m or more, which means that their interior
will not be affected by short transients. The
thicknesses used for concrete walls in the models
are therefore of no great importance, except
possibly for some of the thinnest walls.

3.1.5   The pressure vessel

The pressure vessel had a 5.22 m inside diameter
and a height including the top-cupola of 24.55 m.
The net volume of the vessel, i.e. the free water
space was 420 m^3. In BD18 the pressure vessel was
filled with 278 tons of water which was heated
and pressurized to 4.6 MPa. A temperature stratifi-
cation was established with about 25°C subcooling
in the lower region and with saturation temperature
in the upper region (cf Figure B.10). The reason for
establishing temperature stratification was to pro-
long the period of subcooled single-phase liquid
flow into the containment and facilitate the
measurements of the discharge flow rate in the
early phase of the blowdowns.

The pressure vessel was thermally insulated from
the containment during the blowdown.

3.1.6   The discharge pipe

The pipe rupture was simulated in Room 122 of the
lower drywell (see Figure B.2).

The design of the discharge outlet is shown in
Figure B.11.

3.1.7   Discharge flow

Measured and evaluated data for the discharge flow
are shown on Figures 12, 13 and 14 (copies of Dia-
grams E:4 through E:6 in Ref 14).

In Table A.11 are given suggested values of mass
flow and specific enthalpy, as manually extracted
from these curves. No data were given for specific
enthalpy after ~ 120 s, but a value of 1 140 kJ/K,
corresponding to saturated liquid, appears appro-
priate to use.

3.1.8   Initial conditions

The initial conditions for BD18 are given in
Ref 14. A summary of these data, relevant for
2-node models and for the 5-node model of Fig-
ure 7, is given in Table A.12.

3.2   Requested computations

The standard problem is intended to cover only the
thermal-hydraulic part of the experiment, but not
the dynamic part (oscillations). The reason is that
general containment codes normally are not capable
of handling the oscillatory phenomena correctly.
For such purpose special codes are used.

Each participant in the standard problem was to
perform the calculations with the computer code
available to him and in such a way that the time
history behaviour occurring in the experiment of
pressures, temperatures, masses in the containment
compartments, as well as the pressure differentials
between the containment compartments, were precal-
culated as realistic as possible.

Calculations were suggested for 3 time intervals,
0 - 1.4 s, 0 - 4.4 s and 0 - 220 s. Since there
was only one submittal for the 0 - 1.4 s interval,
this submittal will be discussed together with the
0 - 4.4 s submittals.

For the representation of the containment two dif-
ferent approaches were offered, either

-           Full representation of both drywell and
            wetwell

or

-           Starting with the flow in the vents (vent
            pipe header), thereby avoiding the prob-
            lems connected with representation of the
            quite complicated Marviken drywell.

The second alternative was not used by anyone, but
instead a similar approach was used by some par-
ticipants, controlling vent flow, in particular
air flow, by input modifiers.

The variables for which results were requested are
listed in Table A.13. The variables are indicated
on basis of measuring positions, as shown in Fig-
ures B.4 through B.6.

4.   SUBMITTED RESULTS

Results were submitted for all three time-periods
specified in Table A.13. Since there was only one
submittal (ARIANNA-1, Italy) over the 0 - 1.4 s
time period, this case will be discussed together
with the 0 - 4.4 s cases. We will thus in the fol-
lowing discuss two time-periods, 0 - 4.4 s (from
now on denoted by "short-time" period) and 0 -
220 s ("long-time" period).

4.1   Computer codes used

Submitted results were obtained from the codes

-         ARIANNA-1 (University of Pisa, Italy)

-         CONTEMPT-LT/26 (University of Pisa, Italy)

-         CONTEMPT-LT/28 (VTT, Finland)

-         COPTA-7 (STUDSVIK, Sweden)

-         ZOCO-V (ECN, Netherlands)

In Section 4.1.1 through 4.1.5 a brief description
will be given of each of these codes, mainly as
given in the submittal reports (Ref 19 through 22).
Finally, in Section 4.1.6, the code differences of
greatest importance to the standard problem will
be shortly discussed.

4.1.1   ARIANNA-1 Code

ARIANNA-1 is a code (23) for the analysis of thermal-hydraulic transients in a dry containment.

It can provide up to 100 volumes connected by 200 junctions, 20 of which may have time-dependent or Δp-dependent areas.

In each volume a stagnant homogeneous mixture of steam, air and water is assumed. The up-to-date version of the code includes a simplified model of deentrainment from which a pool results in each volume. This model takes into account only the effects of the fall-down of water droplets with low kinetic energy; the water impingement on internal structures is not taken into consideration by the ARIANNA-1 Code.

Mass and energy addition, into as many as five individual volumes, is provided.

The transient is described as a sequence of quasi-steady states. Mass and energy flows in each time-step are based on the thermodynamic conditions of the previous time-step.

The calculations are based on the following assumptions:

-       stagnation pressures in the connected
        volumes give the Δp across the vent;

-       fluid properties are assumed on the basis
        of the thermodynamic properties of the
        upstream volume and are frozen throughout
        the flow process.

The flow models used for the calculations are summarized in Table A.14.

Thermodynamic equilibrium is assumed in each volume; the state variables are determined by the solution of the state implicit equation with an iterative method.

For the calculation of the ISP17 a special compartment model has been introduced in ARIANNA-1. For this compartment the pressure is calculated by a time dependent input function and can be used to simulate the wet-well backpressure at the end of the vent pipes.

Particular care is given to the modelling of the heat structures and the heat transfer coefficients, so that it is possible:

-     to provide up to 100 heat structures;

-     to define up to 25 different materials;

-     to choose from among three geometrical shapes (slab, cylindrical and spherical), described as one-dimensional;

-     to define up to 25 constant, up to 25 time-dependent and 1 structure-temperature dependent heat transfer coefficients;

-     to use the Uchida correlation, a natural convection model and/or the irradiation model.

ARIANNA-1 cannot presently* predict the long-term behaviour of containment systems, because the compartments modelled with this code may contain two separated regions (vapor and liquid pool), but pool boiling, evaporation and steam condensation are not allowed.

---

*   A new version of the ARIANNA-2 Code which takes into account these phenomena and the carry-over of droplets between adjacent volumes is under development at DCMN.

4.1.2   CONTEMPT-LT/26 Code

CONTEMPT-LT/26 is a well known computer code (24)
specifically written for the long-term analysis
of the containment transient during a LOCA, par-
ticularly in pressure suppression systems (see
Table A.15). The code can be used to model one
to four compartments (vessel and suppression pool
included), together with the engineered safety
systems (as fan coolers and/or water sprays)
present in the containment.

The code is not suitable for the analysis of the
transient in a subdivided drywell, because the
compartments are specialized; only compartment
Number 3 can be used to simulate the drywell of
a pressure suppression containment.

4.1.3   CONTEMPT-LT/28

The analyses have been performed using version 2
of the CONTEMPT-LT/28 code, revised by VTT. The
additions and corrections made to the original
program (25) are the same as presented in refe-
rence 28, excluding the subprogram HEAT which
was recoded for the LT/28-version by the supporter.
The main remedies of the version used, are the
updatings of the volume and internal energy of
vapor regions caused by changes of liquid region
volume, and the addition of a model for steam
flow through the wetwell pool. The version has
also a new output routine, which allows to plot
all variables existing in the common areas. A
brief description of the code follows below.

CONTEMPT-LT/28 is a digital computer program,
written in FORTRAN IV, developed to describe the
long-term behaviour of water-cooled nuclear
reactor containment systems subjected to postu-
lated loss-of-coolant accident (LOCA) conditions.
The program calculates the time variation of com-
partment pressures, temperatures mass and energy
inventories, heat structure temperature distri-
butions, and energy exchange with adjacent com-
partments. The program is capable of describing
the effects of leakage on containment response.
Models are provided to describe fan cooling and
spray cooling engineering safety systems. Up to
four compartments can be modeled with CONTEMPT-LT,
and any compartment except the reactor system may
have both a liquid pool region and an air-vapor
atmosphere region above the pool. Each region is
assumed to have a uniform temperature, but the
temperatures of the two regions may be different.
CONTEMPT-LT can be used to model all current
boiling water reactor pressure suppression systems,
including containments with either vertical or

horizontal vent systems. CONTEMPT-LT can also
be used to model pressurized water reactor dry
containments, subatmospheric containments, and
dual volume containments with an annulus region,
and can be used to describe containment responses
in experimental containment systems.

As already mentioned the most significant changes
in the code are directed to the vapor regions and
steam condensing in the liquid pool. The influence
of the volume (surface) changes of the liquid pool
to the vapor region balance was not taken into
account in the original version. As to the wet-
well the updating of vent pipe submergence depth
and static back pressure was failing also. These
are now corrected in the VTT versions.

The original condensation model for vent steam
assumed that the air rises from the wetwell pool
fully dry. This has been replaced by a more natural
model, which transfers air into the vapor region
in the state of 100 % humidity, i.e. steam accom-
panying air has a partial pressure corresponding
the saturated pressure of water in the pool tem-
perature.

In connection with the wetwell vapor region heat
balance it is possible to choose a use of c_p of c_v
(specific heat at a constant pressure or at a
constant volume) for energy increase caused by
added air. Naturally c_p, i.e. enthalpy was used
in these analyses. The use of c_v omits the com-
pression work made by gas flowing into the control
volume.

The CONTEMPT-LT program can model four compart-
ments. The primary reactor compartment is, however,
rather simple having one region only. The water

discharge rate from the reactor to the drywell
has to be given by an input table. The primary
model has not been utilized in the analyses
under discussion.

Each of the remaining three compartments: drywell,
annular (or dual) compartment and wetwell has two
regions, a vapor region and a liquid region. These
cannot be divided into subcompartments, and are
assumed to be in thermal equilibrium. However, the
temperatures of the two regions of each compart-
ment can be different. In the energy and mass
balance of the regions several activities can
be taken into account. These include direct
additions of water, steam, air and energy, heat
transfer into structures and between compartments.
There is no educated model for liquid water in
the vapor regions. All water condensed from steam
is dropped immediately on the bottom or, in the
case of suppression containment, kept optionally
floating in the gas region.

The vent model has a dynamic part for water clear-
ing and a stationary part for choked or unchoked
gas flow. It is possible to describe rather com-
plicated flow systems with different elements and
flow paths. However, only a multiple of a straight
pipe is modelled in the present analyses. The
irreversible energy looses in the other parts of
drywell have been equivalenced and added to the
entrace coefficient.

The code provides the capability to allow a user
to modify the mixture composition of the flow
through the vents. This can be achieved by vent
flow mass fraction modifiers, which are used to
calculated the final mass fractions. Modifiers
are applicable for all mixture elements: liquid

water, steam and air. Liquid water can also be
separated through a distinct input constant.
Modifiers are time dependent and given by an
input table.

The CONTEMPT-LT code applies a multilevel iteration
process for numerical solution of balance equations.
The process has also a certain trial procedure
for temperature. Heat transfer to the structures
is calculated by means of Crank-Nicholson implicit
scheme. The vent clearing process utilizes a
five step Runge-Kutta technique.

4.1.4   COPTA-7

COPTA is a computer model for analyzing pressure
and temperature transients in a multicompartment
containment building, resulting from a postulated
loss-of-coolant accident. Both pressurized water
reactor dry containments and boiling water
reactor pressure-suppression containments can be
modelled.

The analysis is performed by dividing the contain-
ment into an arbitrary (but limited) number of
compartment, connected by an arbitrary number of
pipes and orifices. Each compartment is normally
assumed to contain a gaseous and a liquid phase,
the phases need not be in thermal equilibrium
with each other. The two phases may exert influence
on each other by mass and energy transport
across the liquid surface - water drops falling
into the liquid phase, air and steam bubbling up
from the liquid and heat transfer across the
surface. Simplier compartment models, assuming
e.g. thermal equilibrium, are also available.

The gaseous phase will contain non-condensable
gases (normally air) and either super-heated or
saturated steam and may contain entrained droplets.
Up to 5 different non-condensable gases may be
treated at the same time. The entrained water
droplets fall down to the liquid phase by gravity.

The liquid phase will contain subcooled or
saturated water and may contain air/steam bubbles.
The air bubbles formed e.g. after vent clearing
in a BWR LOCA will rise to the pool surface and
also carry steam, corresponding to saturation
conditions, to the gaseous phase. There is a
choice between two different vent clearing and
pool swell models, one simple, based on a constant
bubble rise velocity, and one more sophisticated.
In other problem areas, boiling may occur, in
which case steam bubbles are formed, and rise to
the gaseous phase.

For each compartment the conservation equations
for mass and energy are solved for each phase
and each component. The flow between connected
compartments is calculated using the linear
momentum equation.

The computer model also considers such phenomena
as heat transfer to internal structures and
walls (using the one-dimensional heat equation),
cooling of primary and secondary containment
with fans or water spray (with optional heat
exchangers), reversed flow through vaccum-breakers
and arbitrary heat inputs (resulting e.g. from
hydrogen burning).

Mathematically the problem is formulated as a
system of non-linear differential equations and
the program contains three different numerical

methods for solving these equations, two explicit
methods which are used mainly for short-term
transients and testing, and one implicit method
based on the midpoint rule which is recommended
for long-term transients.

The version COPTA-7 used for ISP17 differs from
the version COPTA-6, described in the basic code
description (26) mainly in the following aspects

-       Extended flash models (allows inter-
        polation between the two flash models
        contained in COPTA-6).

-       Allows the user to specify that some
        given amount of air will not participate
        in the vent pipe flow (implemented
        specially for ISP17).

4.1.5 ZOCO-V

The calculations for ISP17 are performed with the
modified code ZOCO-V. A full description of the
code is given in Ref 27. The ZOCO-code is a multi-
node model and the communication between the nodes
is done by a one-dimensional analytical model for
the flow paths. In principle the following
equations are used:

mass balance $\frac{d}{dt}m = F_i - F_o$

energy balance $\frac{d}{dt}mu = F_i h_i - F_o h_o + Q$

mass flow $F = C_d\, A\, \sqrt{\frac{2\Delta P}{v}}$

equation of state $P = f(\rho, T)$

heat transfer $Q = \alpha A(T - T_{wall}).$

Including a model for the wall temperature these
equations represent the total model. The nodes may
consist of water, steam and air in homogeneous
thermal hydraulic equilibrium with each other. The
following changes are made compared to the original
ZOCO-V version:

a   An automatic switch from superheated steam
to equilibrium conditions with water.

b   Heat transfer to walls. Instead of cal-
culating the boundary wall temperature,
the mean temperature of the outer wall is
changed from $Q = \alpha A(T - \overline{T_{wall}})$ into

$$Q = \alpha_t A(T - T_{wall}) \text{ where } 1/\alpha_t = 1/\alpha + \sigma/2\lambda.$$

c   The carry-over factor is defined as that
part of all the water in the room which
is as particles in the steam-air mixture.

d   Waterlift-model.
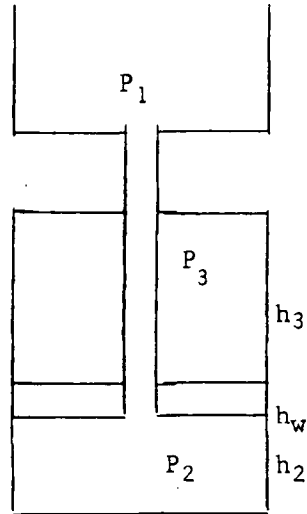
A_v = vent area

A_p = pool area

k = $\frac{cp}{cv}$ air

h_w = submerged length of the vent pipe

g = 9.81 m/s²

F_i = air flow

h_i = $c_{p(air)}$ T_i

D_v = vent diameter

V_s = pool surface velocity

V_v = velocity in the vent

The length of the vent pipe is extended with its diameter. Moment of vent clearance:

$$P_2 = P_1 \quad T_2 = T_1$$

$$h_2 = \frac{\pi}{4}D_v^2 \times D_v / A$$

$$(mu)_2 = P_2 V_2 / (k-1)$$

$$v_s = \frac{Av}{Ap} v_v$$

After vent clearance:

$$\frac{d}{dt}(mu)_2 = F_i h_i - P_2 A_v$$

$$\frac{d}{dt}(mu)_3 = P_3 A_v$$

$$\frac{d}{dt} v_s = (P_2 - P_3)/(\rho_w h_w) - g$$

$$\frac{d}{dt} h_2 = v_s \qquad \frac{d}{dt} h_3 = -v_s$$

$$\frac{d}{dt} m_{2air} = F_i$$

It is assumed that for the calculation of the
waterlift the steam condensates immediately in
the wetwell:

$$P_2 = (k - 1)(mu)_2/(h_2 A_p)$$
$$P_3 = (k - 1)(mu)_3/(h_3 A_p)$$

The range of application of the code ZOCO-V for
the calculation of temperatures and pressures in
the containment is:

pressure	.02 - 5.0 bar
temperature	18 - 152°C.

The maximum number of compartments is 11. The
possible combinations are:

a   One wetwell compartment and 1 - 10 com-
        partments of drywell type.

b   No wetwell compartment and 1 - 11 com-
        partments of drywell type.

4.2   Basic input data used

A summary of some of the basic input data used by
the submittals is given in Tables A.16 through
A.19.

The main differences concern

- Drywell heat absorbing areas (Table A.16)
- Heat transfer coefficients (Table A.17)
- Nodalization (Tables A.18 and A.19)
- Flashing (Tables A.18 and A.19)
- Air modifiers (Tables A.18 and A.19)

A brief discussion of these is intended to be
included here later on.

4.3   Main differences between codes and
           data as related to ISP17

A summary of some basic code characteristics is
given in Table A.15.

ARIANNA-1 is a dry containment code. It can thus
not treat the wetwell phenonema. The gas volume of
the drywell did, however, increase due to the water
plug movement only by less than 0.6 % up to vent
clearing. Therefore it is quite possible to use
such a program for the period up to vent clearing
(0 - 1.4 s).

An advantage of ARIANNA-1 is that the drywell may
be subdivided into a large amount of subcompart-
ments (maximum 100), and therefore presumably give
better results for pressure differences, flow com-
position etc in the drywell.

In the submitted run, a subdivision of the drywell
into 17 subcompartments was used (see Figure B.7).

The code CONTEMPT-LT/26 does not allow subdivision
of the drywell into subcompartments and therefore
cannot be used to compute e.g. pressure differences
in the drywell.

The code is also not capable of predicting the
pool swell in its present version.

In order to correctly compute the air mass flow
from the drywell to the wetwell, an input data
table has been used to control this flow.

In the submitted calculations, an insufficiency
was present in the code, meaning that no steam
was carried to the wetwell gas phase by the air

rising through the wetwell pool. This was later
corrected and results from the corrected version
were added in the parameter study.

The version CONTEMPT-LT/28 similarly cannot com-
pute pressure differences in the drywell and pool
swell.

For the air mass flow an input data table has been
used to modify the flow composition through the
vent pipes in such a way that the evaluated air
mass transfer was very closely approximated.

Both the CONTEMPT codes can make predictions on
the steam evaporating from the pool surface, after
that the flow of air has ceased, but this effect
is practically negligible.

The COPTA-7 code has been run with a 4-node sub-
division of the drywell in the short-time case
and with a single node for drywell in the long-
time case.

In order to get the right final value of air
transferred to the wetwell, some amount of air
has been assumed retained in the drywell, partici-
pating in the thermo-dynamics but not in the vent
pipe flow.

Different flashing models have been used for the
two geometrical subdivisions, in order to get
approximately the same flow of liquid water into
the vent pipes, and at the same time approximating
the pressure differences in the drywell suf-
ficiently well.

The ZOCO-V code uses the 4-node subdivision also
in the long-time run.

The code assumes thermal equilibrium in all com-
partments, i.e. also in wetwell, and therefore
underpredicts wetwell gas temperatures in roughly
the first half of the transient.

No specific assumptions have been made concerning
air flow modifiers, which means that the final
amount of air transferred to the wetwell will be
overpredicted.

The assumption of thermal equilibrium and the
slightly too large flow of air to some extent
balance in the first part of the long-time tran-
sient.

5.   COMPARISON OF CALCULATED RESULTS AND
            EXPERIMENTAL DATA

In this chapter we will discuss the results ob-
tained by the participants in relation to the
experimental data. We will start with the short-
time behaviour and than continue with the long-
time behaviour. A summary of the submitted re-
sults is given in Table A.20.

Curves for submitted results as well as for meas-
ured or evaluated experimental data are plotted
in Diagrams C.1 through C.35. The same symbols have
been used throughout in these diagrams, with dashed
lines for experimental results, chain-dashed for
the two Swedish submittals, chain-dotted for the
two Italian and solid lines for the Finnish and
Dutch submittals.

5.1   Short-time behaviour

Six sets of results, produced by five computer
codes were submitted for the short-time period.
These sets of results are

- ARIANNA-1, 17 nodes

- CONTEMPT-LT/26, 2 nodes

- CONTEMPT-LT/28, 2 nodes

- COPTA-7, 2 nodes

- COPTA-7, 5 nodes

- ZOCO-V, 5 nodes

Two types of diagrams, A and B, have been produced
for the short-time period.

The A-type diagrams Diagram C.1A through C.17A)
contain results produced by runs with drywell sub-
divided into subcompartments. A run with the COPTA

code using only one node for drywell is also in-
cluded in order to illustrate the influence of
drywell subdivision (see Table A.20).

The B-type diagrams (Diagram C.1B through C.17B)
contain results produced by runs using only one
node for drywell. The results produced by the ZOCO
Code, using 4 subcompartments for drywell, is also
included, mainly because it is the only multi-com-
partment run that continues into the long-time case,
as the other B-type runs do.

In some cases either A or B type diagrams are
missing, since they have been considered of less
interest. Some of the key results for the short-
time cases are listed in Table A.21.

5.1.1 Short-time pressure difference between drywell and wetwell (Diagrams C.1A and C.1B)

Curves for the short-time pressure difference
between compartment 110 (lower drywell) and 105
(wetwell) are plotted in Diagrams C.1A and C.1B.
Most submittals approximate the measured curve
quite well, as a rule with a slight overestimate.
The main exception is the Finnish submittal that
overestimates the pressure difference by roughly
50 %. The main reason for this is probably (se
Section 5.1.8) that the standard heat transfer
coefficient used (Uchida) is too low for this
case, giving too fast pressurization of the dry-
well. Another reason is the influence of the
omission of rooms 123 and 124 and their heat
soaking structures.

5.1.2   Short-time pressure difference between header and wetwell

The same statements as for drywell to wetwell hold
for the short-time pressure difference between
header and wetwell as shown in Diagrams C.2A and
C.2B. Of the submitted results only the multi-node
submittals differ from the previous two diagrams.

5.1.3   Short-time pressure difference between compartments 122 and 124

The short-time pressure difference between the
break compartment 122 and the top compartment 124
is shown in Diagram C.3A, comparing the three
multinode submittals with experimental values.
Note, that in this diagram, as well as in the two
following, the zero level is not at the bottom of
the diagram. Note also, that the experimental
pressure difference for these three diagrams
(C.3A - C.5A) is obtained as the difference between
measured data by probe 122M144 and appropriate
probes for the other compartments. Any error in
the 122M144 data will thus be present in all of
these three diagrams.

5.1.4   Short-time pressure difference between compartments 122 and 110

The short-time pressure difference between the
break compartment 122 and lower drywell (110) is
shown in Diagram C.4A. All three submittals
approximate the experimental results fairly well,
the Swedish submittal slightly overestimating and
the Dutch slightly underestimating for most of
the transients, while the Italian submittal is
quite close.

5.1.5   Short-time pressure difference between
           compartments 122 and 106

The short-time pressure difference between the
break compartment 122 and the header 106 is shown
in Diagram C.5A. All three submittals approximate
this quantity quite well. The Italian submittal,
using 17 nodes for drywell, even appears to
approximate the oscillatory behaviour of the pres-
sure difference.

A final point to make is that there appears to be
an initial negative pressure difference for the
measured data in all three Diagrams C.3A through
C.5A. This emanates from an initial decrease in
the measured pressure for the break compartment 122
(see Diagram C.7A). Whether this is real or not is
hard to say. It could have some connection with
the initial cold water plug in the discharge pipe
(which has not been modelled by the participants)
or it could be some measuring error. None of
the submittals exhibits this initial negative
peak.

5.1.6   Short-time pressure transient for com-
           partment 124

The short-time pressure transients for the top
compartment 124 are shown in Diagram C.6A. All the
submittals approximate the experimental curve
quite well with a slight overestimate for the
two 5-node submittals. The Italian submittal fits
the experimental curve quite well.

5.1.7   Short-time pressure transient for com-
           partment 122

The short-time pressure transients for the break
compartment 122 are shown in Diagram C.7A. As for
the top compartment, all submittals fit the experi-

mental curve quite well, with slight overpredict-
ions for the 5-node submittals and quite good fit
for the ARIANNA run.

5.1.8   Short-time pressure transient for com-
         partment 110

The short-time pressure transients for compartment
110 in lower drywell are shown in Diagrams C.8A
and C.8B. All the submittals approximate the
experimental curve quite well, except the Finnish
submittal, which somewhat overestimates the
experiment. The main reason for this overestimate
is that the standard heat transfer coefficient
(Uchida) has been used for the drywell structures,
giving a too fast heating of the drywell and
therefore too fast pressurization of the drywell.
It also leads to an overestimate of the steam
flow rate into the pool, the heating rate of the
pool, and therefore also to some extent increases
the drywell pressure through increased wetwell
pressure and increased pressure difference over
the vent pipes. In a parameter study (case SF3),
a much higher value (up to 5 kW/m^2,K compared to
the Uchida maximum of 1.6 kW/m^2,K) has been used
for the heat transfer coefficient in drywell, and
that run shows considerably better correspondance
with the experimental curve. Another, but less
important reason is that in the Finnish submittal,
the uppermost subcompartments have not been
included, giving slightly smaller compressible
volume and heat soakage area, and therefore faster
pressurization.

The two 5-node runs (Italy and Sweden) show a
similar, but much smaller, overestimate.

5.1.9   Short-time pressure transient for com-partment 106

The short-time pressure transients for compartment 106, the header, are shown in Diagrams C.9A and C.9B. Essentially the same comments are valid as for Diagrams C.8A and C.8B.

5.1.10   Short-time pressure transient for wetwell

The short-time transient for wetwell are shown in Diagram C.10B. The correspondace with the measured curve is fairly good, with the Finnish and Dutch submittals slightly overestimating and the Swedish and Italian submittals slightly underestimating the pressure rise. The reasons are slightly different.

For the Finnish submittal, the main reason is probably that the heat transfer between the pool and the wetwell atmosphere, which is quite large between approximatively 2 and 20 s due to water splashing, has been ignored. The initially too high steam flow rate gives an overestimate of the pool temperature, which influences the wetwell pressure through the rising air/steam bubbles. Another contributing factor could be overestimation of the initial air flow in con-nection with too fast vent clearing (see Dia-grams C.27 and C.30). Overestimate of the flow of air is probably also the main cause of the overestimate by the Dutch submittal. Since ZOCO-V uses thermal equilibrium for the wetwell compartment, corresponding to an infinite heat transfer coefficient between the pool and the wetwell atmosphere, one should in fact have expected an underestimate of the pressure rise, instead of an overestimate.

The underestimates by the Swedish and Italian
submittals are probably mainly caused by underesti-
mates of the initial air flow. This underestimate,
which to a large extent emanates from the use of
a 1-room model for drywell, more than compensates
the effect of the omission of heat transfer be-
tween pool and wetwell atmosphere.

5.1.11   Short-time temperature transient in compartment 124

The short-time temperature transients for the top
compartment 124 are shown in Diagram C.11A. Apart
from the initial transient the correspondence
is very good. The initial transient is mainly of
theoretical interest, but it could be of some
value to discuss the possible reasons for the
different shapes of the curves.

The ARIANNA and COPTA curves both exhibit a mini-
mum after some tenths of a second. The reason for
this is that water drops enter from the break
compartment 122 in the slightly superheated top
compartment 124 and are instantaneously evaporated
according to the equilibrium models used. This
process requires so much energy that the tempera-
ture drops, even though the entering mixture is
hotter than the compartment 124. When compartment
124 has reached saturation, the temperature starts
to rise.

The behaviour of the ZOCO transient is somewhat
hard to explain.

5.1.12   Short-time temperature transient in compartment 122

The short-time temperature transients for the
break compartment 122 are shown in Diagram C.12A.
The correspondence with measured values is quite

good. For the initial 0.1 s transient similar
arguments hold as for Diagram C.11A. It also
appears from Diagram C.12A that the temperature
measurements are some 0.2 s slow. In the "Zero
time" section of Chapter 4 of MXB-218 (14) it
is stated that all the PCM-data (i.e. data in M-
tables and M-diagrams) were slow by 187 ms due
to incorrect zero signal conversion. This delay
has however been corrected when plotting the "MX-
data" in the present report.

5.1.13   Short-time temperature transient in
          compartment 111

The short-time temperature transients for com-
partment 111 in lower drywell are shown in Dia-
grams C.13A and C.13B. Essentially the same argu-
ments hold as for Diagram C.12A.

5.1.14   Short-time temperature transient in
          compartment 106

The short-time temperature transients for com-
partment 106, the header, are shown in Diagrams
C.14A and C.14B. The submittals using a single
node for drywell, for that reason, deviate fairly
much from the measured values. This has, however,
only small effect on the other results, since this
excess heat is mainly stored in the wetwell pool.
The submittals using four nodes for drywell show
fairly good correspondence to the measured values.

5.1.15   Short-time temperature transient in
          wetwell vapor

The short-time temperature transients for the
wetwell vapor are shown in Diagrams C.15A and
C.15B. All the submittals show a considerably
faster temperature increase than the curve for
measured data. One possible reason for this could

be that the heat transfer coefficient for the
temperature transducers is quite small up to the
break-through of the pool water surface at around
3 s (see Diagram C.17), slowing down the tempera-
ture response of the probes. After break-through,
the furiously splashing water will tend to retain
the vapor phase at the temperature of the pool,
until the air flow rate is decreased sufficiently
(from around 10 s, compare Diagrams C.25 and C.27).

The differences between the submittals are mainly
due to different vent clearing time and initial
air flow, to some extent also to other effects,
such as heat transfer to solid structures in
the wetwell vapor.

5.1.16   Water plug size

Curves showing the sizes of the water plugs in
the vent pipes are given in Diagrams C.16A and
C.16B. If the dynamics of the water plugs are
modelled similarly for the codes involved, these
curves should be closely related to the curves
for header pressures shown in Diagrams C.9A and
C.9B. A check reveals that this appears to be
true for the computed curves. Compared to the
measured curve, the computed curves give a slightly
too fast vent clearing time, though the difference
is fairly small.

5.1.17   Pool swell

Only two of the codes contain special models for
pool swell, COPTA and ZOCO. The submitted results
from these two codes are shown in Diagram C.17A,
together with measured curves for different verti-
cal location in the Marviken wetwell. The bottom
of the header, which drastically changes the
available cross-sectional area, is roughly 4.8 m

above the vent pipe outlet (zero point of level
scale). Therefore one should not pay too much
attention to the behaviour above that level for
the measured data.

Anyhow, the pool swell models give a roughly
correct picture of the pool swell and for COPTA
also for the break-through time (ZOCO does not
indicate break-through within the time period
studied).

5.2   Long-time behaviour

Results produced by four computer codes are com-
pared for long-time behaviour. The results com-
pared are produced by

-     CONTEMPT-LT/26, 2 nodes

-     CONTEMPT-LT/28, 2 nodes

-     COPTA-7, 2 nodes

-     ZOCO-V, 5 nodes

The ZOCO-V run uses a subdivision of drywell into
4 subcompartments, all the others use a single
node to represent drywell. The ZOCO-V run also,
unlike the other runs, does not make any attempt
to artificially control the flow of air through
the vent pipes.

Therefore the ZOCO run is stopped at around 75 s
when the amount of air transferred to the wetwell
exceeds the total amount transferred at the end
of the experiment.

The COPTA run specifies the amount of air retained
in drywell at the end of the test and is therefore
approximatively correct concerning the total amount

of air transferred to wetwell at the end of the
blowdown, while the time history differs from the
actual one.

Both of the CONTEMPT runs control the flow com-
position in such a way that also the time history
of air transfer is approximatively correct.

The transfer of air into the wetwell is of quite
great importance for the long-time behaviour, and
therefore the results for many other parameters
(pressures, differential pressures, temperatures)
depend to a large extent on the assumptions made
for the air transfer.

5.2.1   Long-time pressure difference drywell -
             wetwell

In Diagram C.18 the test data are represented by
two dashed lines, corresponding approximately to
the minimum and maximum values of the pressure
oscillations. Thus they do not represent error
limits or confidence intervals, although for much
of the transient they might be of roughly the same
order of magnitude as these.

The peak pressure difference at around 30 s is
quite exactly predicted by all runs (although the
Finnish submittal also does exhibit a substan-
tially larger peak at around 7 s).

Most parts of the submitted results fall between
the minimum and maximum of the oscillations. Ex-
ceptions are

-          The early transient from 5 s or less to
           between 10 s and 20 s, where most runs
           overpredict the pressure difference,
           Italy the least and Finland the most.
           As discussed earlier, the deviation

for the Finnish submittal is mainly due
to a too low heat transfer coefficient
in drywell.

-       The Italian submittal slightly underpre-
        dicts in the later phase of the blowdown.

-       After the cessation of the blowdown the
        decrease of pressure difference for the
        Italian submittal stops at around the
        hydrostatic pressure corresponding to
        the submergence depth, while the Finnish
        and Swedish submittals continue below
        this value, fairly close to the experi-
        mental curve.

The behaviour after the cessation of the blowdown
should not be given too much attention in this
standard problem, since most participants probably
have not tried to fit this part by choosing correct
heat transfer values etc, but it could all the same
be worthwhile for the participants to think about
the information that this "tail" may give on some
input parameters.

5.2.2   Long-time pressure difference header -
         wetwell

Many of the comments made for the previous diagram
(pressure difference drywell - wetwell) are valid
also for Diagram C.19 (pressure difference header -
wetwell). The pressure oscillations in the header
were considerably larger than in the drywell, which
is reflected by the larger distance between the
dashed test curves. Of the submitted results nat-
urally only the ZOCO results differ from those in
the previous diagram. We can see, for instance,
that all results overpredict the pressure differ-
ence up to 15 s or more.

5.2.3   Long-time drywell pressure

The drywell pressure (Diagram C.20) depends to a
large extent on the wetwell pressure and the

pressure difference required to maintain the flow
through the vent pipes. The correspondence with
measured data is on the whole quite good, with
a few exceptions:

o   The Finnish submittal overpredicts the
           drywell pressure up to 30 s, as discussed
           earlier mainly due to the use of a too
           low heat transfer coefficient in drywell.

o   The Swedish submittal overpredicts the
           drywell pressure between 10 s and 120 s
           mainly due to overprediction of the wet-
           well pressure, which arises from the
           overprediction of the rate of transfer
           of air to the wetwell atmosphere.

o   The Dutch submittal predicts the drywell
           pressure quite well until 40 s, when it
           starts to overpredict due to overpre-
           diction of the wetwell pressure (see
           discussion in Section 5.2.5).

o   The "tail" after 170 s is fairly well
           predicted by the Finnish and Swedish
           submittals, but less well (not attempted?)
           by the Italian submittal.

5.2.4   Long-time header pressure

Mainly the same comments as for Diagram C.20 are
valid also for Diagram C.21.

In fact, among the submittals, only the ZOCO-V
curve differs from those for the drywell pressure.

5.2.5   Long-time wetwell pressure

The long-time wetwell pressure, shown in Dia-
gram 22, depends to a very large extent on the
amount of air transferred to the wetwell. Other
parameters with large influence are mainly heat
transfer to and from the wetwell atmosphere and
steam addition to the atmosphere. The Marviken
containment is somewhat strange in the aspect that
use of a high heat transfer coefficient in the

wetwell atmosphere could increase the wetwell
pressure, since the heat transfer from drywell
through the large steel walled blowdown pipes
could increase faster than the heat soakage of
the concrete walls in wetwell for some range of
HTC values. This, however, happens for fairly high
HTC values, which normally are not used for the
wetwell atmosphere.

Comparing Diagram C.22 with Diagram C.30 we see
that the tendencies for the wetwell pressure quite
closely follow the tendencies for the amount of
air in the wetwell. The only exception is ZOCO-V,
where overprediction of air in the wetwell still
gives a very close approximation of the wetwell
pressure up to 40 s or more. The reason is here
that the equilibrium assumption of equal tempera-
tures for pool water and wetwell atmosphere coun-
teracts the larger amount of air.

Since the Finnish submittal has an almost perfect
fit of air and steam transfer to the wetwell atmos-
phere, the main cause for the deviations, which in
fact are very small, is most certainly an under-
estimate of the heat transfer to the pool water in
the "splashing period".

For the other two submittals (Sweden and Italy),
the possible inaccuracies in the models used for
heat transfer to and from the wetwell atmosphere,
as well as the steam addition to the wetwell
atmosphere, are so small, that the inaccuracies
in the rate of air flow to the wetwell dominates
over other effects. This does not mean that these
models are correct, only that the main deviation
is caused by deviations in air mass.

The influence of the rate of steam addition to the
wetwell atmosphere (compare Diagram C.34) could
possibly be observed for the last 100 s of the
transients. There the wetwell pressures of the
Italian submittal, and to some extent also the
Swedish submittal, are slightly lower than would
be expected from the comparisons for amount of air
in the wetwell.

5.2.6   Long-time drywell temperatures

The drywell temperatures (Diagram C.23) are quite
accurately predicted in all submittals. Slight
underpredictions of the drywell temperature could
be noticed for the two CONTEMPT runs after 10 s
and for the COPTA run in the last part of the
transient. These effects are small and are probably
explained by the choices made of heat transfer and
heat conduction parameters.

5.2.7   Long-time header temperatures

The header temperature curve is quite close to the
drywell temperature curve and three of the four
submitted curves are identical for drywell and
header. Therefore most of what is said for the dry-
well temperature comparison is also valid for the
header temperature, (Diagram C.24), although the
differences are perhaps even smaller here.

5.2.8   Long-time wetwell gas temperature

The wetwell gas temperature curve shown in Dia-
gram 25 is an average over values from some 30
different thermocouples that were located in the
wetwell gas space.

None of the submittals approximates this curve
very well for the first 20 - 30 s. Differences
in the order of tenths of degrees are noticed.

For the ZOCO-V run the reason is quite evident,
the assumption of thermal equilibrium inevitably
leads to an underestimate of the wetwell gas
temperature for such cases as ISP17.

For the other runs, the main reason is presumably
that the influence of the large contact area be-
tween the pool water and the wetwell atmosphere
during the period of high air flow and water
splashing has been underestimated or deliberately
neglected.

It should be noticed, however, that the seemingly
large differences do not have that large effect
on the pressures or other parameters, since the
main influence is through the state equation for
air $P_a V_a = m_a R_a T_k$, where T_k is the temperature in
Kelvin. Thus an error of say 15 K corresponds to
a relative error in P_a or m_a of around 5 %.

In the later part of the transient the curve for
the Swedish submittal decreases faster than the
experimental curve and the CONTEMPT curves. The
reason for this is partly because the transfer of
air to the wetwell occurred faster in the Swedish
submittal. There could also be some influence from
the choice of heat transfer and heat conduction
parameters, but this influence is hard to estimate.

There are two more points of some theoretical
interest, although a thorough evaluation is per-
haps not feasible. The first is that there is a
crossover between wetwell gas temperature and pool
temperature at roughly 150 s. The second is that
the end of the blowdown at 170 s leads to a de-
compression of the drywell, leading to a reentry
of the water plug in the vent pipes. The volume
of this water plug, which is of the order of some

meter (or meters) times 2 m², corresponds to an
adiabatic expansion of the wetwell atmosphere,
in addition to the ongoing thermal exchange with
pool water and solid structures. This effect is
possible to detect on the experimental curve and
also on the CONTEMPT runs (although perhaps over-
estimated?).

5.2.9   Long-time average pool temperature

The experimental value of the pool temperature
(Diagram C.26) has been evaluated from several
thermocouples in the pool.

This temperature is strongly connected with the
amount of steam condensed in the pool. The MX
curve for the total amount of steam through the
vent pipes (Diagram C.31) has in fact been computed
from the temperature rise of the pool water. There-
fore it is not any surprise that Diagrams C.26 and
C.31 show the same tendencies. On the contrary this
indicates some degree of consistency, concerning
condensation of the steam, between the codes used
for the submitted runs, and the code used to com-
pute the steam flow through the vent pipes. The
fact that the IRE curve for steam flow is fairly
close to the MX curve (see Diagram C.28 and C.31)
indicates that this is also true vis-a-vis the
experiment.

We can therefore use Diagram C.26 together with
Diagrams C.28 and C.31 to comment both on total
steam flow and on pool temperature.

The three runs with a single node for drywell
slightly overpredict the steam flow and conse-
quently the pool temperature, while the ZOCO-V
run with four nodes for drywell quite closely
predicts the steam flow, but somewhat underpre-
dicts the pool temperature.

The last point is somewhat surprising, since the
ZOCO-V run also underpredicts the wetwell gas
temperature (Diagram C.25).

The reason why the models with one node for dry-
well overpredict the steam flow is not quite clear,
whether it has to do with the number of nodes and
questions attached to that (water separation, con-
densation etc) or whether it has to do with choice
of flashing models and heat soakage in the drywell.

5.2.10   Long-time air flow

Curves for the air flow through the vent pipes are
shown in Diagram C.27. Note, that in this diagram
the time span is only 0 - 55 s (compared to
0 - 220 s for the other diagrams) and that the zero
level is not at the bottom of the page.

The picture is quite messy and even the two curves
representing the test data (MX and IRE) are quite
different.

The MX data are not actually measured, but computed
through use of the ideal gas law on the measured
pressures and temperatures of the wetwell gas
phase. The resulting curve for total amount of air
transferred has then been differentiated and
smoothed. The Finnish submittal is based on this
curve but using slightly different values, essen-
tially neglecting the smoothing for the first
10 - 20 s.

It is therefore hard to claim any certainty for
"measured values", but it seems fairly probable
that the correct curve should fall somewhere be-
tween the Finnish submittal and the IRE curve,
presumably closer to the Finnish submittal.

If we turn to integrated air flow (Diagram C.30)
the picture is considerably clearer.

We see that the two "measured" curves are fairly
close to each other and that the Finnish submittal
almost exactly matches the "MX-DATA".

The Italian submittal somewhat underpredicts the
air transferred in the beginning and overpredicts
in the last part of the transient.

Both the Dutch and the Swedish submittal overpre-
dict the air transferred in the beginning. The
Dutch submittal stops when essentially all of the
drywell air has been transferred, while the Swedish
submittal discontinues the air flow when approxi-
mately the right amount of air has been trans-
ferred.

All these tendencies are direct consequences of the
input data chosen and the differences thus do not
depend on differences in the codes but on differ-
ences in approach.

As commented earlier, the amount of air transferred
has a great impact on the wetwell pressure (Dia-
gram 22) and also to some extent on the drywell
pressures and the wetwell gas temperature.

5.2.11 Long-time steam flow

Two curves representing experimental data for
steam flow through the vent pipes are shown in
Diagram C.28. The IRE curve is a smoothed (by
hand) representation of results from the infrared
measurements. The curve denoted "MX-DATA" is
obtained from measurements of the pool tempera-
ture. The fact that these two curves, obtained in

totally different ways agree fairly well gives us
some confidence to use them and also indicates
roughly the possible errors associated with them.
The "IRE-DATA" curve is probably closer to the
correct values, at least close to the steep parts
(due to the smoothing method used for the "MX-
DATA"). From the integrated values (Diagram C.31)
we see that the total amount of steam added to the
wetwell is predicted almost identically by the two
methods.

Returning to Diagram C.28, we see that the Dutch
submittal very closely predicts the steam flow up
to 75 s.

The other three submittals overpredict the steam
flow for most of the transient. The total overpre-
diction is of the order of 20 % for the Italian and
Swedish submittals and slightly larger for the
Finnish submittal.

Possible causes for this overprediction could be
the use of a one-node representation of drywell
or the models and values used for flashing and
condensation.

The prediction of the steam flow has a close re-
lation to the prediction of pressure differences
between drywell and wetwell (Diagrams C.18 and
C.19).

5.2.12   Long-time flow of water

As for the flow of air and steam there are two
curves representing the flow of liquid water
through the vent pipes (see Diagram C.29). The
curve "IRE-DATA" has been measured by infra-red
technique and then smoothed "by hand". The "MX-

DATA" curve has been obtained from the steam flow
curve by using an assumption of constant steam
quality adjusted as to satisfy the mass and energy
balance for the pool water.

The "IRE-DATA" and "MX-DATA" curves differ enor-
mously, the "MX-DATA" implying a transfer of
totally 19 tons of liquid water, while the "IRE-
DATA" imply only 0.8 tons. At least one of these
must be totally wrong and it seems reasonable from
different reasons to conclude that the "MX-DATA"
curve is wrong. We cannot, however, claim that the
"IRE-DATA" curve is right. The correct values could
be somewhere between those two curves. In fact, the
mass balance measurements (see Figure B.15) indi-
cate that the computations and the IRE measurements
could have underestimated the total water and/or
steam flow by as much as 8 - 10 tons. Therefore
the comparison is mainly between the codes and not
so much code to experiment.

The submittals from Italy and Sweden indicate re-
sults of the same order of magnitude as the IRE-
DATA. There are some significant differences, but
since we cannot rely on the test data, no definite
conclusions may be given. In the CONTEMPT code a
choice has to be made between two extreme vapor
region models. Either is all liquid water contained
in the vapor region or is all liquid water immedi-
ately transferred to the floor. Since the drywell
model used in the Finnish submittal does not allow
liquid water (water drops) in the vapor region,
the flow of liquid water is caused by a numerical
residual only, which explains this apparently
strange curve.

The same arguments may be used for the integrated
mass flow of liquid water, Diagram C.32.

5.2.13   Total flow of air through vents

These data have been discussed earlier (see e.g. 5.2.10).

5.2.14   Total flow of steam through vents

These data have been discussed earlier (see e.g. 5.2.11).

5.2.15   Total flow of liquid water through vents

These data have been discussed earlier (see e.g. 5.2.12).

5.2.16   Mass of sump water

The reported mass of sump water (Diagram C.33) is evidently wrong, since the final amount, 260 tons, exceeds the amount expelled from the pressure vessel. A possible reason for this could be temperature drift in the differential pressure transducers used to measure water levels. If similar errors are present for the pool water measurements, this could explain much of the differences also for the measured flow of liquid water through the vent pipes.

Disregarding the experimental curve, we see in Diagram C.33 that all the four submittals give approximately the same sump water amounts. Although not a proof, this gives a strong indication that all the computed values are at least approximately correct, and certainly more correct then the experimental curve.

Measurements made after the blowdown (Figure 7:3 in Ref 11) did in fact give a final value of approximately 160 tons, and parameter studies made by Sweden cover a range of 148 - 175 tons.

5.2.17   Long-time total mass of steam in wetwell
          atmosphere

The experimental value ("MX-DATA") for the mass of
steam in the wetwell atmosphere in Diagram C.34
was computed in the following way: The initial
value was computed assuming 100 % relative humidity
in the wetwell, and the air entering the wetwell
atmosphere was assumed to carry steam corresponding
to 100 % humidity at the temperature of the pool
water. No steam evaporation was added to this.

Similar methods are used also by the codes for the
Finnish and Swedish submittals, and the differences
compared to the experimental curve arises mainly
due to differences in pool water temperature (both
submittals), timing of air transfer (Sweden) and
initial humidity (86 % used by Sweden).

The results for the Dutch submittal are completely
different due to the equilibrium assumption in the
ZOCO-V Code.

Finally, the Italian submittal was run by a code
version that did not account for mass transport of
steam together with air into the wetwell atmosphere
and therefore gives a constant value for the steam
content. In a revised version of the code this fa-
cility has been implemented.

5.2.18   Total mass of steam + water through the
          vent

The curves shown in Diagram C.35 are the sums of
the individual curves for steam and water, shown
in Diagrams C.31 and C.32 respectively. Therefore
the discussion is quite similar as for these dia-
grams. We can see that all the submitted curves
for most of the transient fall between the "MX-DATA"
curve and the "IRE-DATA" curve.

5.2.19   Mass and energy balance

The mass and energy balances for some of the codes
at 171 s is shown in Figure B.15.

5.3   Concluding remarks

The correspondence between calculated results and
measured data is in general good. Quite different
approaches have been used by the participants,
which means that the comparisons to a high degree
are between the approaches chosen and measurements
as well as between codes and measurements. Most
of the existing differences may be explained by
reference to the approaches and models used by the
participants. For some parameters (mainly flow of
water and to some extent also steam to the wetwell
pool) the measured data are quite uncertain, pre-
cluding definite and exact judgements on submitted
results.

6.   COMMENTS BY PARTICIPANTS

This chapter is intended to include comments
received by participants, as given in the planned
workshop or in written contributions.

7.   PARAMETER STUDIES

This chapter is intended to comment upon parameter
studies submitted by the participants and presented
in appendices. Parameter studies have been made
by three of the participants; Italy, Finland and
Sweden.

8.   REFERENCES

1.   WINKLER
          CSNI report No 41.
          Comparison report on OECD-CSNI Containment
          Standard Problem No 1.
          May 1980.

2.   NGUYEN and WINKLER
          CSNI report No 65.
          Comparison report on OECD-CSNI Containment
          Standard Problem No 2.
          May 1982.

3.   MARSHALL and WOODMAN
          CSNI report No 77.
          Comparison report on Containment Analysis
          Standard Problem No 3.

4.   Design report for the HDR containment
          experiments V21.1 to V21.3 and V42 to
          V44 with specifications for the pre-
          test computations.
          Report No 3, 280/82 KfK, Karlsruhe,
          Jan 82.

5.   Working Group on Water Reactor Contain-
          ment Safety.
          Summary record of the Third Meeting held
          at the Chateau de La Muette, Paris on
          24th - 26th February, 1982.
          SEN/SIN (82) 11.

6.   MARKLUND, J-E
          Proposal for an international contain-
          ment standard problem based on the Mar-
          viken full scale pressure suppression
          experiment SD-82/128, 82-09-06.

7.   The Marviken Full Scale Containment Ex-
          periments.
          First series.
          Summary report MXA-1-301.
          October 1974.

8.   The Marviken Full Scale Containment Ex-
          periments.
          Second series.
          Summary report MXB-301.
          March 1977.

9.   MARKLUND, J-E
          Specifications for TBISP17 - An inter-
          national standard problem based on the
          Marviken full scale pressure suppression
          experiment BD18.
          STUDSVIK Technical Report SD-83/12,
          1983-03-23.

10.   MARKLUND, J-E
       Preparatory meeting for ISP17.
       STUDSVIK Technical Report SD-83/24,
       1983-08-18.

11.   The Marviken full scale Containment Ex-
       periments.
       Description of the test facility. MXB-101.

12.   The Marviken full scale Containment Ex-
       periments.
       Measurement system. MXB-102.

13.   The Marviken full scale Containment Ex-
       periments.
       Data accuracy. MXB-105.

14.   The Marviken full scale Containment Ex-
       periments.
       Blowdown 18 results. MXB-218.

15.   The Marviken full scale Containment Ex-
       periments.
       Appendix to Blowdown 18 results. MXB-
       218 App.

16.   The Marviken full scale Containment Ex-
       periments.
       Summary report MXB-301.

17.   The Marviken full scale Containment Ex-
       periments.
       Report abstracts. MXB-401.

18.   MARKLUND, J-E
       Representation of walls and other struc-
       tures in a 5-room model of the Marviken II
       containment.
       Studsvik report SD-83/17.

19.   BELLUCCI, L, MAZZINI, M, ORIOLI, F,
       PACI, S and ROMANACCI, R
       OECD-CSNI International Standard Problem
       No 17: Marviken Full Scale Pressure Sup-
       pression Experiment BD18. Calculation re-
       sults using ARIANNA and CONTEMPT-LT/26
       computer codes.
       Univ of Pisa, RL 082(84).

20.   WOUDSTRA, A
       Calculational results of OECD Standard
       Problem ISP17 by means of the modified
       code ZOCO-V.
       ECN, Memo No 0.375.03-GR38 (OB79-24).

21.   EERIKÄINEN, L
        TBISP17 - International Containmnt
        Safety Standard Problem on the Marviken
        Full Scale Pressure Suppression experi-
        ment BD18.
        Finnish calculations with the CON-
        TEMPT-LT/28 program.

22.   MARKLUND, J-E
        Calculations by the code COPTA on OECD-
        CSNI International Standard Problem No 17,
        based on Marviken Blowdown 18.

23.   CERULLO, N, GORLANDI, A M, ORIOLO, F
        ARIANNA: Un codici di calcolo per
        l'Analisi del Transitorio Termoidraulico
        in Sistemi di Contenimento Compartimentali
        XXXVI Congresso Nazionale
        dell'Associazione Termotecnica Italiana
        (ATI).
        Viareggio, 5 - 8 Ottobre 1982.

24.   MINGS, W J
        Version 26 Modifications to the CONTEMPT-
        LT Program.
        SRD-83-76, April 1979.

25.   CONTEMPT-LT/028. A computer program for
        predicting containment pressure - tempera-
        ture response to a loos of coolant acci-
        dent.
        NUREG/CR-0255. Idaho, March, 1979.

26.   MARKLUND, J-E and JOHANSSON, Å
        Model description of containment program
        COPTA-6.
        Studsvik report AE-RD-105, 1979-07-12.

27.   ZOCO-V, Ein Rechenmodell zur Berechnung
        von zeitlichen und örtlichen Druck-
        verteilung in Reaktorsicherkeitsbehältern.

28.   EERIKÄINEN, L
        Corrections and additions to CONTEMPT-LT
        computer codes for containment analysis.
        Revised version of CONTEMPT-LT/26.
        Helsinki 1980, Technical Research Center
        of Finland, Nuclear Engineering Labora-
        tory, Report 44, 24 p.

LIST OF TABLES

Table A.1

Test conditions for the blowdown tests in the second Marviken test series.

BLOW-DOWN number	DISCHARGE CONDITIONS				VESSEL CONDITIONS		CONTAINMENT CONDITIONS						SPECIFIC FEATURE
	top pipe pre-purging	main discharge line			pres-sure	mass of water and steam	depth wetwell pool	vent pipe subm	pool volume	number of open vent pipes	vent pipe flow area	wetwell pool temper-ature	
		ori-fice diam mm	flow re-duction from sec	time of blow-down sec	MPa	Mg	m	m	m^3		m^3	°C	
17	no	330	–	163	4.77	277	4.50	2.80	560	57	4.03	12	As BD 10 in MX-I
18	no	280	–	171	4.64	288	4.51	2.81	561	28	1.98	16	Reduced VP flow area
19	yes	280	–	146	4.71	289	4.54	2.84	564	28	1.98	16	As BD 18 except prepurging
20	yes	280	–	143	4.82	290	2.20	0.50	277	28	1.98	9	As BD 19 except lower pool depth
21	no	280	200	211	4.71	290	4.50	2.80	257/294	27/1	1.91/ 0.07	15	As BD 18 except pool partition
22	yes	280	125	340	4.73	290	4.48	2.78	256/293	27/1	1.91/ 0.07	17	As BD 19 except pool part and red flow after 125 s
23	yes	280	15	520	4.82	284	4.50	2.80	257/294	27/1	1.91/ 0.07	18	As BD 22 except low disch flow rate after 15 s
24	yes	280	80	220	4.80	284	4.50	2.80	257/294	27/1	1.91/ 0.07	16	As BD 22 except detuning of vent system
25	yes	330	70	180	4.89	286	5.51	3.81	314/344	27/1	1.91/ 0.07	13	As BD 24 except larger pool depth and single cell studies

TABLE A.2

Survey of the data channels.

Measurement position	Parameter	Scanning rate			Remarks
		10 Hz	952 Hz	continuous	
Pressure vessel	Pressure	2		1	
	Temperature	10			
	Mass of water	4		1	DP-over-vessel
	Water level			10	Special type of probe
Main discharge line (Original steam line system)	Pressure	5	1		
	Temperature	3	1		
	Mass flow	2			Pitot tube
Top pipe (Prepurging line)	Pressure	1			
	Temperature	2			
Drywell	Pressure	9	8	1	
	Diff pressure	2			
	Temperature	16	7		
	Water level	1			DP-channel
Downcomers and vent pipe header	Pressure	1	5		
	Temperature	3	7		
	Flow velocity		} 6	} 11	Radioactive tracer method and infrared attenuation technique
	Mass composition				
Vent pipes and around vent pipes	Pressure		4		
	Temperature	10	17		
	Water level		13		Level probes of spark plug type
	Phase boundary		39		Level probes of spark plug type
Wetwell	Pressure	2	10	1	
	Temperature	100			
	Mass of water	2			DP-channels
	Water level		43		Level probes of spark plug type
	Impact load		6		Strain gauges
	Visualization				Two TV-cameras
Miscellaneous					
Drywell-wetwell	Diff pressure	2	2		
Header-wetwell	"-		2		
DP-over-vessel, lead tubes	Temperature	4			

Table A.3

Error limits of pressure channels, DP-channels and temperature channels.

Parameter	Type	Location	Max error	Probable error
Pressure	VARIAN	Vessel and discharge pipe	± 70 kPa	± 6 kPa
Pressure	PCM	Vessel and discharge pipe	± 90 kPa	≈± 50 kPa
Pressure	VARIAN	Containment	± 6.3 kPa	± 0.4 kPa
Pressure	PCM	Containment	± 8.1 kPa	± 1.2 kPa
DP	VARIAN	DP-over-vessel	<± 4.8 kPa	± 1.0 kPa
DP	VARIAN	Containment	± 1.8 kPa	± 1.0 kPa
DP	PCM	Containment	± 2.1 kPa	± 2.0 kPa
Temperature	VARIAN	Vessel, pipes and containment	± 2.9°C	± 1°C
Temperature	PCM	Vessel, pipes and containment	± 4.3°C	± 1°C

STUDSVIK ENERGITEKNIK AB SD-84/43   Appendix A.5 (21)
             NR-84/428
             1984-06-04

Table A.4

Containment volumes for BD18.

Room	Volume, m^3
124	312.0
A	102.0
B	133.5
123	43.9
123.1	10.6
123.2	70.9
123.3	10.3
122	175.5
121	298.5
114	16.7
113	63.7[1]
112	115.9
111	100.2
111.1	185.1
110	121.0
104	66.5
106	140.8
Drywell, excl v p	1967.1
Vent pipes[2]	5.3
DW, active volume	1972.4
Wetwell, excl v p	2133.0
Water plugs[3]	5.6
WW, active volume	2138.6
Inactive vent pipes[4]	10.9

[1] The drain pipe valve just below the
   floor of room 113 is assumed to be
   closed during blowdown

[2] 28 pipes, 1.98 m^2, 5.5 - 2.81 = 2.69 m
   length

[3] 28 pipes, 1.98 m^2, 2.81 m submergence
   depth

[4] 29 pipes, 1.98 m^2, 5.5 m length

Table A.5

Flow areas in drywell.

Connection	Description	Area (m^2)
124 – B	18 Ducts by-passing the floor of room 124	3.55
124 – 122	4 ventilation pipes, $\emptyset$ 0.48 m x 28 m	0.60[a]
B – A	Inlet gap to radiation shield tank	6.05
B – 122	3 pipes $\emptyset$ 0.7 m x 5.90 m, with butterfly valves in the ceiling of room 122	1.0[b]
	1 pipe from the original ventilation drum, $\emptyset$ 0.8 m x 6.5 m	0.50
123.8 – 123.3	48 openings, 0.1 m x 0.7 m, in the reactor skirt	3.36
123.8 – 121	Pipe, $\emptyset$ 0.7 m x 5.90 m, with one-way flapper valve max opening 0.26 m	0.29
123.3 – 123.1	Part of annulus	1.60
123.3 – 123	Annular, rectangular and trapezoidal openings	0.94
123.1 – 123	Rectangular openings	0.41
123 – 123.2	4 doors in the insulation box (max opening)	1.25[c]
123 – 121	2 shafts	2.98
123.1 – 121	Trapezoidal duct	0.44
123.1 – 122	10 rectangular ventilation openings, 0.8 m x 0.05 m	0.40
122 – 121	Circular opening	0.78
	Rectangular opening at the optional water break position	0.67
	Circular opening around the main discharge line	0.20
	Square opening	0.12
	Gap around steam break valve	0.47
	Minor holes and gaps	0.54
122 – 111.1	Entrance opening with stairs	3.80
121 – 111.1	Rectangular door opening and two minor holes.	2.50
121 – 113	Annulus along the containment wall	1.54
121 – 112	Annulus along the containment wall	2.0
	3 rectangular and square openings	0.32
121 – 110	Annulus along the containment wall	2.90
	3 rectangular openings	1.75
111.1 – 111	Imaginary boundary at the grating below the door to room 121	24.5
111 – 110	Rectangular opening	11.4
112 – 110	Rectangular openings, one of them along the containment wall	1.70
113 – 112	Rectangular opening	10.0
113 – 114	Entrance and rectangular openings in the ceiling	2.60
111 – 112	Rectangular entrance opening plus minor holes in the wall	2.20

Table A.5 (cont'd)

Connection	Description	Area (m^2)
111 - 113	Rectangular opening	4.94
113 - 105	Drain pipe	0$^{d)}$
110 - 105	3 pipes with vacuum breaker check valves	0$^{e)}$
111.1 - 104	2 rectangular openings	5.92
104 - 106	4 blowdown pipes	4.60
106 - 105	57 open vent pipes, ∅ 0.30 m	4.03$^{f)}$
106 - 105	28 open vent pipes (alternatively)	1.98$^{g)}$

a) One of the ventilation pipes is partly closed at the exit in room 122

b) The flow area in one of the valves is slightly reduced because of damage

c) The doors were closed before the majority of the blowdowns

d) An orifice plate and a valve are installed in the drain pipe

e) Closed during blowdown. The valves begin to open at a pressure difference between wetwell and drywell of 0.22 bar and are fully open at a pressure difference of 0.28 bar (max flow area through all four valves: 0.45 m^2)

f) Only valid for Blowdown 17 (only the permanently blocked vent pipe)

g) The distribution of the open vent pipes for the particular blow- downs is shown in the corresponding test results report (MXB-218 to -225).

Table A.6

Flow paths for the 4-node drywell.

Between rooms	Between rooms	A (m^2)
	124 - 122	0.60
	B - 120	1.50
	123.1 - 122	0.40
1 - 2		2.50
	122 - 111.1	3.80
	122 - 121	2.78
2 - 3		6.58
	123.2 - 121	0.29
	123 - 121	2.98
	123.1 - 121	0.44
1 - 3		3.71
3 - 4	111.1 - 104	5.92
4 - 5	106 - 105	1.98

Table A.7

Summary of heat soakage areas.

| | Areas m^2 | | | |
	Drywell	Pool	Above pool	Totally
Concrete only	951.5	213.5	683.3	1 848.3
Painted	1 184.3	-	133.5	1 317.8
Steel lined	1 606.8	369.5	-	1 976.3
Steel only	1 984.7	3.7	678.1	2 666.5
Subtotal	5 727.3	586.7	1 494.9	7 808.9
Aluminium	1 021.4	-	-	1 021.4
Grand total	6 748.7	586.7	1 494.9	8.830.3

Table A.8

Suggested values of heat soakage constants.

	λ W/(m^2*K)	ρ kg/m^3	c_p J/(kg*K)
Concrete	1.63	2 400	880
Steel	55	7 800	460
Aluminium	210	2 690	896

The value of λ for concrete may be too low, taking reinforcements into account.

Table A.9

Aluminium content in the containment.

Room*	mC_p, MJ/K
1:5	1.20
2:5	0.01
3:5	0.55
Drywell	1.76

*   See Figure 7

Table A.10

Total steel content in the containment.

	Total heat capacity, MJ/K			
	Drywell	Pool	Above pool	Totally
Steel liner	50.9	12.6	-	63.5
Steel only	91.0	0	7.3	98.3
Steel total	141.9	12.6	7.3	161.8

Table A.11

Suggested discharge flow data for Blowdown 18.

Time (s)	Mass flow kg/s	Spec enth kJ/kg	Integrated Mass, tons	Integrated m*H, GJ
0.00	0.	0.	0.000	0.000
0.00	0.	765.	0.000	0.000
.12	1 800.	765.	.108	.083
.25	3 060.	765.	.424	.324
.50	3 000.	765.	1.181	.904
.70	2 800.	765.	1.761	1.347
.90	2 370.	765.	2.278	1.743
1.20	2 070.	765	2.944	2.252
2.00	2 050.	818.	4.592	3.557
3.00	2 040.	885.	6.637	5.298
4.00	2 060.	933.	8.687	7.161
4.40	2 068.	940.	9.513	7.935
5.00	2 080.	956.	10.757	9.114
6.00	2 140.	970.	12.867	11.147
8.00	1 800.	985.	16.807	14.995
10.00	1 840.	995.	20.447	18.599
11.00	1 880.	998.	22.307	20.453
14.00	1 740.	1 000.	27.737	25.877
20.00	1 700.	1 006.	38.057	36.228
30.00	1 660.	1 012.	54.857	53.178
42.00	1 580	1 013.	74.297	72.861
50.00	1 540.	1 023.	86.777	85.565
58.00	1 210.	1 039.	97.777	96.895
65.00	1 370.	1 049.	106.807	106.325
74.00	1 160.	1 060.	118.192	118.326
80.00	1 140	1 068.	125.092	125.667
85.00	1 120	1 075.	130.742	131.721
120.00	1 000.	1 075.	167.842	171.603
137.00	1 000.	1 140.	184.842	190.431
140.00	1 000.	1 140.	187.842	193.851
164.00	960.	1 140.	211.362	220.664
171.00	280.	1 140.	215.702	225.611
175.00	80.	1 140.	216.422	226.432
190.00	0.	1 140.	217.022	227.116

Input data acc to Diagram E.4, E.5, E.6 in MXB-218.

Table A.12

Summary of geometry and initial conditions for BD 18.

Room no	Volume m³	Temp °C	Initial conditions Humidity g/kg	Pressure bar	Water tons
1:5	683	61.0	12	1.045	–
2:5	175	49.5	9	1.045	–
3:5	901	21.9	4	1.045	–
4:5	213*	19.0	4	1.045	–
Drywell	1 972*	37.5	7	1.045	–
Wetwell	2 133**	16.0	–	1.045	549
WW, gas	1 583	16.0	12	1.045	–
WW, liq	550**	16.0	–	1.045	549**
Header	146*	18.5	?	1.045	–

*   Incl 5.3 m³ of air in 28 open vent pipes, but
           excl 5.5 m³ of air in blocked vent pipes.

**   Excl 5.6 m³ of water in 28 open vent pipes and
           5.4 m³ of water in blocked vent pipes.

Table A.13

Requested computations for ISP17.

Quan-tity	Unit	EUC code	Compartment	Measurement position	Compare diagram in MXB-218	Case[1] (1.4s) 4.4s	220s	Remarks
Δp	kPa	70	110-105	110M213	M:22	C	C	Slightly high
"	"	"	106-105	106M215	M:23	(B)[4]	(B)	
"	"	"	122-124	122M144-124M142	M:6,4	(A)		
"	"	"	122-110	" -110M147	M:6,9	(A)		
"	"	"	122-106	" -106M163	M:6,14	(A)		
p	MPa	87	124	124M142	M:4	(A)		
"	"	"	122	122M144	M:6	A		
"	"	"	110	110M147	M:9	A	C	
"	"	"	106	106M163	M:14	B	B	Smoothed
"	"	"	105	105M122	M:18	C	C	(1-2 kPa high)
T	K	84	124,vapor	124M572	M:24	A		
"	"	"	122 "	122M574	M:24	A		
"	"	"	111 "	111M576	M:25	A	C	
"	"	"	106 "	106M586	M:28	B	B	
"	"	"	105 "	Average	E:16	C	C	
"	"	"	105,liquid	"	E:16		C	
G_a	kg/s	78	Vents	Evaluated	E:12,40		B	Flow of air
G_s	"	"	"	"	E:10,41		B	"- vapor
G_w	"	"	"	"	E:11,39		B	"- liquid
Δm_a^V	kg	80	Vents	Evaluated	E:15,25		B	Integrated
Δm_s^V	"	"	"	"	E:13		B	flows of air, steam
Δm_w^V	"	"	"	"	E:14		B	and liquid
Δm_w^{DW}	kg	80	Drywell	Evaluated	-		B	Sump water [3]
m_s^{WW}	kg	80	105,vapor	Evaluated	E:26		C	
Z_v[2]	m	83	Vents	Evaluated	E:29	C		Water plug level
Z_p[2]	"	"	105,G1	Evaluated	E:27	C		Pool swell
"	"	"	105,G3	"	E:27	C		"

$$
\begin{array}{rcl}
9A + 0A &=& 9A \\
3B + 10B &=& 13B \\
6C + 7C &=& 13C \\
\hline
\text{Totally: } 18 + 17 &=& 35 \text{ diagrams}
\end{array}
$$

[1] "PWR programs": Only A (up to 1.4s)
   "Starting from header": C + some of B (B normally = input data, but interesting
   for comparison purpose)
   "Full representation of drywell": A+B+C

[2] Relative vent pipe outlet

[3] Water on drywell floor, cf Table E:7 in MXB-218

[4] Brackets indicate variables of less interest for the evaluation.

Table A.14

Flow models in ARIANNA Computer Code.

Thermodynamic state	Junction geometry	Subcritical flow	Critical flow
Superheated Steam	Orifice (L/A=0)	Ideal Gas Model (G_{id})	Ideal Gas Model (G_{id}^{cr})
	Pipe (L/A>0)	Momentum Equation (G_{ME})	$\min (G_{id}^{cr}, \ G_{ME}^{cr})$
Saturated Steam	Orifice (L/A=0)	$(G_{id} \cdot \dfrac{G_{moody}}{G_{id}^{er}})$	Moody Model (G_{moody})
	Pipe (L/A>0)	Momentum Equation (G_{ME})	$\min (G_{moody}, \ G_{ME}^{cr})$

Table A.15

Some basic computer code characteristica.

1.	Code	ARIANNA-1	CONTEMPT-LT/26	CONTEMPT-LT/28	COPTA-7	ZOCO-V
2.	Basic code description	Ref 23	Ref 24	Ref 25	Ref 26	Ref 27
3.	Changes made to the code compared to basic code description	Simplified wetwell model (backpressure)	No*	See Ref 28 (Volume change effect, steam in air bubbles)	Extended flash model Possibility to retain air in drywell	Automatic swith superheat to saturation Heat transfer Carryover
4.	Maximum possible number of compartments					
	a Drywell type	100	1 - 2	1 - 2	10	11
	b Wetwell type	-	1	1	10	1
	c Totally	100	2 - 3	2 - 3	10	11
5.	Contains press-vessel model?		Simplified	Simplified	Yes	
6.	Pool swell model	-	No	No	Yes	Yes
7.	Compartment thermodynamics	Equilibrium	Non-Eq	Non-Eq	Non-Eq	Equilibrium

* Changes made in parameter studies.

Table A.16

Summary of surface areas for heat absorbing structures.

Code	CONTEMPT LT/26	CONTEMPT LT/28	COPTA-7	ZOCO-V	ARIANNA
1. Drywell					
a) Concrete only	1 138	1 653	951	950	288
b) Painted concrete	-		765	765	1 158
c) Lined concrete	1 606	711[1]	1 607	1 607	1 607
d) Totally concrete	2 744	2 364	3 323	3 323	3 053
e) Downcomers	26	195	198	-	-
f) Other steel	1 809	799	1 787	2 037	1 901
g) Aluminum	1 021		(1 021)[2]	606	635
h) Totally, DW	5 592	3 358	6 329	5 966	5 589
2. Wetwell, gas phase					
a) Concrete only	1 357.5	1 152	683	683	
b) Painted concrete	-	120	553	553	
c) Lined concrete	23.3	-	-	-	
d) Totally concrete	1 298.8	1 262	1 236	1 236	
e) Downcomers	148.4	195	193	-	
f) Other steel	471.0	485	485	625	
g) Aluminum	-	-	-	-	
h) Totally, WW gas	2 018.2	1 943	1 914	1 861	
3. Wetwell, pool					
a) Totally concrete	330.5	479	584	-	
b) Steel	-	479	4	-	
Totally, WW pool	330.5	959	587	-	
4. Drywell + Wetwell	7 904.6	6 260	8 830	7 827	
5. Additional mC_p, kJ/K					
a) Drywell			-	1.8	
b) Wetwell vapor			-	-	

[1] Structures of rooms 123 and 124 excluded
[2] Treated as mC_p

Table A.17

Models used for heat soakage.

Code	CONTEMPT LT/26	CONTEMPT LT/28	COPTA-7	ZOCO-V	ARIANNA
1. Condensation model[1]					
a) Drywell	Cond	Cond/Bulk	Bulk	Bulk	?
b) Wetwell, vapor	Bulk	Bulk	Bulk	Bulk	-
c) Pool	Bulk	Bulk	Bulk	Bulk	-
2. HTC, $W/(m^2 {}_*K)$					
a) Drywell	DCMN[2]	Uchida	5 000		DCMN
b) Wetwell, vapor	Nat conv[3]	Nat conv	Uchida		-
c) Pool	2.27	5 000	500		-

[1]   Cond = Condensation on walls, Bulk = Bulk heat transfer from the volume.

[2]   DCMN = Correlation developed by DCMN (Dipartimento di Construzioni Meccaniche E Nucleari).

[3]   Natural convection = 0 - 10 $W/(m^2 {}_*K)$.

Table A.18

Some computer run details for short-time cases.

Item		CONTEMPT LT/26	CONTEMPT LT/28	COPTA-7	COPTA-7	ZOCO-V	ARIANNA-1 0 - 1.45 S
1.	Computer code	CONTEMPT LT/26	CONTEMPT LT/28	COPTA-7	COPTA-7	ZOCO-V	ARIANNA-1 0 - 1.45 S
2.	Computer utilized	IBM370/168	CYBER173	CYBER 170/835	CYBER 170/835	CYBER173	IBM370/168
3.	CPU time (s)	47	-	42	112	120	485
4.	Maximum time-step (s)	.01	-	.02	.005	.00125	.001
5.	Number of drywell compartments	1	1	1	4	4	17
6.	Flashing model for break flow (Equilibrium/pressure model)	Eq	Eq	Pressure flashing	80 % Eq 20 % flash	(Eq)	Eq
7.	Model for mass concentrations at vent flow entrance a) Air b) Steam c) Water	Air mod	Air mod	383 kg air locked	As gas phase	As gas phase	-
8.	Vent flow model. In particular a) Dynamic/Steady state b) Comp/Incompressible	SS Compr	SS Compr	SS Compr	SS Compr	SS Compr	-
9.	Pool model. In particular a) Surface area (m^2) b) Surface HTC (W/m^2-K) c) Temp of rising air d) Steam content of rising air e) Air rise velocity	141.0 Evap-cond As pool 0 ∞	118 0-1.35 As pool Sat ∞	113.5 0 As pool Sat Pool swell model	113.5 0 As pool Sat	107.7 Eq Pool swell model	-

Table A.19

Some computer run details for long-time cases.

Item		CONTEMPT-LT/26	CONTEMPT-LT/28	COPTA-7	ZOCO-V*
1.	Computer code	CONTEMPT-LT/26	CONTEMPT-LT/28	COPTA-7	ZOCO-V*
2.	Computer utilized	IBM 370/168	CYBER173	CYBER170-835	CYBER175
3.	CPU time (s)	1 477	600	269	496
4.	Maximum time-step (s)	.02	0.2	5	.005
5.	Number of drywell compartments	1	1	1	4
6.	Flashhing model for break flow (Equilibrium/pressure model)	Equilibrium	Equilibrium	Pressure flashing	Eq model
8.	Model for mass concentrations at vent flow entrance a) Air b) Steam c) Water	Air flow modifiers	Air flow modifiers	383 kg of air locked in DW	Header composition
8.	Vent flow model after vent clearing	Steady state Compr	SS Compr	SS Compr	SS Compr
9.	Pool model. In particular				
	a) Surface area (m^2)	141	118	113.5	107.7
	b) Surface HTC (W/m^2-K)	Evap-cond	0 to 1.35	0	
	c) Temp of rising air	As pool	As pool	As pool	Eq model
	d) Steam content of rising air	None	Sat	Sat	
	e) Air rise velocity, m/s	∞	∞	1	

*   Up to 75 s.

Table A.20

Submitted results for ISP17.

| Code | Number of dry-well subcompartments | Type of diagram | | |
		A 0 - 1.4 s 0 - 4.4 s	B 0 - 4.4 s	C 0 - 220 s
ARIANNA-1	17	x		
CONTEMPT-LT/26	1		x	x
CONTEMPT-LT/28	1		x	x
COPTA-7	1	$(x)^1$	x	x
COPTA-7	4	x		
ZOCO-V	4	x	x	x^2

[1]   As parameter study

[2]   0 - 75 s

Table A.21

Some key results for short-time cases.

Item	CONTEMPT LT/26	CONTEMPT LT/28	COPTA-7 2 nodes	COPTA-7 5 nodes	ZOCO-V 5 nodes	MX-DATA
1. Time for vent clearing (v.c.), s	1.26	0.89	1.25	1.11	1.08	1.36
2. Header pressure at v.c., MPa	.147	.166	.138	.145	.144	.135-.140
3. Water plug speed at v.c., m/s	8.53	19.3	7.15	11.4	31.8	5.5-6.5
4. Drywell pressure at 4.4S, MPa	.168	.210	.171	.193	.194	.168-.172
5. Peak pool swell, m (above initial level)			3.43	4.17	3.15	2.0-3.5
6. At time =			2.70	2.39	4.4	2.7-3.2
7. Maximum pool surface velocity, m/s			4.39	5.54	1.44	2.0-5.0
8. At time =			2.70	2.39	1.75	2.0-3.2

LIST OF FIGURES

Figure B.1

The exterior of the Marviken Power Plant.

Figure B.2

Cross-sectional view of the containment.

Sensing elements　　　　**Signal Electronics**　　　　**Data Recording and Reproducing**

Diagrams for evaluation

| Radiation detector | → | Radiation detector electronics | → | Tape recorder B&H CPR 4010 | → | Light beam recorder | → | [diagram] |

Diagrams for evaluation

| Thermocouples | → | DC amplifiers | | Process computer VARIAN 620 | → | Tape unit | | Digital computer CDC-CYBER | → | [diagram] |

Adaption unit

Digital-digital interface

| Pressure/ Diff. pressure Accelerometer | → | Pressure signal amplifiers |

Digital

| Thermocouples Level Probes Infrared ray | → | DC amplifiers/ Level probe/ Infrared ray/ Signal electronics | → | PCM modulator J&E TM 8K10 | → | Tape recorder AMPEX PR-2200 | → | PCM demodulator J&R TD 8K10 |

Analog

| | | | | Light beam recorder |

| Level probes | → | Level probe signal electronics | → | Light beam recorder |

Diagrams for evaluation

| Pressure transducers | → | Pressure signal amplifiers | → | Pen-recorder | → | [diagram] |

| Video cameras Microphones | → | Pre-amplifiers | → | Audio/Video recorder | → | Television |

——— Data acquisition

—·—·— Data transfer

— — — Reproduce

Figure B.3

Lay-out of the measurement system.

124M142 —   — 124D110

122D202 —

111D115 —
111M146 —
110M147 —
112D216 —
104D117 —
104M148 —
104D118 —
104M149 —
110M212 —
110M213 —
108M150 —
108M151 —
108M153 —

108M152 —

108M154 —

108M155 —
108M156 —
106M163 —
105D217 —
105D218 —

123D111
122M143
122M144
122D112
122D201
122D113
121D114
121M145
110D116
110R192
112D203
112D204
105D120
105M122
105D121
105R193
106M214
106M215
106D119
107M160
107M157
107M161
107M158
107M162 (VP 06)
107M159 (VP 37)

106M164   Figure B.4

105M166   105M168
105M165   105M167

Pressure and differential pressure measurement
positions.

124M572 — 124D417
124 124D418
124D419

123D420
123D421

122M573 — 122D422
122M574 — 122D423

111D429 — 121D424
111M576 — 121M575
111D430 — 121D425

104M578 — 112M577
104D431 — 113D427
104M579 — 112D428
104D432 — 114D426

108M580
108M583
108D433   108G331 - 108G339
                 & 108N327 - 328
108D434   108M321 - 108M326
108M581
108M584   106D436

108M582
106M586   106D435
106M585

107M437 - 107M445   107M590
(VP 31)   107M587

107M593 - 107M595   107M591

107M588
107M592 (VP 06)
107M589 (VP 37)

107D447 - 107D456
(VP 11)

Figure B.5

Temperature flow velocity and mass composition
measurement positions.

Height above
pool bottom
m

Vent pipe header

Height (m)	G1	G2	G4	G3
8.00				105M647
7.50				105M646
7.00				105M645
6.50	105M624	105M634	105M657	105M644
6.25	105M623	105M633	105M656	105M643
6.00	105M622	105M632	105M655	105M642
5.75	105M621	105M631	105M654	105M641
5.50	105M620	105M630	105M653	105M640
5.30	105M619	105M629	105M652	105M639
5.10	105M618	105M628	105M651	105M638
4.90	105M617	105M627	105M650	105M637
4.70	105M616	105M626	105M649	105M636
4.50	105M615	105M625	105M648	105M635

G1   G2   G4   G3

Figure B.6

Locations of level probes in the wetwell.
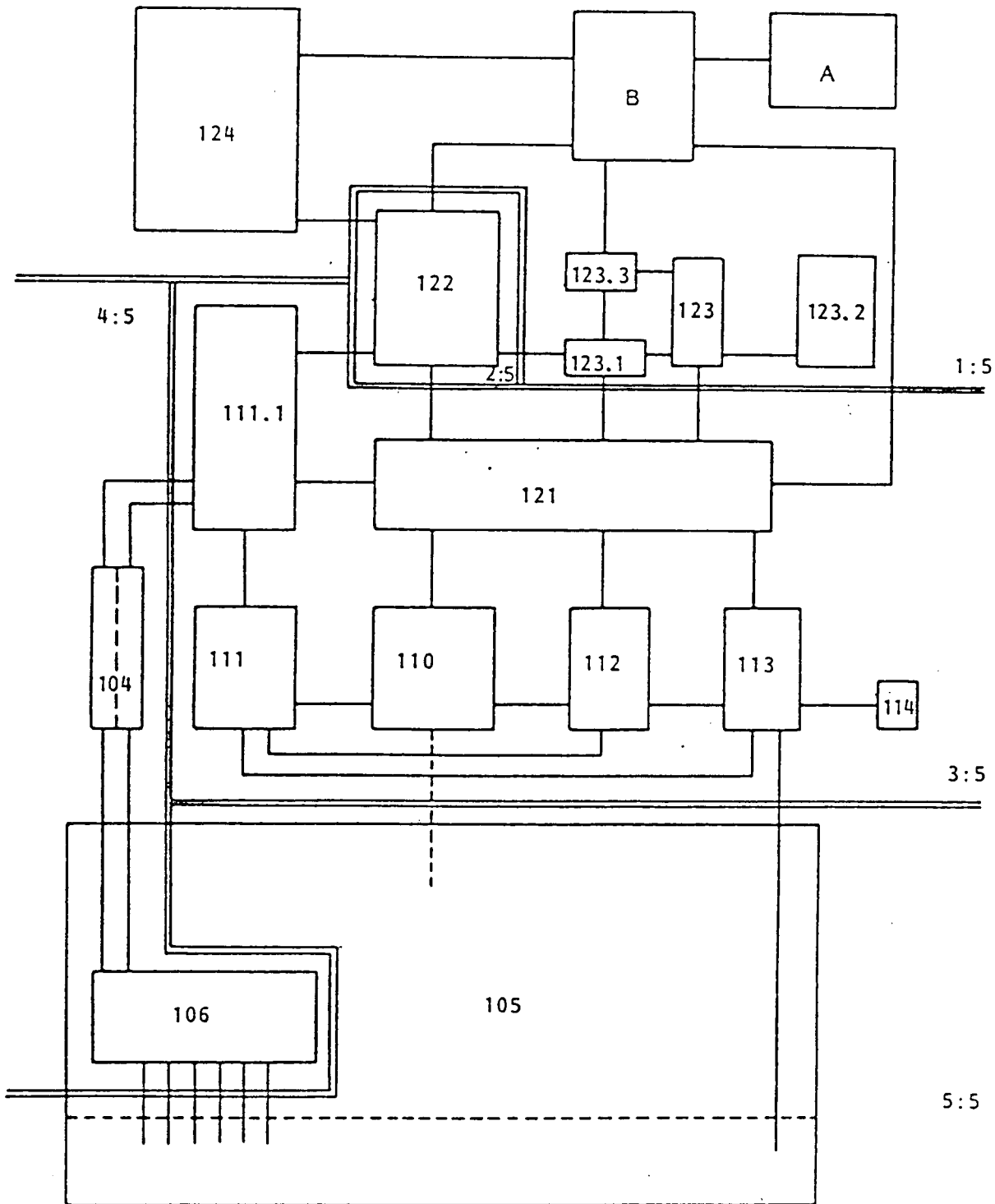
Figure B.7

Schematic diagram of rooms and connections in the
Marviken containment (50 cm² $\overset{\Lambda}{=}$ 1 000 m³).

Figure B.8

Cross-sectional area and volume for lower wetwell
in BD 18.

⊕   Blocked vent pipes

Permanently
closed

Drain pipe
(closed during blowdown)
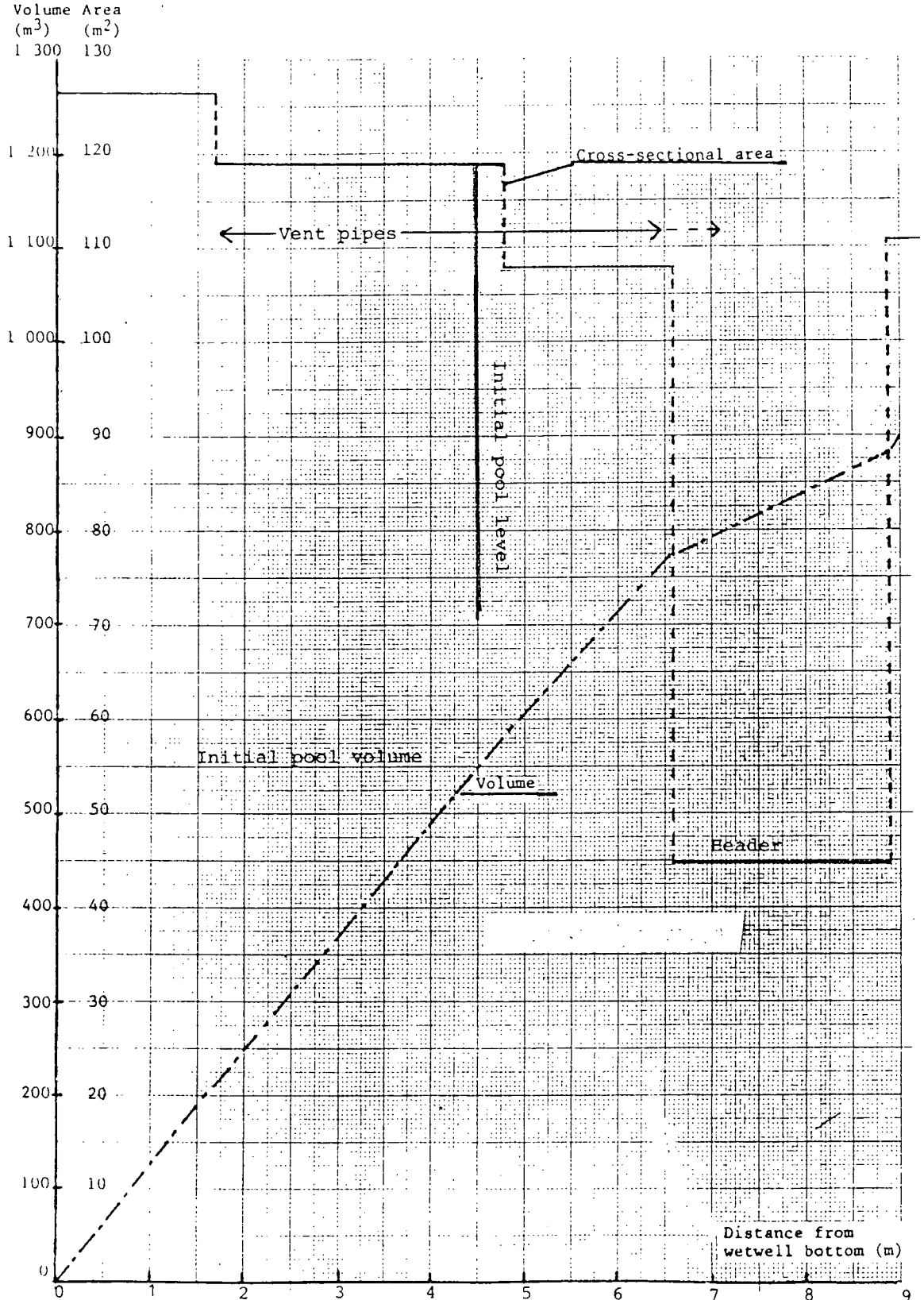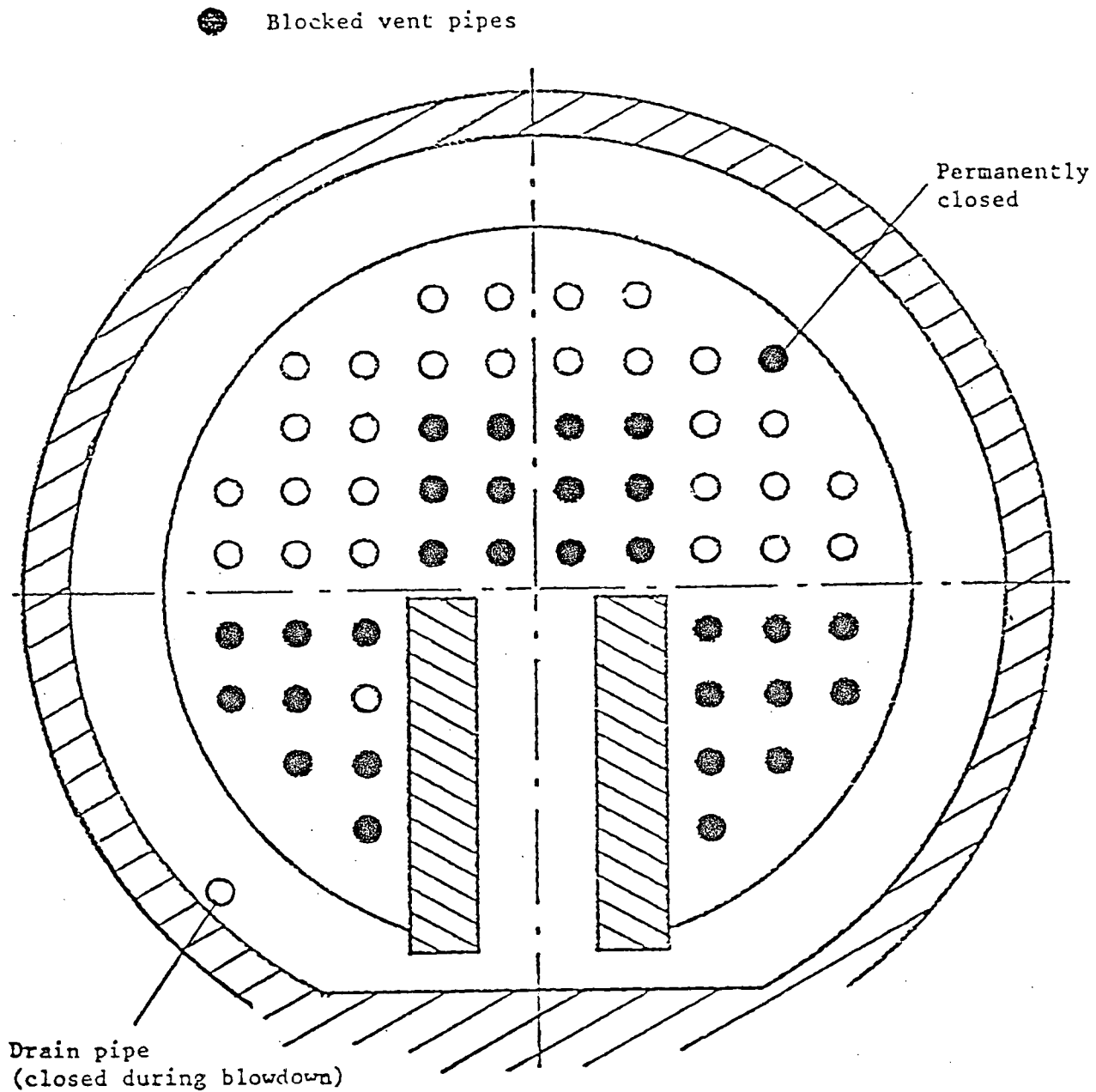
Figure B.9

Vent pipe blocking for Blowdown 18.
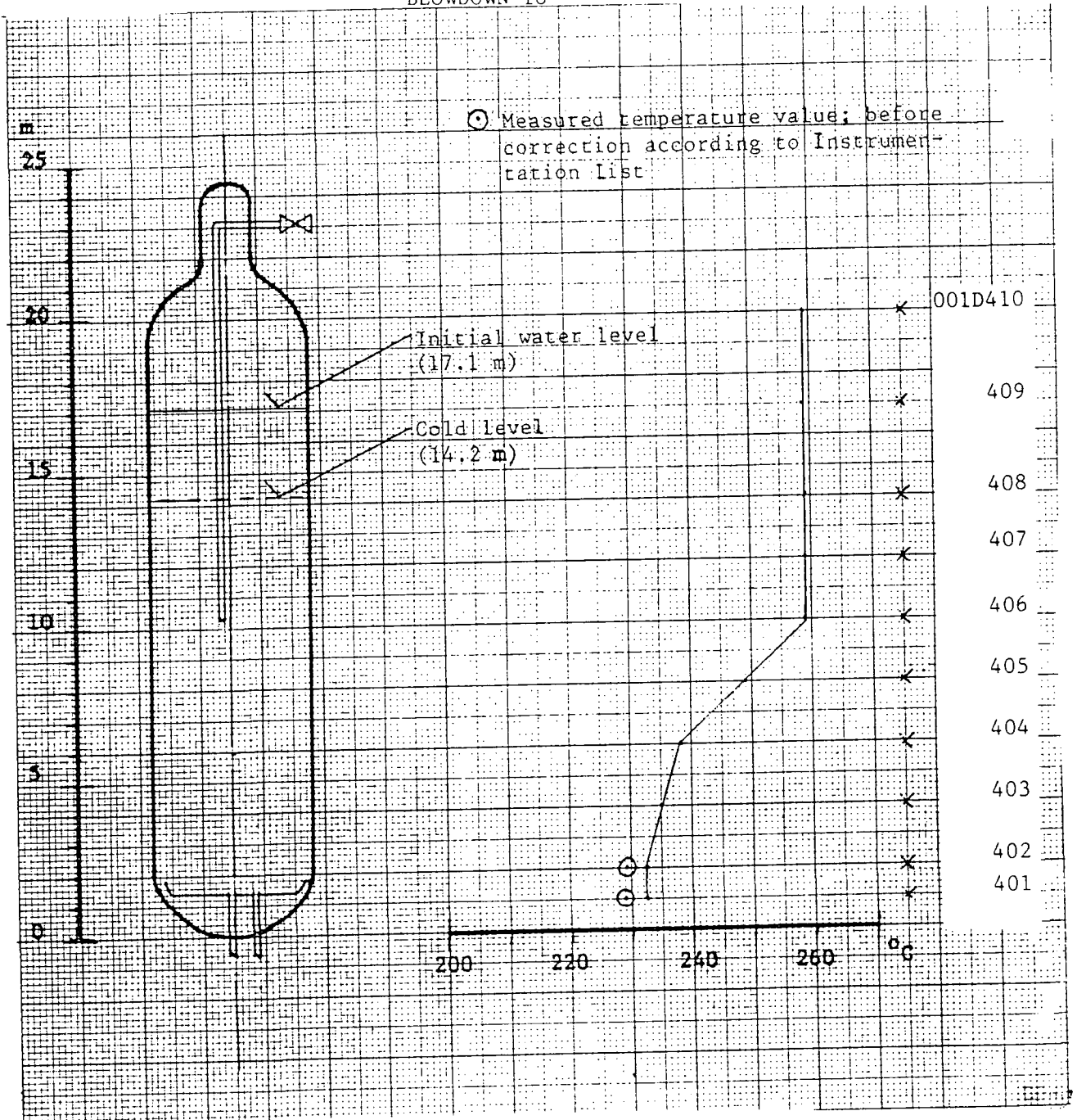
Figure B.10

Initial temperature profile versus height in the
pressure vessel.

Figure B.11

Discharge outlet of main discharge pipe with
rupture disc arrangement.

Figure B.12

Discharge flow rates calculated from DP-over-vessel data
and from the flow pressure drop.

BLOWDOWN 18

⊙ MASS FLOW FROM THE VESSEL

┆ ─ ─ based on pressure drop (003D108-003D107)
       in the discharge pipe
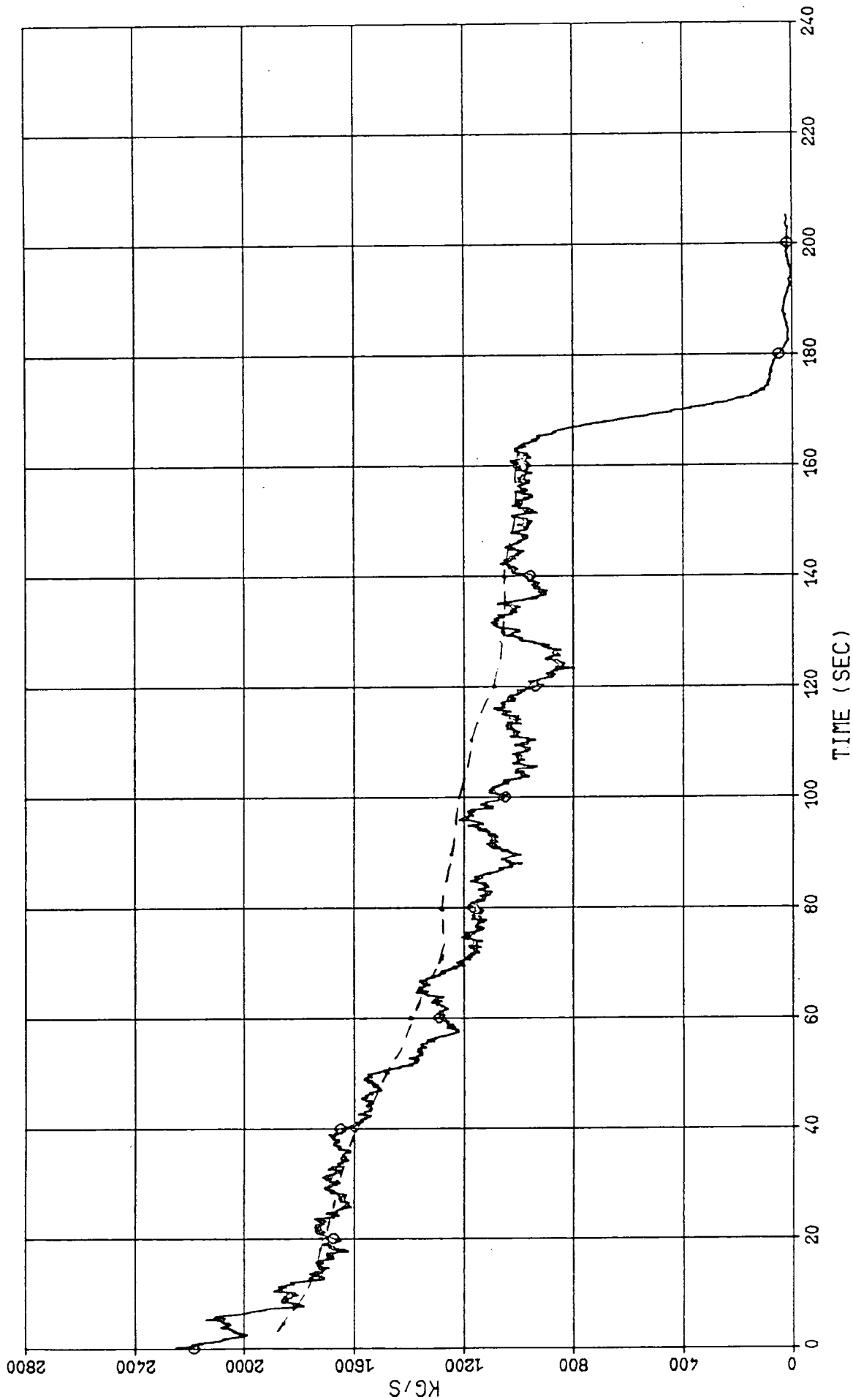
Figure B.13

Discharge flow rate at the beginning of blowdown 18.
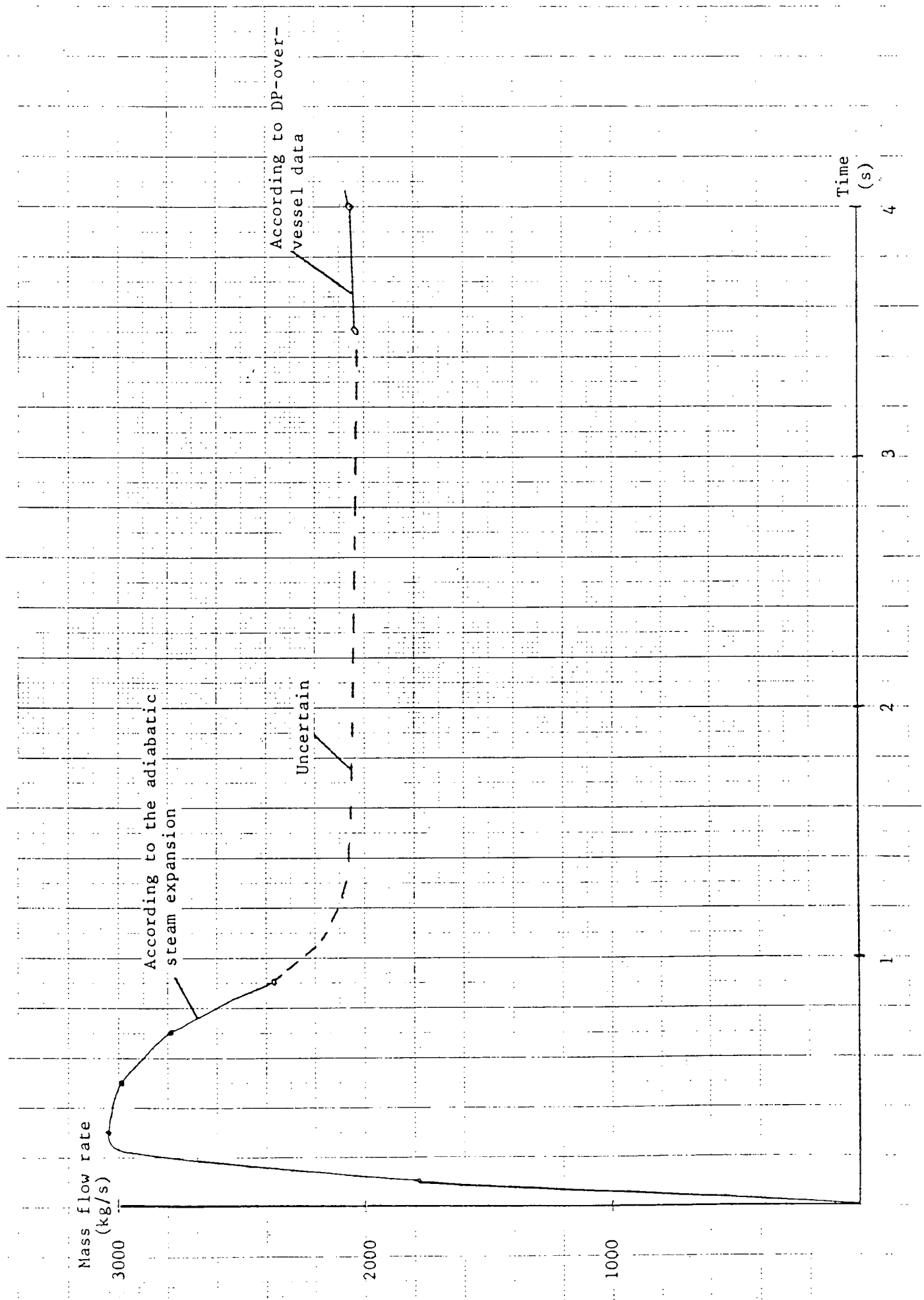
Figure B.14

Specific enthalpy of the discharge flow in Blowdown 18.
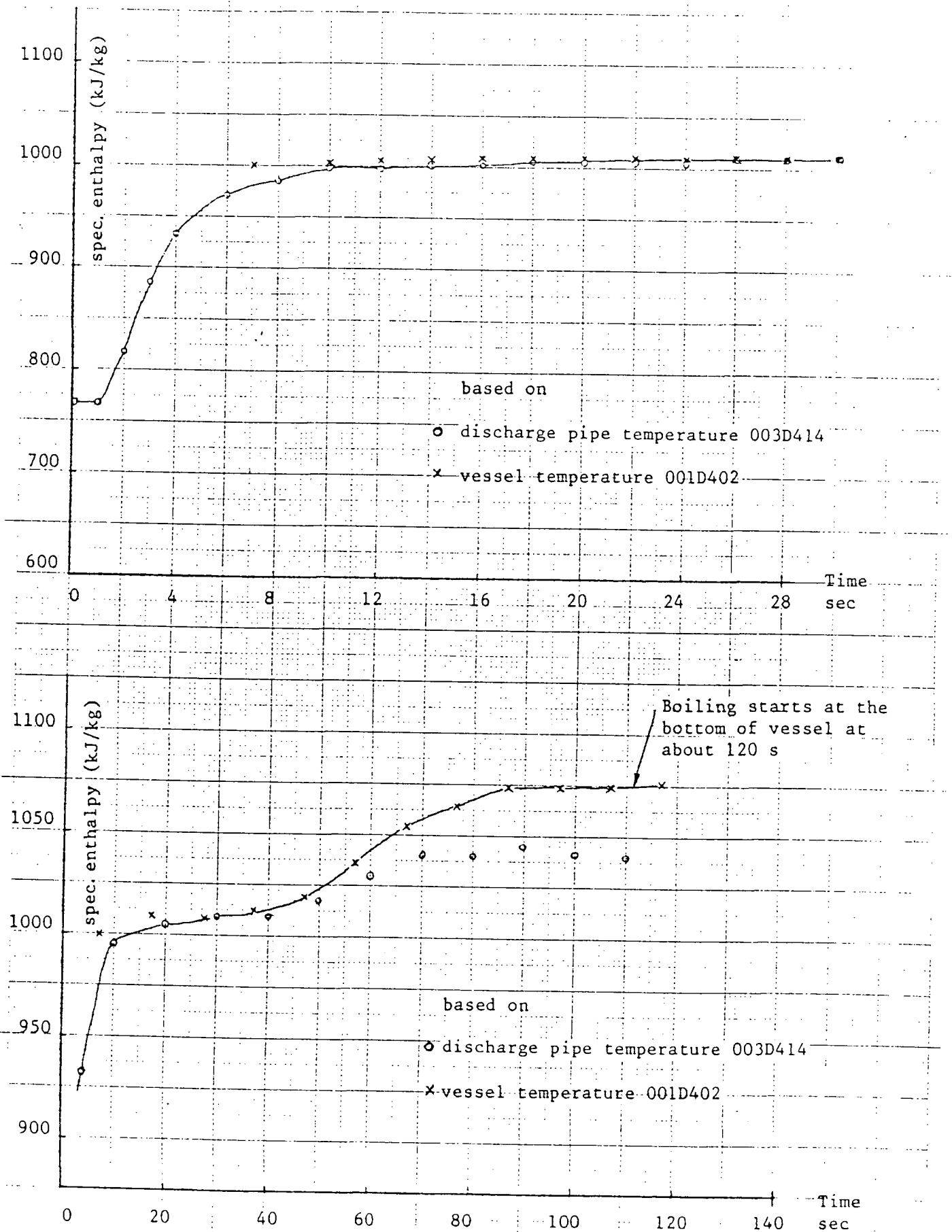
Figure B.15

Mass and energy balance for ISP17, 0 - 171 s.

	Total escape			Containment increase	
	Tons	GJ		Tons	GJ
MX =	216	226		216.4	224.5
IT =	210.9	221.7		213.7	262.3
SF =	216.2	223.5		216.2	219.7
SW =	216.4	226.5		216.5	226.3

Drywell 1973 m³

Drywell increase

	Steam,tons	GJ
MX =	2.4	6.5
IT =	2.83	7.64
SF =	2.33	5.53
SW =	2.44	6.28

DW heat soakage,GJ

IT = 17.7
SF = 10.5
SW = 14.4

Vent flow

	Tons	GJ
Air		
IRE =	1.76	0.66
MX =	1.89	--
IT =	2.14	
SF =	1.91	
SW =	1.86	

Steam		
IRE =	34.5	93.7
MX =	35	94
IT =	41.6	
SF =	45	
SW =	41.2	

Water		
IRE =	0.77	0.4
MX =	19	9.9
IT =	0.80	
SF =	~1	
SW =	0.82	

Water plug		
MX ⎫		
IT ⎬ =	5.56	0.4
SF ⎮		
SW ⎭		

Sump

Sump increase

	Tons	GJ
MX =	160	87
IT =	168.5	85.6
SF =	168.1	82.8
SW =	171.6	92.5

Heat transfer, GJ

IT = 0.016
SF = 0.016
SW = 0.027

Total heat soakage,GJ

MX = 28
IT = 17.8
SF = 10.6
SW = 14.7

Wetwell 2138 m³ (Initially 1583+555)

Wetwell increase

	Steam,tons	GJ
MX =	.0205	
IT =	.0000	1.01
SF =	.0255	0.57
SW =	.0138	0.14

WW vapor soakage,GJ

IT = 0.087
SF = 0.082
SW = 0.075

Pool (Initially 549+5.6 tons)

Pool increase

	Tons	GJ
IRE =	35.3+5.6	95
MX =	54.0+5.6	103
IT =	42.4+5.6	150.3
SF =	45.7+5.6	120.8
SW =	42.4+5.6	112.7

Pool soakage,GJ

IT = 0
SF =
SW = 0.213

IRE = Acc. to infra-red measurements, MX = Acc. to Fig 7:3 in ref 11

IT = Italy, SF = Finland, SW = Sweden

LIST OF DIAGRAMS

Short-time transient, 0 - 4.4 s

C.1A, C.1B	Pressure difference	110 - 105
C.2A, C.2B	Pressure difference	106 - 105
C.3A	Pressure difference	122 - 124
C.4A	Pressure difference	122 - 110
C.5A	Pressure difference	122 - 106
C.6A	Pressure in room	124
C.7A	Pressure in room	122
C.8A, C.8B	Pressure in room	110
C.9A, C.9B	Pressure in room	106
C.10B	Pressure in	wetwell
C.11A	Temperature in room	124
C.12A	Temperature in room	122
C.13A, C.13B	Temperature in room	111
C.14A, C.14B	Temperature in room	106
C.15A, C.15B	Temperature in	wetwell vapor
C.16A, C.16B	Water plug size	
C.17A	Pool level	

Long-time transient, 0 - 220 s

C.18	Pressure difference drywell-wetwell
C.19	Pressure difference header-wetwell
C.20	Drywell pressure
C.21	Header pressure
C.22	Wetwell pressure

LIST OF DIAGRAMS (cont'd)

ISP17,PRESSURE DIFF 110-105,110M213,DIAG M.22,TABLE M.4
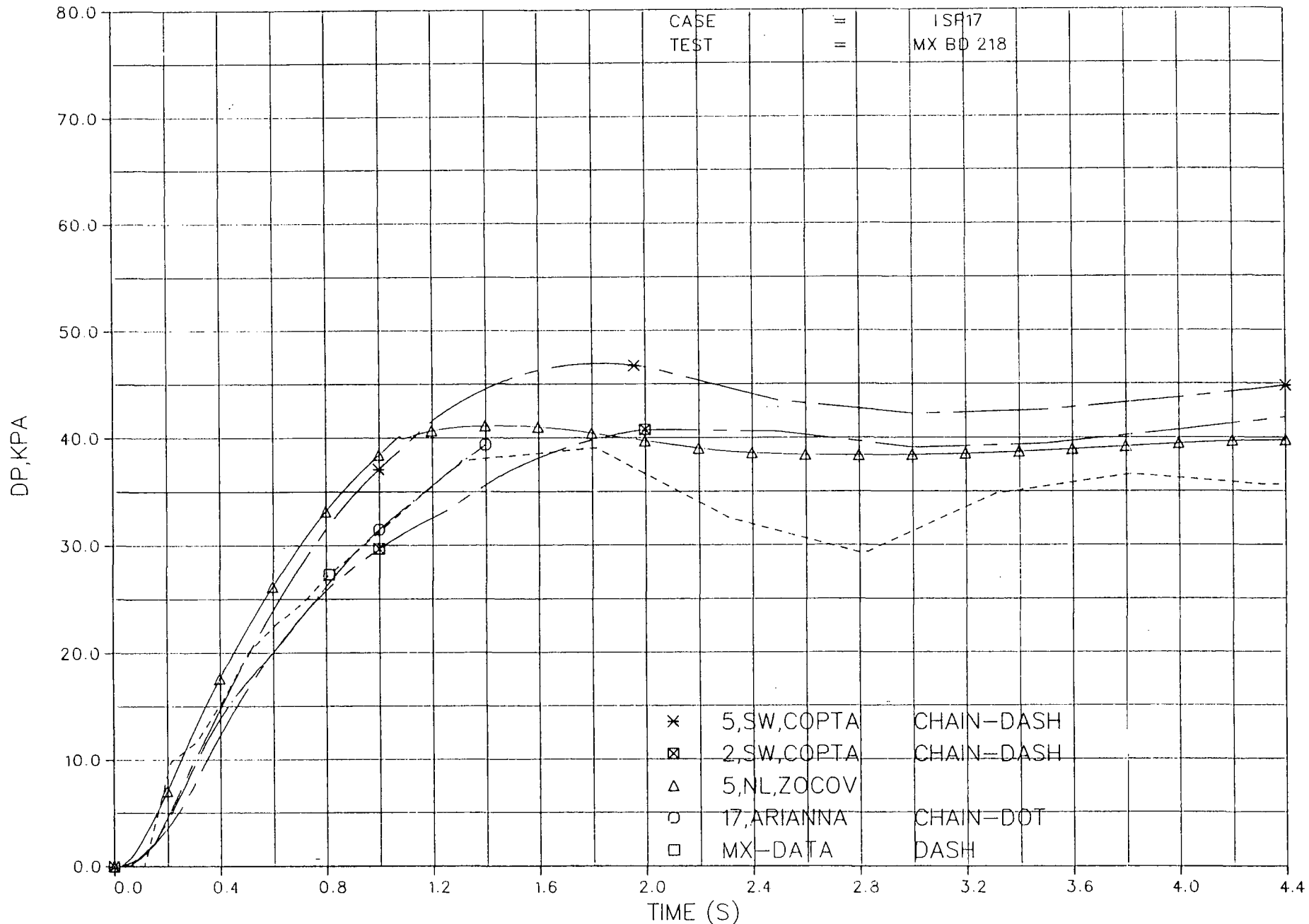
Diagram 1A. Short-time pressure difference, 110-105

ISP17,PRESSURE DIFF 110-105,110M213,DIAG M.22,TABLE M.4
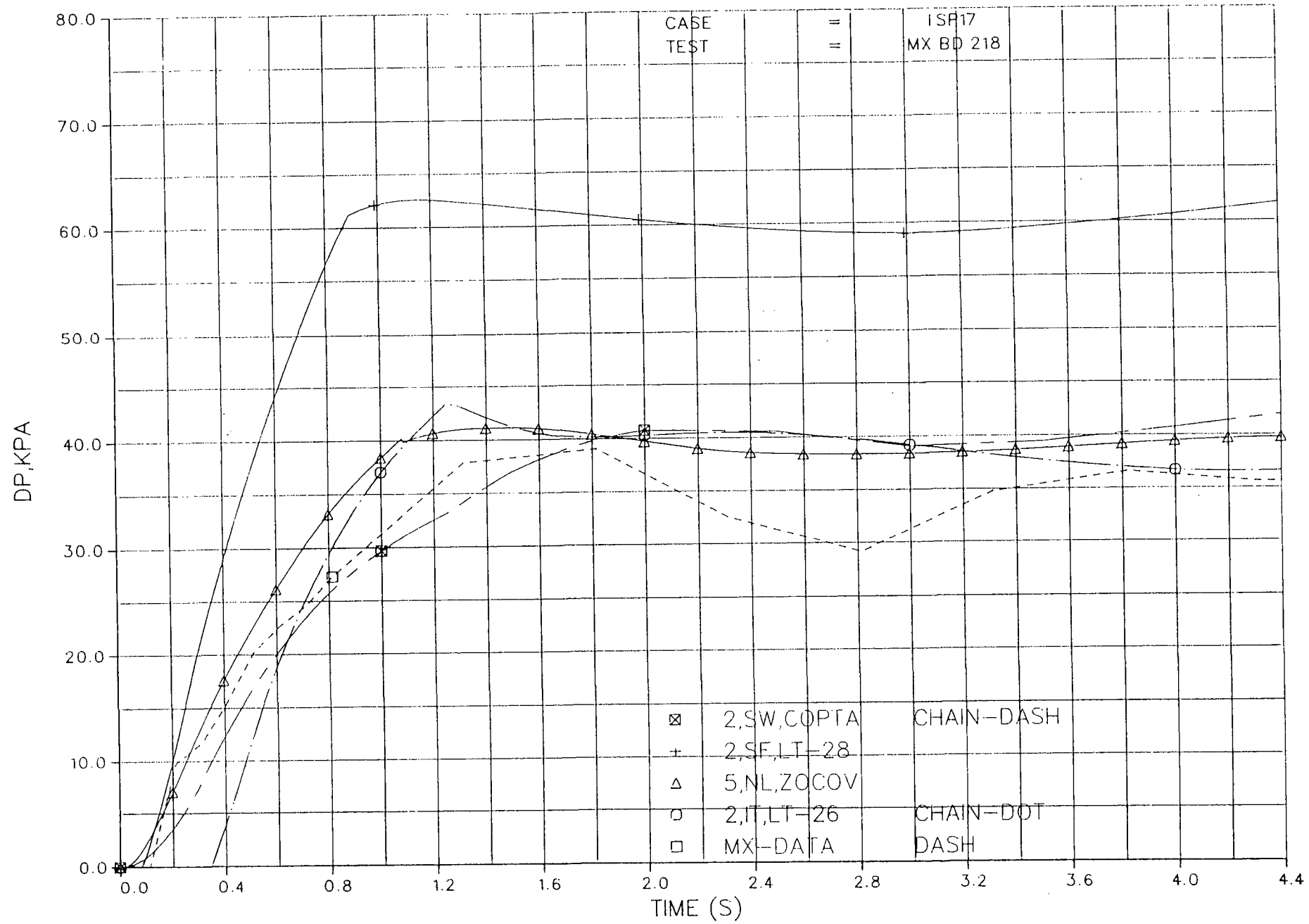
Diagram 1B.   Short-time pressure difference, 110-105

ISP17,PRESSURE DIFF 106-105,106M215,106M215,DIAG M.23,TABLE M.4
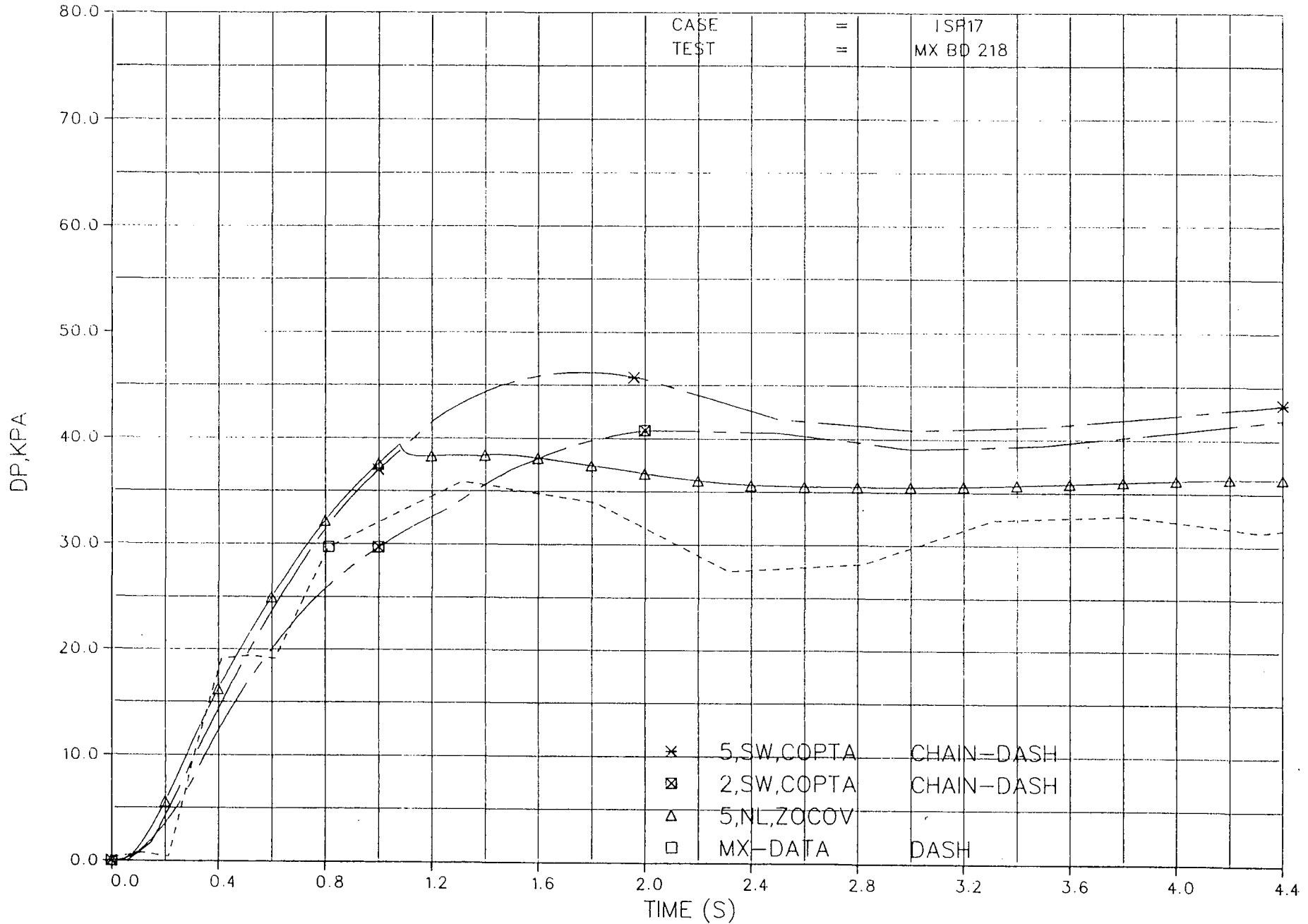
Diagram 2A. Short-time pressure difference, 106-105

ISP17,PRESSURE DIFF 106-105,106M215,DIAG M.23,TABLE M.4
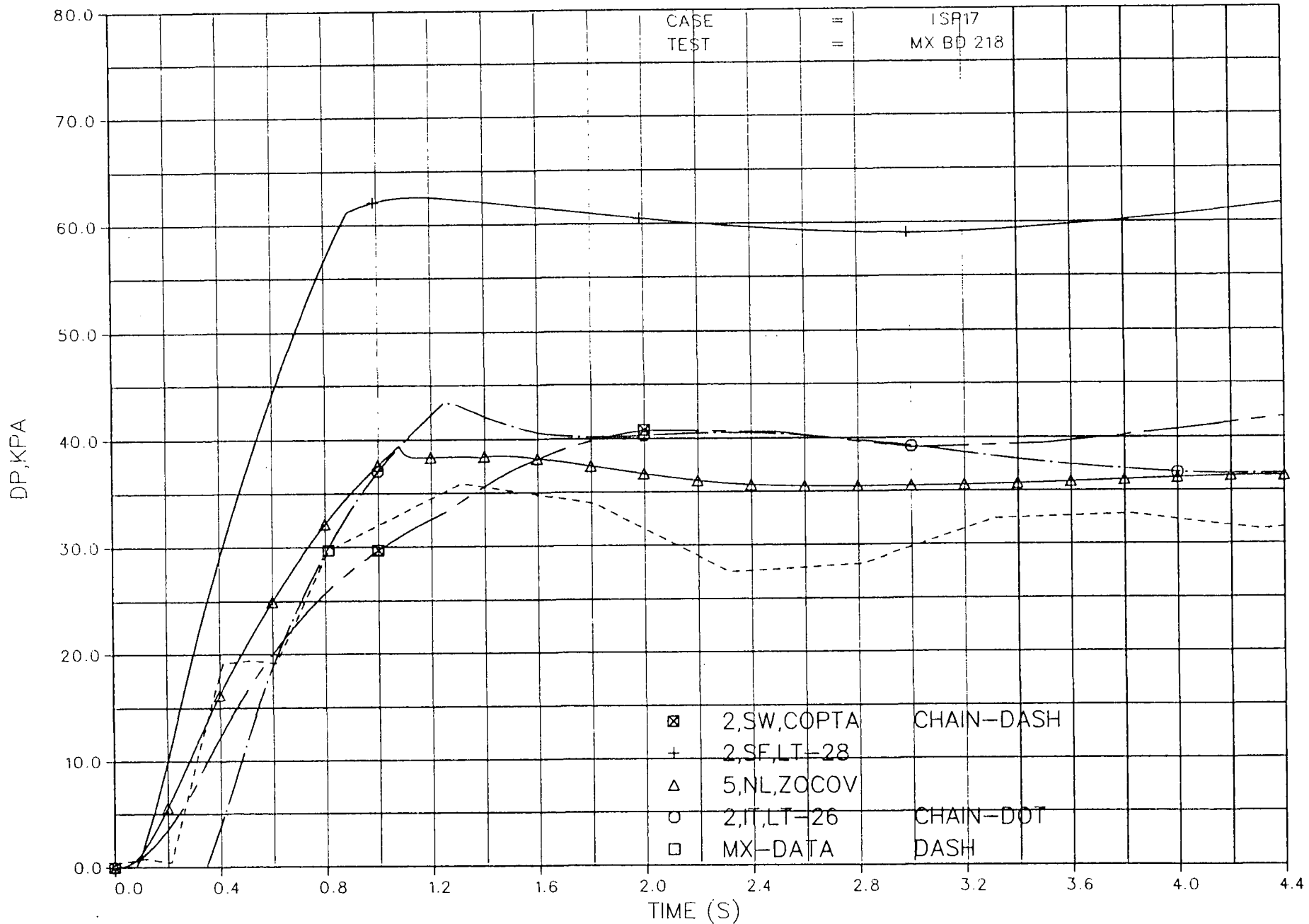
Diagram 2B.   Short-time pressure difference, 106-105

ISP17,PRESSURE DIFF 122−124,122M144−124M142,DIAG M.6,4,TABLE M.2
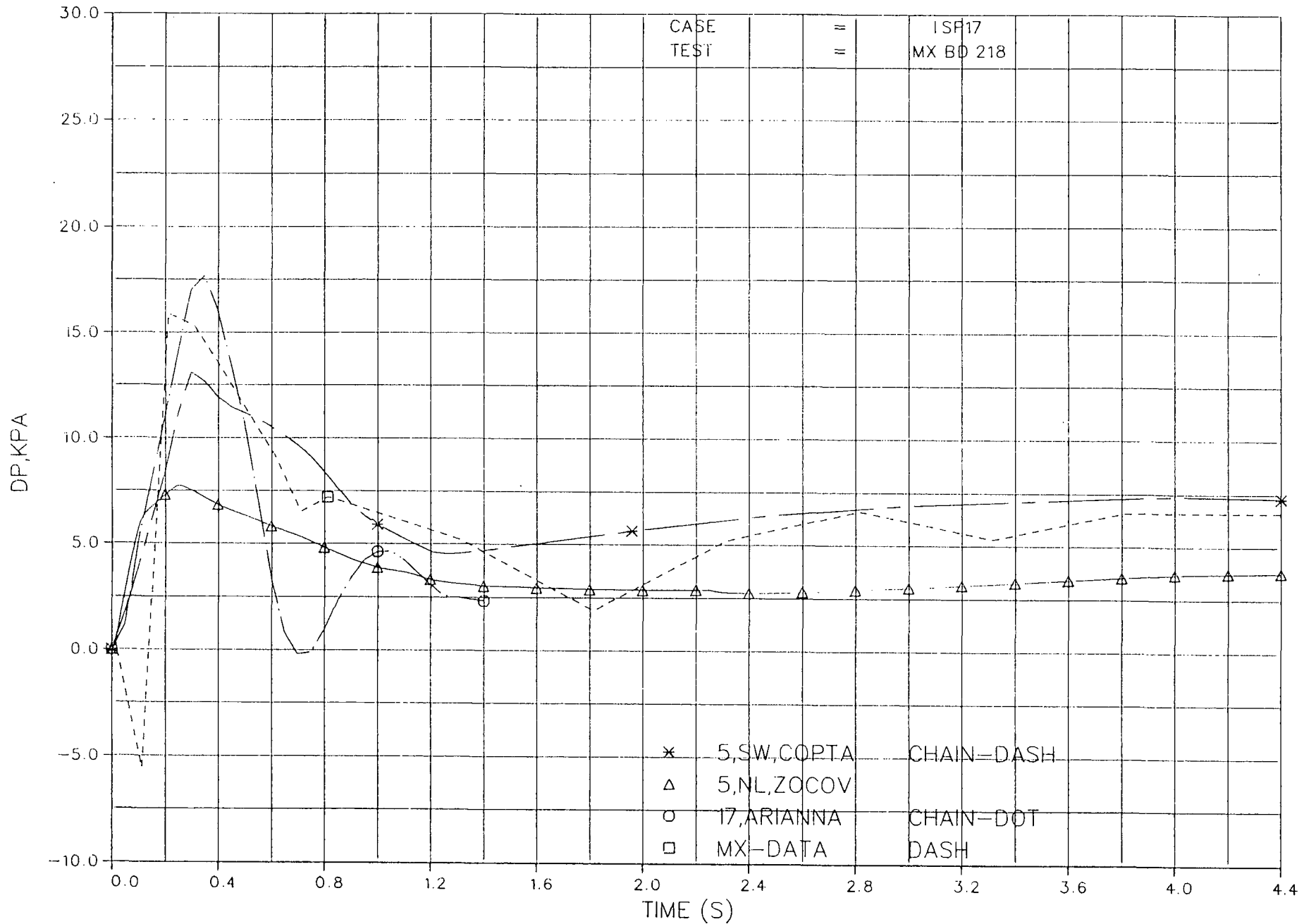
Diagram 3A. Short-time pressure difference, 122-124

Diagram 3B. Intentionally omitted

ISP17,PRESSURE DIFF 122-110,122M144-110M147,DIAG M.6,9,TABLE M.2
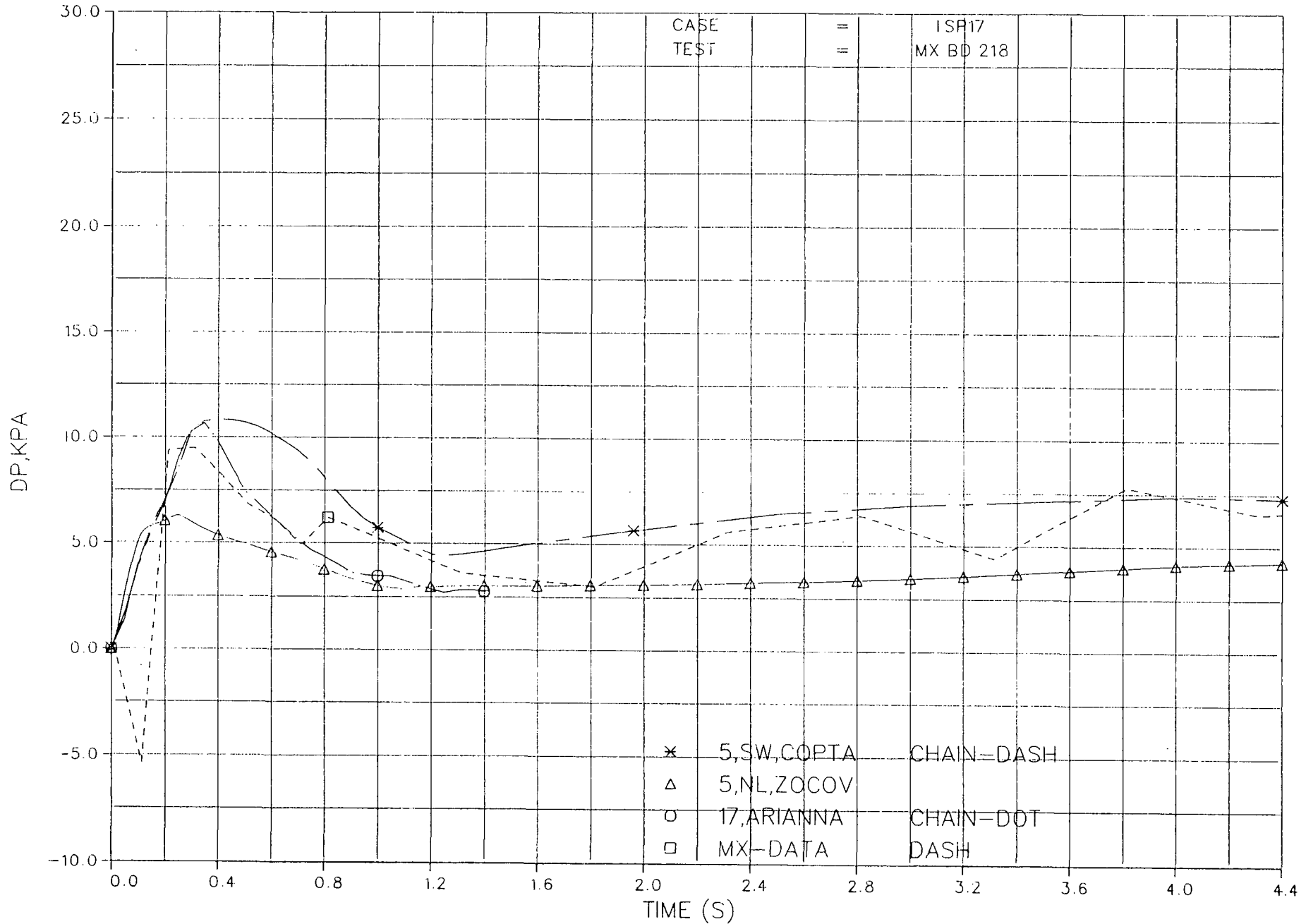
Diagram 4A.   Short-time pressure difference, 122-110

Diagram 4B. Intentionally omitted

ISP17,PRESSURE DIFF 122-106,122M144-106M163,DIAG M.6,14,TABLE M.2,5

| CASE | = | ISP17 |
| TEST | = | MX BD 218 |

DP,KPA

TIME (S)

✳	5,SW,COPTA	CHAIN-DASH
△	5,NL,ZOCOV	
O	17,ARIANNA	CHAIN-DOT
▢	MX-DATA	DASH
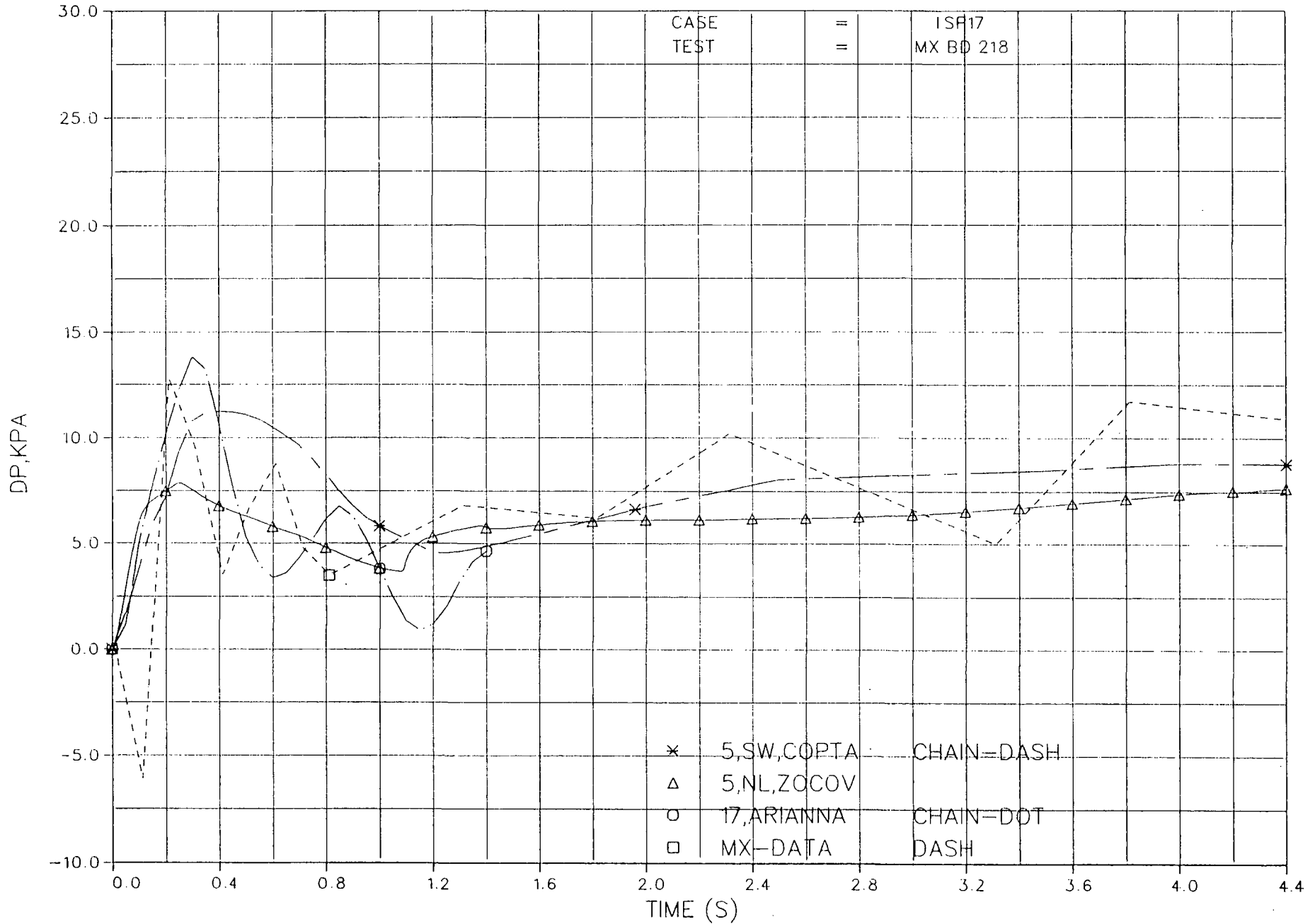
Diagram 5A.   Short-time pressure difference, 122-106

Diagram 5B. Intentionally omitted

ISP17, PRESSURE IN ROOM 124,124M142,DIAG M.4,TABLE M.2
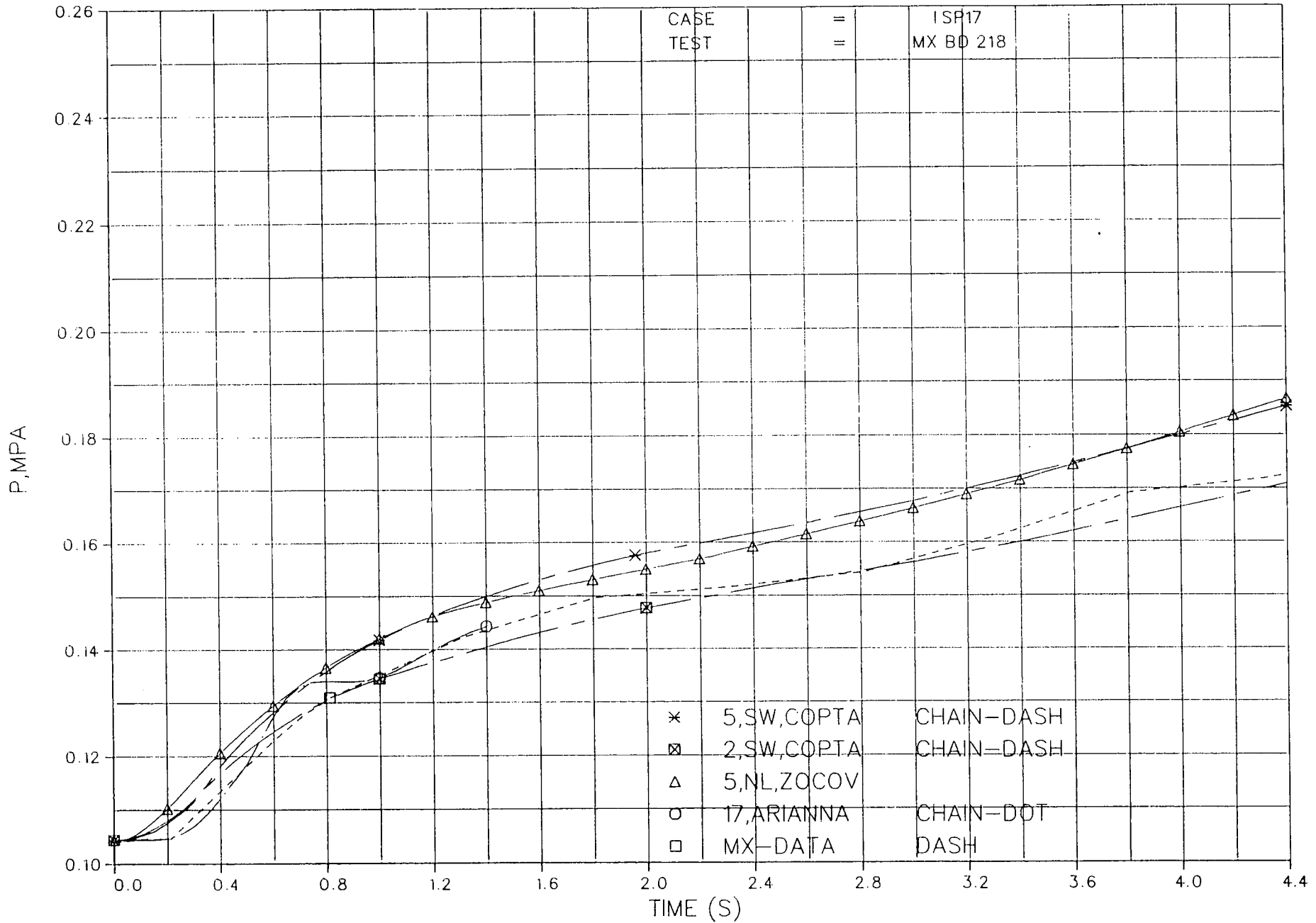
Diagram 6A.   Short-time pressure transient in room 124

Diagram 6B. Intentionally omitted
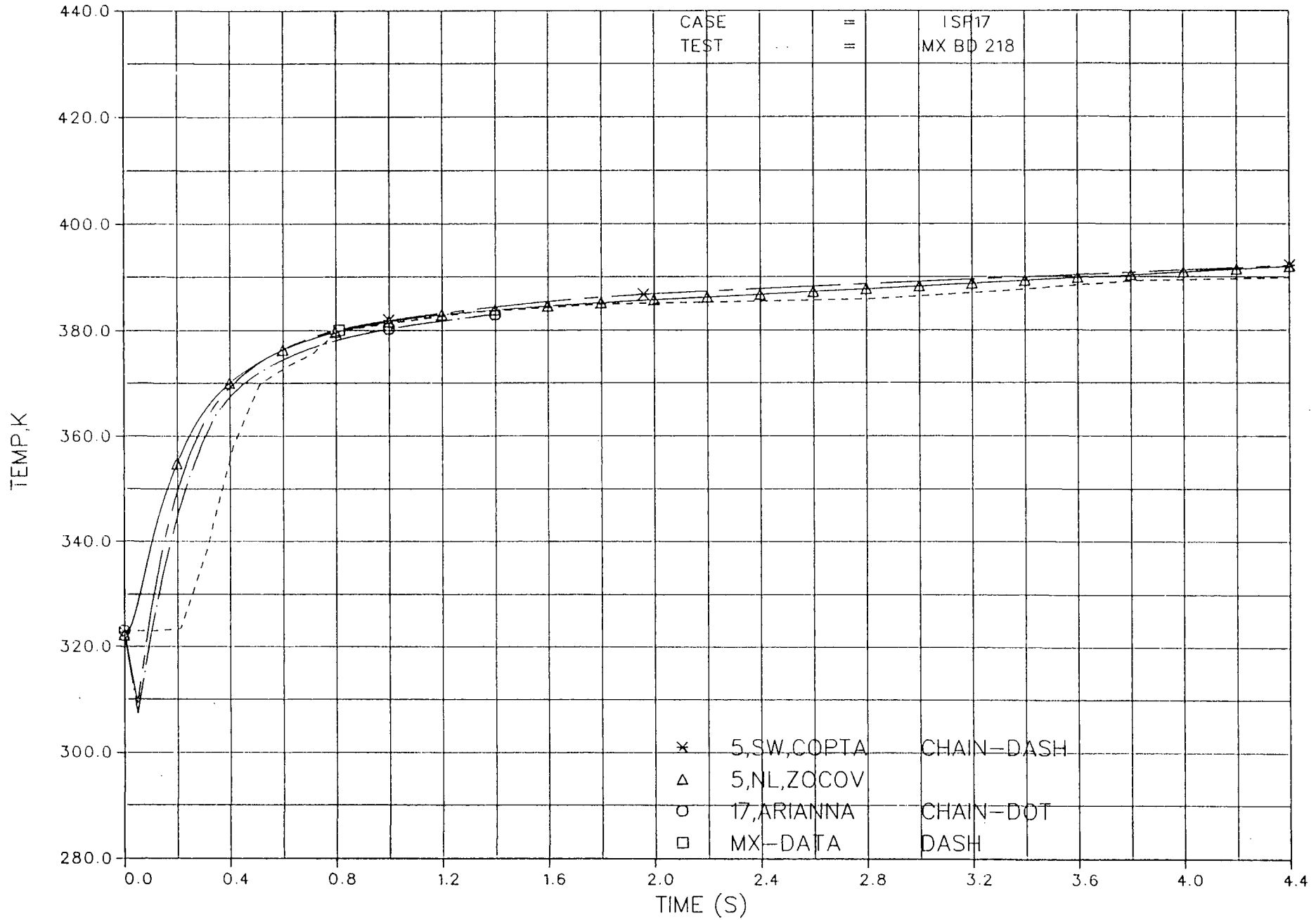
ISP17, PRESSURE IN ROOM 122,122M144,DIAG M.6,TABLE M.2
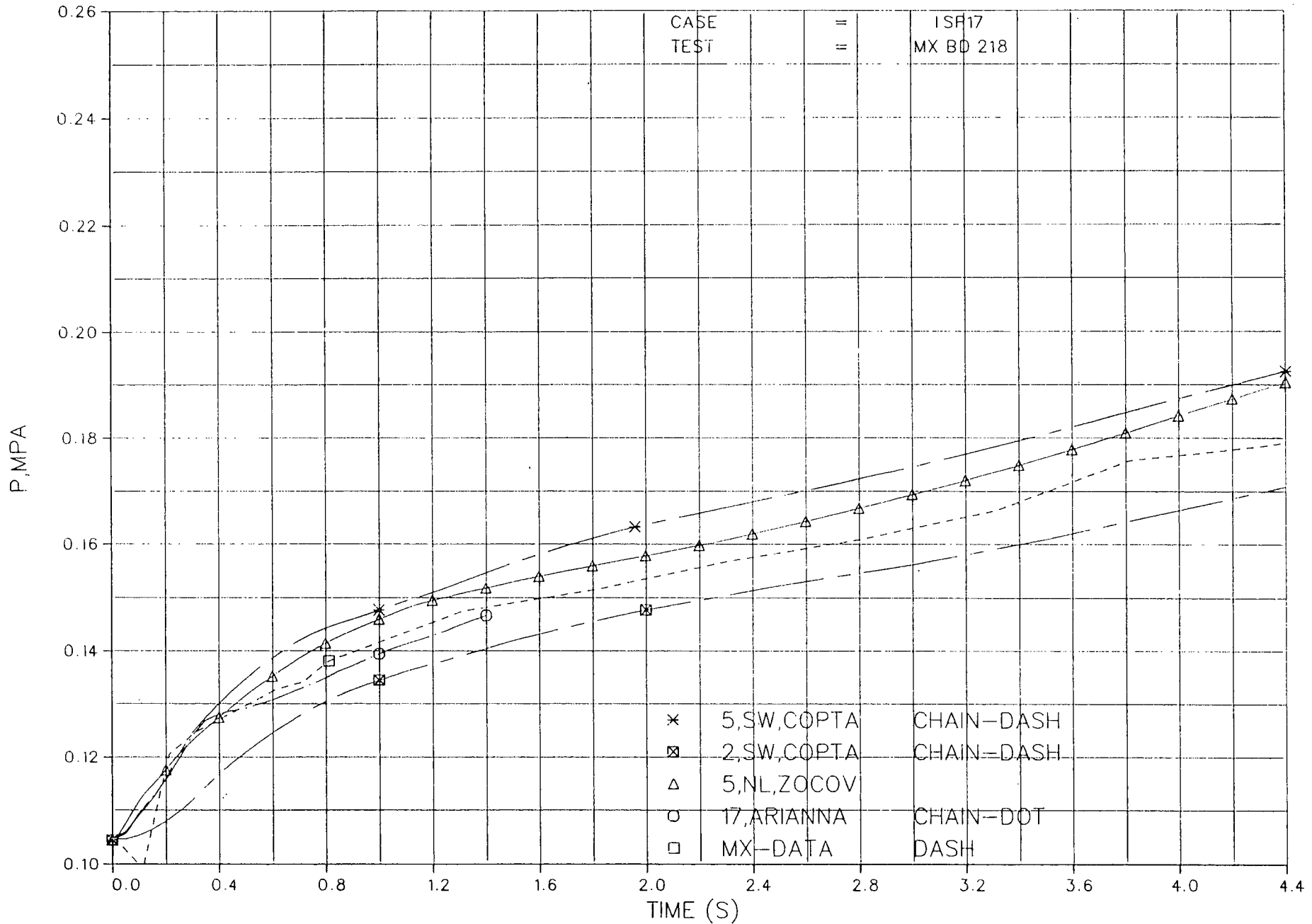
Diagram 7A. Short-time pressure transient in room 122

Diagram 7B. Intentionally omitted

ISP17, PRESSURE IN ROOM 110,110M147,DIAG M.9,TABLE M.2
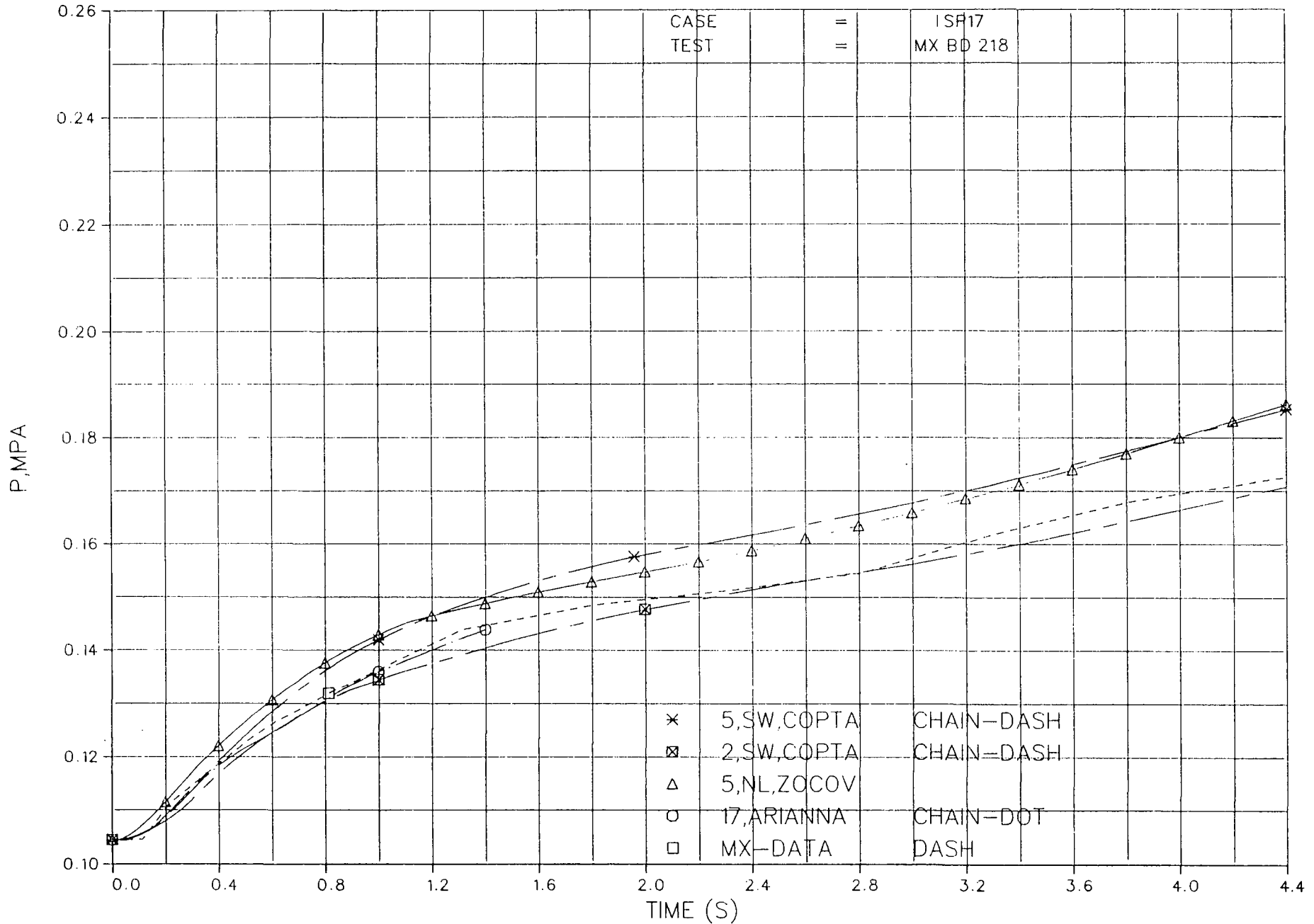
Diagram 8A.   Short-time pressure transient in room 110

ISP17, PRESSURE IN ROOM 110,110M147,DIAG M.9,TABLE M.2

| | CASE | = | ISP17 |
| | TEST | = | MX BD 218 |

⊠	2,SW,COPTA	CHAIN−DASH
+	2,SF,LT−28	
△	5,NL,ZOCOV	
○	2,IT,LT−26	CHAIN−DOT
□	MX−DATA	DASH
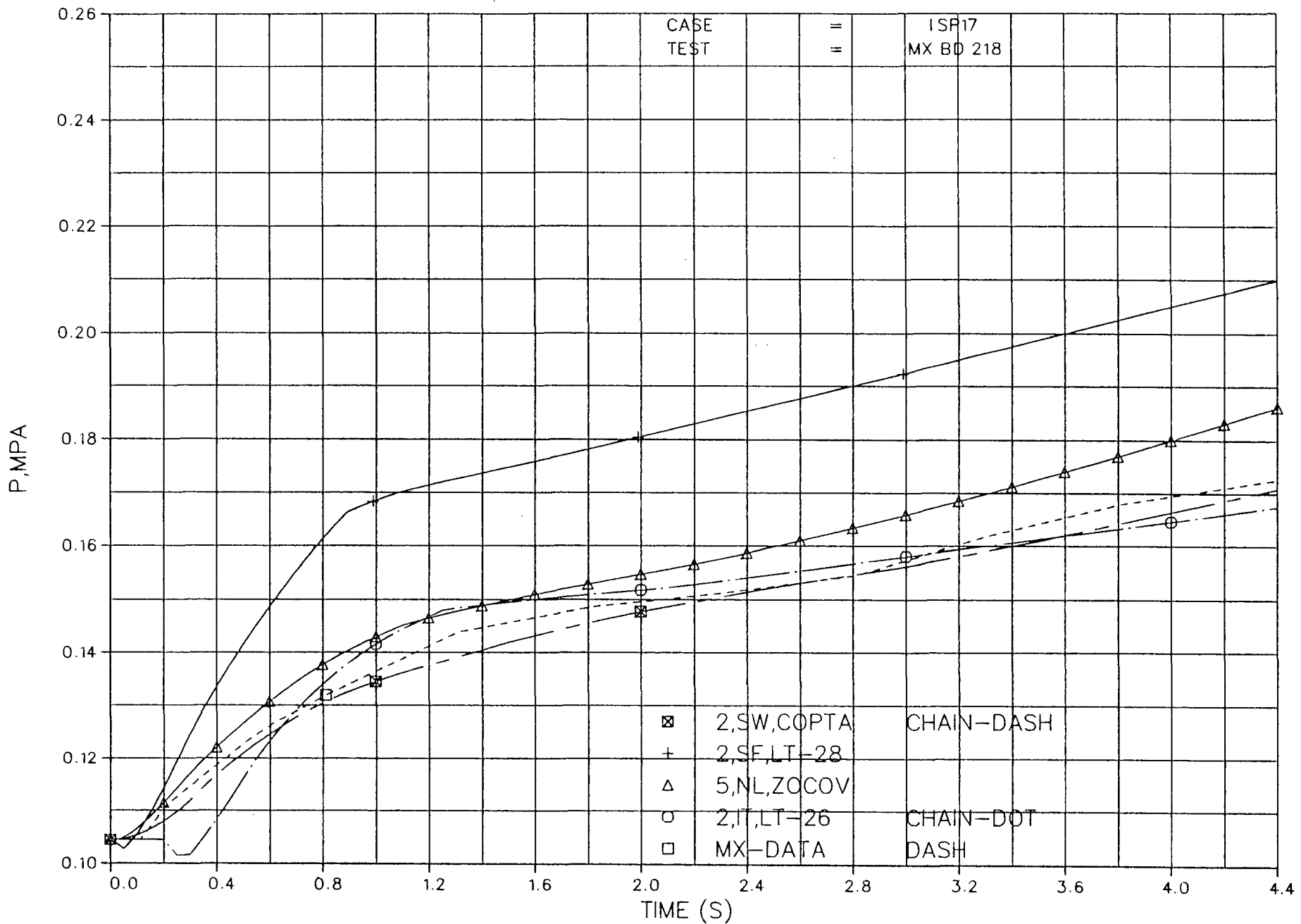
Diagram 8B. Short-time pressure transient in room 110

ISP17, PRESSURE IN ROOM 106,106M163,DIAG M.14,TABLE M.5
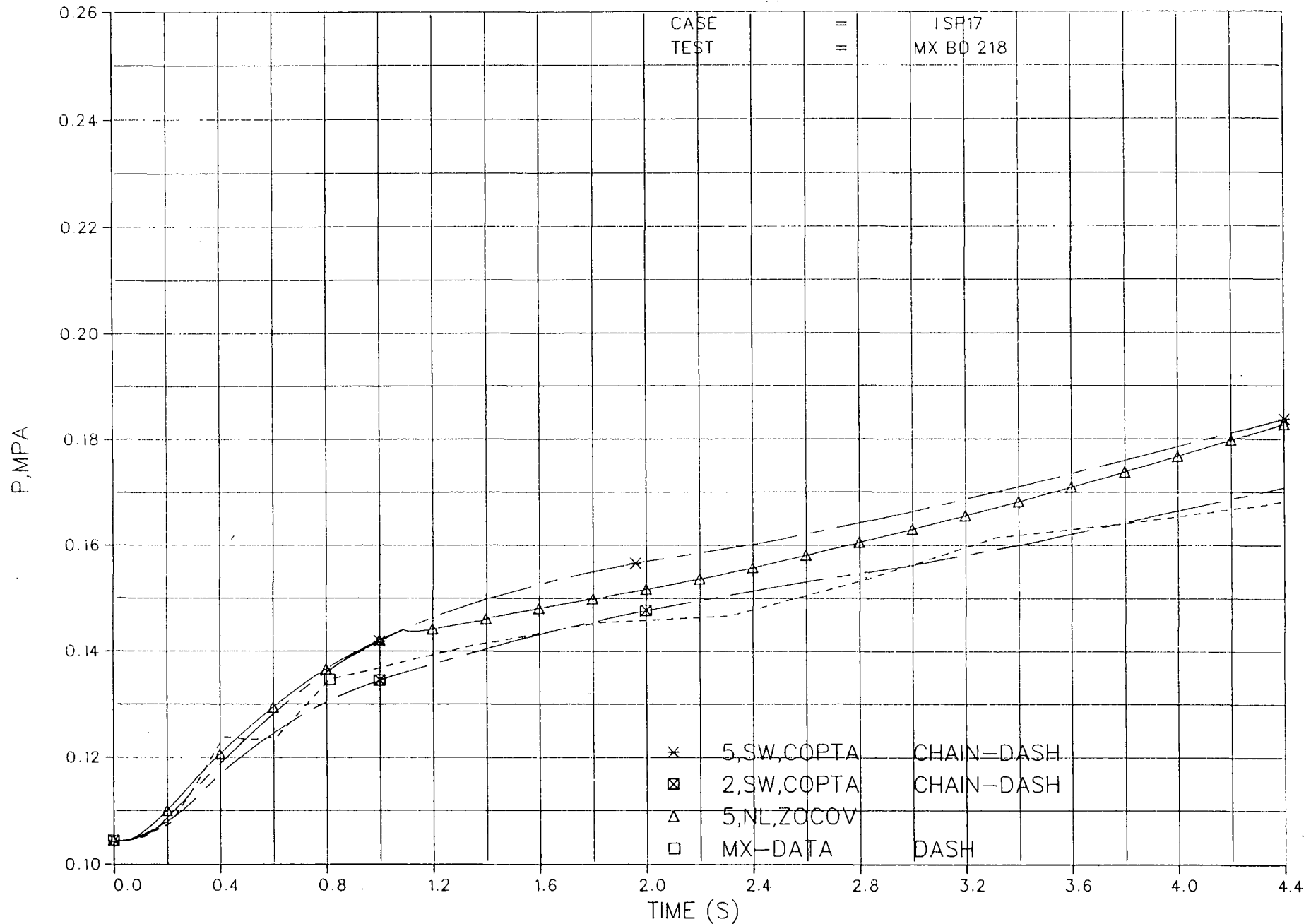
Diagram 9A.   Short-time pressure transient in room 106

ISP17, PRESSURE IN ROOM 106,106M163,DIAG M.14,TABLE M.5

| CASE | = | ISP17 |
| TEST | = | MX BD 218 |

Legend:
- ⊠ 2,SW,COPTA — CHAIN—DASH
- + 2,SE,LT—28
- △ 5,NL,ZOCOV
- ○ 2,IT,LT—26 — CHAIN—DOT
- □ MX—DATA — DASH

P,MPA (y-axis)
TIME (S) (x-axis)
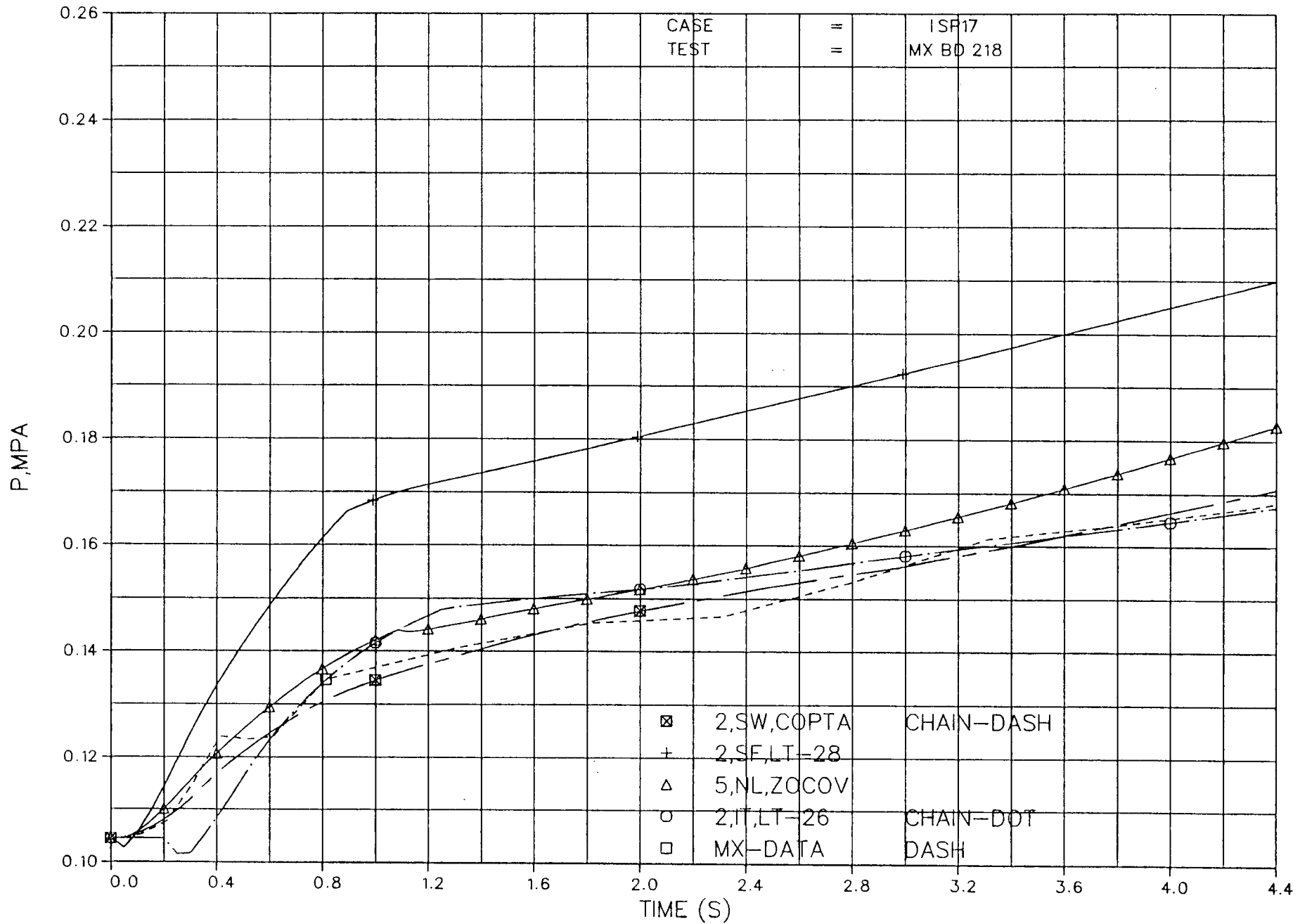
Diagram 9B.   Short-time pressure transient in room 106

Diagram 10A. Intentionally omitted

ISP17,WETWELL PRESSURE,105M122,DIAG M.18,TABLE M.4
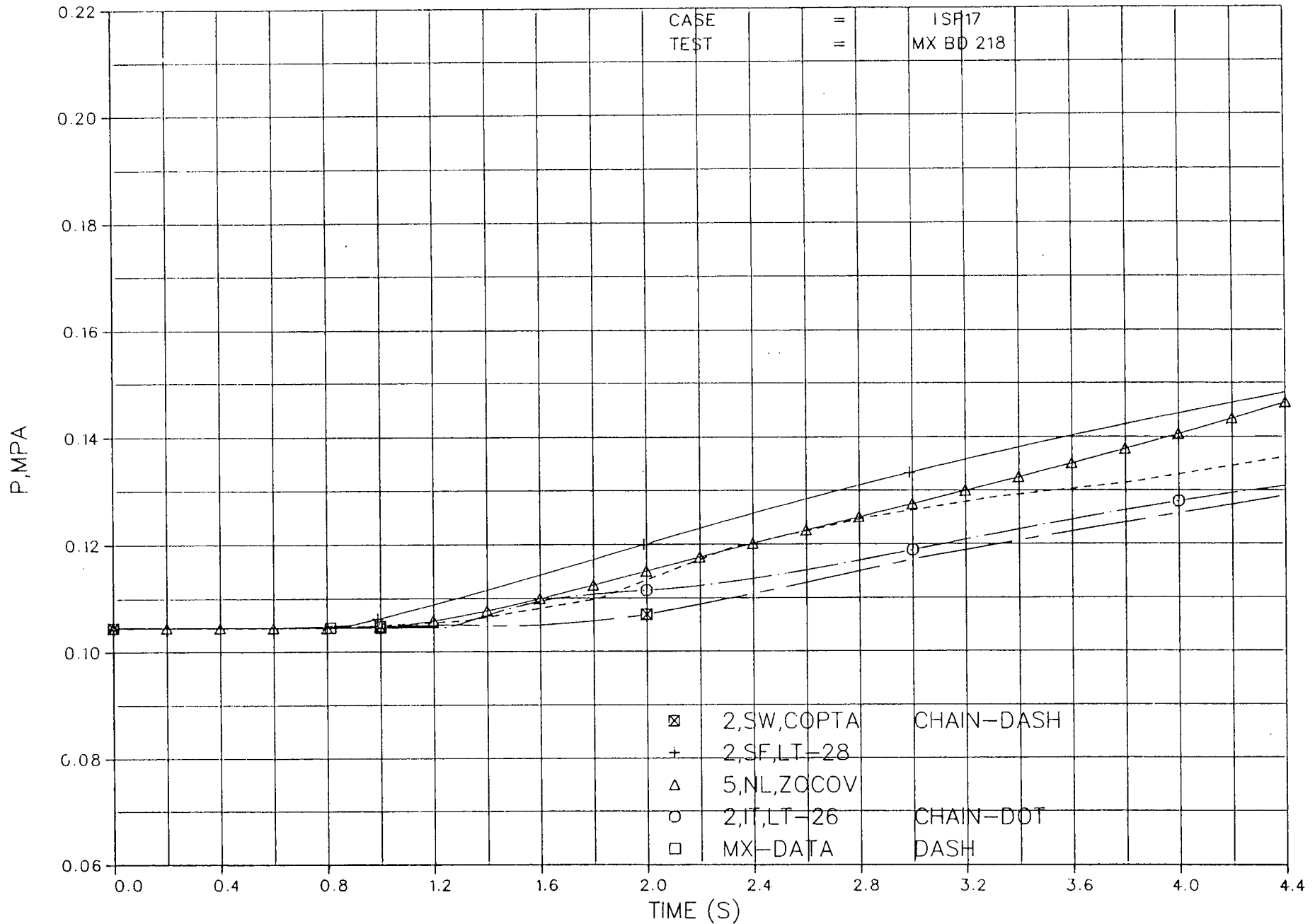
Diagram 10B.   Short-time pressure transient in wetwell

ISP17,TEMPERATURE IN ROOM 124,VAPOR,124M572,DIAG M.24,TABLE M.6

CASE	=	ISP17	
TEST	=	MX BD 218	

Legend:
- × 5,SW,COPTA — CHAIN=DASH
- △ 5,NL,ZOCOV
- ○ 17,ARIANNA — CHAIN=DOT
- □ MX—DATA — DASH

Axis: TEMP,K (vertical), TIME (S) (horizontal)
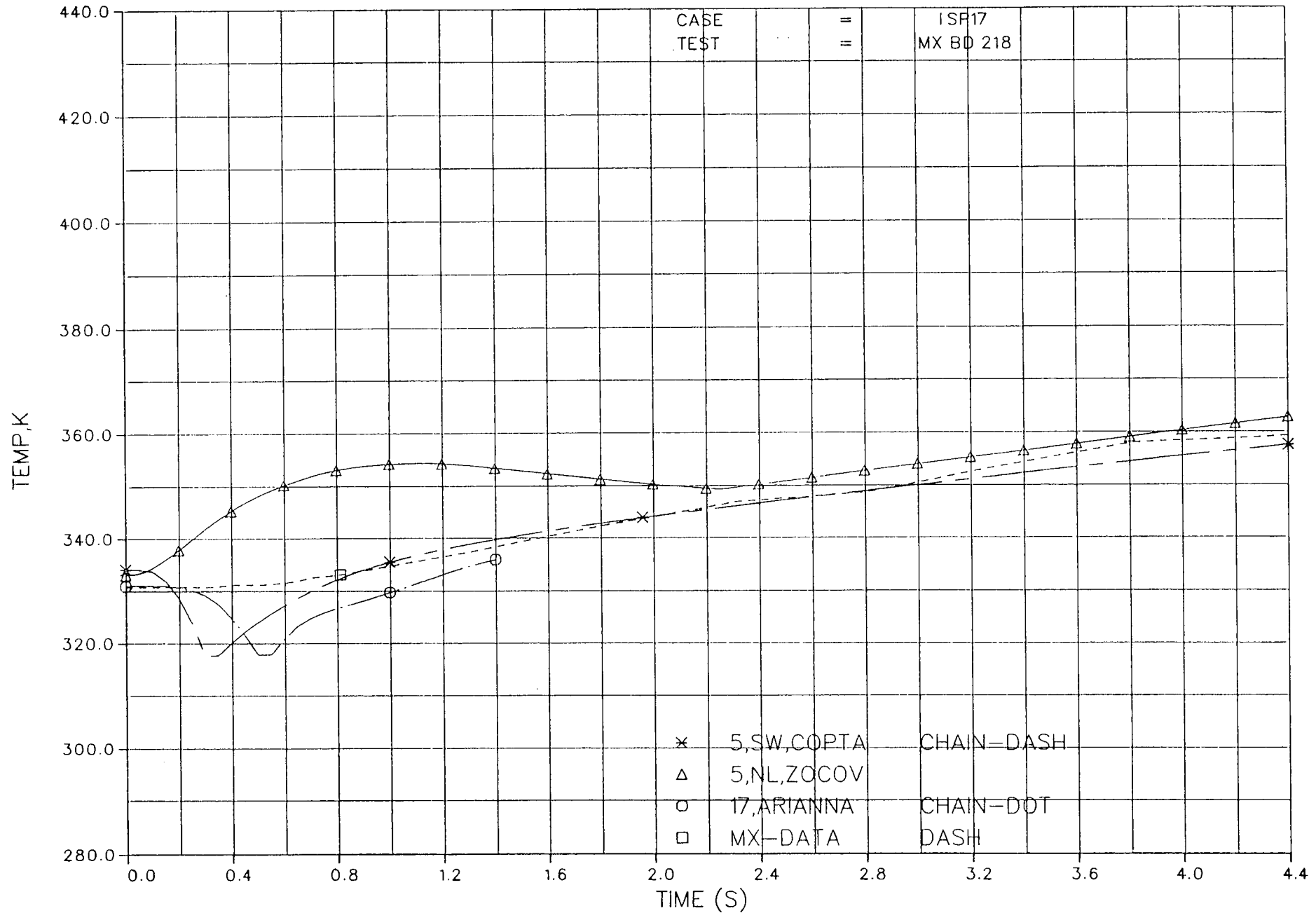
Diagram 11A.   Short-time temperature transient in room 124

Diagram 11B. Intentionally omitted

ISP17,TEMPERATURE IN ROOM 122,VAPOR,122M574,DIAG M.24,TABLE M.6

CASE	=	ISP17	
TEST	=	MX BD 218	

Y-axis: TEMP,K — 280.0, 300.0, 320.0, 340.0, 360.0, 380.0, 400.0, 420.0, 440.0

X-axis: TIME (S) — 0.0, 0.4, 0.8, 1.2, 1.6, 2.0, 2.4, 2.8, 3.2, 3.6, 4.0, 4.4

Legend:
* 5,SW,COPTA   CHAIN—DASH
△ 5,NL,ZOCOV
○ 17,ARIANNA   CHAIN—DOT
□ MX—DATA   DASH

Diagram 12A. Short-time temperature transient in room 122

Diagram 12B. Intentionally omitted

ISP17,TEMPERATURE IN ROOM 111,VAPOR,111M576,DIAG M.25,TABLE M.6

| CASE | = | ISP17 |
| TEST | = | MX BD 218 |

Legend:

✳	5,SW,COPTA	CHAIN—DASH
⊠	2,SW,COPTA	CHAIN—DASH
△	5,NL,ZOCOV	
○	17,ARIANNA	CHAIN—DOT
□	MX—DATA	DASH
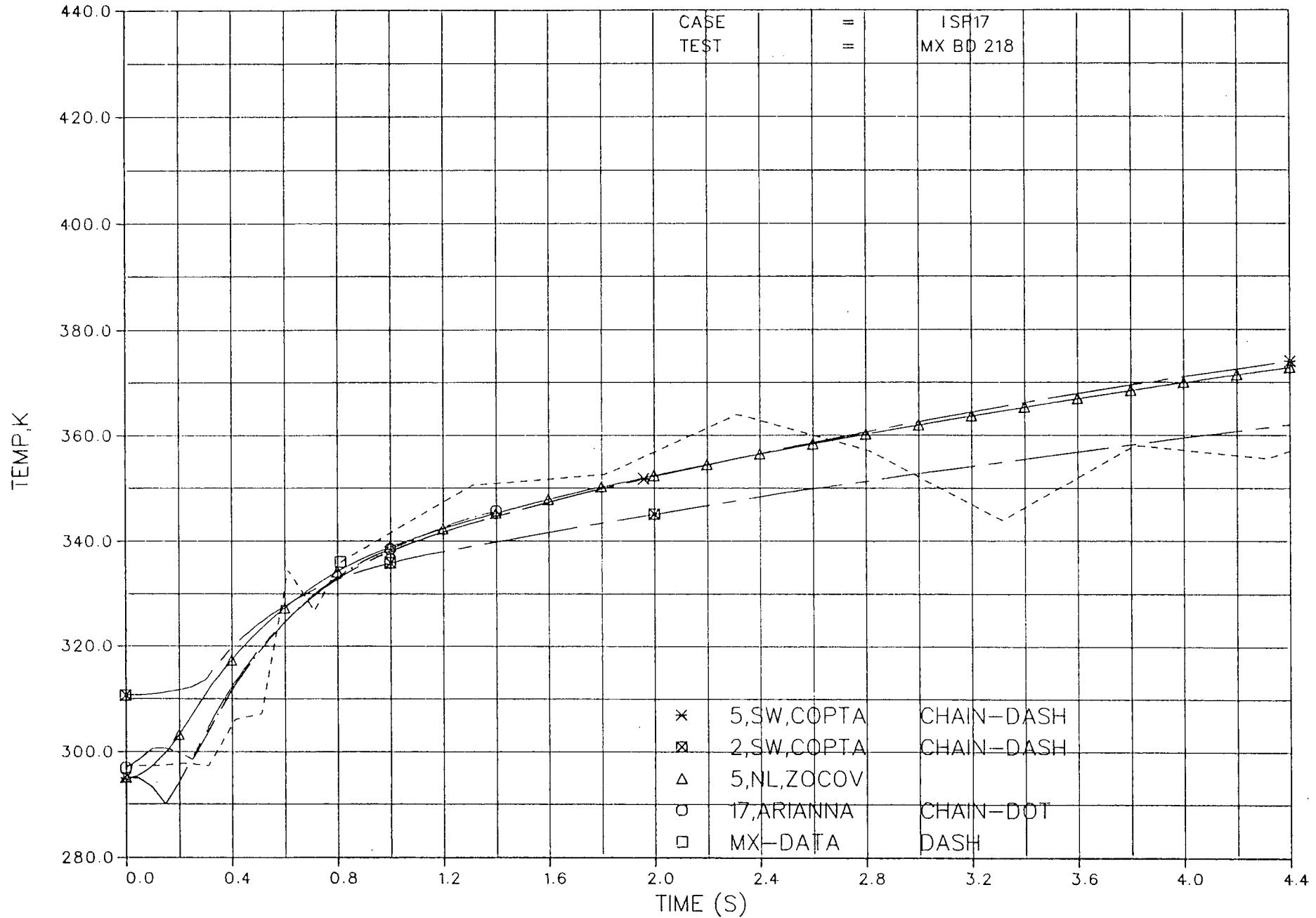
Diagram 13A.   Short-time temperature transient in room 111

ISP17,TEMPERATURE IN ROOM 111,VAPOR,111M576,DIAG M.25,TABLE M.6
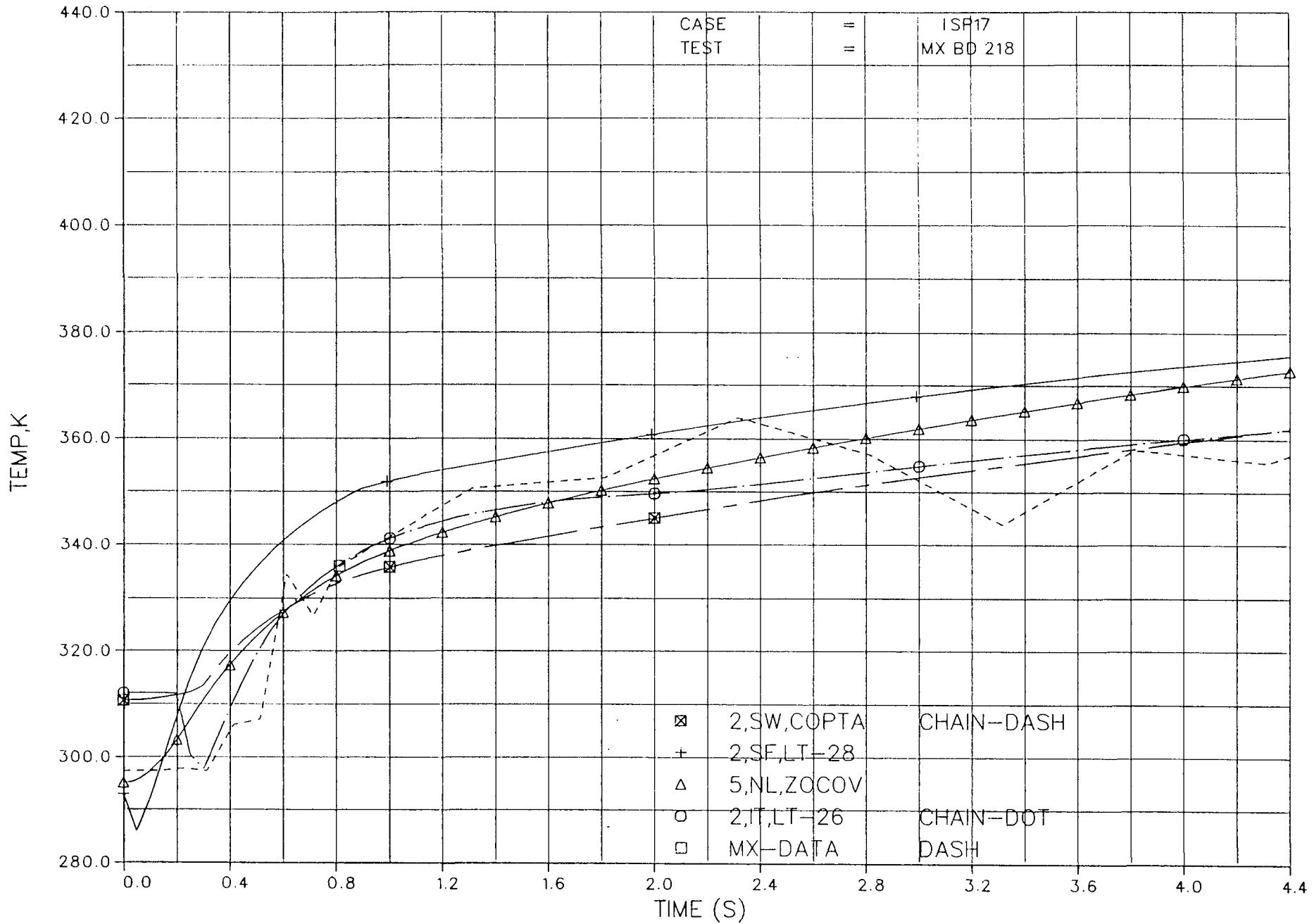
Diagram 13B. Short-time temperature transient in room 111

ISP17,TEMPERATURE IN ROOM 106,VAPOR,106M586,DIAG M.28,TABLE M.7

| CASE | = | ISP17 |
| TEST | = | MX BD 218 |

Legend:
- ✕ 5,SW,COPTA   CHAIN—DASH
- ⊠ 2,SW,COPTA   CHAIN—DASH
- △ 5,NL,ZOCOV
- □ MX—DATA   DASH

TIME (S)

TEMP,K
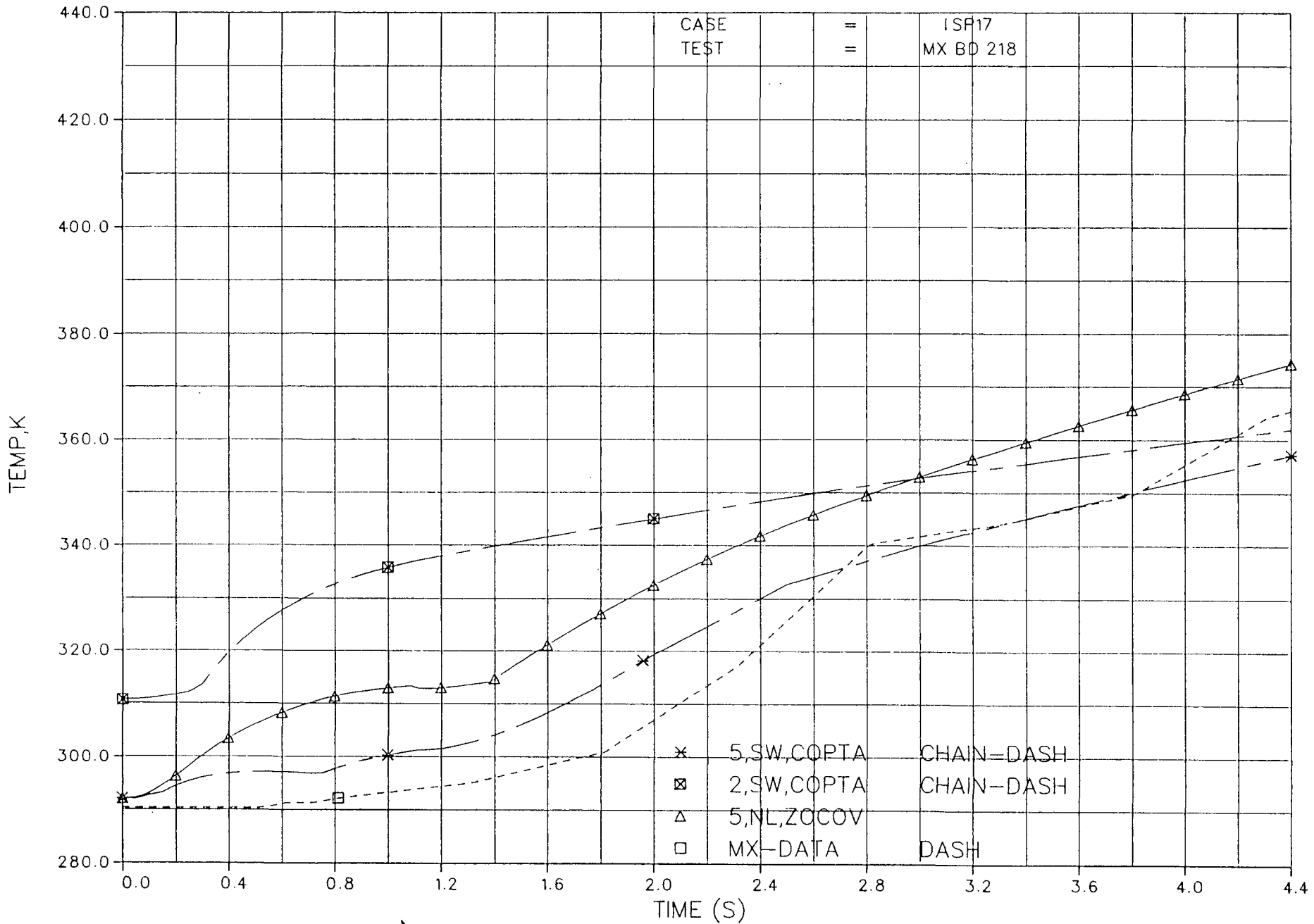
Diagram 14A.   Short-time temperature transient in room 106

ISP17,TEMPERATURE IN ROOM 106,VAPOR,106M586,DIAG M.28,TABLE M.7

CASE	=	ISP17
TEST	=	MX BD 218

⊠	2,SW,COPTA	CHAIN—DASH
+	2,SF,LT—28	
△	5,NL,ZOCOV	
○	2,IT,LT—26	CHAIN—DOT
□	MX—DATA	DASH
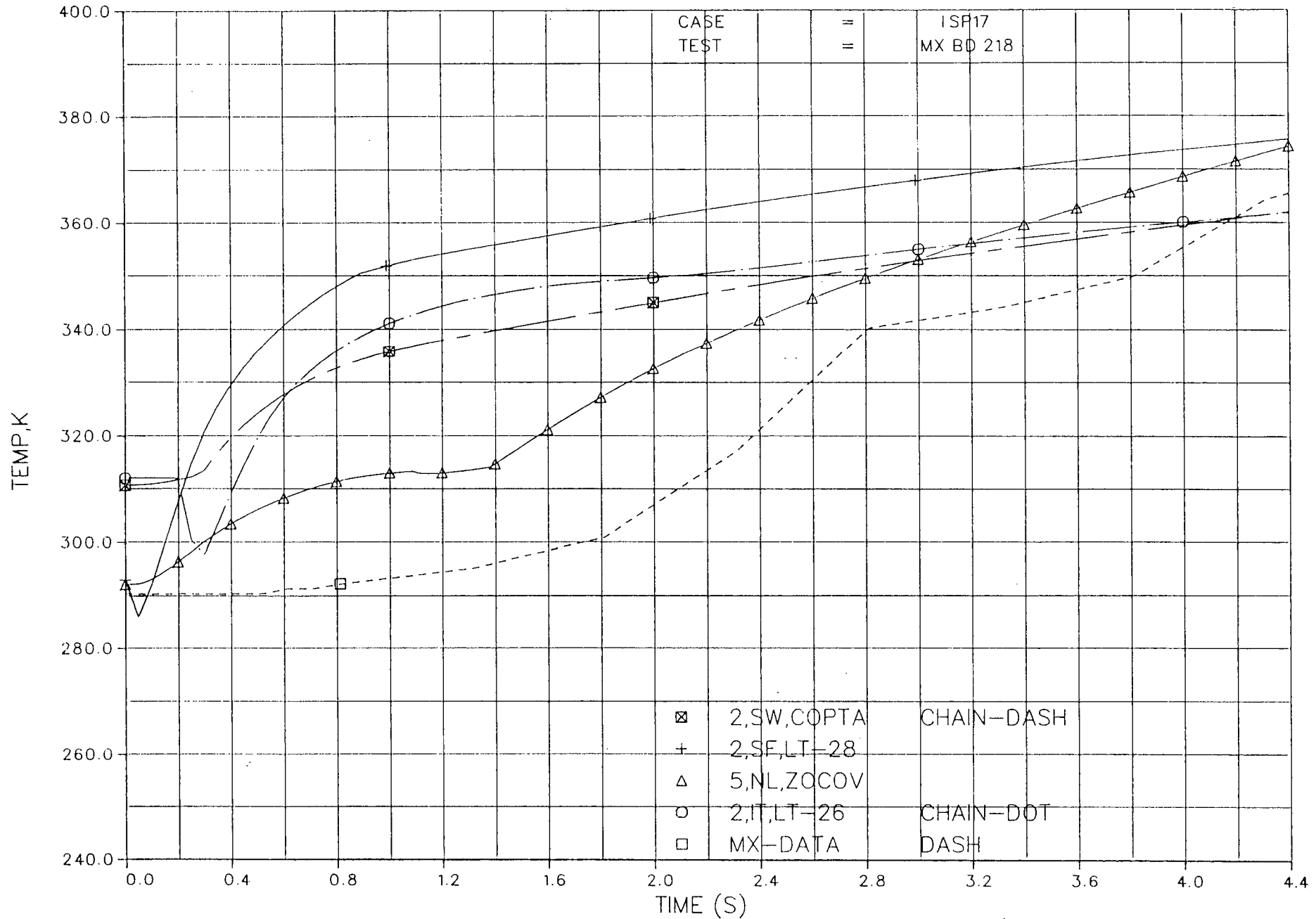
Diagram 14B.   Short-time temperature transient in room 106

Diagram 15A.   Short-time temperature transient in wetwell vapor

ISP17,TEMPERATURE IN ROOM 105,VAPOR,AVERAGE,DIAG E.16,TABLE E.6 (MX—DATA SLOW?)

	CASE	=	ISP17
	TEST	=	MX BD 218

Legend:

⊠	2,SW,COPTA	CHAIN—DASH
+	2,SF,LT—28	
△	5,NL,ZOCOV	
○	2,IT,LT—26	CHAIN—DOT
□	MX—DATA	DASH

Axis: TEMP,K vs TIME (S)
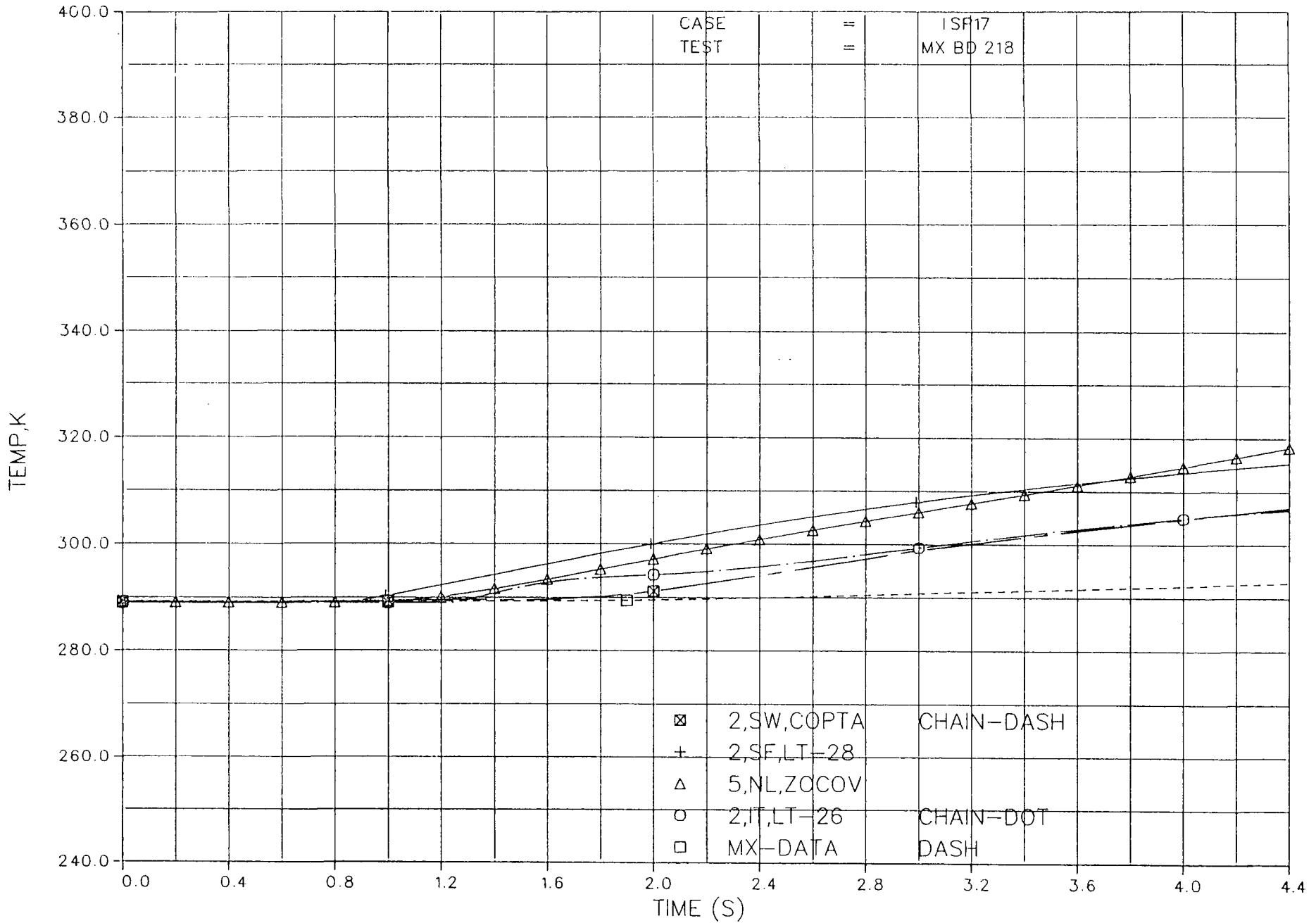
Diagram 15B.   Short-time temperature transient in wetwell vapor

ISP17,WATER PLUG SIZE IN VENT PIPES,DIAG E.29

CASE	=	ISP17	
TEST	=	MX BD 218	

✳	5,SW,COPTA	CHAIN—DASH
⊠	2,SW,COPTA	CHAIN—DASH
△	5,NL,ZOCOV	
◇	MX—DATA	DASH
◇	MX—DATA	DASH

SIZE,M

TIME (S)

Diagram 16A.   Water plug size

ISP17,WATER PLUG SIZE IN VENT PIPES,DIAG E.29
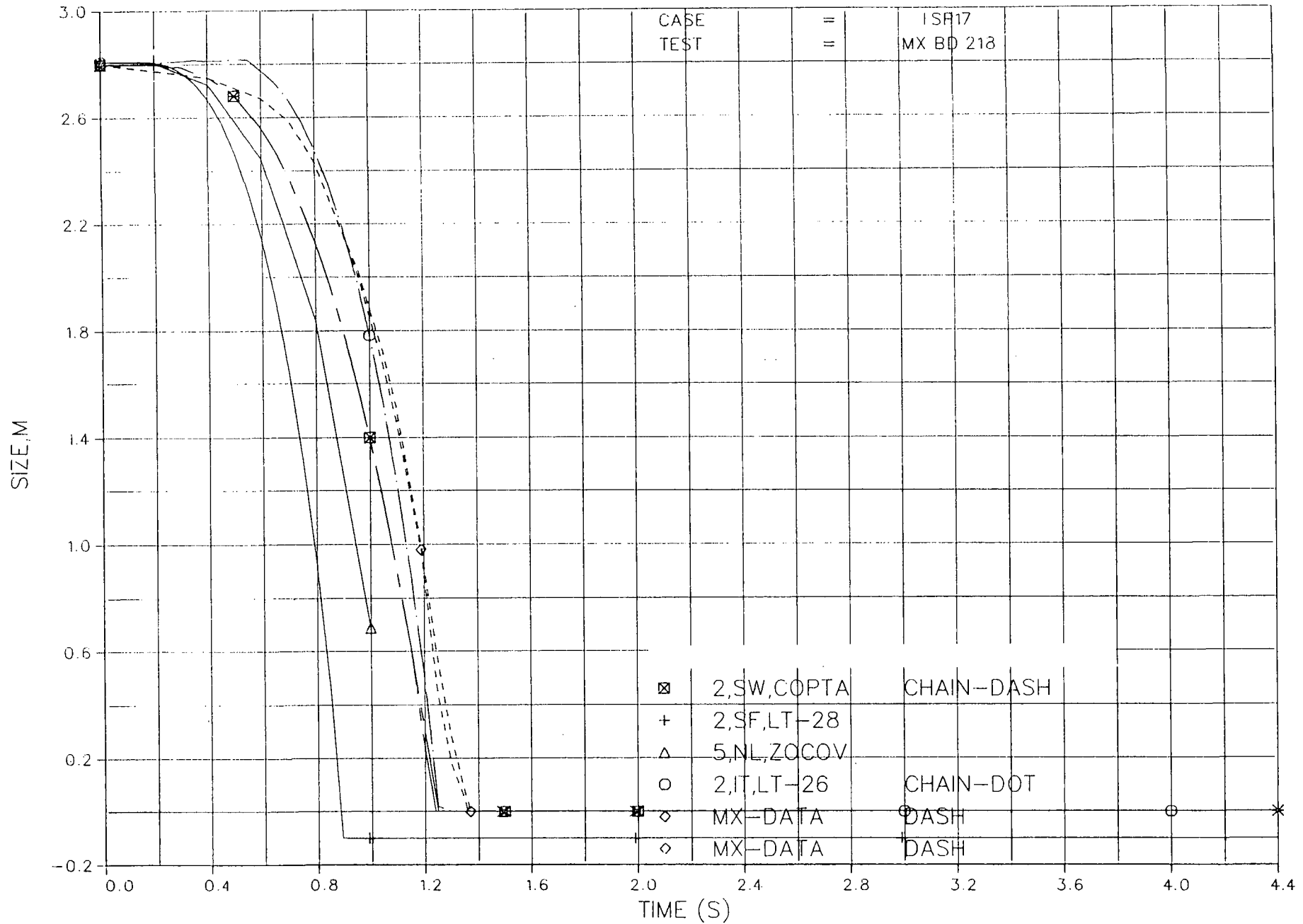
Diagram 16B.   Water plug size

ISP17,POOL LEVEL,DIAG E.27

Legend:
- ✳ — 5,SW,COPTA — CHAIN−DASH
- ⊠ — 2,SW,COPTA — CHAIN−DASH
- △ — 5,NL,ZOCOV
- ◇ — MX−DATA — DASH
- ◇ — MX−DATA — DASH

CASE = ISP17
TEST = MX BD 218
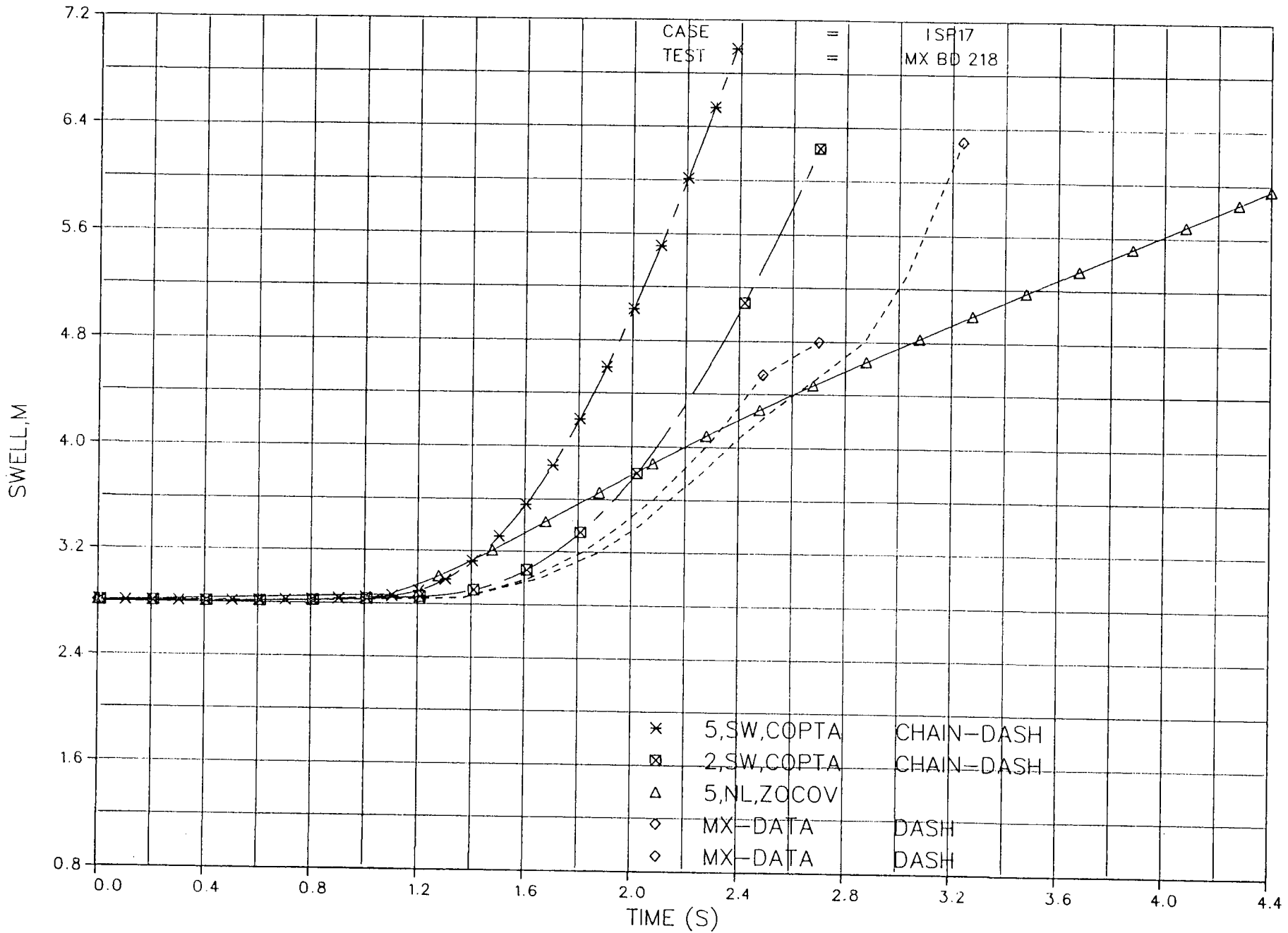
Diagram 17A.   Pool level

Diagram 17B. Intentionally omitted

ISP17,PRESSURE DIFF DRYWELL—WETWELL,110M213,DIAG M.22,TABLE M.4
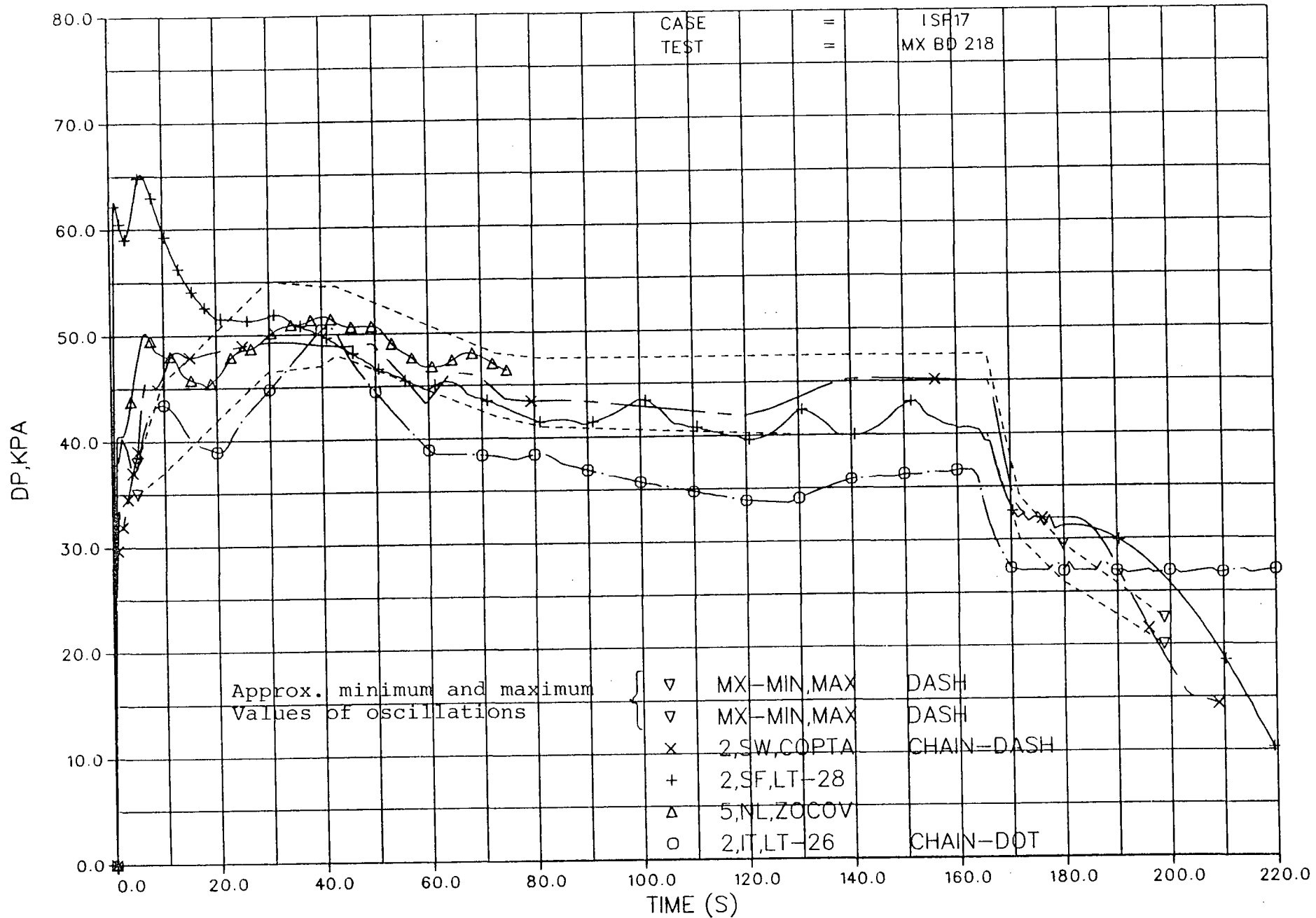
Diagram 18. Long-time pressure difference drywell-wetwell

ISP17,PRESSURE DIFF HEADER—WETWELL,106M215,DIAG M.23,TABLE M.4

CASE	=	ISP17	
TEST	=	MX BD 218	

Approx. minimum and maximum
Values of oscillations

▽	MX—MIN,MAX	DASH
▽	MX—MIN,MAX	DASH
×	2,SW,COPTA	CHAIN—DASH
+	2,SF,LT—28	
△	5,NL,ZOCOV	
○	2,IT,LT—26	CHAIN—DOT
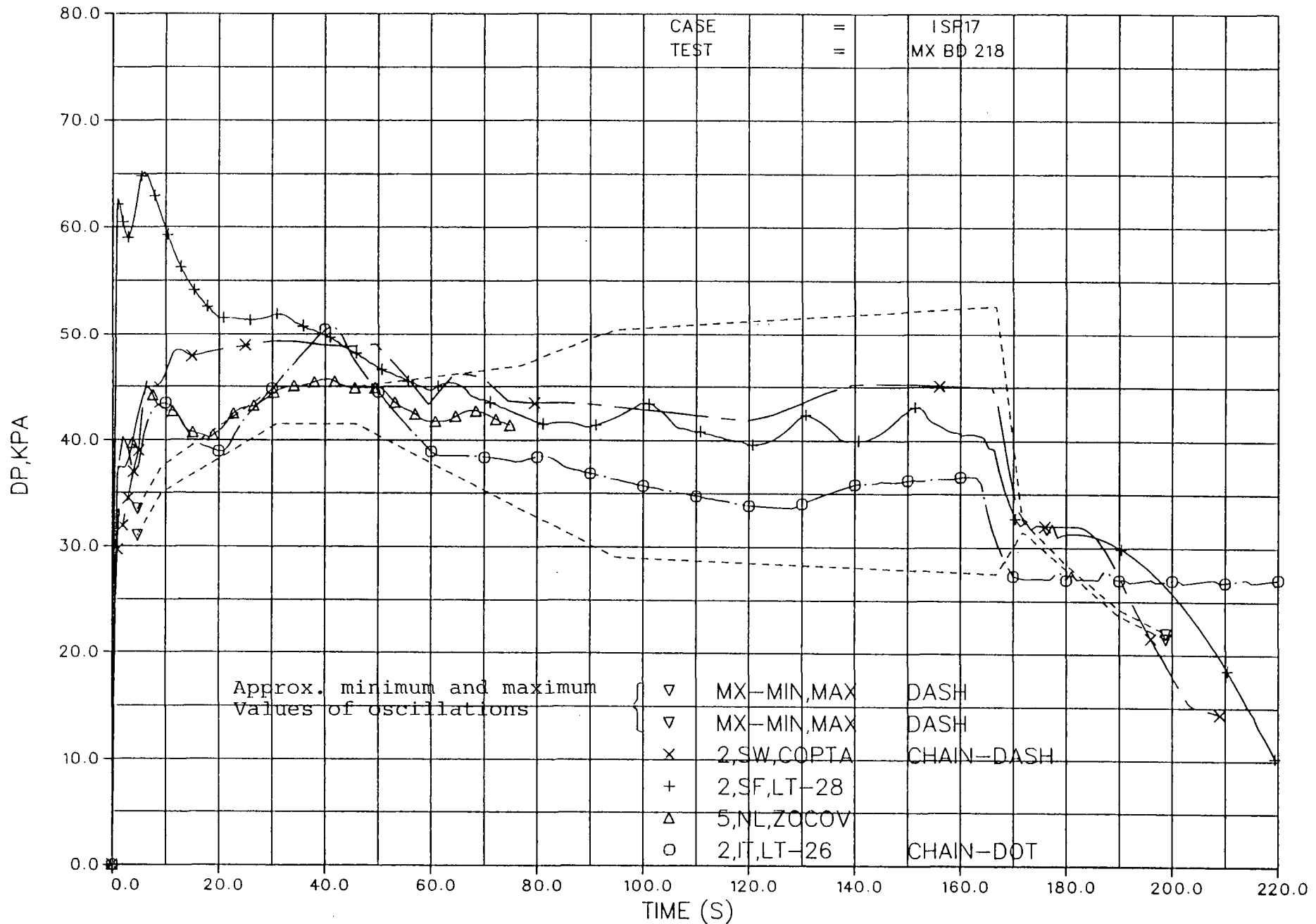
Diagram 19. Long-time pressure difference header-wetwell

ISP17,DRYWELL PRESURE,110M147,DIAG M.9,TABLE M.2
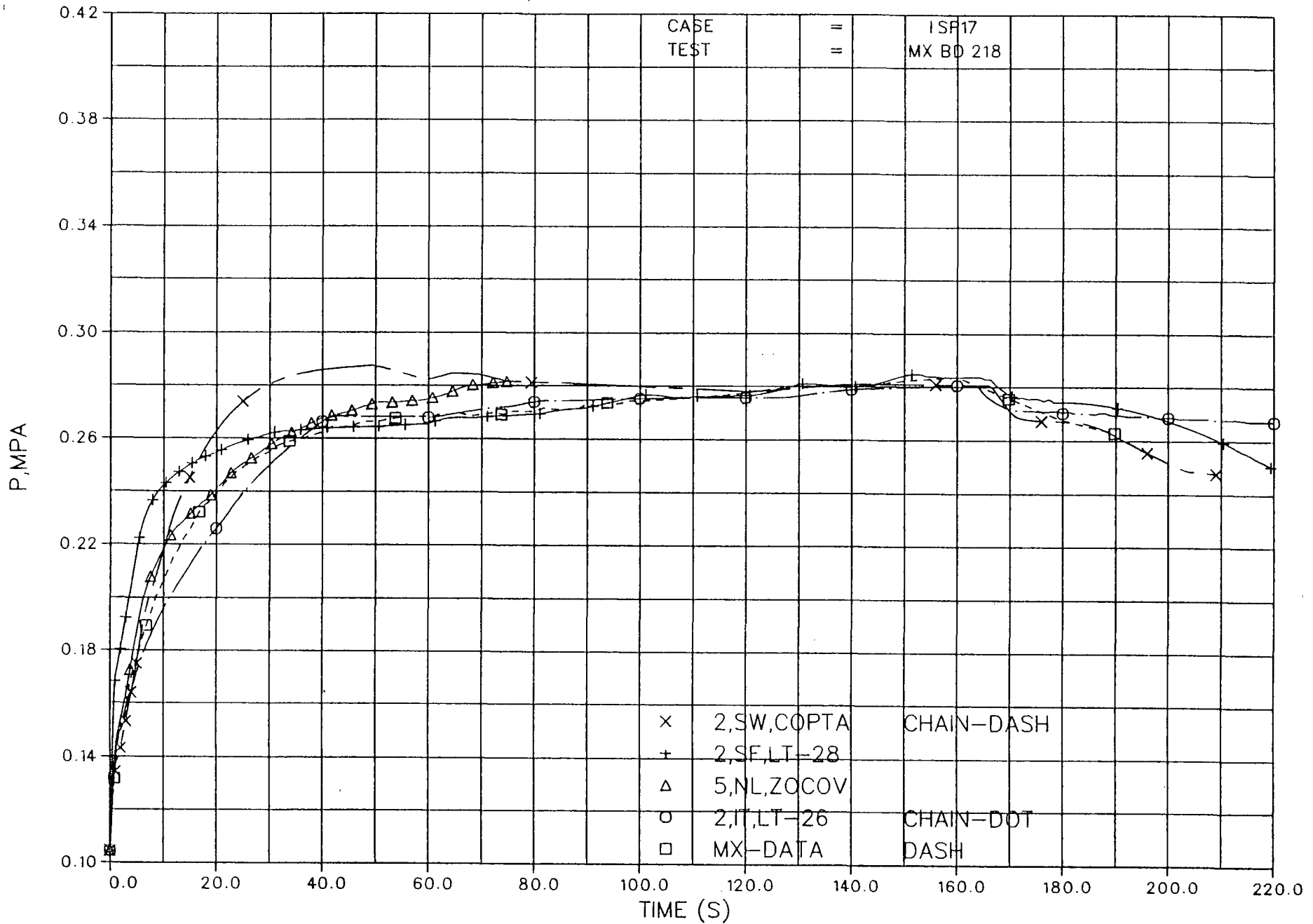
Diagram 20.   Drywell pressure

ISP17,HEADER PRESSURE,106M163,DIAG M.14,TABLE M.5
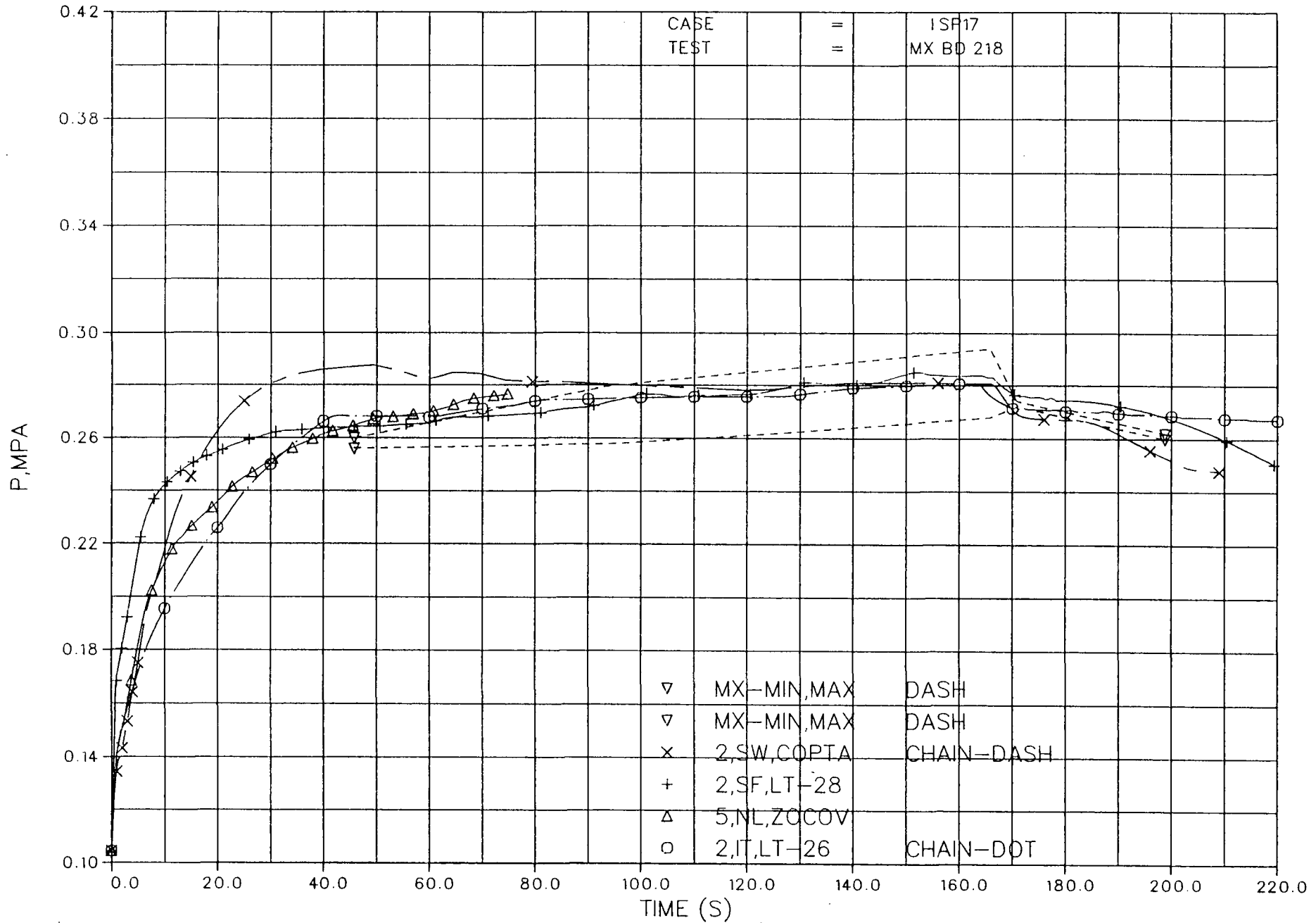
Diagram 21. Header pressure

ISP17,WETWELL PRESSURE,105M122,DIAG M.18,TABLE M.4

CASE		=	ISP17
TEST		=	MX BD 218

×	2,SW,COPTA	CHAIN—DASH
+	2,SF,LT—28	
△	5,NL,ZOCOV	
○	2,IT,LT—26	CHAIN—DOT
□	MX—DATA	DASH

P,MPA

TIME (S)
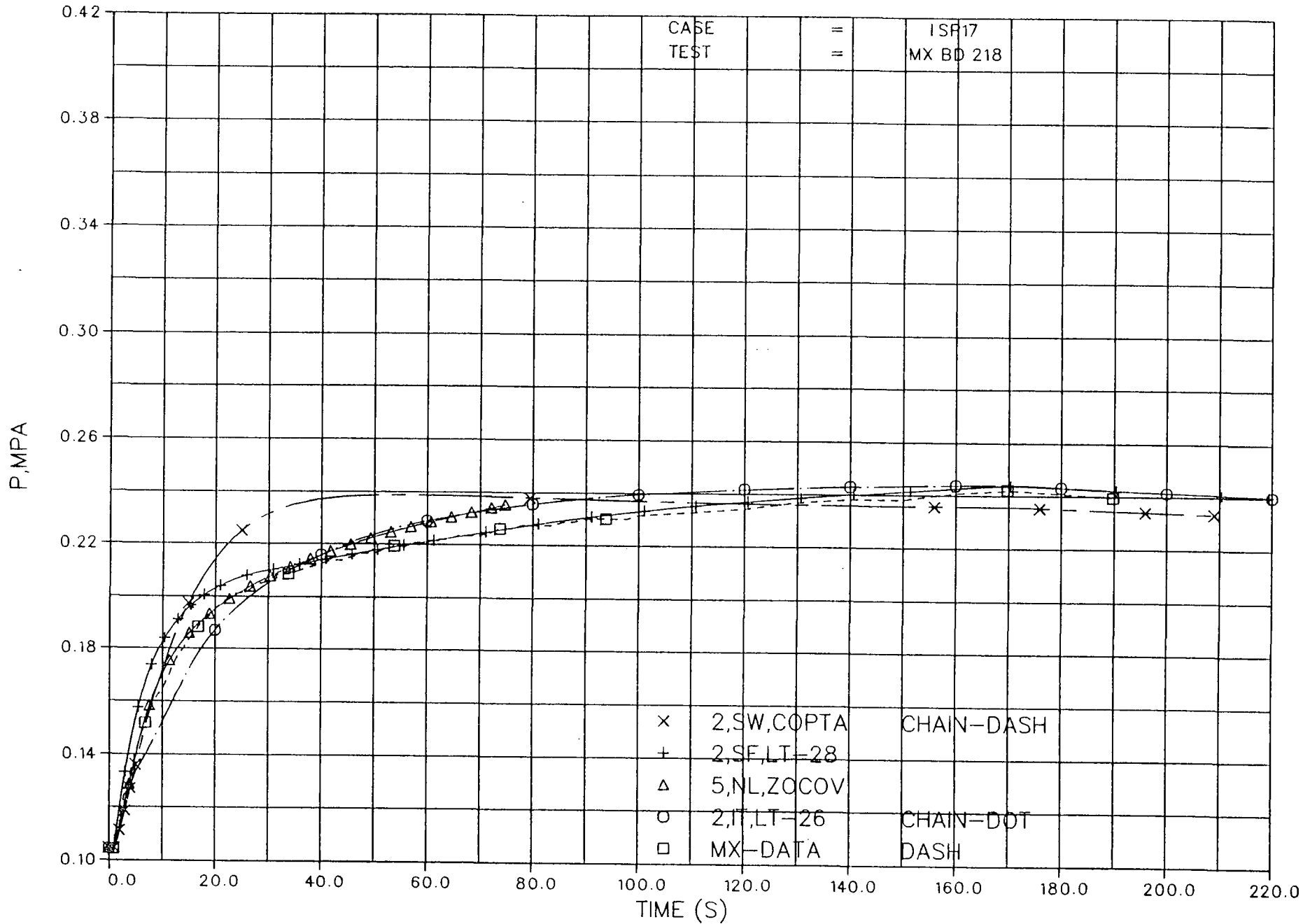
Diagram 22. Wetwell pressure

ISP17,DRYWELL TEMPERATURE,111M576,DIAG M.25,TABLE M.6
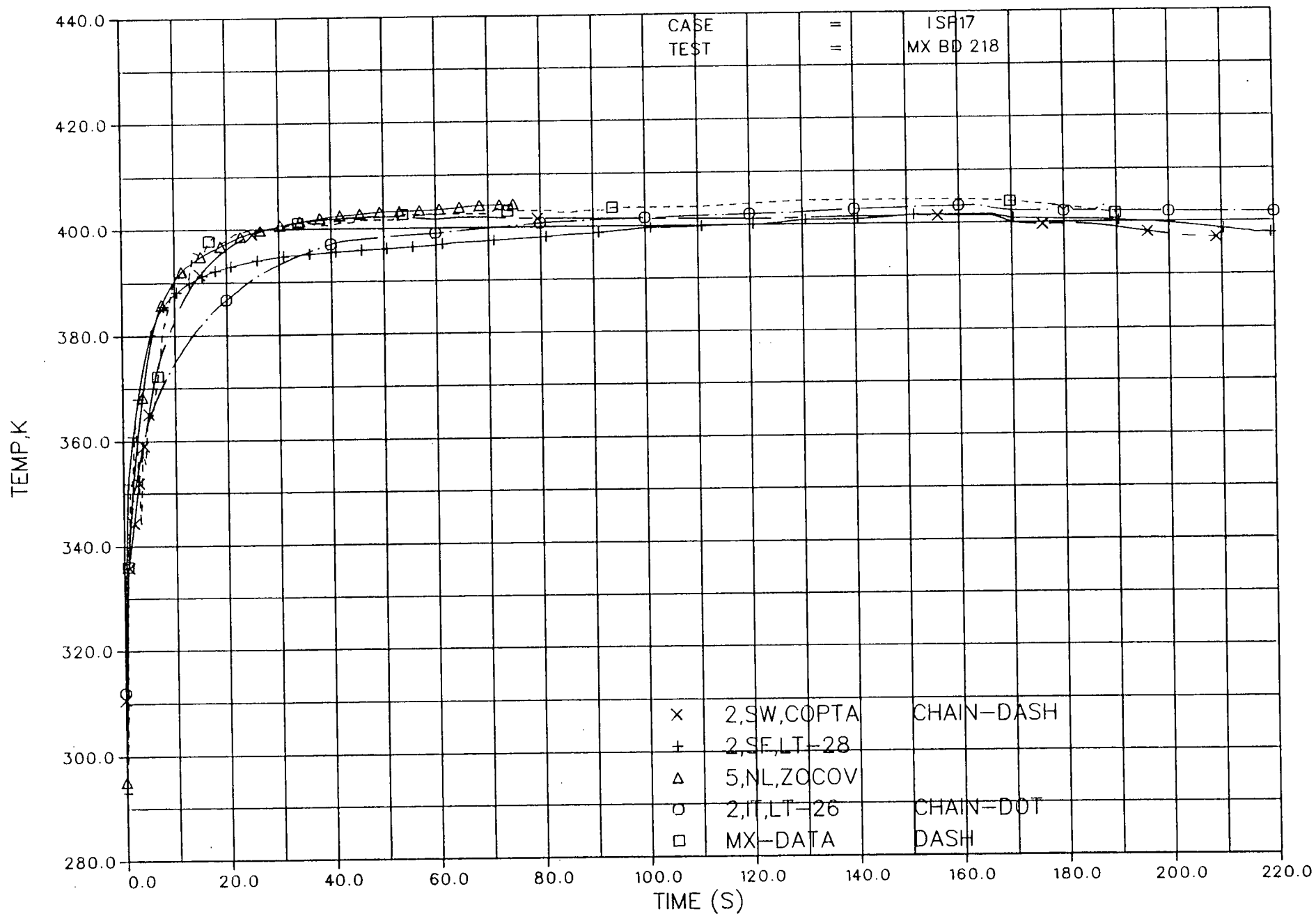
Diagram 23. Drywell temperature

ISP17,HEADER TEMPERATURE,106M586,DIAG M.28,TABLE M.7
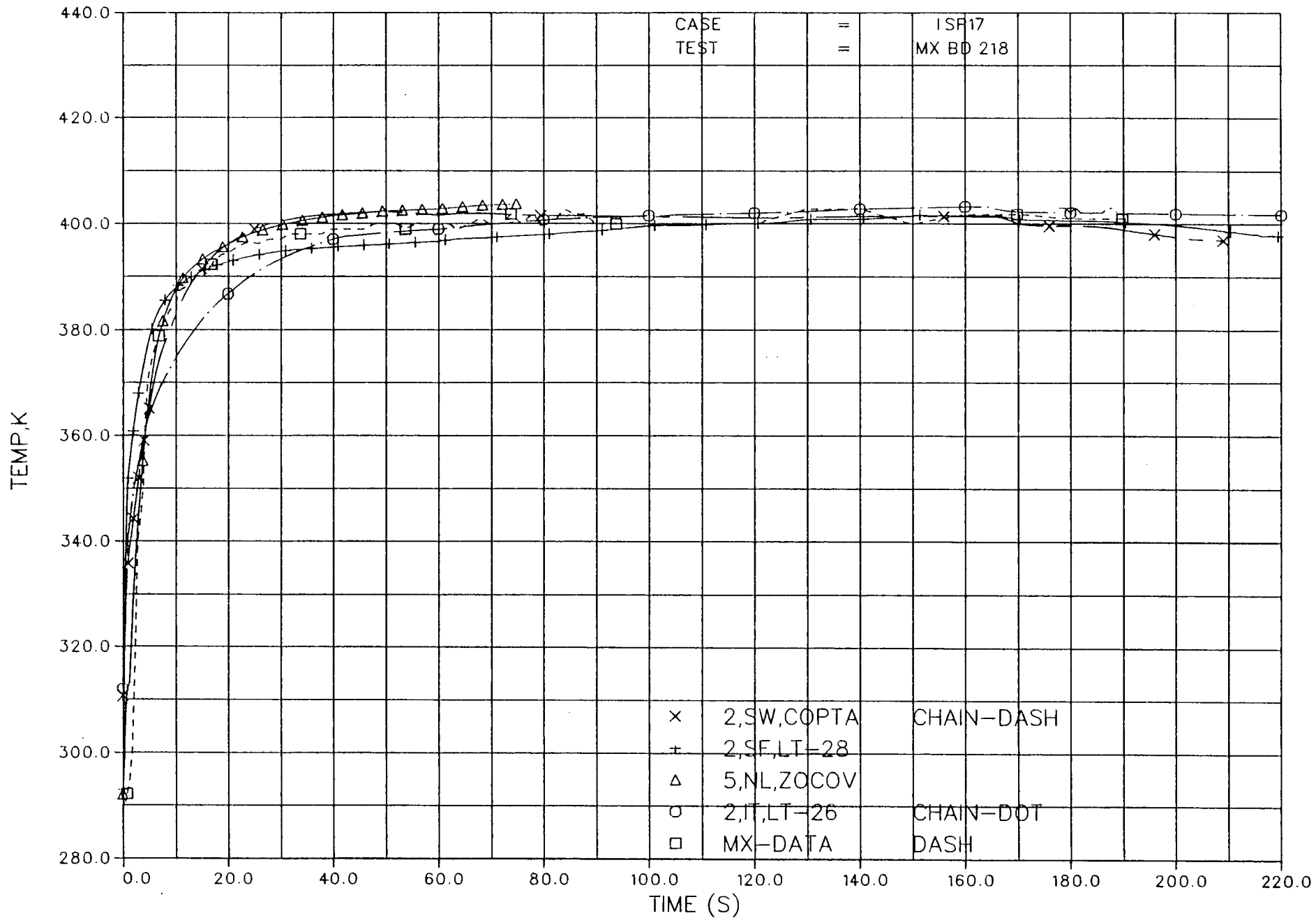
Diagram 24. Header temperature

ISP17,WETWELL GAS TEMPERATURE,AVERAGE,DIAG E.16,TABLE E.6
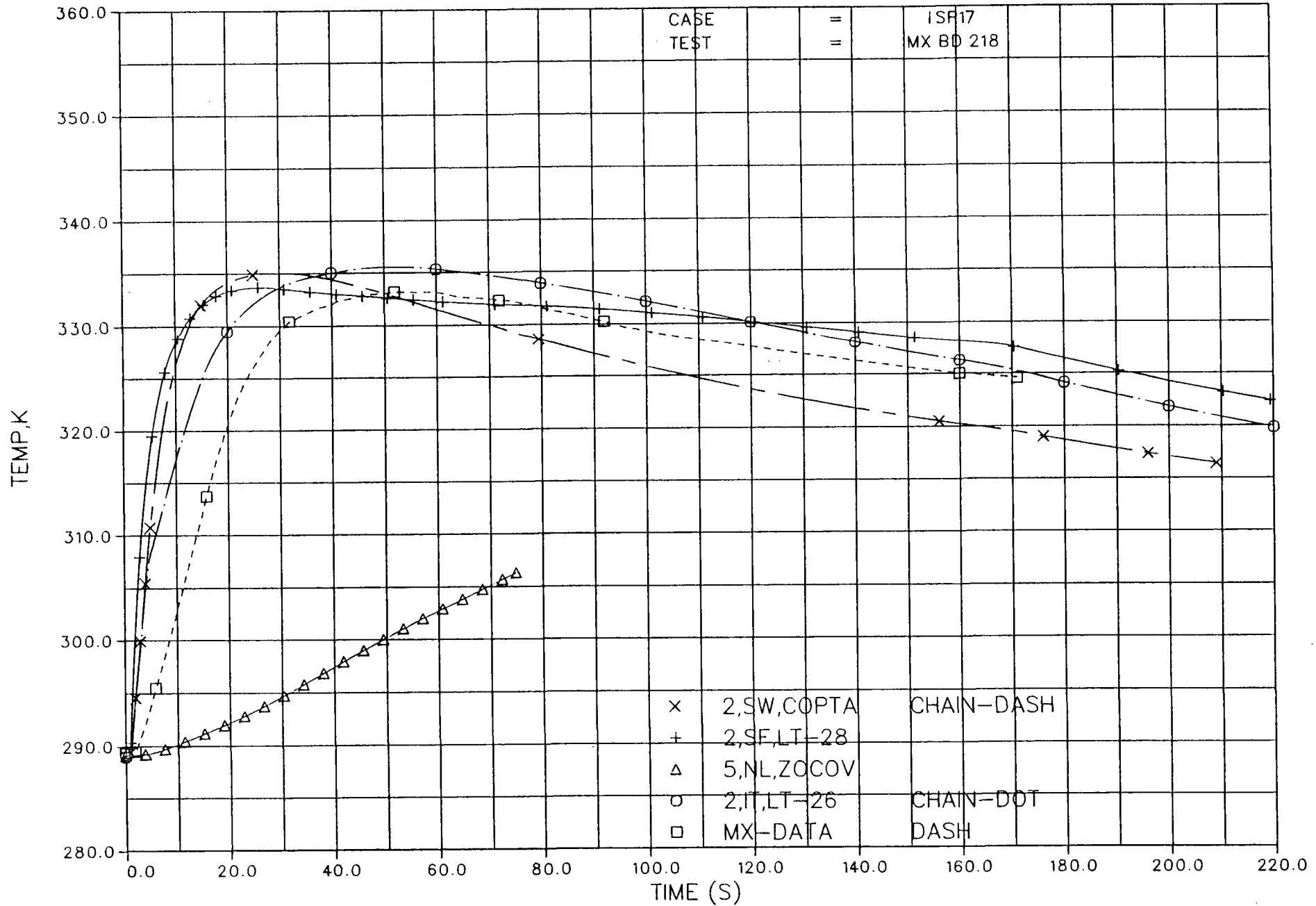
Diagram 25.   Average wetwell gas temperature

ISP17,AVERAGE POOL TEMPERATURE,DIAG E.16,TABLE E.6

CASE		ISP17
TEST	=	MX BD 218

X	2,SW,COPTA	=	
+	2,SF,LT-28		CHAIN-DASH
△	5,NL,ZOCOV		
○	2,IT,LT-26		CHAIN-DOT
□	MX-DATA		DASH

TIME (S)

TEMP,K
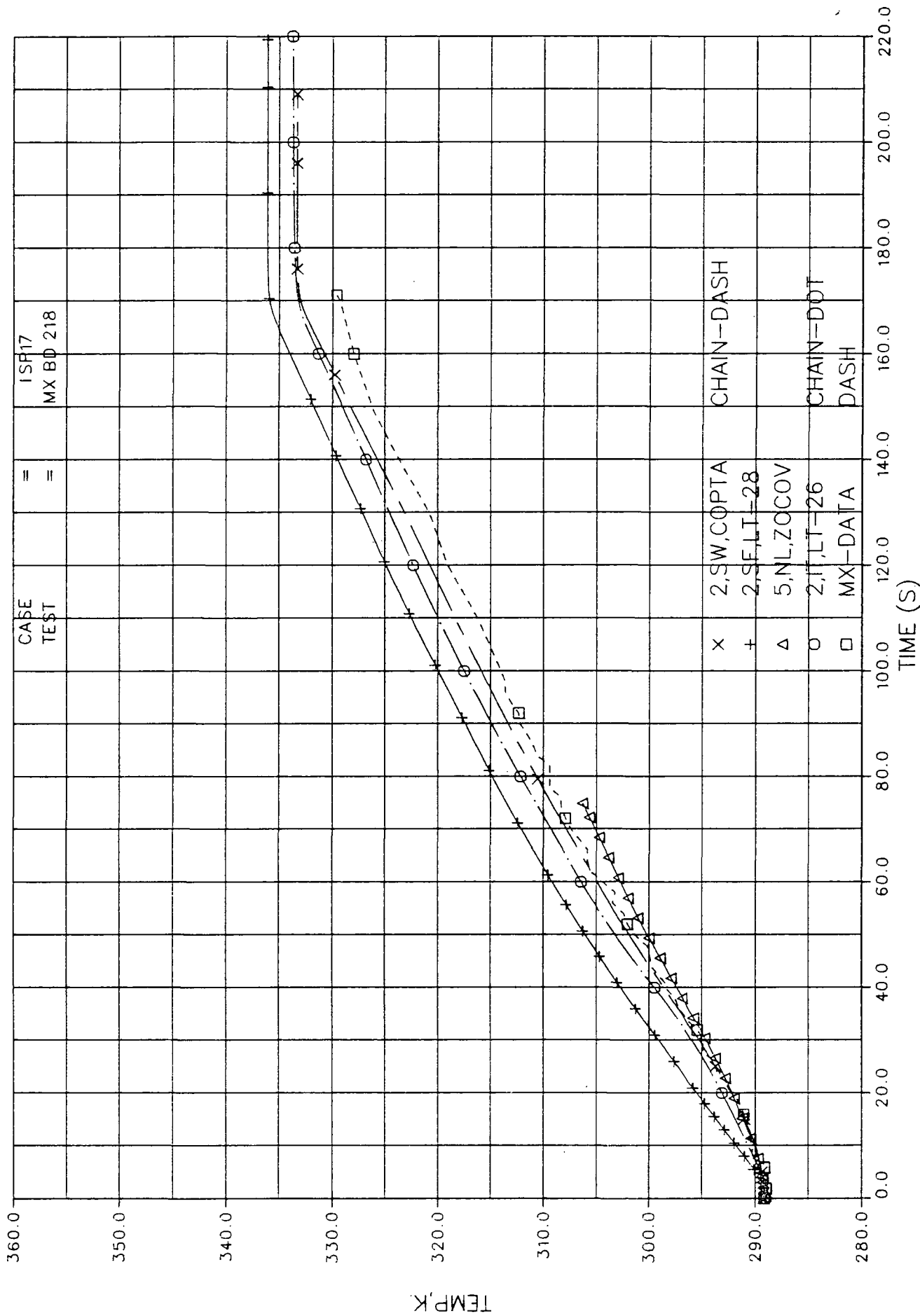
Diagram 26. Average pool temperature

ISP17,VENT PIPE AIR FLOW,DIAG E.12,25,TABLE E.5 AND IRE (ENLARGED)
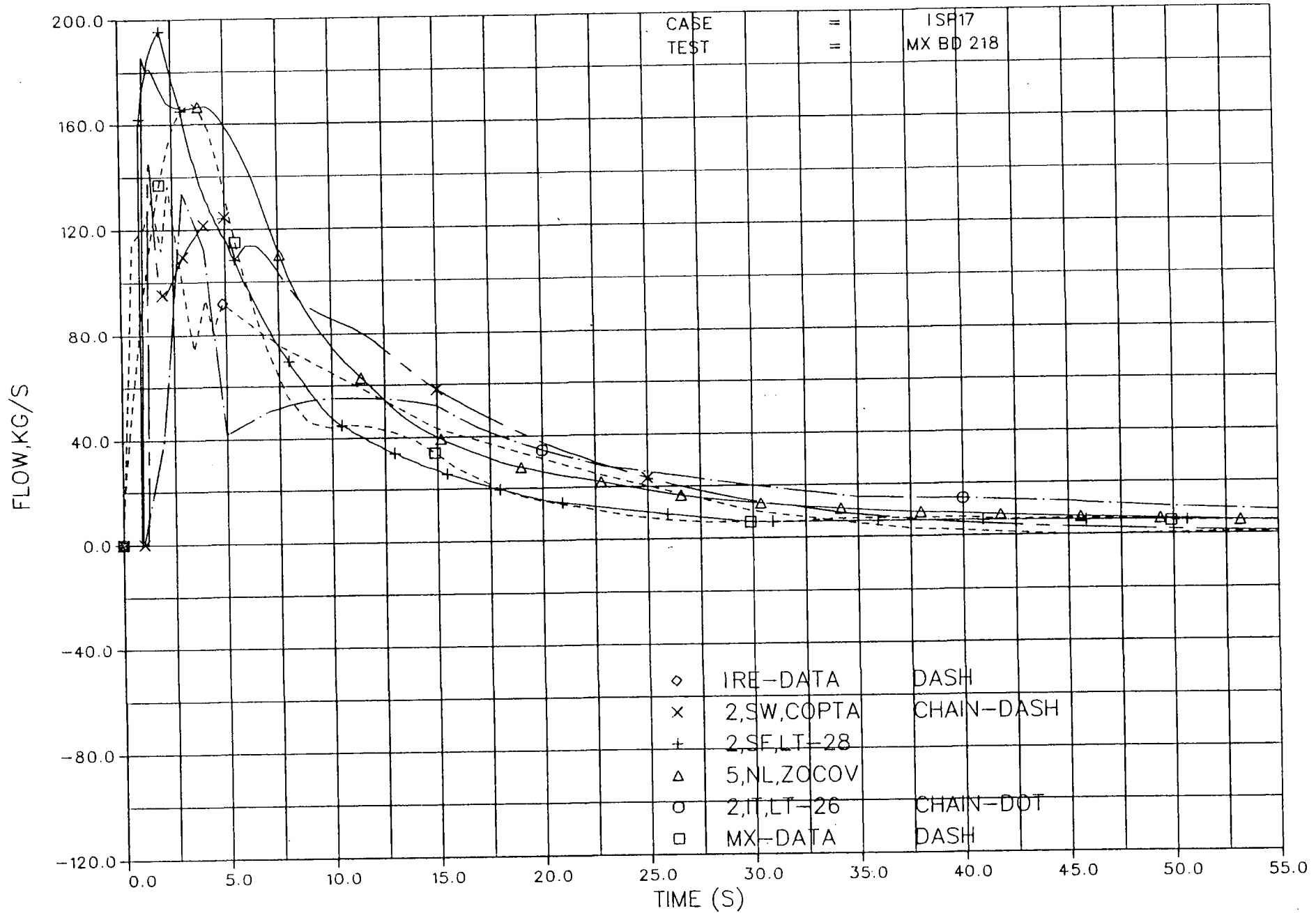
Diagram 27.   Vent pipe air flow

ISP17,VENT PIPE STEAM FLOW,DIAG E.10,41,TABLE E.5 AND IRE

STUDSVIK ENERGITEKNIK AB

SD-84/43
NR-84/428
1984-06-04

Appendix C.47 (54)

| CASE | = | ISP17 |
| TEST | = | MX BD 218 |

◇	IRE-DATA	DASH
×	2,SW,COPTA	CHAIN-DASH
+	2,SF,LT-28	
△	5,NL,ZOCOV	
○	2,IT,LT-26	CHAIN-DOT
□	MX-DATA	DASH

FLOW,KG/S

TIME (S)
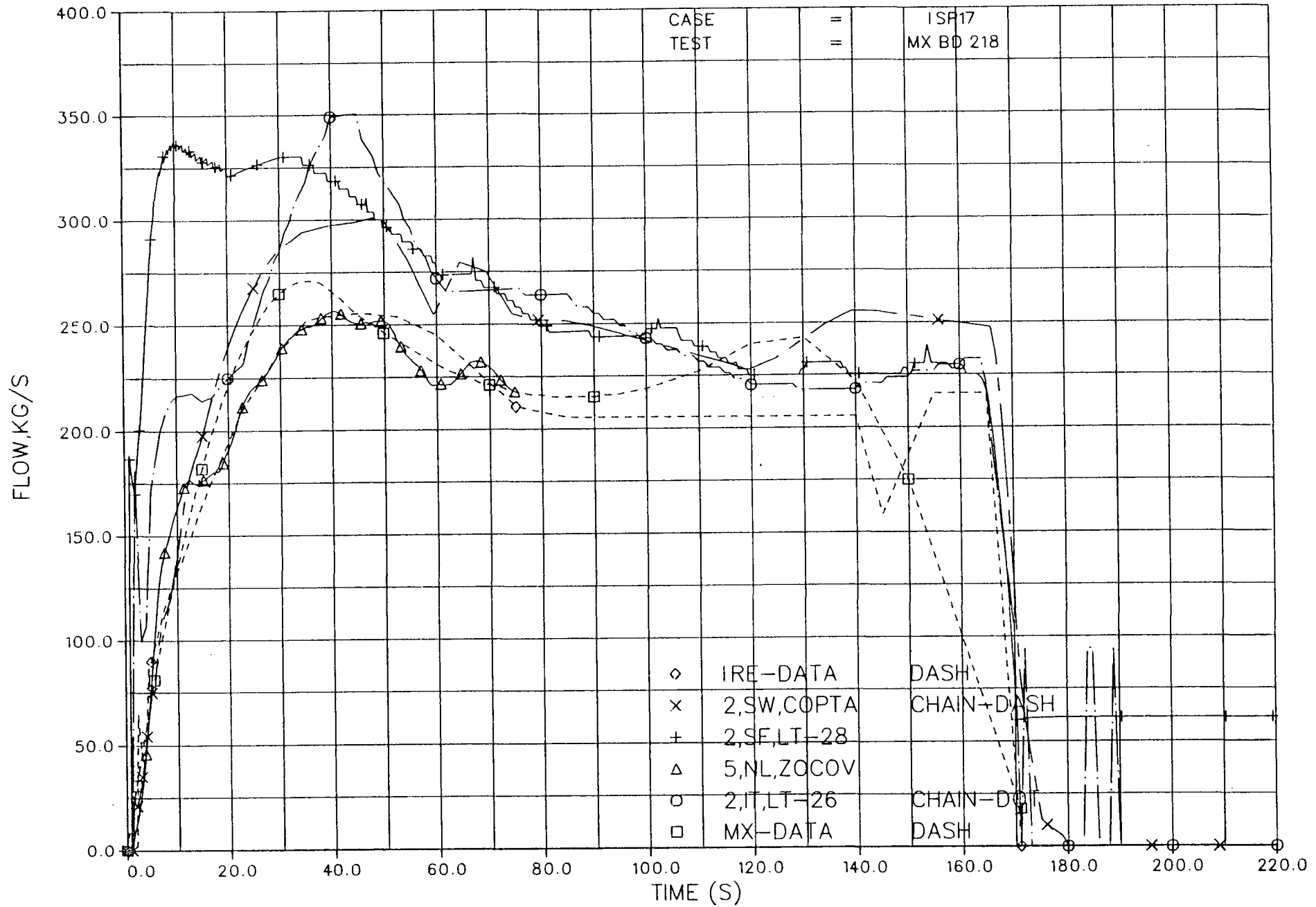
Diagram 28.   Vent pipe steam flow

ISP17,VENT PIPE FLOW OF WATER,DIAG E.11,39,TABLE E.5 AND IRE

| CASE | = | ISP17 |
| TEST | = | MX BD 218 |

Legend:
◇	IRE-DATA	DASH
×	2,SW,COPTA	CHAIN-DASH
+	2,SF,LT-28	
○	2,IT,LT-26	CHAIN-DOT
□	MX-DATA	DASH

FLOW,KG/S (y-axis)
TIME (S) (x-axis)
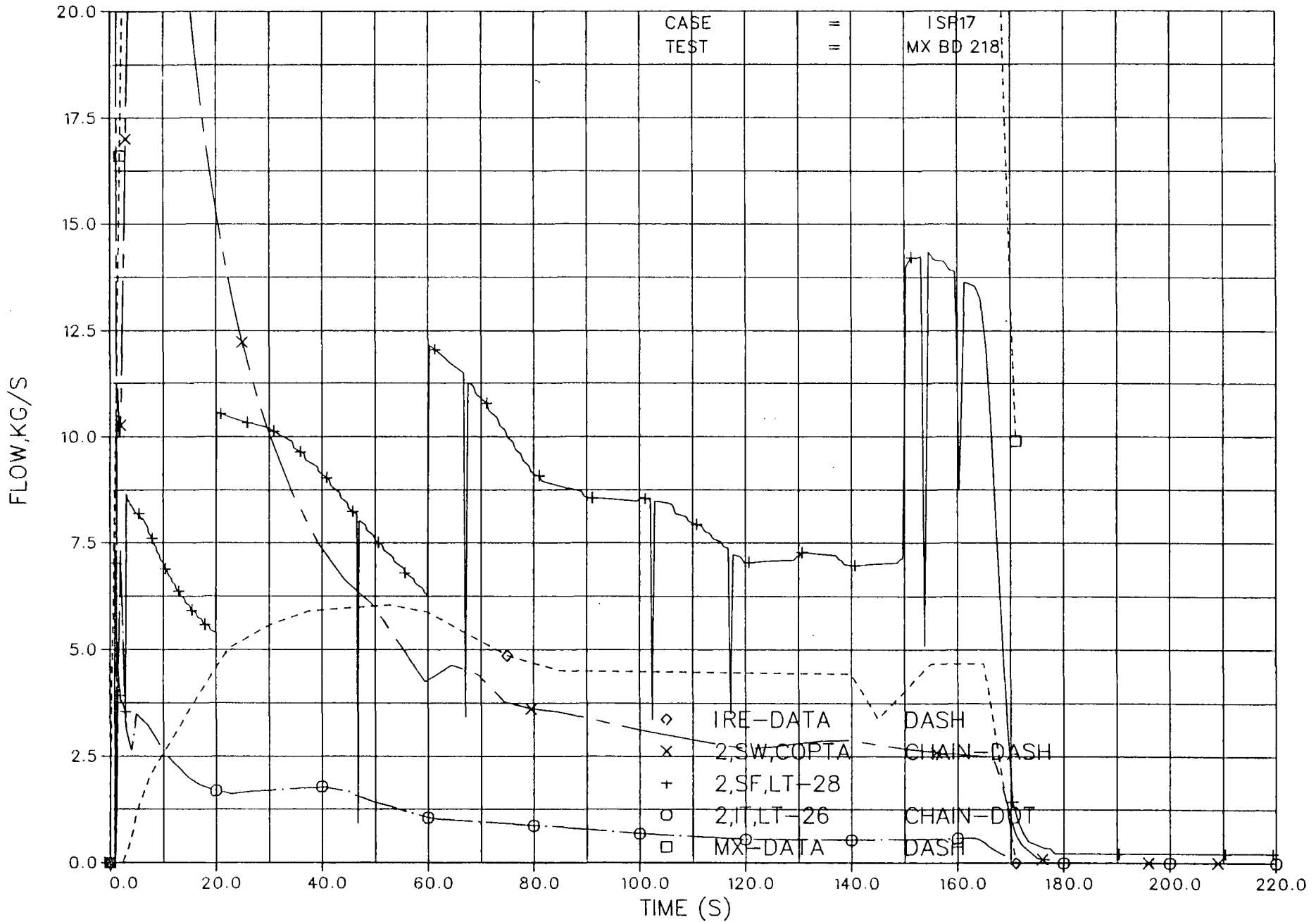
Diagram 29. Vent pipe flow of liquid water

Diagram 30. Total air through vents

ISP17,TOTAL STEAM THROUGH VENTS,DIAG E.13,TABLE E.5 AND IRE
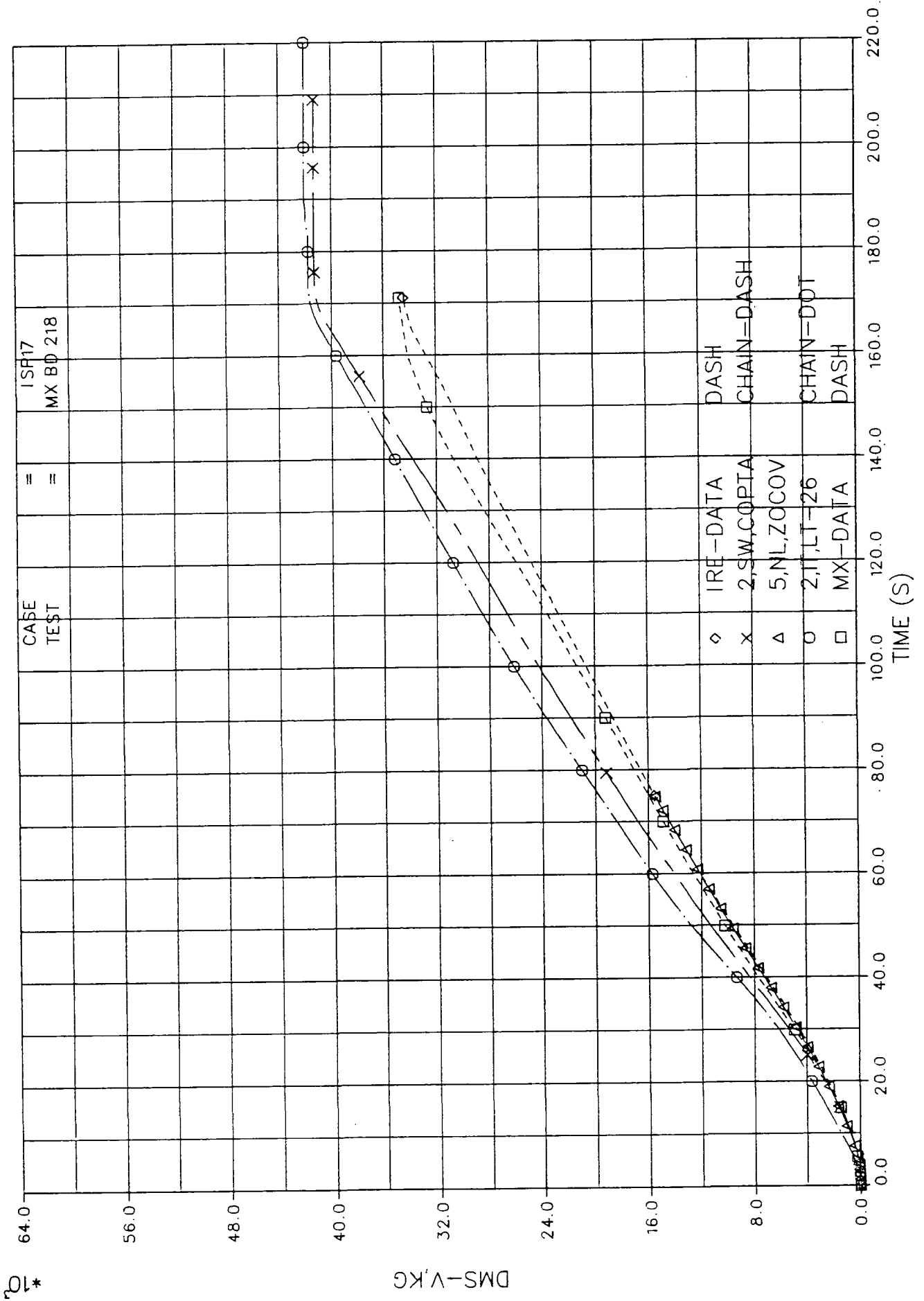
Diagram 31.   Total steam through vents

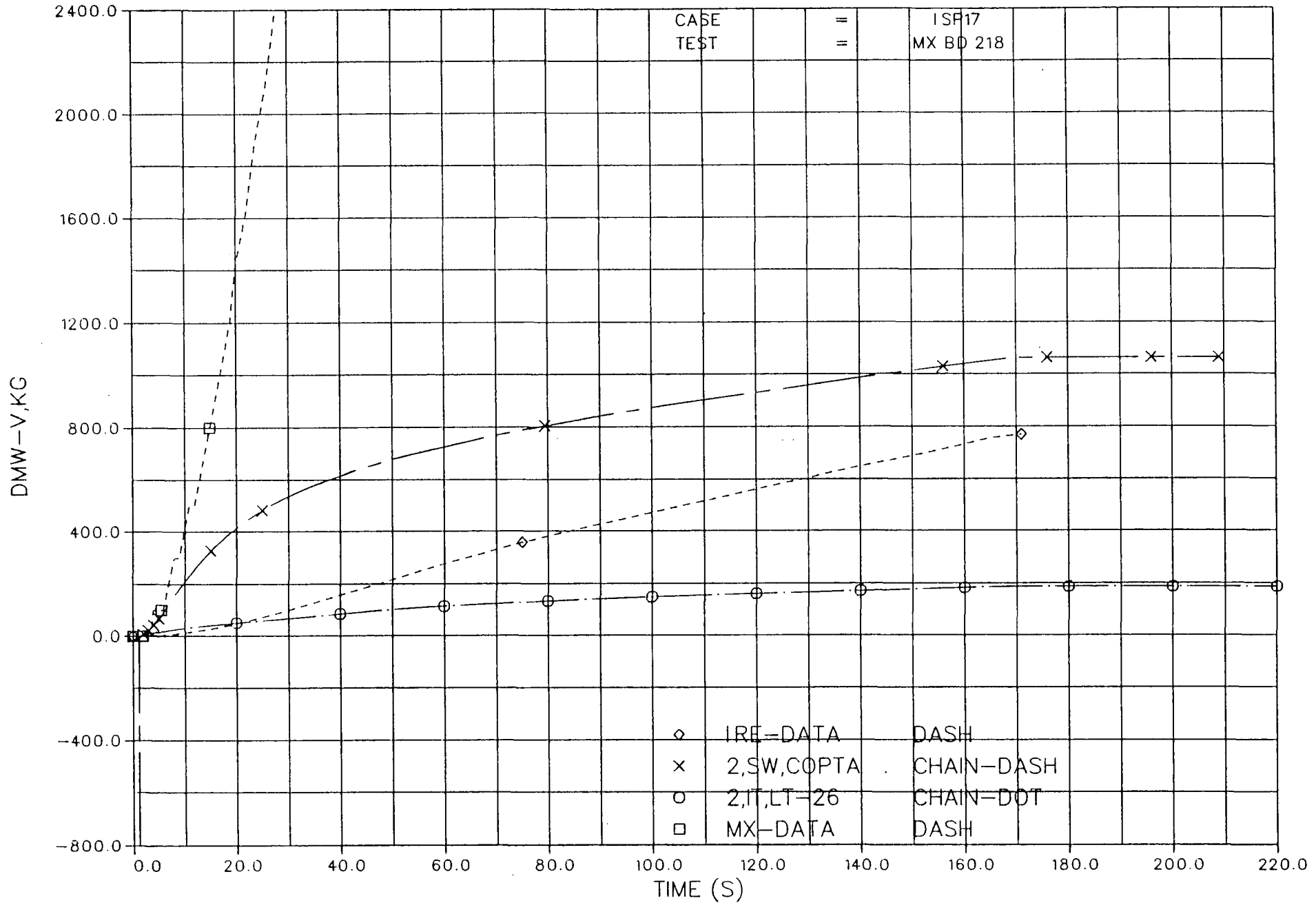# ISP17,TOTAL LIQUID WATER THROUGH VENTS,DIAG E.14,TABLE E.5 AND IRE

Diagram 32.   Total liquid water through vents
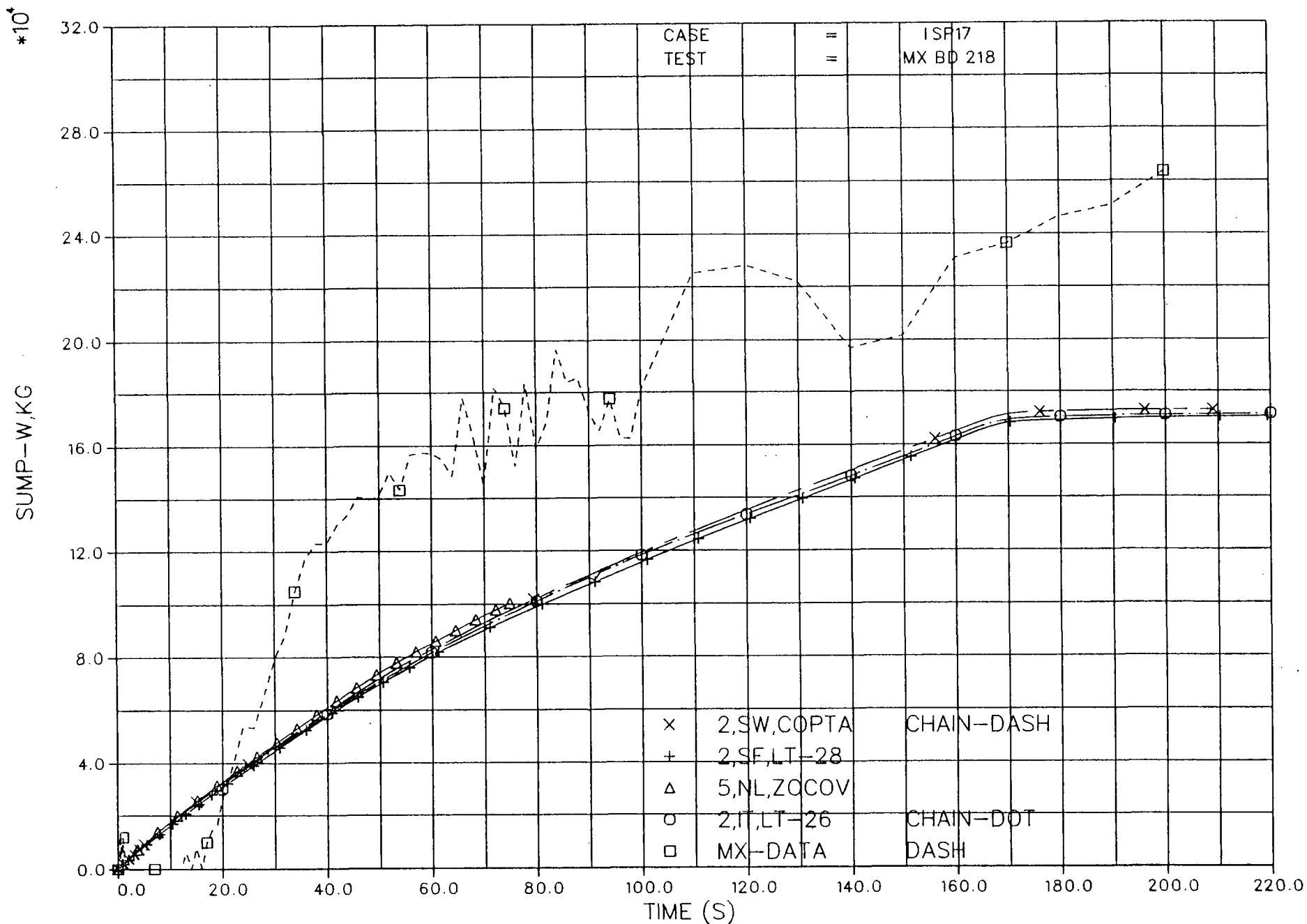
ISP17,MASS OF SUMP WATER,TABLE E.7 (MX-DATA TOO HIGH)

Diagram 33. Mass of sump water
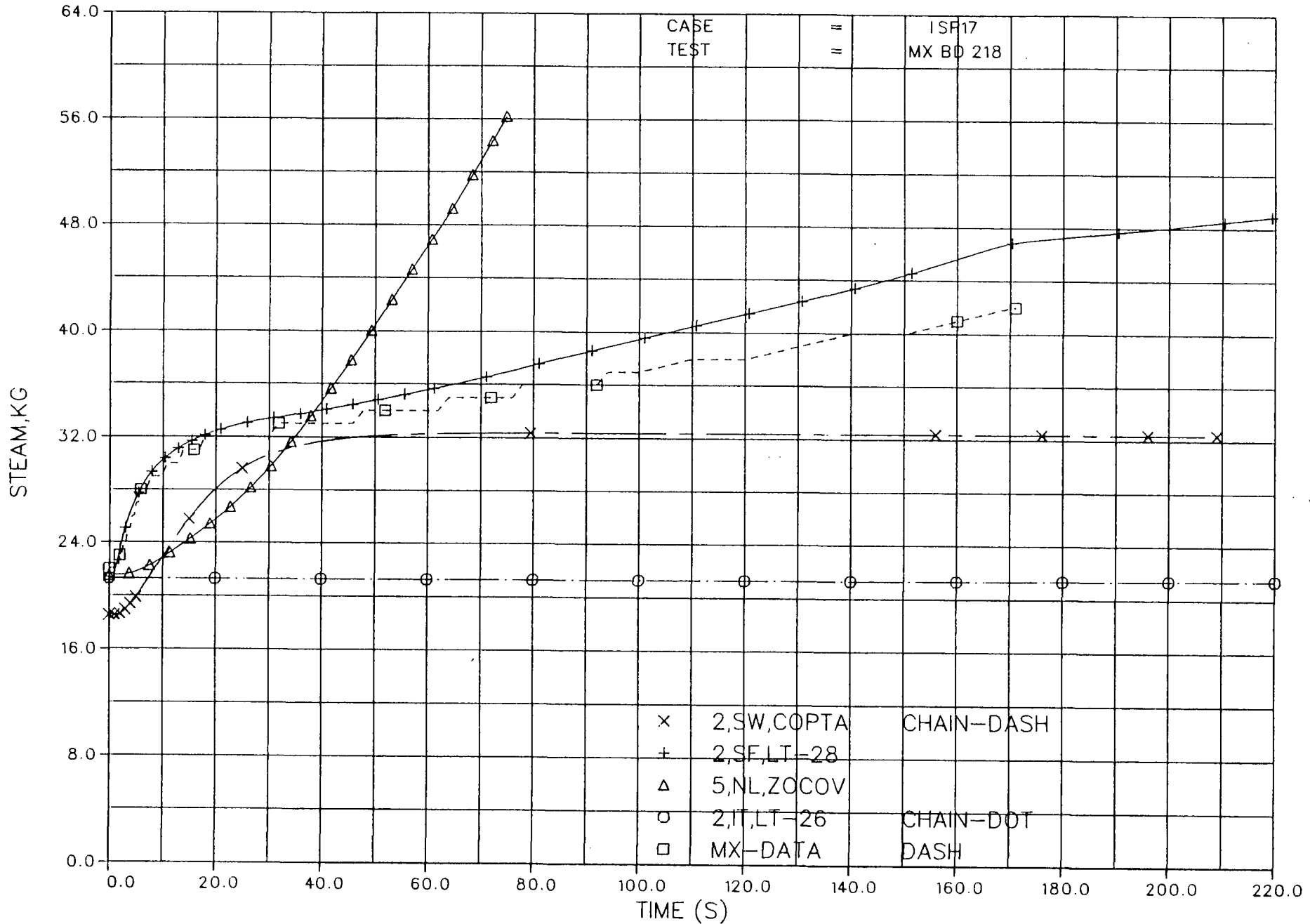
ISP17,MASS OF STEAM IN WETWELL GAS,DIAG E.26,TABLE E.6

Diagram 34.   Mass of steam in wetwell gas

ISP17,TOTAL MASS OF STEAM + WATER THROUGH VENTS,DIAG E.21,TABLE E.5 AND IRE

CASE	=	ISP17		
TEST	=	MX BD 218		

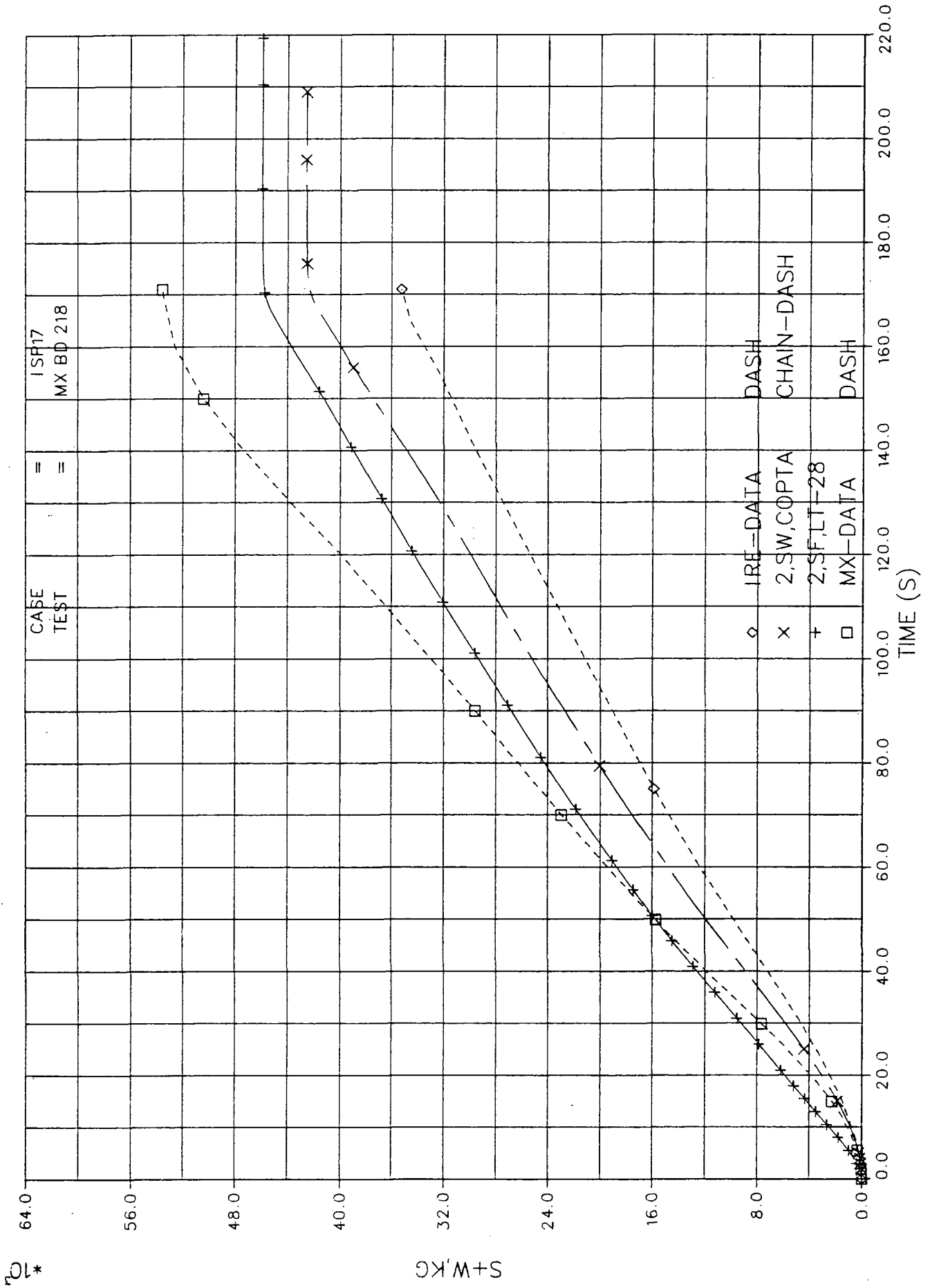|	IRE-DATA	DASH
◇		
×	2.SW,COPTA	CHAIN-DASH
+	2.SF,LT-28	
□	MX-DATA	DASH

TIME (S)

S+W,KG

*10³

Diagram 35.   Total mass of steam + water through vents