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SPES-3 Facility Analysis, reference data for postulated Accident Simulation, Criteria for general and special instrumentation selection

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SPES-3 Facility Analysis, Reference data for postulated Accident Simulation, Criteria for general and special instrumentation selection

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Summary

List of figures and tables

1. Introduction

IRIS (International Reactor Innovative and Secure) reactor is an integral modular, medium size PWR, under development by an international consortium with about 20 partners led by Westinghouse (1). The licensing process required by the U.S. Regulatory Commission (NRC) foresees an experimental campaign to verify the behaviour of the new plant and its safety system capabilities to cope with postulated accidents.

Fig. 1 shows a typical configuration of major component. The most innovative characteristic or IRIS is the elimination of some possible accidents, like the large LOCA (Loss of Coolant Accident). The integral structure of the reactor eliminates the main connection lines between the Vessel and the Steam Generators (as in the standard PWR design). The Reactor Vessel of IRIS includes the Core and 8 Steam Generators symmetrically arranged around it and directly connected to the outlet of the Core.

The IRIS containment is smaller with respect to the standard containment of a PWR and can effort a bigger internal pressure because of its spherical shape. It is strongly coupled to the Reactor Vessel. In case of a SBLOCA (Small Break LOCA), the pressure inside the containment rapidly rises up to the pressure in the Reactor Vessel and stop the water to flow out of the break. Then the long term cooling ensures a safe removal of the decay heat.

From the preliminary safety assessment (2), the need of the typical safety systems are evaluated and they are shown in Fig. 2.

An experimental facility called SPES3-IRIS (Simulatore Per Esperienze di Sicurezza) will built at SIET laboratories (Piacenza, ITALY) (3). It will be scaling 1:100 volume and 1:1 height scale the primary, secondary containment and the safety system of IRIS reactor.

The SPES3-IRIS is an integral test facility of the IRIS reactor with the general design criteria of reference.

2. The SPES-3 components

The design of SPES-3-IRIS facility includes the *primary system* with:

- Reactor Pressure Vessel (RPV) including power channel, circulation pump, pressurizer;
- Emergency Boration Tank (EBT);
- Automatic Depressurization System (ADS);

the *secondary systems* with:

- Main Steam Line Isolation Valve (MSLIV), including three SGs simulating eight, with helical coils (loop A and B simulate two SGs each, loop C simulates four);

the *containment system* with:

- dry well (DW),
- quench tank (QT),
- reactor vessel cavity (RVC) ,
- Pressure Suppression System (PSS),
- Long term Gravity Make-up System (LGMS);

the *safety system* with:

- Emergency Heat Removal System (EHRS) ;
- Refuelling Water Storage Tank (RWST);

the non safety systems with:

- Start-up Feed Water (FW).

The main parameters preserved by scaling are the fluid thermodynamic conditions (temperature, pressure, enthalpy); vertical elevation; power to volume ratio (not preserved during the steady state and initial part of transients); power to flow ratio; transit time of fluid and the heat flux.
Additional scaling criteria are applied to design selected components in order to better reproduce specific phenomena occurring in the IRIS plant during an accident.
Typical data of components are geometrical information (volume, total height , volume, nozzle of pipe connection: diameter and elevation).

Fig. 3 shows the SPES-3 IRIS Facility components. The SPES-3 facility has to prove that the thermodynamical coupling between the Reactor Vessel and the Containment can effectively stop the leak and guarantee a safe course in case of accident.

From the main base transient case are given in reference (6) and are reported in Tab. 1.

transient case	name
DVI-B-DEG at 10 MW	SPES3-89
EBT-B-DEG at 10 MW	SPES3-90
ADS-ST-DEG at 10 MW	SPES3-91
FL-B- DEG break at 10 MW	SPE3-93
SL-B-DEG break at 10 MW	SPES3-92

Tab. 1:. Reference base transient cases

3. Containment Piping of SPES-3 IRIS Facility

The *containment piping* includes the pipe lines that connect:

- the dry-well (DW) to the pressure suppression system PSS (PSS vent lines);
- the pressure suppression system PSS to the Long Term Gravity Make up System LGMS : (PSS-LGMS Pressure Balance Lines);
- the LGMS to Direct Vessel Injection (DVI) lines;
- the Direct Vessel Injection DVI lines.
- the Automatic Depressurization System (ADS) lines (two depressurization trains).

Fig. 4 and Fig. 5 and show primary system and containment flow diagram. We can see the main volume components (RPV, DW, LGMS,RWST, QT etc.)

4. Components and Piping connections of SPES-3 IRIS Facility

The piping line (diameter, length, lay-out) that connect the SPES-3 components are very important for the theoretical and experimental study of flow rate between the components.
Fig. 6 shows the connection of the reactor pressure vessel RPV (Pressurizer region of RPV) to the quench tank QT by the Automatic Depressurization System ADS. The 3 ADS trains of IRIS are simulated in SPES3 by 2 ADS trains. In SPES3 single train simulating one IRIS train with a nozzle Φ = 49.2 mm (2 inch); double train simulating two IRIS trains. The nozzle is Φ = 77.3 mm (3 inch). All trains discharge into the Quench Tank through a common vertical collector and a sparger. Collector to QT is Φ = 3” sch. 80 .
The quench tank QT is connected to the dry-well DW by vertical pipe of 5” sch. 40 diameter (Fig. 7).
Fig. 8shows the connection of Dry-Well to reactor vessel cavity RVC. There are two horizontal pipes: Φ = 2” sch. 40 gas return line and Φ = 4” sch. 40 liquid discharge line.

Direct vessel injection (DVI) from the emergency borate tank EBT to the reactor pressure vessel RPV it is possible via the DVI lines (Fig. 9). There are 2 upper connections: main delivery and siphon breaker; 1 lower connection for lower downcomer injection. Blind disks allow to set the required connection. The pipe are ½ “ sch. 80. The EBTs are 2 tanks of 0.178 m^3 volume and 5.5 m height. The pipes that connect the EBT tanks to the DVI are 3/8 “ sch. 80. Fig. 10 shows the upper connection while Fig. 11shows the bottom EBT connection.

An important connection is the pipe that connect the Dry-Well (D-W) to the pressure suppression system (PSS) (Fig. 12). There are two connections: the upper connection free (Φ = 3/4” sch. 40), the bottom connection with a check valve (Φ = 2 1/2” sch. 40). The discharge into PSS is made through a sparger. The dry-well is a cylindrical tank with 35.36 m^3 volume and 15.9 m height.

In the SPES-3 IRIS facility there are some connections between the bottom of the large gravity make-up system (LGMS) with the DVI lines (3/8 “ sch. 40) (fig. 12); there are two connection between the top of LGMS and PSS (fig. 13). Connection between PSS and DVI lines (Φ = 3/8” sch. 40) are shown in Fig. 15. Reactor vessel cavity is connect to the DVI line by pipe lines of Φ = 3/8” sch. 40 as shown in Fig. 16.

Fig. 17 shows the connection between the reactor pressure vessel to the steam collector by the steam lines . Steam lines A and B enter directly to the RPV (single loop), SL C divides in two branches before it enters to the RPV. The refuelling water storage tank (RWST) it is important as heat sink. Inside there is the Emergeny Heat Removal System (EHRS). Fig. 19 and Fig. 20 show the pipe connections at bottom and top of EHRS.

5. Break lines of SPES-3 IRIS Facility

SPES-3 IRIS include the break lines that are designed to simulated five base transient cases (4) . According to IRIS Integral system test specification of Westinghouse, base transient case of primary reactor side are *DVI break, EBT break, ADS break*.

Feed line break (FL break) and Steam line break (SL break) are connected to the secondary side of plant and it are designed to study non LOCA event of IRIS Plant.

The SPES3 break lines do not exist in IRIS but they are needed in the facility to lead the break flow into the containment tanks.

All the break line systems are suitable to simulate both the split and double ended guillotine break.

Reference break types (equivalent diameter double ended guillotine (DEG)) and line positions are defined in the reference test matrix. Fort each test all the times of events are defined with respect to the break time assumed at t=0 s.

During the run of proposed transient case the fluid flowing from the Reactor Vessel to the Containment and viceversa is mainly a two-phase mixture of steam and liquid. That is why the measurement of the two-phase flow rates in the SPES-3 pipe lines is crucial to assess the effective efficiency of the IRIS integral structure. Very important are the pipe lines that connect the component of IRIS plant and the main event about the safety components.

To carry out the experimental test matrix are important the break lines. They are very important, from special instrumentation point of view, because flow rate in these lines is two-phase flow.

The tests that will be performed are:

- Low elevation SBLOCA (small break LOCA): this accident is caused by the rupture of a DVI line. Both the double-ended guillotine and the split break tests will be simulated. The SPES3 DVI-B line is equipped with two break lines that separates from the horizontal portion of the DVI-B, and connect the DVI-B line to the Cavity. The demonstration of the efficiency of the long term recirculation is also foreseen as the long term extension of the previous events.
- High elevation SBLOCA (small break LOCA): the high elevation break is located on the EBT connection to the RV. One of the two EBT tank in SPES3 is equipped with two break lines (double-ended guillotine break line and split break line). The double-ended guillotine break will be simulated.
- ADS break: the ADS break is located on one of the two ADS lines in SPES3. This line is equipped with two break lines that connect the ADS to the Drywell. The double-ended guillotine break will be simulated.
- Feedwater line break: one of the three feed line in SPES3 is equipped with two break lines (double-ended guillotine line and split break line)that are connected to the Cavity. The double-ended guillotine break will be simulated.
- Steam line break: one of the three feed line in SPES3 is equipped with two break lines (double-ended guillotine line and split break line) that are connected to the Drywell. The double-ended guillotine break will be simulated.

Tab. 2 reports the SPES3 test matrix main goals.

Test type	break	purpose	note
Lower break	SBLOCA: DEG and SPLIT of DVI	Verify the dynamic coupling between primary system and containment	All safety systems available except for a single failure on an ADS train
Upper break	SBLOCA : DEG break of EBT to RPV line	The maximum containment pressure, the RPV mass and core temperature	
ADS break	SBLOCA: DEG break of ADS single train		Maximum PRZ steam space break
FL break	DEG break of FL	Verify the plant response to non LOCA events	Partial EHRS actuation
SL break	DEG break of SL		

Safe Shutdown Sequence	Loss of all power	Verify	

Tab. 2: SPES 3 Test Matrix main Goals

The SPLIT break lines and the DEG break line are reported in Fig. 21 for the DVI line.
Fig. 23shows the SPLIT and the DEG break line that connect the EBT to the RPV. Fig. 22 shows the connection lines used to simulate the ADS break to dry-well.
Fig. 26and Fig. 27 show the feed line break to reactor vessel cavity RVC for a non LOCA transient.
Fig. 24 and Fig. 25 show the steam lines break to dry well for the SPLIT case and for DEG case.

The SPES-3 facility has been designed to study fourteen geometrical configuration set-up by calibrated or break orifices. Tab. 3 gives the type of the transient and the size of orifice.

transient	name	Size mm	SPES-3 Line number
ADS Double Train (4” equivalent line)	ADS DT	12.34	GL 131
ADS Double Train (6” equivalent line)	ADS DT	18.64	GL 132
ADS Single Train (4“ equivalent line)	ADS ST	8.73	GL 134
ADS Single Train (6“ equivalent line)	ADS ST	13.18	GL 135
ADS break line SPLIT	ADS ST BL	13.18	GL 133
ADS break line DEG	ADS ST BL	13.18	GL 133
DVIB break line SPLIT (2” / 1” equivalent break)	DVI—B BL	4.28/2.54	LL 620
DVIB break line DEG (2” equivalent break)	DVI—B BL	4.28	LL 620
EBT-B to RPV balance line break SPLIT (4” equivalent break)	EBT-B to RPV BL	8.73	LL 632
EBT-B to RPV balance line break SPLIT (4” equivalent break)	EBT-B to RPV BL	8.73	LL 632
FL-B BL SPLIT (12 “ equivalent break)	FL-B BL	25.72	LL 314
FL-B BL DEG (12 “ equivalent break)	FL-B BL	25.72	LL 314
SL-B break SPLIT (16 “ equivalent break)	SL-B BL	32.54	GL 360
SL-B break DEG (16 “ equivalent break)	SL-B BL	32.54	GL 360

Tab. 3: Orifice table

6. Instrumentation of the SPES3 facility

A large set of instruments (about 600) must be installed on SPES3 to provide data both for the test run and analysis.

It consists of conventional instrumentation (relative and absolute pressure transmitters, temperature sensors) and special instrumentation for two-phase flow measurement.

The quantities directly measured by *conventional instrumentation* in the lines are:

- fluid and wall temperatures
- absolute and differential pressures
- velocity
- volumetric flow

While *special instrumentation* is used for void fraction and volumetric flow in break lines.

Derived quantities are:

- level by differential pressure and density,
- mass flow by differential pressure and density,
- mass flow by volumetric flow and density,
- mass flow by volumetric flow and void fraction,
- mass by level and density,
- mass flow by heat transfer (heated thermocouples),
- heat losses by wall thermocouples,

When SPES-3 work at normal steady state single phase flow must be measured (liquid lines (LL) , gas lines (LG)). Traditional instrumentations are fluid and wall temperature measurements, absolute pressure measurement in the volume component, differential pressure measurements for pressure drop, liquid level, or for single phase flow rate.

These measurements are very important for facility controls, flow regulations, safety, technical and scientific reasons.

Normal steady state two-phase flow is typical of steam generator components inside RPV.

During the transients of postulated accidents, two-phase flow is presents in all the break lines. Suitable instrumentations downstream and upstream of orifices, to estimate liquid and vapour flow rates, void fractions, pressures and temperatures are necessary.
The pipe lines that need to be monitoring from two phase flow point of view are all the DVI break lines, ADS break lines, EBT break line, FL break line and SL break line.
The locations where special instrumentation is needed are presented in Tab. 4.

SPES3-IRIS facility instrumentation

Location	Instrument type	Plant code	M. U.	Notes
PRIMARY SIDE AND CONTAINMENT				
ADS break line (DEG) flowrate	Special I	F133-004		Special instrument for Two-phase measure. TBD
ADS break line (DEG) flowrate	Special I	F133-005	m^3/s	Special instrument for Two-phase measure. TBD
ADS break line (split) flowrate	Special I	F133-002		Special instrument for Two-phase measure. TBD
ADS break line (split) flowrate	Special I	F133-006	m^3/s	Special instrument for Two-phase measure. TBD
ADS line DT (Stage-I) flowrate	Special I	F131-002		Special instrument for Two-phase measure. TBD
ADS line DT (Stage-I) flowrate	Special I	F131-003	m^3/s	Special instrument for Two-phase measure. TBD
ADS line DT (Stage-II) flowrate	Special I	F132-002		Special instrument for Two-phase measure. TBD
ADS line DT (Stage-II) flowrate	Special I	F132-003	m^3/s	Special instrument for Two-phase measure. TBD
ADS line ST (Stage-I) flowrate	Special I	F134-002		Special instrument for Two-phase measure. TBD
ADS line ST (Stage-I) flowrate	Special I	F134-003	m^3/s	Special instrument for Two-phase measure. TBD
ADS line ST (Stage-II) flowrate	Special I	F135-002		Special instrument for Two-phase measure. TBD
ADS line ST (Stage-II) flowrate	Special I	F135-003	m^3/s	Special instrument for Two-phase measure. TBD
DVI-B break line (DEG) flowrate	Special I	F620-005		Special instrument for two-phase measure. TBD
DVI-B break line (DEG) flowrate	Special I	F620-006	m^3/s	Special instrument for two-phase measure. TBD
DVI-B break line (split) flowrate	Special I	F620-003		Special instrument for two-phase measure. TBD
DVI-B break line (split) flowrate	Special I	F620-007	m^3/s	Special instrument for two-phase measure. TBD
EBT-B break line (DEG) flowrate	Special I	F632-004		Special instrument for two-phase measure. TBD
EBT-B break line (DEG) flowrate	Special I	F632-005	m^3/s	Special instrument for two-phase measure. TBD
EBT-B break line (split) flowrate	Special I	F632-002		Special instrument for two-phase measure. TBD
EBT-B break line (split) flowrate	Special I	F632-006		Special instrument for two-phase measure. TBD

SG-A inlet flowrate (pump delivery line)	Special I	F201-002	m^3/s	Turbine flowmeter has larger rangeability than nozzles or diaphragm
SG-B inlet flowrate (pump delivery line)	Special I	F201-003	m^3/s	Turbine flowmeter has larger rangeability than nozzles or diaphragm
SG-C inlet flowrate (pump delivery line) first inject. point	Special I	F201-004	m^3/s	Turbine flowmeter has larger rangeability than nozzles or diaphragm
SG-C inlet flowrate (pump delivery line) second inject. point	Special I	F201-005	m^3/s	Turbine flowmeter has larger rangeability than nozzles or diaphragm
SECONDARY LOOP A and RWST				
SECONDARY LOOP B				
FL-B break line (deg) flowrate	Special I	F317-002		Special instrument for Two-phase measure. TBD
FL-B break line (deg) flowrate	Special I	F317-005	m^3/s	Special instrument for Two-phase measure. TBD
FL-B break line (split) flowrate	Special I	F317-004		Special instrument for Two-phase measure. TBD
FL-B break line (split) flowrate	Special I	F317-006	m^3/s	Special instrument for Two-phase measure. TBD
SL-B break line (split) flowrate	Special I	F360-003		Special instrument for Two-phase measure. TBD
SL-B break line (split) flowrate	Special I	F360-006	m^3/s	Special instrument for Two-phase measure. TBD
SL-B break line (DEG) flowrate	Special I	F360-004		Special instrument for Two-phase measure. TBD
SL-B break line (DEG) flowrate	Special I	F360-007	m^3/s	Special instrument for Two-phase measure. TBD
SECONDARY LOOP C				

Tab. 4: Special instrumentation location

The diameters, lengths and orientations of pipes are very important in the selection of instrumentation. From Fig. 21 to Fig. 27 is show that the break lines proposed are all horizontal pipes. In Tab. 5, Tab. 6, Tab. 7 and Tab. 8 the most important geometrical characteristics for the DVI break lines and for ADS lines are resumed.

DVI-B line break (lower break)	Nominal Size	Φ in (mm)	Φ out (mm)	Thickness (mm)	Elevation start (mm)	Elevation stop (mm)	Δelevation (mm)	Length (mm)	Vertical inclination (°)	Horizontal inclination (°)
DVI-B Line break SPLIT										
From TEE to DVI-B break line SPLIT	1/2" x 1/2" x 1/2" x Sch. 80				8488.9				0	180 x135
Pipe	1/2" Sch. 80	13.8	21.3	3.73	8488.9	8488.9	0	886	0	135
L/D	64.20	**VENTURI FLOW-METER**								
Break valve and orifice	1/2" ANSI 2500									135
RC	1/2"x 2 1/2" Sch. 40								0	135
Pipe	2 1/2" Sch. 80	62.7	73	5.16	8488.9	8488.9	0	886	0	135
L/D	14.13									
Bend 45°	2 1/2" Sch. 80	62.7	73	5.16					0	180
Pipe	2 1/2" Sch. 80	62.7	73	5.16	8488.9	8488.9	0	1810.52	0	180
L/D	28.88	**TWO PHASE FLOW-METER**								
Bend 71.7°	2 1/2" Sch. 80	62.7	73	5.16					0	108.3
Pipe	2 1/2" Sch. 80	62.7	73	5.16	8488.9	8488.9	0	267.23	0	108.3
L/D	4.26									
Bend 41.7°	2 1/2" Sch. 80	62.7	73	5.16					0	150
Bend 90°	2 1/2" Sch. 80	62.7	73	5.16					0	240
RC	2 1/2"x 4" Sch. 40								0	240
Flange	4 " ANSI 300									
Cavity nozzle A1	4"	102.3			8488.9	8488.9	0	200		240 (60)

Table 10: DVI break line (SPLIT) characteristics.

Tab. 5: DVI break line (SPLIT) characteristics

DVI-B line break (lower break)	Nominal Size	Φ in (mm)	Φ out (mm)	Thickness (mm)	Elevation start (mm)	Elevation stop (mm)	Δelevation (mm)	Length (mm)	Vertical inclination (°)	Horizontal inclination (°)
DVI-B Line break DEG										
From TEE to DVI-B break line DEG	½" x 1/2" x 1/2" x Sch. 80				8488.9				0	180 x135
Pipe	½" Sch. 80	13.8	21.3	3.73	8488.9	8488.9	0	680.61	0	135
L/D	49.32	**VENTURI FLOW-METER**								
Break valve and orifice	½" ANSI 2500									135
RC	½"x 2 1/2" Sch. 40								0	135
Pipe	2 1/2" Sch. 40	62.7	73	5.16	8488.9	8488.9	0	680.61	0	135
L/D	10.86									
Bend 45°	2 1/2" Sch. 40	62.7	73	5.16					0	180
Pipe	2 1/2" Sch. 40	62.7	73	5.16	8488.9	8488.9	0	1025.44	0	180
L/D	16.35	**TWO PHASE FLOW-METER**								
Bend 7.4°	2 1/2" Sch. 40	62.7	73	5.16					0	187.4
Pipe to Cavity nozzle	2 1/2" Sch. 40	62.7	73	5.16	8488.9	8488.9	0	157	0	187.4
RC	2 1/2"x 4" Sch. 40								0	187.4
Flange	4 " ANSI 300									
Cavity nozzle B1	4"	102.3			8488.9	8488.9	0	200		187.4 (7.4)

Table 11: DVI break line (DEG) characteristics.

Tab. 6: DVI break line (DEG) characteristics

ADS LINEs	Nominal Size	Φ in (mm)	Φ out (mm)	Thickness (mm)	Elevation start (mm)	Elevation stop (mm)	Δelevation (mm)	Length (mm)	Vertical inclination (°)	Horizontal inclination (°)
SINGLE TRAIN										
RPV nozzle	2" (Sch. 160)	49.2							0	136
Flange	2" ANSI 2500 lap joint flange									
RC	2"x 1 1/2" Sch. 80									136
Pipe	1 1/2" Sch. 80	38.1	48.3	5.08	21465.73	21465.73	0	203.1	0	136
L/D	5.33									
Bend 90°	1 1/2" Sch. 80	38.1	48.3	5.08			0			136
Pipe	1 1/2" Sch. 80	38.1	48.3	5.08	21465.73	22465.73	1000	1000	90	0
L/D	26.25									
Bend 90°	1 1/2" Sch. 80	38.1	48.3	5.08						96.2
Pipe	1 1/2" Sch. 80	38.1	48.3	5.08	22465.73	22465.73	0	457.54	0	96.2
L/D	12.01									
Safety valve SV09	1 1/2" ANSI 2500									
TEE to ADS break line SPLIT	1 1/2" x 1 1/2" x 1 1/2" x Sch. 80									96.2 x 186.2
Pipe	1 1/2" Sch. 80	38.1	48.3	5.08	22465.73	22465.73	0	393.49	0	96.2
L/D	10.33									
Break valve IV21	1 1/2" ANSI 2500									
TEE to ADS break line DEG	1 1/2" x 1 1/2" x 1 1/2" x Sch. 80									96.2 x 186.2
Pipe	1 1/2" Sch. 80	38.1	48.3	5.08	22465.73	22465.73	0	346.72	0	96.2
L/D	9.10									
TEE to 6" eq. line	1 1/2" x 1 1/2" x 1 1/2" x Sch. 80								0	96.2 x 6.2
Pipe	1 1/2" Sch. 80	38.1	48.3	5.08	22465.73	22465.73	0	306.33	0	96.2
L/D	8.04									
4" eq. Valve IV17	1 1/2" ANSI 2500									
Pipe	1 1/2" Sch. 80	38.1	48.3	5.08	22465.73	22465.73	0	813.28	0	96.2
L/D	21.35						TWO PHASE FLOW METER			
TEE to ADS collective pipe to QT	1 1/2" x 3" x 3" x Sch. 40								90	96.2
6" eq. Valve line										
from TEE to 6" eq. Valve line	1 1/2" x 1 1/2" x 1 1/2" x Sch. 80								0	6.2
Pipe	1 1/2" Sch. 80	38.1	48.3	5.08	22465.73	22465.73	0	562.06	0	0
L/D	14.75									
Bend 45°	1 1/2" Sch. 80	38.1	48.3	5.08						51.2
Pipe	1 1/2" Sch. 80	38.1	48.3	5.08	22465.73	22465.73	0	556.7	0	51.2
L/D	14.61									
Bend 83.8°	1 1/2" Sch. 80	38.1	48.3	5.08						135
Pipe	1 1/2" Sch. 80	38.1	48.3	5.08	22465.73	22465.73	0	891	0	135
L/D	23.39						TWO PHASE FLOW METER			
6" eq. Valve IV18	1 1/2" ANSI 2500									
Pipe	1 1/2" Sch. 80	38.1	48.3	5.08	22465.73	22465.73	0	500	0	135
L/D	13.12									
Slip on flange ANSI 300	1 1/2"								0	135
DRY-WELL nozzle	1 1/2"	38.1	48.3	5.08	22465.73	22465.73	0	200	0	135

Table 31: ADS line single train connections main characteristics.

Tab. 7: ADS line single train connection- main characteristics

ADS LINEs	Nominal Size	Φ in (mm)	Φ out (mm)	Thickness (mm)	Elevation start (mm)	Elevation stop (mm)	Δelevation (mm)	Length (mm)	Vertical inclination (°)	Horizontal inclination (°)
DOUBLE TRAIN										
RPV nozzle	3" (Sch. 160)	73.7							0	76
Flange	3"ANSI 2500 lap joint flange									
RC	3"x 2 1/2" Sch. 80									76
Pipe	2 1/2" Sch. 80	59	73	7.01	21465.73	21465.73	0	325.2	0	76
L/D	5.51									
Bend 90°	2 1/2" Sch. 80	59	73	7.01			0			76
Pipe	2 1/2" Sch. 80	59	73	7.01	21465.73	23465.73	2000	2000	90	0
L/D	33.90									
Bend 90°	2 1/2" Sch. 80	59	73	7.01						117.9
Pipe	2 1/2" Sch. 80	59	73	7.01	23465.73	23465.73	0	807.72	0	117.9
L/D	13.69									
Safety valve SV08	2 1/2" ANSI 2500									
TEE to 6" eq. Valve line	2 1/2" x 2 1/2" x 2 1/2" x Sch. 80								90	117.9x27.9
Pipe	2 1/2" Sch. 80	59			23165.73	23165.73		565.27	0	117.9
L/D	9.58									
4" eq. Valve IV15	2 1/2" ANSI 2500									
Pipe	2 1/2" Sch. 80	59			23165.73	23165.73		672.27	0	117.9
L/D	11.39					TWO PHASE FLOW METER				
RC	2 1/2" x 3" Sch. 80								0	117.9
Bend 90°to ADS collective pipe to QT	3" Sch. 40	77.9							90	117.9
6" eq. Valve line										
from TEE to 6" eq. Valve parallel line	2 1/2" x 2 1/2" x 2 1/2" x Sch. 80								90	27.9
Pipe	2 1/2" Sch. 80	59	73	7.01	23465.73	23465.73	0	792	0	0
L/D	13.42									
Bend 107.1°	2 1/2" Sch. 80	59	73	7.01						135
Pipe	2 1/2" Sch. 80	59	73	7.01	23465.73	23465.73	0	1193.54	0	135
L/D	20.23					TWO PHASE FLOW METER				
6" eq. Valve IV16	2 1/2" ANSI 2500									
Pipe	2 1/2" Sch. 80	59	73	7.01	23465.73	23465.73	0	567.2		135
L/D	9.61									
Slip on flange ANSI 300	2 1/2"									
DRY-WELL nozzle	2 1/2"	59	73	7.01	23465.73	23465.73	0			135
COLLECTIVE PIPE TO QT										
		77.9	88.9	7.62	23465.73				90	115.9
from top Bend 90°from double train		77.9	88.9	7.62	23465.73	22465.73	-1000	1000	90	0
Pipe										
TEE from ADS double train	3" Sch. 40	77.9	88.9	7.62	22465.73	10214.74	-12250.99	12250.99	90	0
Pipe to QT top	1 1/2" x 3" x 3" x Sch. 40	77.9	88.9	7.62	10214.74	7714.74	-2500	2500	90	0
Pipe from QT top to ADS sparger	3" Sch. 40				7714.74	TBD				
ADS Sparger	3" Sch. 40									

Table 32: ADS line double train connections and ADS lines to QT connections main characteristic

Tab. 8: ADS line double train connection and ADS lines to QT connections - main characteristics

Typical break line have a break orifice or a calibrated orifice that define the upstream and the downstream of discharge line. L/d ratio are chosen according to the measuring standard rules as EN ISO 5167-1-2-3-4 standard for orifice and nozzle (5) for the conventional single flow instrumentation. Turbine meters , drag disk meters , vortex meters have to be installed according to single flow measuring rules of manufacturer.

The simulated break line ,according to SPES3-IRIS facility nodalization for RELAP5 are:

Line Number	Name		Orifice	Type	Size (mm)	Notes
GL 131	ADS DT	ADS Double Train (4" eq. Line)	CO 05	Calibrated orifice	9.927	4" eq. Double line
GL 132	ADS DT	ADS Double Train (6" eq. Line)	CO 06	Calibrated orifice	18.64	6" eq. Double line
GL 134	ADS ST	ADS Single Train (4" eq. Line)	CO 07	Calibrated orifice	7.019	4" eq. Line
GL 135	ADS ST	ADS Single Train (6" eq. Line)	CO 08	Calibrated orifice	13.18	6" eq. Line
GL 133	ADS ST BL	ADS break line SPLIT	CO 09	Break orifice	13.18	6" eq. Break
GL 133	ADS ST BL	ADS break line DEG	CO 10	Break orifice	13.18	6" eq. Break
LL 620	DVI-B BL	DVIB Break line SPLIT	CO 01	Break orifice	4.28 / 2.54	2" / 1" eq. Break
LL 620	DVI-B BL	DVIB Break line DEG	CO 02	Break orifice	4.28	2" eq. Break
LL 632	EBT-B to RPV BL	EBT-B to RPV bal. Line Break SPLIT	CO 03	Break orifice	8.73	4" eq. Break
LL 632	EBT-B to RPV BL	EBT-B to RPV bal. Line Break SPLIT	CO 04	Break orifice	8.73	4" eq. Break
LL 314	FL-B BL	FL-B break SPLIT	CO 11	Break orifice	25.72	12" eq. Break
LL 314	FL-B BL	FL-B break DEG	CO 12	Break orifice	25.72	12" eq. Break
GL 360	SL-B BL	SL-B break SPLIT	CO 13	Break orifice	32.54	16" eq. Break
GL 360	SL-B BL	SL-B break DEG	CO 14	Break orifice	32.54	16" eq. Break
LL606	EBT-A to DVI-A	EBT-A to DVI-A line	CO 15	Calibrated orifice	3.4	orifice to match pressure drops
LL636	EBT-B to DVI-B	EBT-B to DVI-B line	CO 16	Calibrated orifice	3.4	orifice to match pressure drops
LL507	EHRS-A CL	EHRS-A Cold Leg	CO 17	Calibrated orifice	6	orifice to match pressure drops
LL527	EHRS-B CL	EHRS-B Cold Leg	CO 18	Calibrated orifice	6	orifice to match pressure drops
LL547	EHRS-C CL	EHRS-C Cold Leg	CO 19	Calibrated orifice	12	orifice to match pressure drops
LL430	LGMS-A to DVI-A	LGMS-A to DVI-A line	CO 20	Calibrated orifice	4	orifice to match pressure drops Measure 1/10 of tube area for lack of IRIS data.
LL432	LGMS-B to DVI-B	LGMS-B to DVI-B line	CO 21	Calibrated orifice	4	orifice to match pressure drops. Measure 1/10 of tube area for lack of IRIS data.

Tab. 9: Simulated break line ,according to SPES3-IRIS facility nodalization for RELAP5

7. Measuring Range and criteria for instruments selection

Starting from the analysis of the RELAP 5 simulation results, the variations of the most important two phase flow parameters has been estimates.
The measurement range is the fundamental point for select the possible instruments, because each type of meter is characterised by advantages and drawbacks that are less or more important in different flow conditions.
With the RELAP code is possibility to analyse the thermohydraulic downstream and upstream the break orifices. Because the different conditions in the different locations, the two options must be studied to select where the special instrumentations could "work" better and where it can be installed in order to minimise the flow perturbations.

Appendix gives the ranges in the upstream locations; while downstream analysis is reported in the report: "Investigation of the two-phase flow instrumentation necessary for the SPES3 facility".

The results analysis concerned different points.
The first point concerns the analysis of the time intervals relatives at each simulations:
During each time intervals the main important parameters to know are:

- mass flow rate of each phase
- velocity of each phase
- pressure
- temperature
- their time variation.

Because the large variations of the parameters during the transients the time intervals are very important, their knowledge permit to decide which type of instruments can measure at each instants and then how many instruments are needed for each line.
In any case the reference spool piece is the series "turbine meter", "drag meter or venturi meter" and void fraction meter (impedance meter).
The second point is the analysis of the void fraction at each interval and the flow pattern, because the influence of the velocity profile and of the void fraction in the two phase flow response is very high.

The analysis showed that the most important characteristics for the two phase instrumentations are:

Two-Phase Flow Handling Capability and Easy Modeling: the instrument selected must work well in two phase flow, then a number of studies for different instruments has been computed and a large amount of literature has been analysed, in order to select the instruments able to work in two phase flow but also able to measure at high pressures and high temperatures

Transient Operation Capability: since the break discharged flow is not steady state, a good transient capability is a required prerequisite. The capability to follow fast transient is required, or at least the capability to mathematically model the dynamic response of the meter so as to correct the signal for dynamic effects.

Minimal Disturbance to the Flow: in order to avoid any significant alteration of the thermal-hydraulic coupling between the Reactor Pressure Vessel and the Containment that could drive somewhat the testing and that the testing is intended to explore, the disturbance to the discharged flow caused by the meter should be as low as possible.

High Span: all the analysed breaks are characterised by a wide variations range for all the parameters, so that the capability of the meter to cover a huge span is a good prerequisite.

Bi-directional Operation Capability: the graph of mass flow rate showed that in certain instants reverse flow conditions are possible; then the selected instruments must be able to not failure in this context. Both Reactor Pressure Vessel discharge into the Containment and a possible reverse flow from the Containment into the Reactor Pressure Vessel have to be measured.

It’s important to highlight that because the important variations of all the parameters it is very difficult to find an instruments, or better a series of instruments (Spool Piece - SP) able to measure during all the time.
The main parameter that needs to be monitored during the simulation of the transient is the mass flow rate coming out of the Reactor Vessel into the containment. Since the density of each phase is not known, it is necessary to measure both the velocity of the two-phase flow (with a flow-meter) and the density of each phase (with a densitometer).
The SP have to couple two, or three instruments, able to measure in the same range and able to avoid failure (instrument break) also if the conditions are out of the measurable range.
The meters must then be characterized of an high robustness if installed inside the pipe.

The choice of the instruments, has been based on the geometry of the lines and on the mass flow rates and void fractions expected in those lines, too.
Influence of the T junctions, the Y junctions and the elbows on the distribution of the flow inside the pipe is important because some instruments need a minimum value of L/D upstream and downstream of straight uninterrupted flow line, in order to measure properly. Then it must take in account that, if an instrument as turbine, venturi or drag disk will be selected the length of the line must be adapted.
Typical spans for commercial meters are not able to measure in all the range, so that an array of differential meters is required to fully cover SPES3 needs, driven by an active control system to place in line the proper meter during the test and valve off all the others.

As it can be deduced from the previous analysis (6), (7), (8) and Appendix, the meters that have an acceptable performance, are the Turbine flow-meter, Drag Disk, Venturi tube and Impedance Probes.
Also considering limits and drawback of these instruments, these are the only devices analysed that could operate in the whole range of void fractions (from 0 to 1), pressure, temperature (span: 200°C and in some lines 400°C) and velocity (gas velocity can reach 200 m/s) , expected in the break lines.
All the other flow meter are limited in their two-phase applications.

Turbine:

- Span, is typically between 10:1 and 100:1.
- Operating temperature ranges span -270°C to 650°C, (-450°F to 1200°F).
- Operating pressure ranges span coarse vacuum to 414 MPa, (60,000 psi).
- Pressure drop at the maximum rated flow rate ranges from around 0.3 kPa (0.05 psi) for gases to in the region of 70 kPa (10 psi) for liquids.
- Signal is influenced by the flow pattern.

Drag:

- Accuracy is $\pm 0.5\%$ of full scale, and $\pm 5.0\%$ for probe type.
- Repeatability is $\pm 0.15\%$ of rate
- The turndown ratio is approximately 15:1
- Response time: from 0.002 to 0.1 sec

- Operating temperature ranges up to 649°C.
- Operating pressure ranges up to 20.70 MPa.
- Flow direction: Unidiretional/Bidiretional

The venturi meter can work at each operating conditions without failure, the most important drawbacks for this instruments is the limited span, usually 5:1. An array of instruments in then required to cover all the mass flow range if this instrument is selected. Concerning the dynamic response an appropriate set of transducers must be used, because the dynamic is different for each time interval of the break simulations.

Concerning the void fraction measurement device the impedance probes can be used for all the range, but particular care must be take in the selection of geometrical shape and material because this devices are strong influenced by flow pattern and temperature. The model to interpret the electric signal must be take in account the temperature effect and the phase distribution inside the pipe. Impedance probes do not influence the flow and, with a good interpretation model, the accuracy is fairly good.

For the void fraction measurements also Wire Mesh Sensor, EIT (Electrical Impedance Tomography) and Ultrasonic flow-meters ahs been analysed.
The ultrasonic meter is not been widely studied for their application in two-phase flow.
The EIT and the Wire mesh sensor can provide an insight of the void fraction distribution and of the flow pattern, instead.
The EIT can just detect bubbles that are travelling slower than the time necessary to complete the entire scan of all the sensors, but actually the dynamic permit to use this technology with velocity up to 20 m/s. The Wire mesh sensor is more invasive than the Tomography, but the pressure drop caused by the instrument is very little compared to the pressure inside break lines and it could be neglected. It can detect fast moving particles with a maximum frequency of 10 kHz (one scan every 0.01 ms).

The Wire mesh sensor is very promising, since it is possible to obtain the velocity of the gas phase and its profile inside the pipe.
But the drawbacks relate to this technology doesn't allow the use in the SPES3 break lines.
The upper limit for the pressure is 7 MPa.
The accuracy in void measurements depends on the mesh geometry, because the bubbles detectable by the sensor must have the same order dimension of the mesh cell. Then little quantity of liquid are

very difficult to detect, and a reduction in mesh dimension require a diameter of the wire so little that breaks due to the mass flow rates and flow velocities are expected.

8. Conclusions

Based on the instruments studies and on the measurement range parameter analysed, it possible to draw some conclusions:

- During transient simulation in the break lines, two phase flow occurs; to measure the thermohydraulic parameters a SP constituted by two, or three instruments must be installed in order to measure the velocity, the mass flow rate of each phase and the void fraction with an acceptable uncertain.
- The available commercial instruments able to be used in the SPES3 facility break lines are characterized by a limited span (but for turbine meters the span is 100:1), and then a certain number of instruments must be used in the same line to measure all the range of the parameters.
- The Spool Pieces selected to work in each range can be positioned in series or in parallel: in the first case all the instruments must be selected in order to avoid out-of-range failure. This configuration is unsuitable because each instrument requires a minimum value of L/D upstream and downstream of the straight uninterrupted flow line, and then high pipe lengths. In the second configuration (parallel SP) each Spool Piece line can be set to work in a certain range. An active control system must be used to place in line the most appropriate instrument during the test and exlude all the others. To verify how this configuration can modify the un-steady behaviour a RELAP code simulation could be useful.
- For the void fraction measurement, by using impedance probes, the most important issues are the temperature-dependent signal and the flow-pattern dependent signal; a very advanced model is required to obtain a good accuracy, but all the range can be measured without sensor failure and disturbance of the flow.
- The number of Spool Piece lines that have to be installed for each measurement point depends on:

    Mass flow rate value released in each time interval,
    Mass flow rate variation during the time interval,
    Pressure e temperature variation,
    Flow velocity.

- Concerning the choice to install the SP downstream or upstream of the break, pressure and velocity values as well as the geometry of the circuit must be considered.

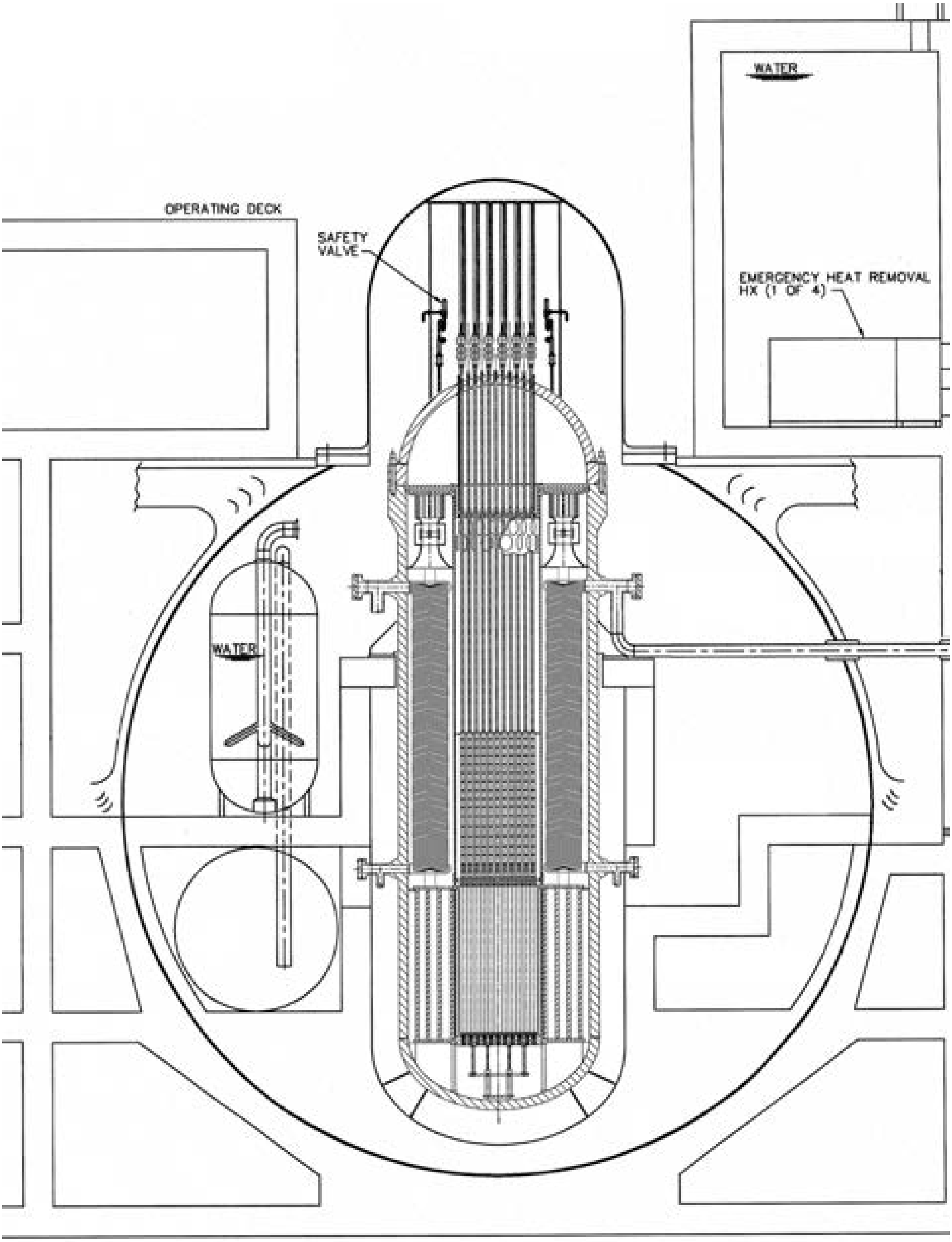

Fig. 1: IRIS Spherical Steel Containment and Major Components

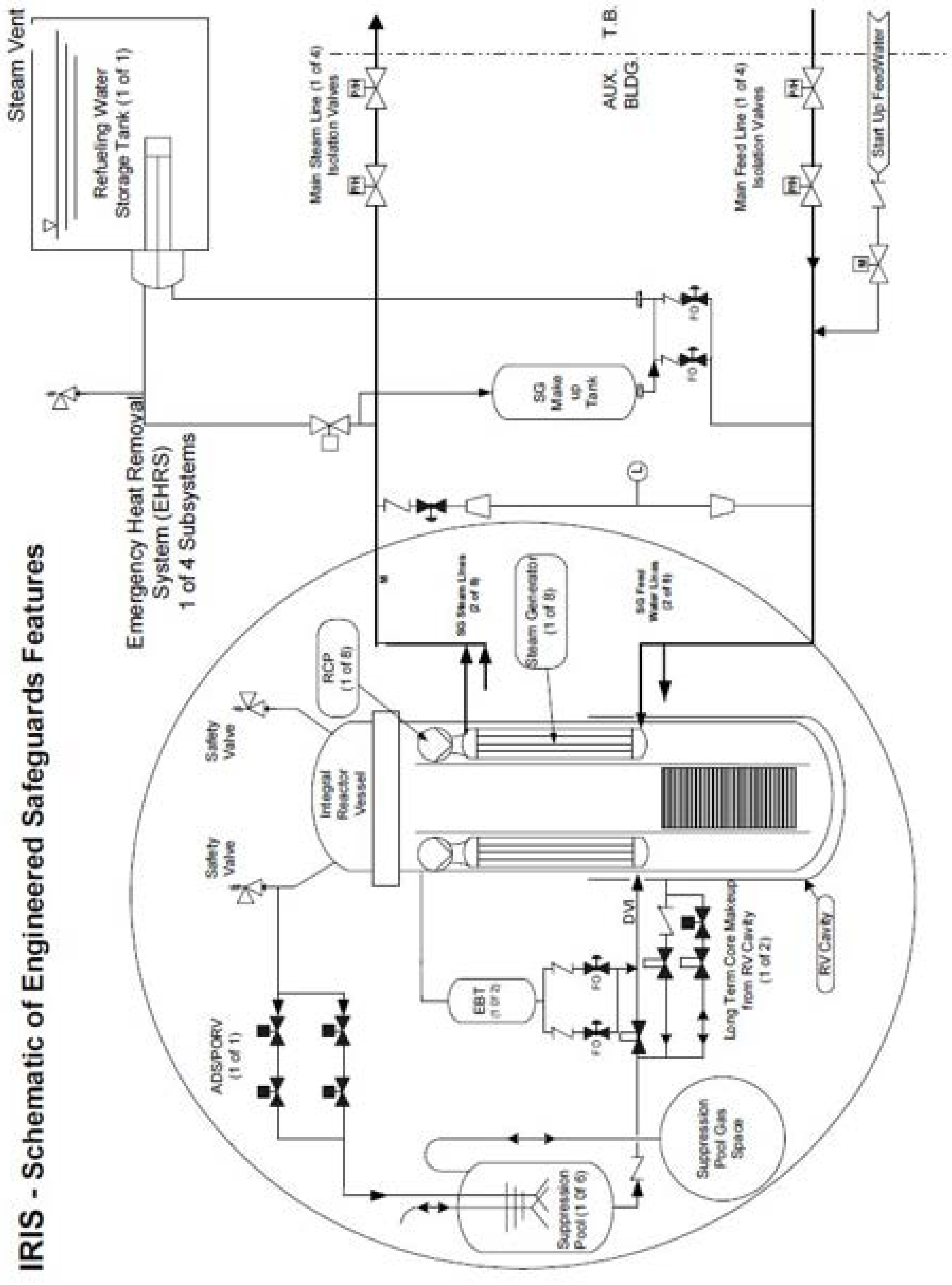

Figure 1.1-1 Engineered Safety Features of IRIS

Fig. 2: Engineering Safeguard System of IRIS

Fig.4.1- SPES3-IRIS facility components located on the load-bearing structure, front and side view

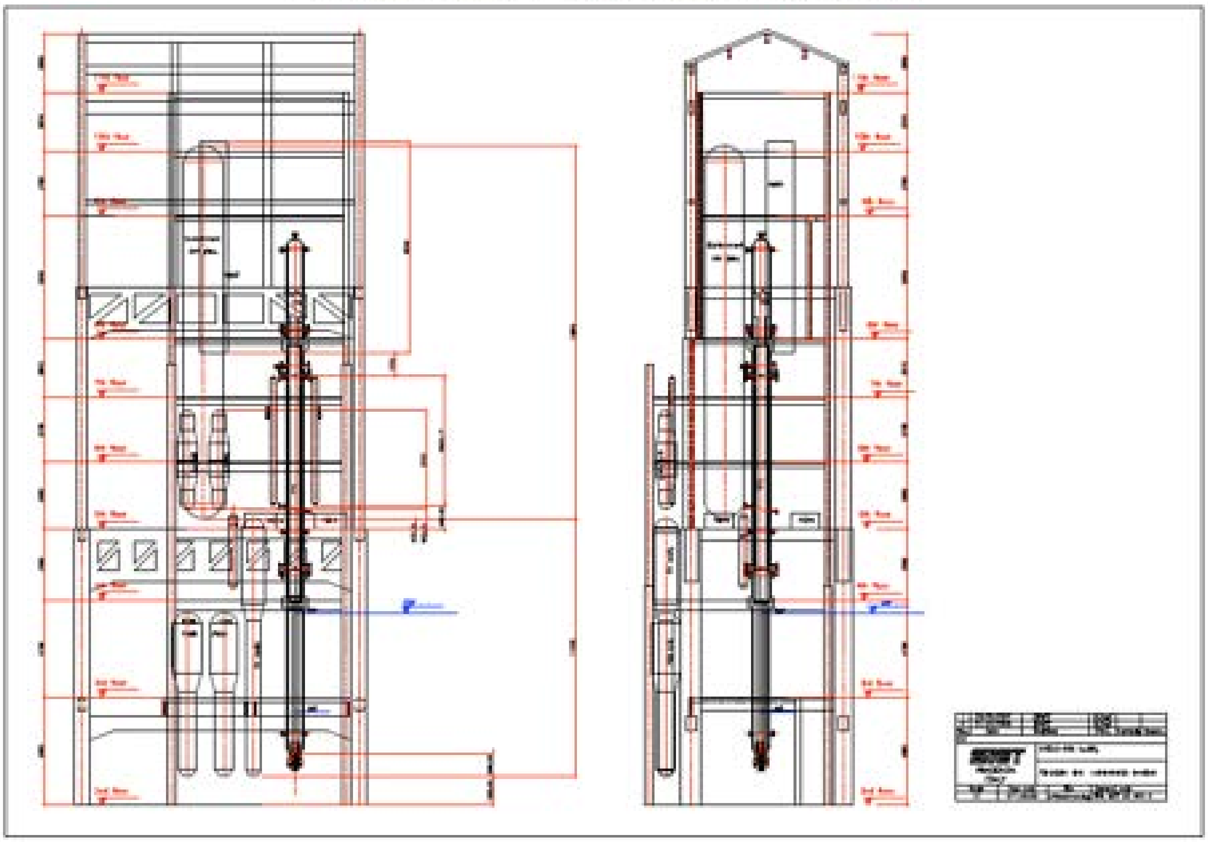

Fig. 3: SPES-3-IRIS component location

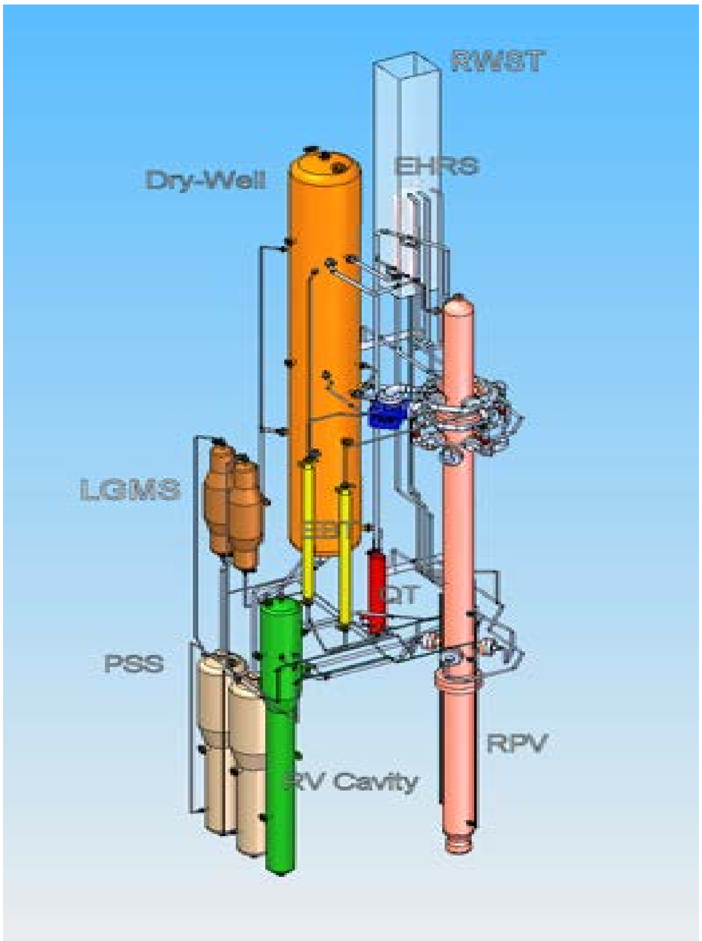

Fig. 4: IRIS GENERAL VIEW

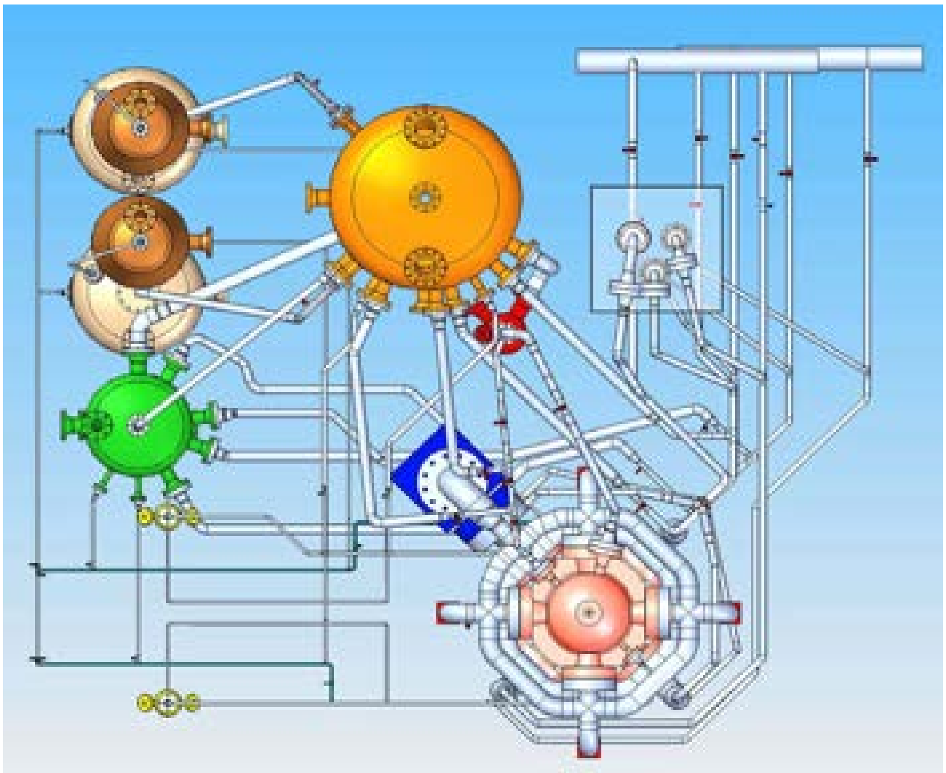

Fig. 5: Top View of SPES-3 Iris Facility

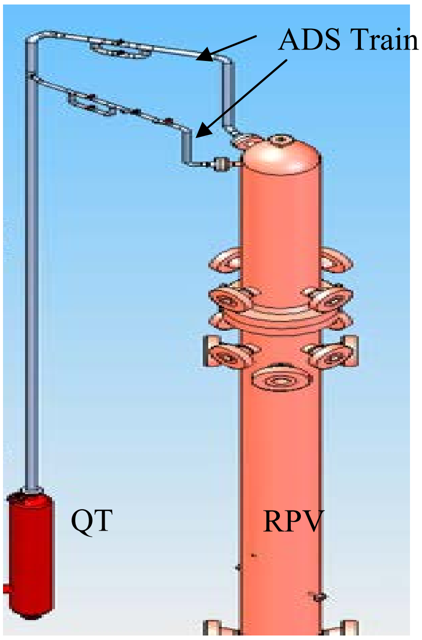

Fig. 6: SPES3- ADS Trains to Quench tank

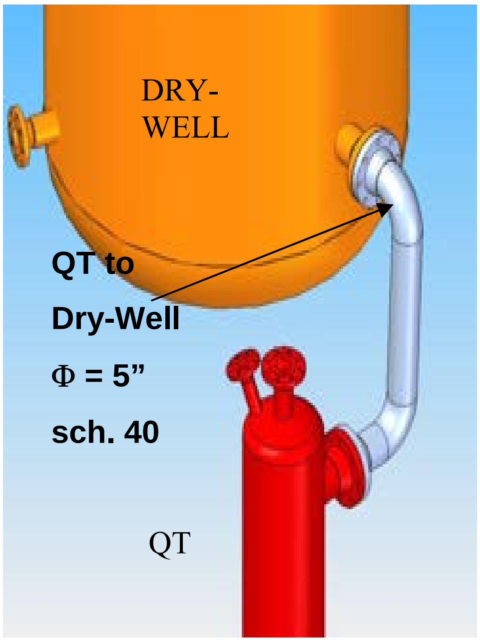

Fig. 7: Quench tank to dry-well connection

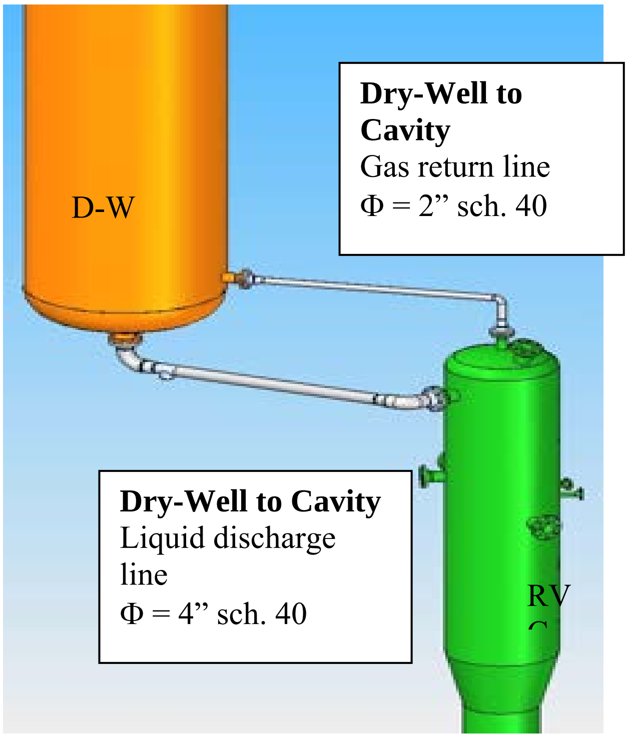

Fig. 8: Dry-Well (D-W)to Reactor Vessel Cavity (RVC)

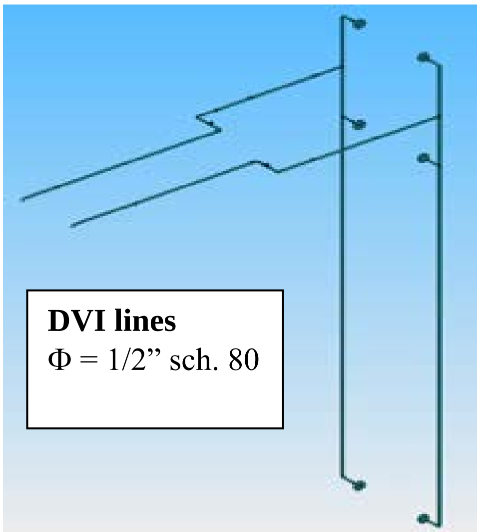

Fig. 9: DVI lines

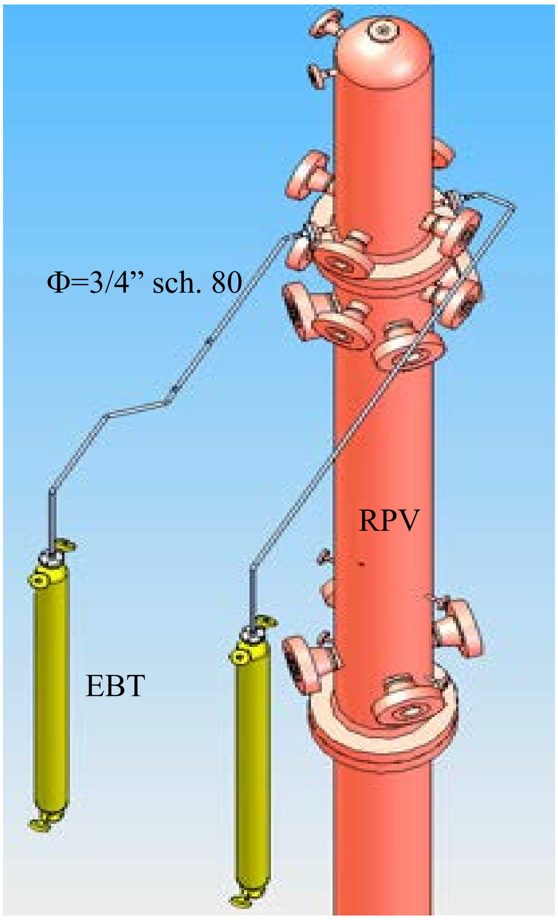

Fig. 10: EBT DVI upper connections

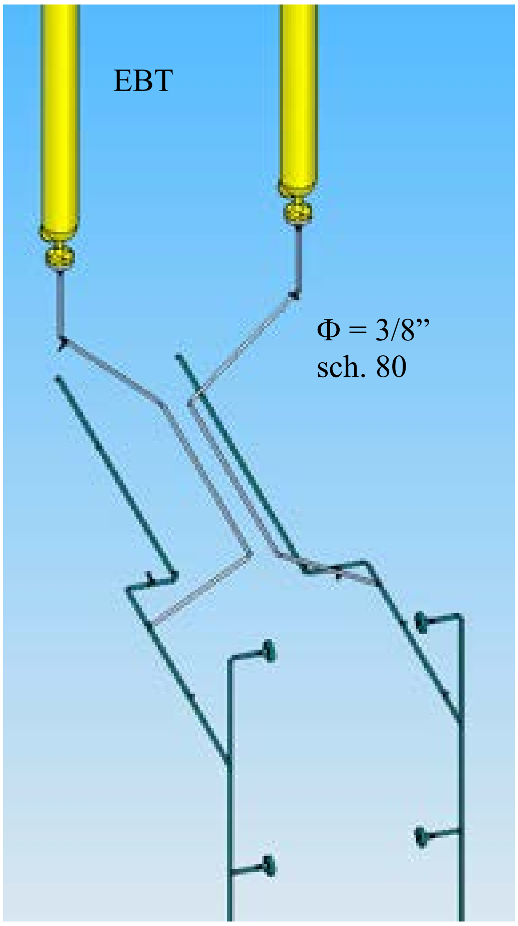

Fig. 11: EBTs bottom connection to DVI lines

Fig. 12: Dry well connection to pressure suppression system

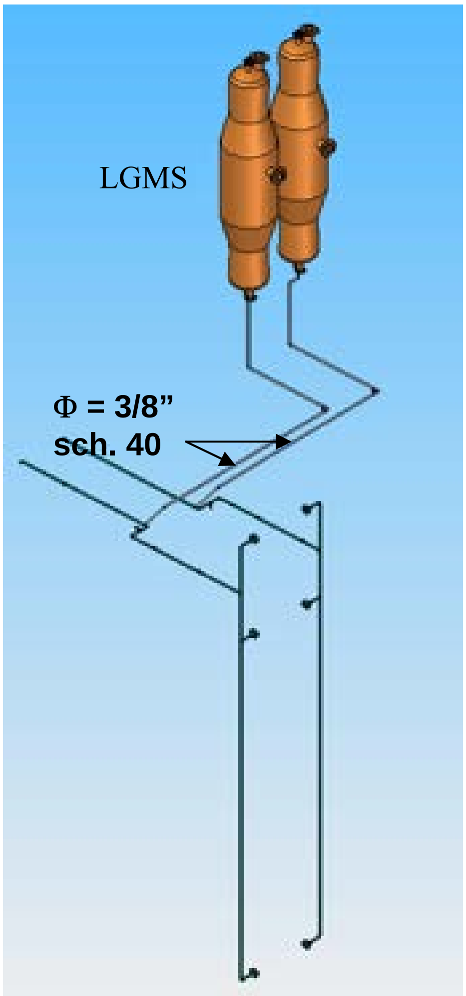

Fig. 13: LGMS to DVI connections

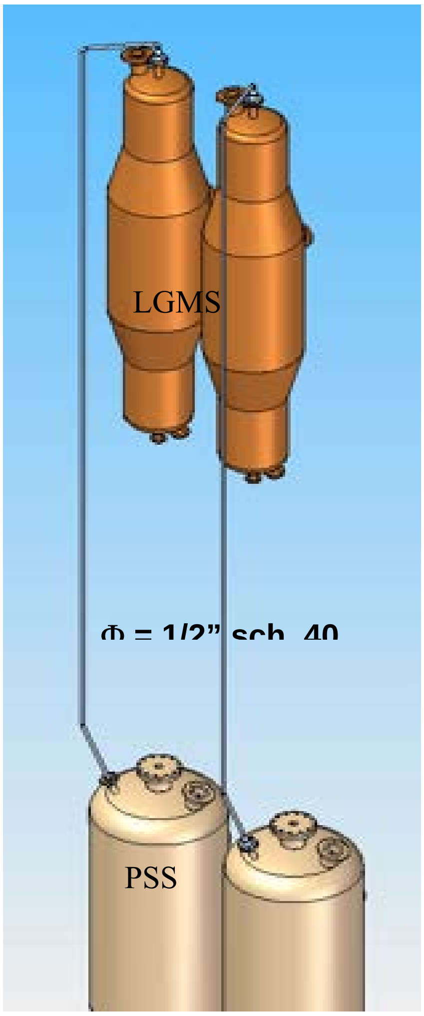

Fig. 14: LGMS to PSS connections

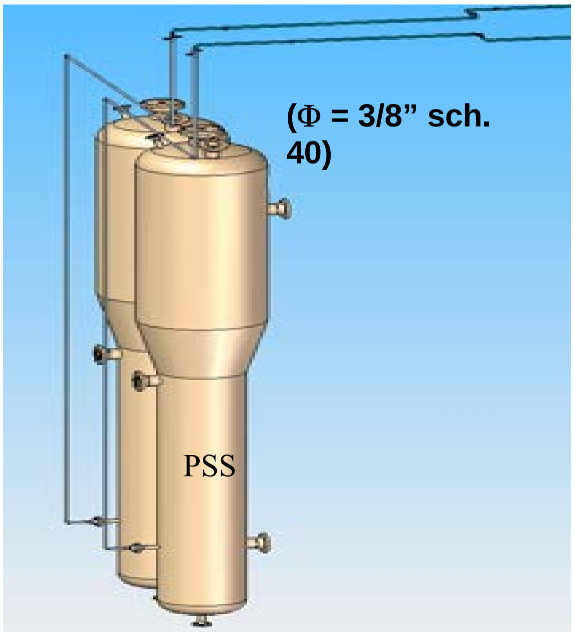

Fig. 15: Connections between PSS and DVI lines

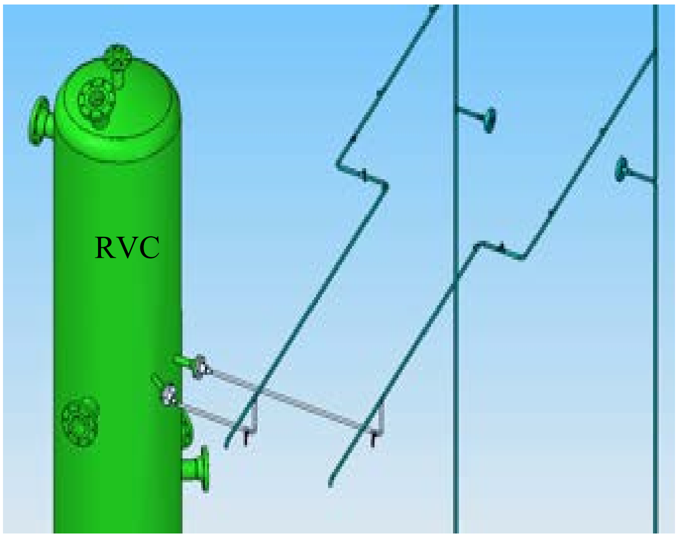

Fig. 16: Reactor vessel cavity RVC to DVI lines.

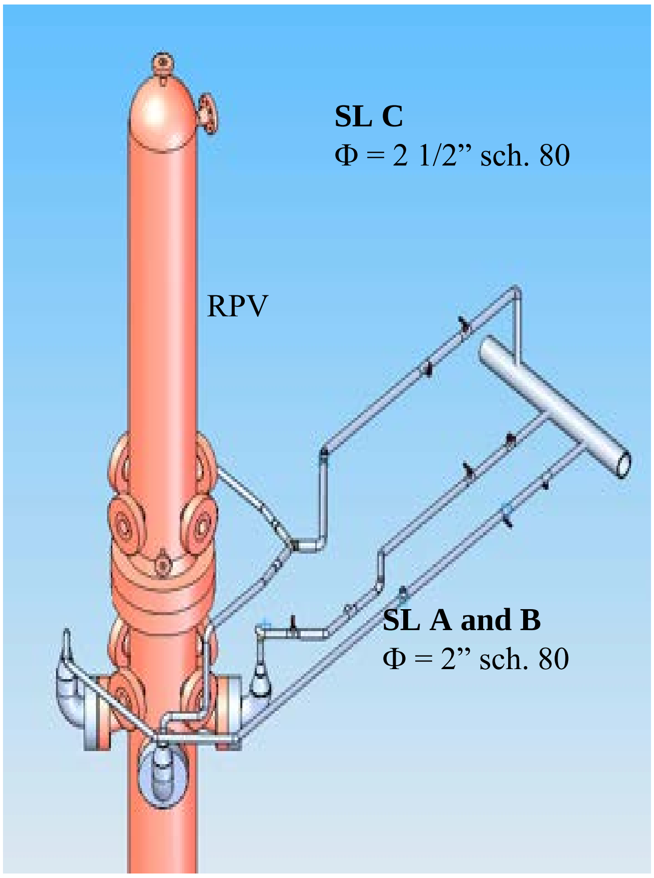

Fig. 17: Steam line connections

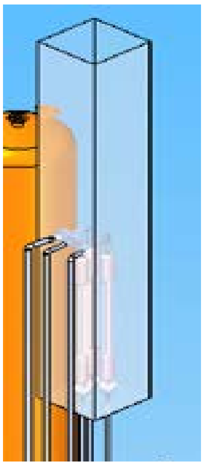

Fig. 18: RWST component (12 m^3 volume, 9 m height)

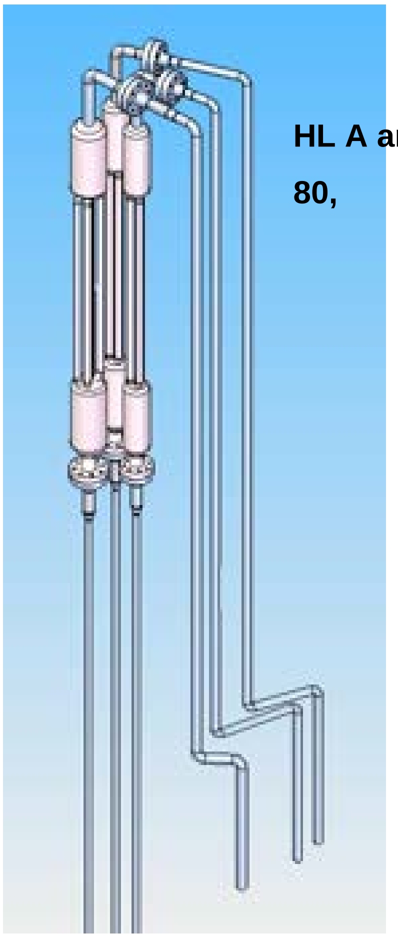

Fig. 19: EHRS top connections

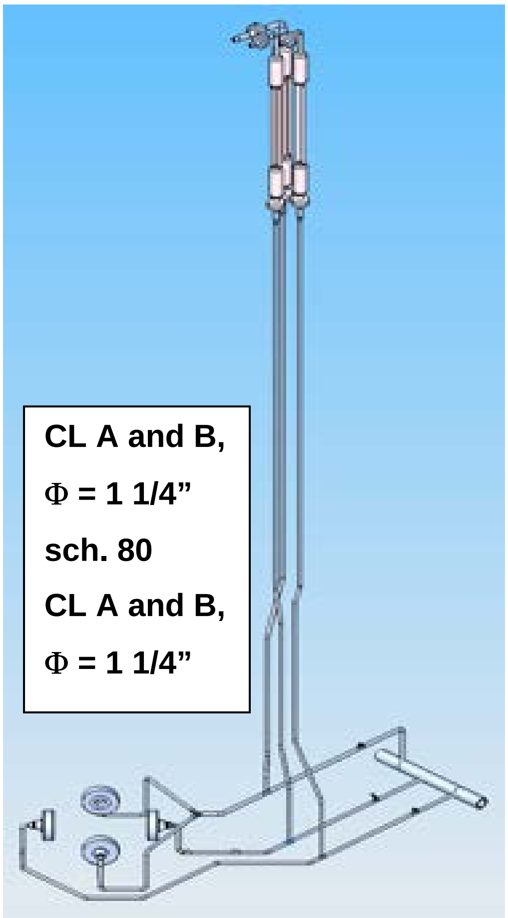

Fig. 20: EHRS bottom connections

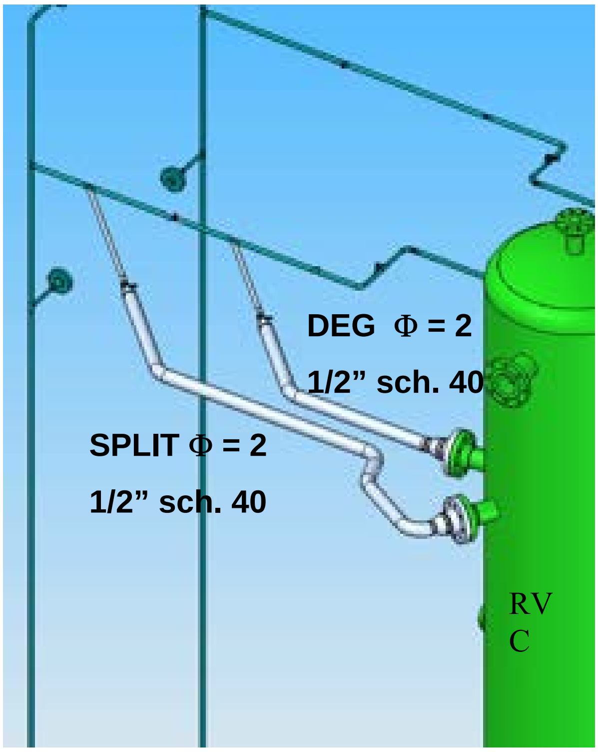

Fig. 21: DVI break to reactor vessel cavity (RVC)

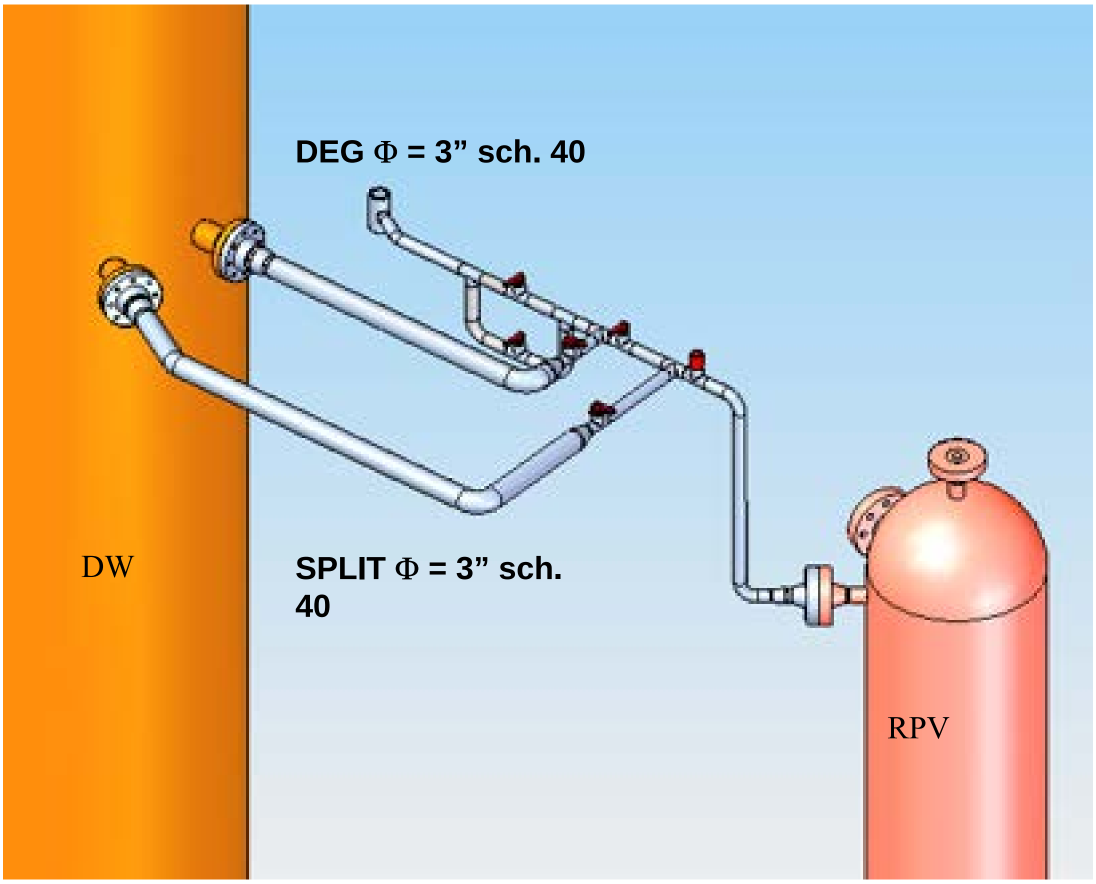

Fig. 22: ADS break lines

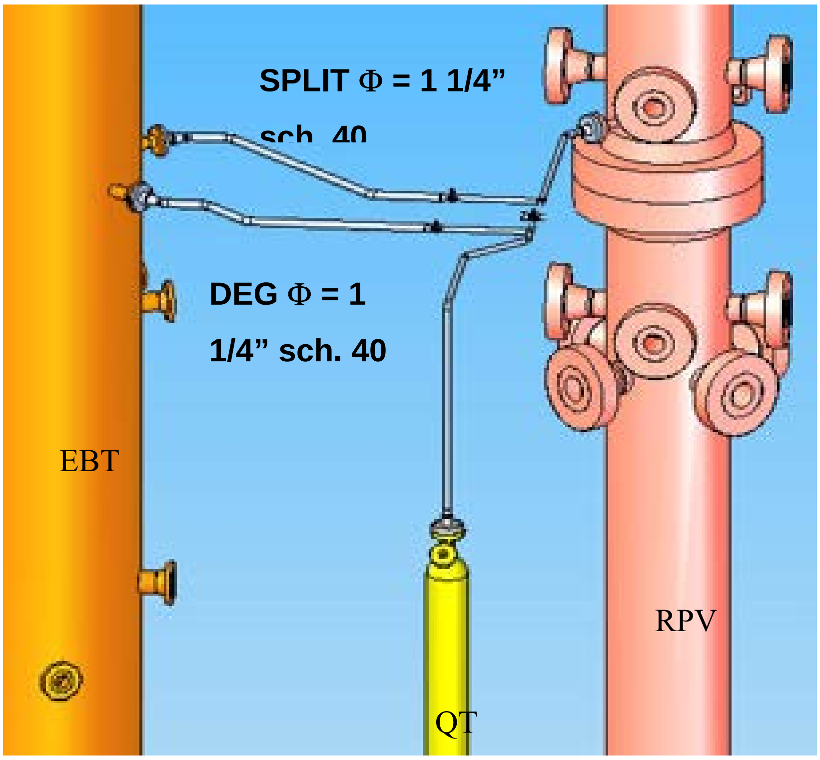

Fig. 23: EBT break to RPV

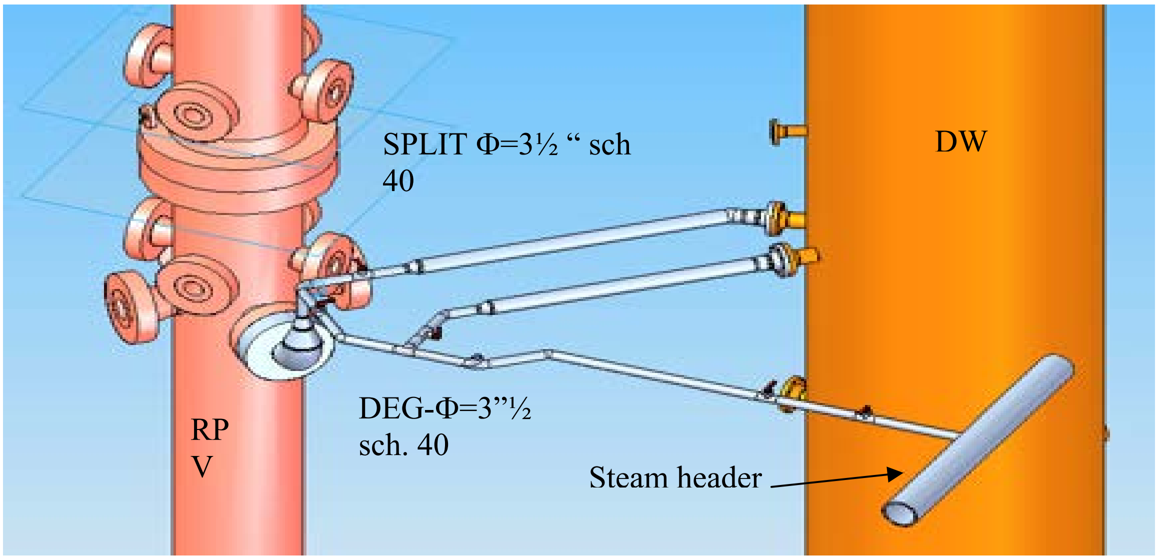

Fig. 24: Steam lines break to dry well

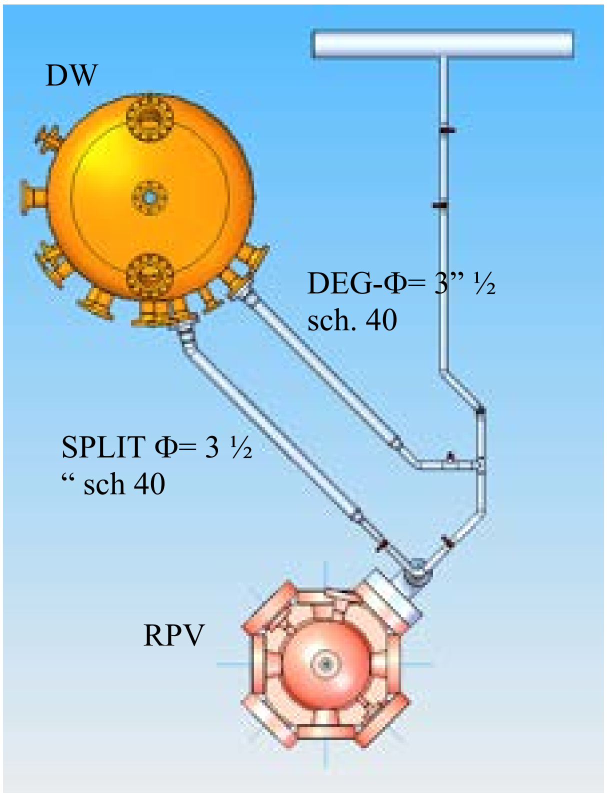

Fig. 25: Steam lines break to dry well (top view)

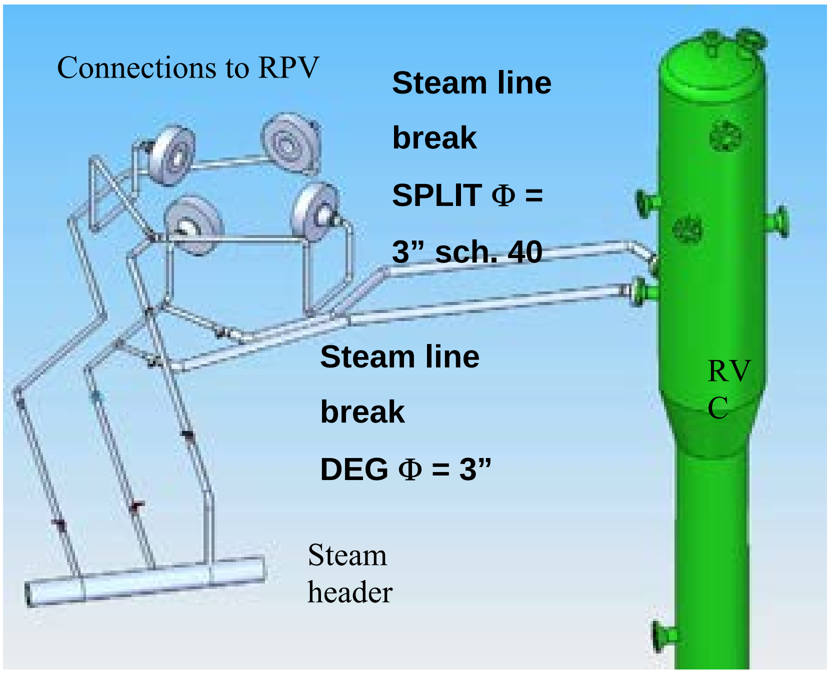

Fig. 26: Feed line break to reactor cavity

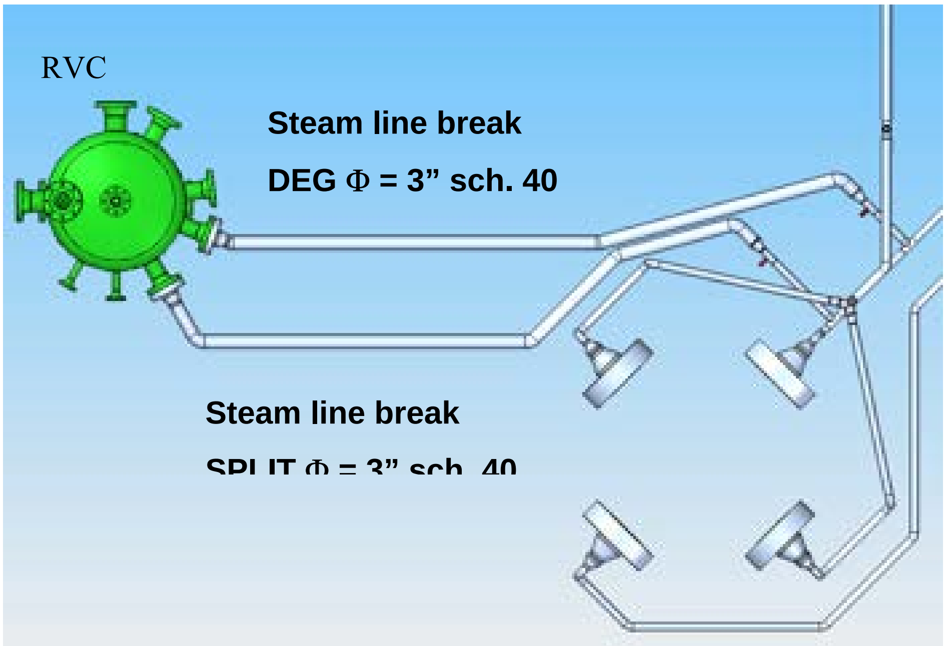

Fig. 27: Feed line break to reactor cavity (top view)

SIMBOL	INSTRUMENTS	CHARACTER
	Thermocouple	T
	Pressure transmitter	M
	Flow meter	F

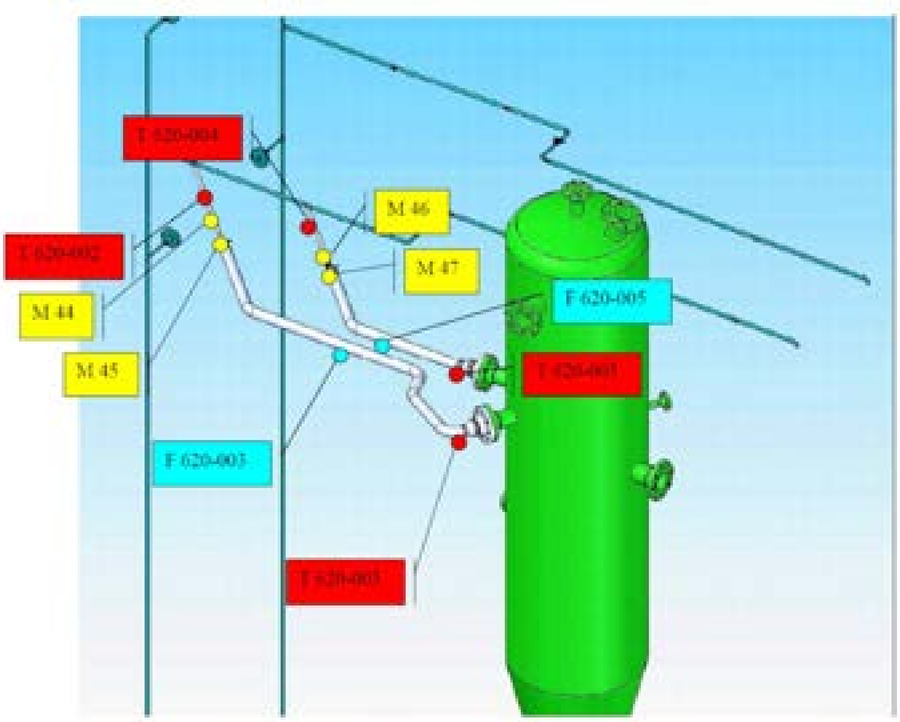

Fig. 28: Instrumentations in the DVI break line.

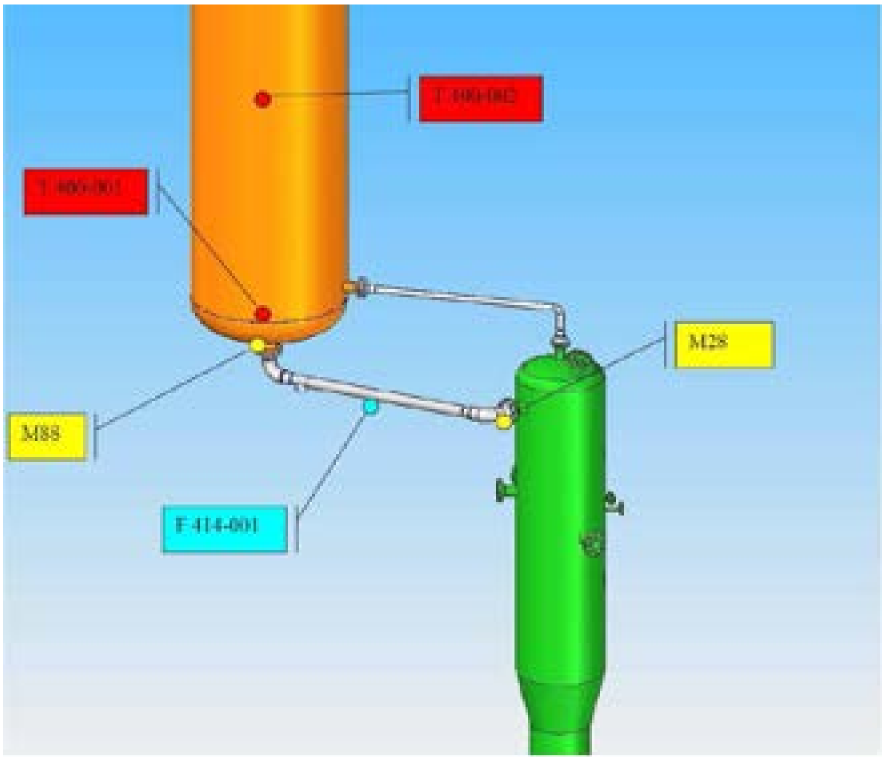

Fig. 29: Drywell to RC connections and instrumentation

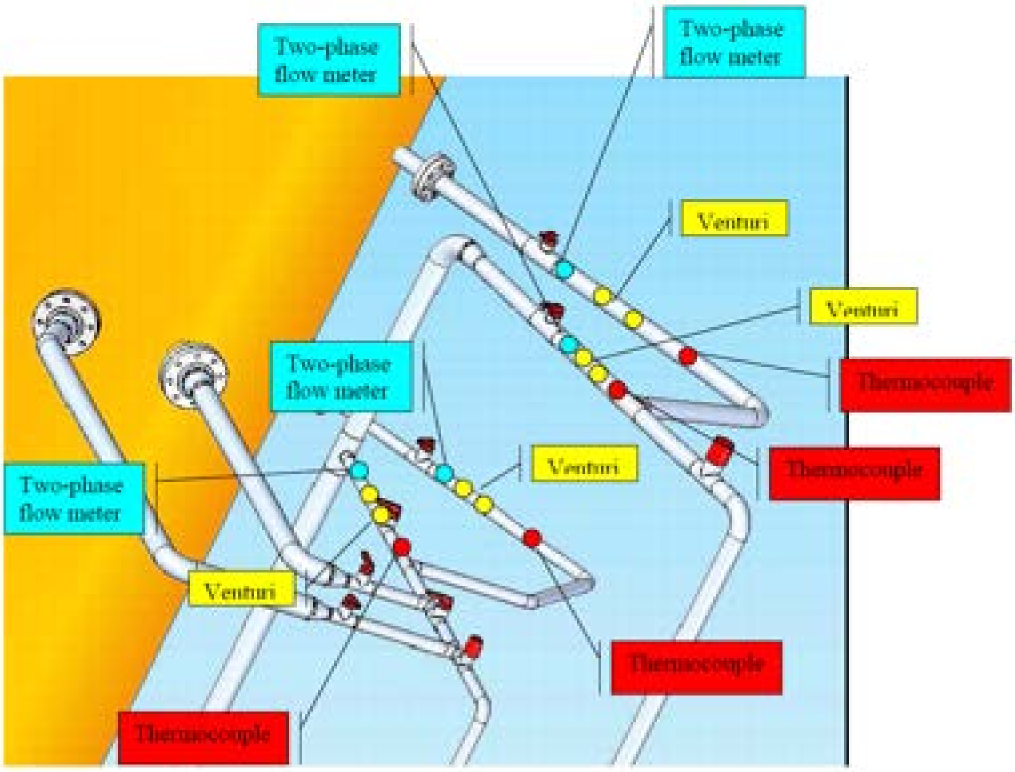

Fig. 30: ADS connection to Drywell.

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(1) WCAP-16082-NP, IRIS Preliminary Safety Assessment, -- Volume I -- July 15, 2003, Westinghouse Electric Company

(2) WCAP-16062-NP, IRIS Plant Description Document, March 21, 2003, Westinghouse Electric Company

(3) ENEA, Centro Ricerche Bologna, Status of SPES3-IRIS Facility design, FPN-P9LU-002;7/6/2007 Introduction

(4) R. Ferri, C. Congiu,SPES3-IRIS facility RELAP5 base Case transient analysis for design support, SIET 01 489 RT 09, Rev.

(5) Standard UNI EN ISO 5167-1,2,3,4: October 2004. Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full.

(6) Investigation of the two-phase flow instrumentation necessary for the SPES3 facility. Annamaria Mosetto. Politecnico di Torino. Dipartimento di Energetica. Relazione per CIRTEN Luglio 2010

(7) State of art and Selection of techniques in Multiphase Flow Measurement. Grazia Monni Politecnico di Torino. Dipartimento di Energetica. Luglio 2010

(8) Spool Piece per la misura della portata: messa a punto di una metodica di misura e risultati sperimentali ottenuti con miscele aria-acqua in deflussi anulari. Grazia Monni Politecnico di Torino. Dipartimento di Energetica. Maggio 2010

Appendix

DESCRIPTION OF THE THERMOHYDRAULICS OF SOME BASE CASES: UPSTREAM BREAK LINES

RELAP5/MOD3 is a "best estimate" system code suitable for the analysis of all transients and postulated accidents in Light Water Reactor (LWR) systems, including both large- and small-break loss-of-coolant accidents (LOCAs) as well as the full range of operational transients.
The RELAP code allows for the determination of the flow main characteristics in each volume that is included in the nodalisation.
For each location a monitoring volume has been defined for the extraction of the variables necessary to the setting of the instrumental range.
The monitoring volumes in the break lines are located UPSTREAM and DOWNSTREAM the orifice that simulates the break. Usually there is only one volume before the break, therefore there is no chance in defining the volume. With regard to the DOWNSTREAM situation, the monitoring volumes has been defined in order to minimize the possible pipe works influence on the flow profile.
The five base cases that will be analysed are summarized in Table 1.

For each case the upstream volume, the junction (motor valve), the downstream volume and the nozzle are indicated in a proper table. Here the volume with instrumentation is specified.
For each case just the DEG (Double Ended Guillotine) break is simulated. This event is the design-basis accident for conventional LWR plants, that is a circumferential break, representing a complete severance of the pipe.
In the SPES3 facility the break is reproduced involving two lines: the DEG break line and the SPLIT break line. The aim of the present work is to show the trend of different variables during the transients:
In order to provide the instrumentation, the main variables taken into consideration are:

- The void fraction and the quality
- The mass flow
- The gas and liquid velocity
- The pressure
- The gas and liquid temperature
-

These variables are presented in 5 graphs for each break line and a table summarizes the maximum and minimum values.
It's of paramount importance to evaluate the mass flow rate and the void fraction in the ADS ST and DT lines (stage I and II) upstream and downstream of the valve. Another table points out the minimum and maximum values for the previous four lines and a graph shows the void fraction only for the ADS ST line (stage I).
With regard to the ADS ST and DT lines usually there is only one volume downstream, therefore the variables are taken there, whereas upstream the monitoring volume has been defined in order to minimize the possible pipe works influence on the flow profile.
All the graphs inserted in this document have been presented with a logarithmic scale for the time axis.

Tabella 1: Base cases for the SPES3 break transients

RELAP base case number	Case name	Description
SPES 89	DVI break	Double Ended Guillotine break of the Direct Vessel Injection Line B
SPES 90	EBT break	Double Ended Guillotine break of the top connection between the Emergency Boration Tank and the Reactor Vessel B
SPES 91	ADS break	Double Ended Guillotine break of the Automatic Depressurization System B, on the Single Train Line
SPES 92	SL break	Double Ended Guillotine break of the Steam Line B
SPES 93	FL break	Double Ended Guillotine break of the Feed Line B

DVI BREAK LINE

SPES3 89, DVI DEG break

DVI DEG break line

Tabella 2: Description of the volumes for the DVI break

UPSTREAM	MOTOR VALVE	DOWNSTRAM	NOZZLE
675010000 (MIS)	676000000	677010000 677020000 677030000 677040000 677050000 677060000 677070000 (MIS) 677080000 677090000	678010000

UPSTREAM

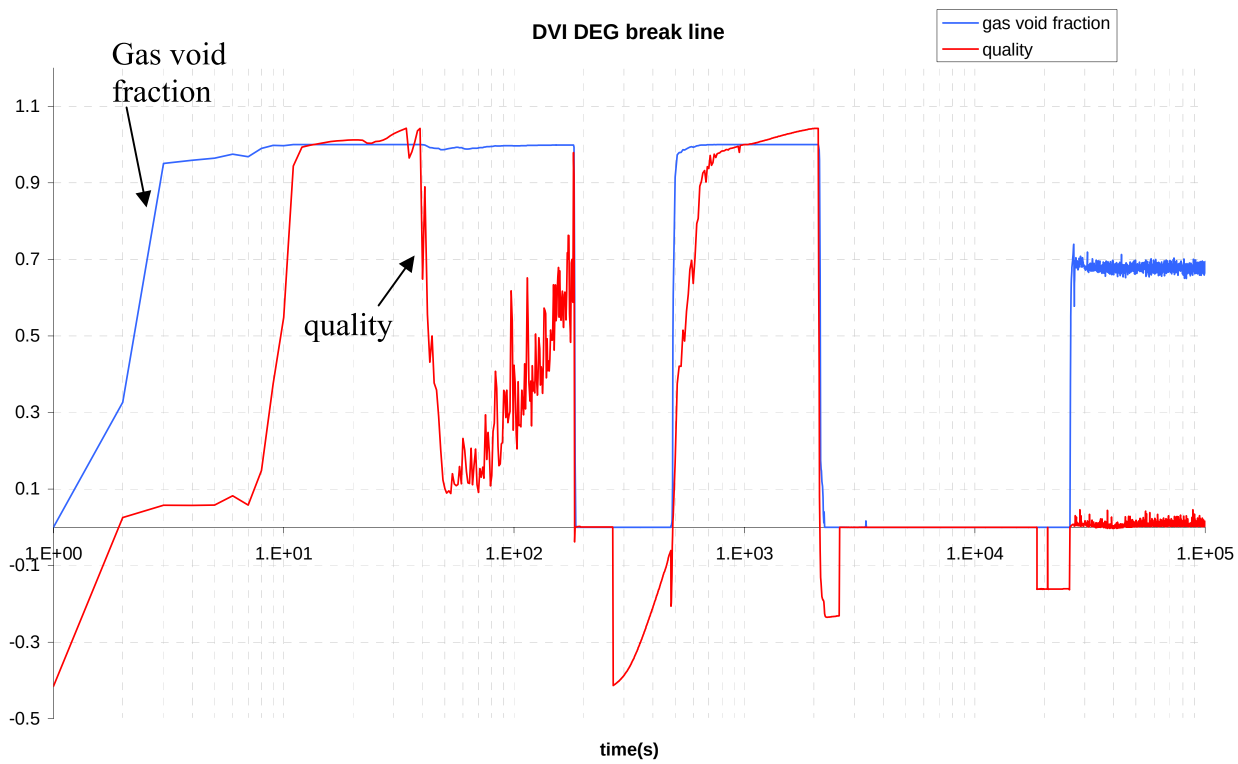

Fig. A 1.1 DVI DEG BREAK LINE: void fraction and mass flow quality

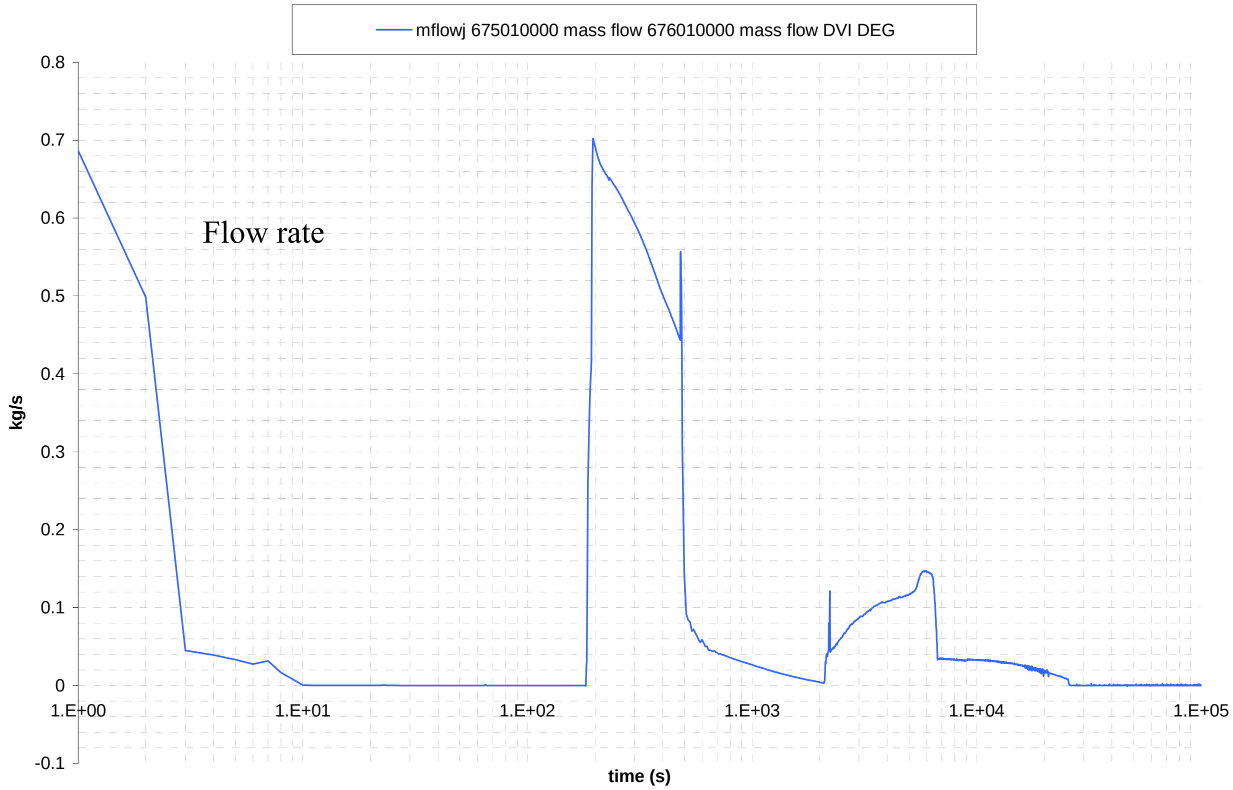

Fig. A 1.2 DVI DEG BREAK LINE: mass flow rate

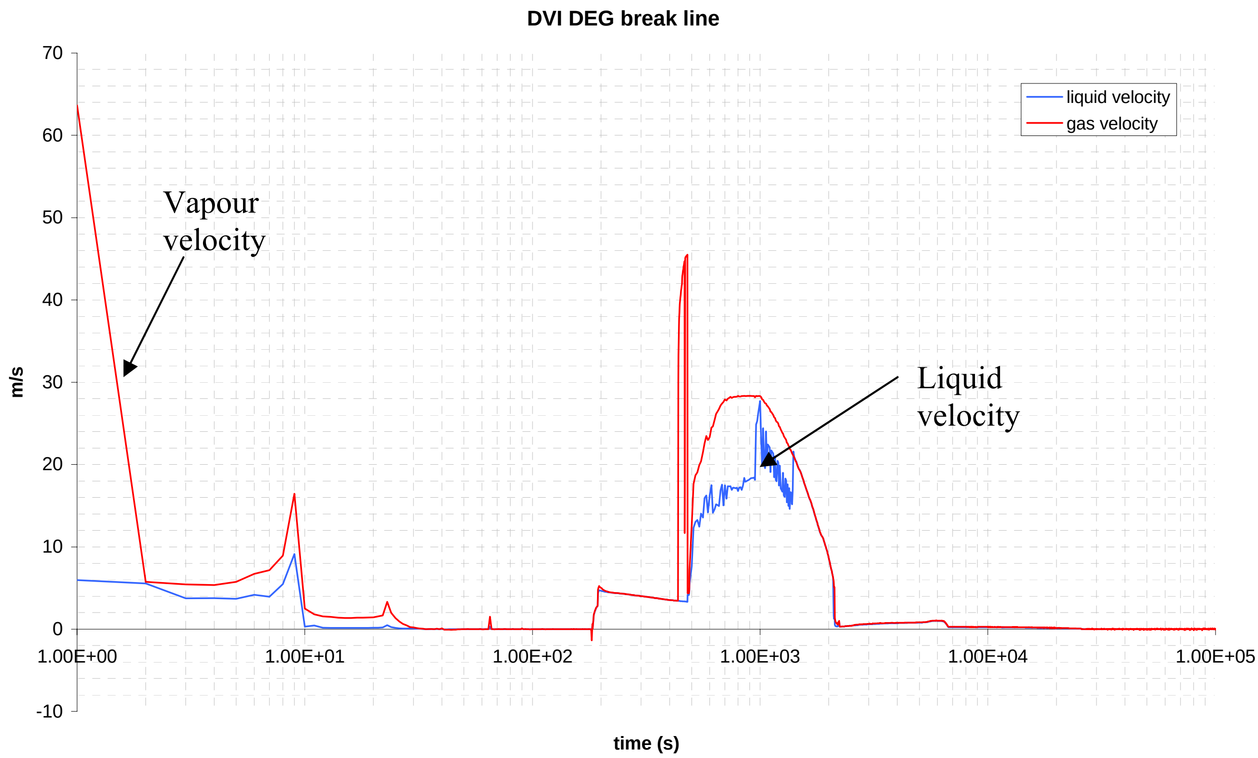

Fig. A 1.3 DVI DEG BREAK LINE: phase velocities

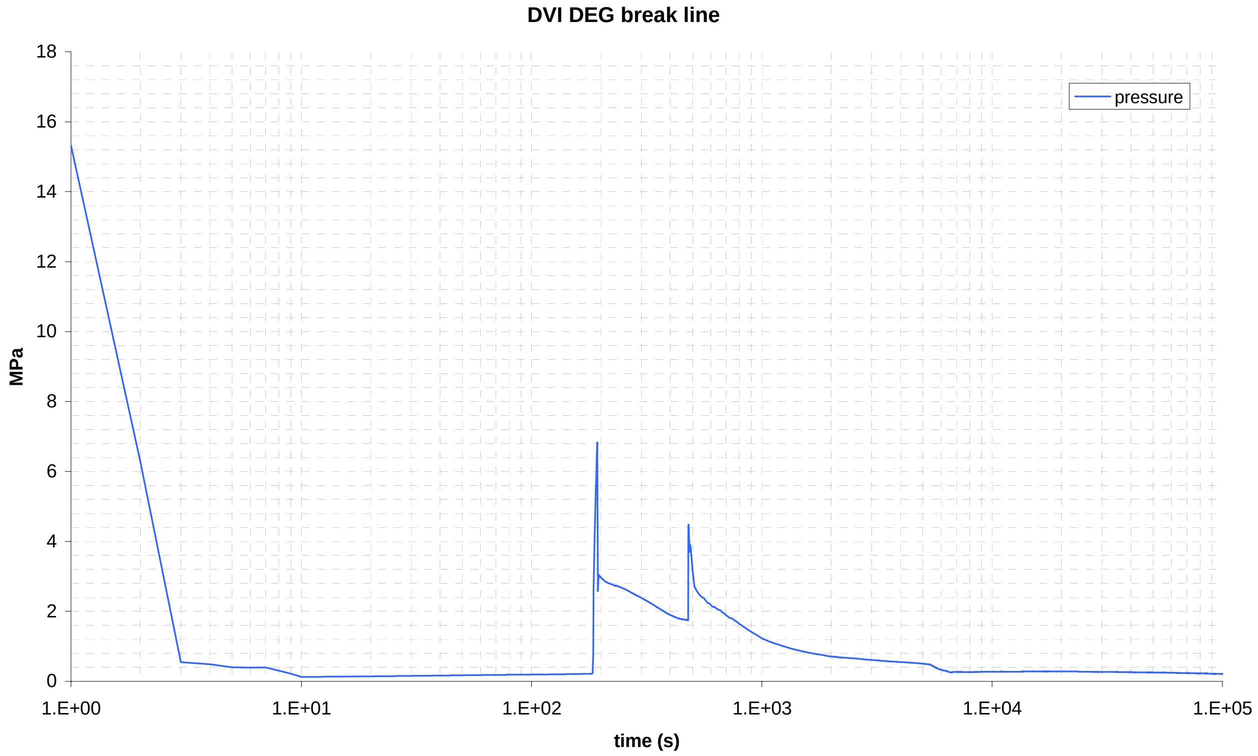

Fig. A 1.4 DVI DEG BREAK LINE: Pressure history

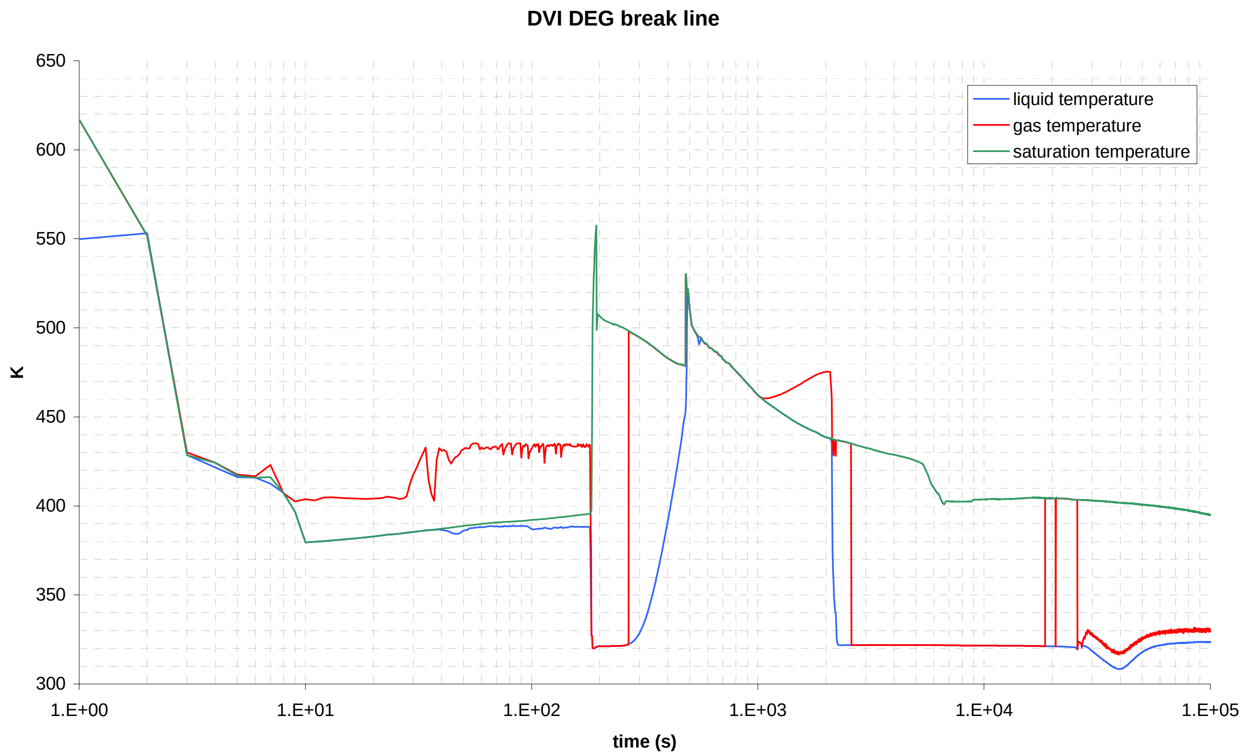

Fig. A 1.5 DVI DEG BREAK LINE: liquid, vapour and saturation Temperature history

DVI DEG break line		MIN	MAX
void fraction		0.0000	1.0000
volume equilibrium quality		-0.9076	1.0429
mass flow rate	kg/s	-0.0005	0.7023
liquid velocity	m/s	-0.2459	27.7336
gas velocity	m/s	-1.3802	63.6599
liquid temperature	K	308.4040	553.2080
gas temperature	K	316.4240	618.6600
pressure	MPa	0.1266	15.6391

Table A.1: Range of main two-phase flow variables

2. DVI SPLIT break line

UPSTREAM	MOTOR VALVE	DOWNSTRAM	NOZZLE
665010000 (MIS)	666000000	667010000 667020000 667030000 667040000 667050000 667060000 667070000 667080000 667090000 (MIS) 667100000 667110000 667120000 667130000 667140000	668010000

UPSTREAM

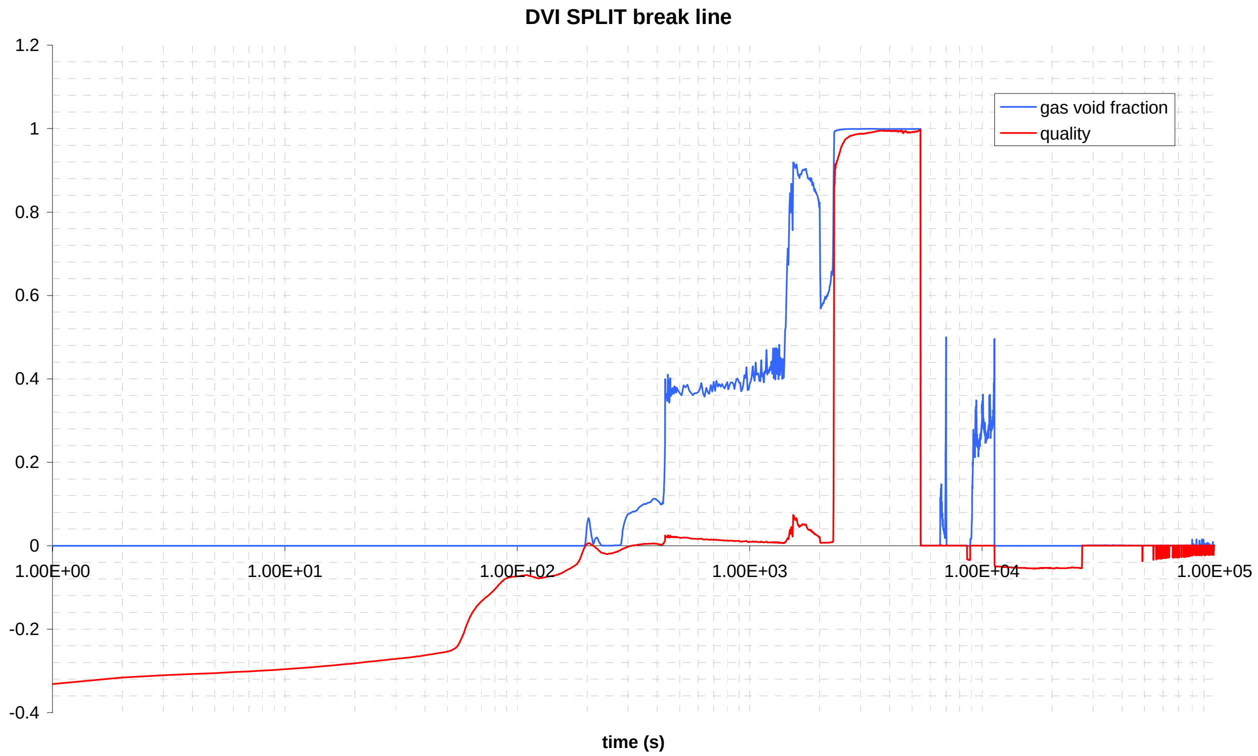

Fig. A-2.1 Void fraction and quality history (DVI SPLIT break line)

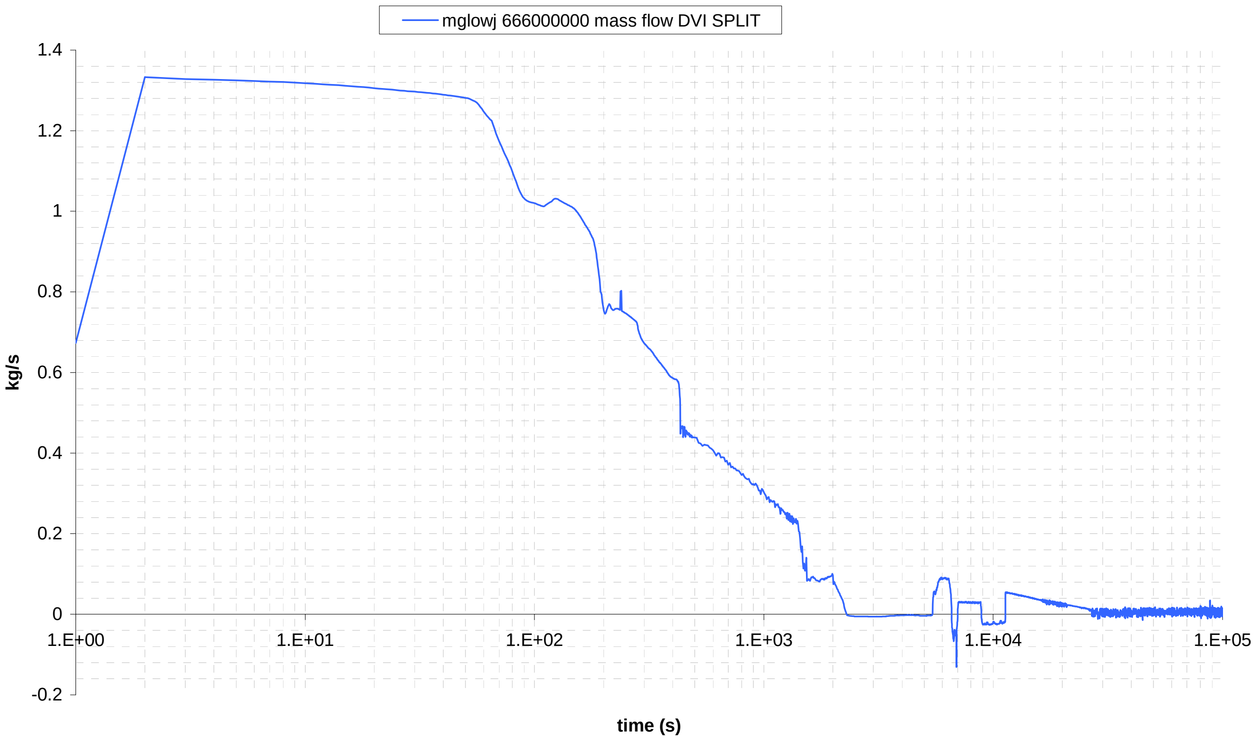

Fig. A2.2 Mass flow transient (DVI SPLIT break line)

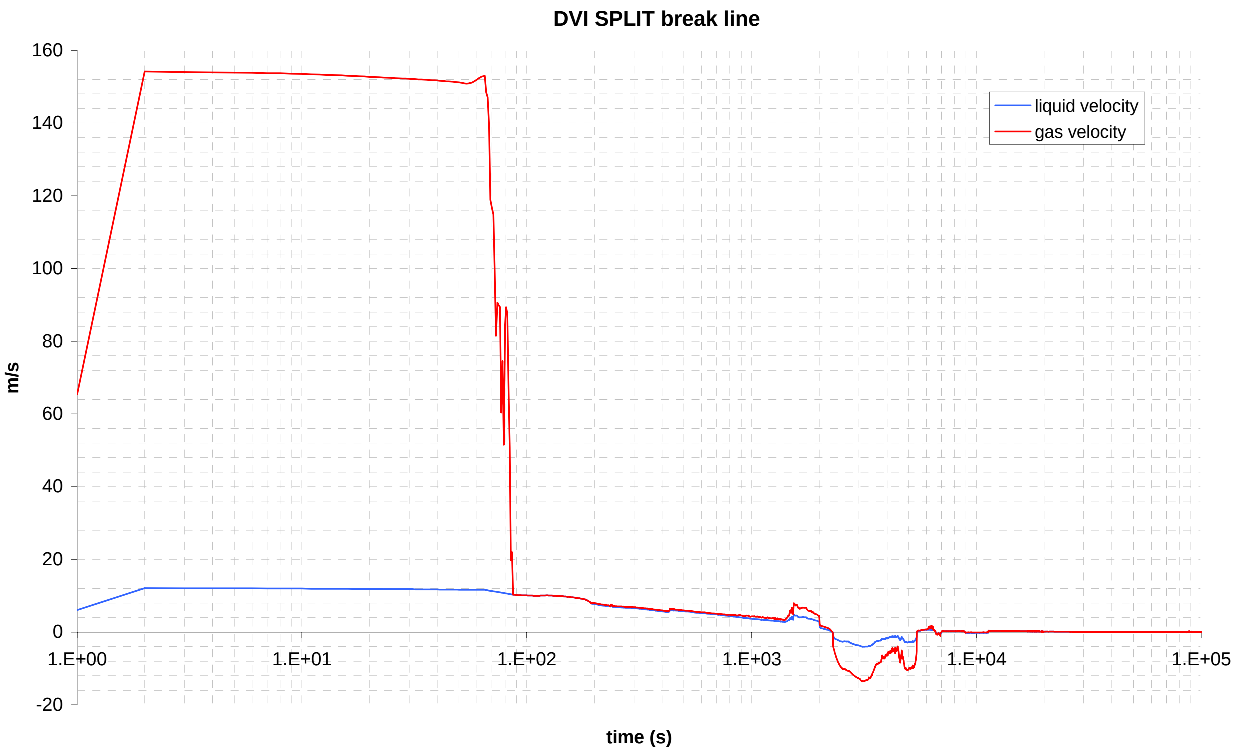

Fig. A2.3 Liquid and gas velocities history (DVI SPLIT break line)

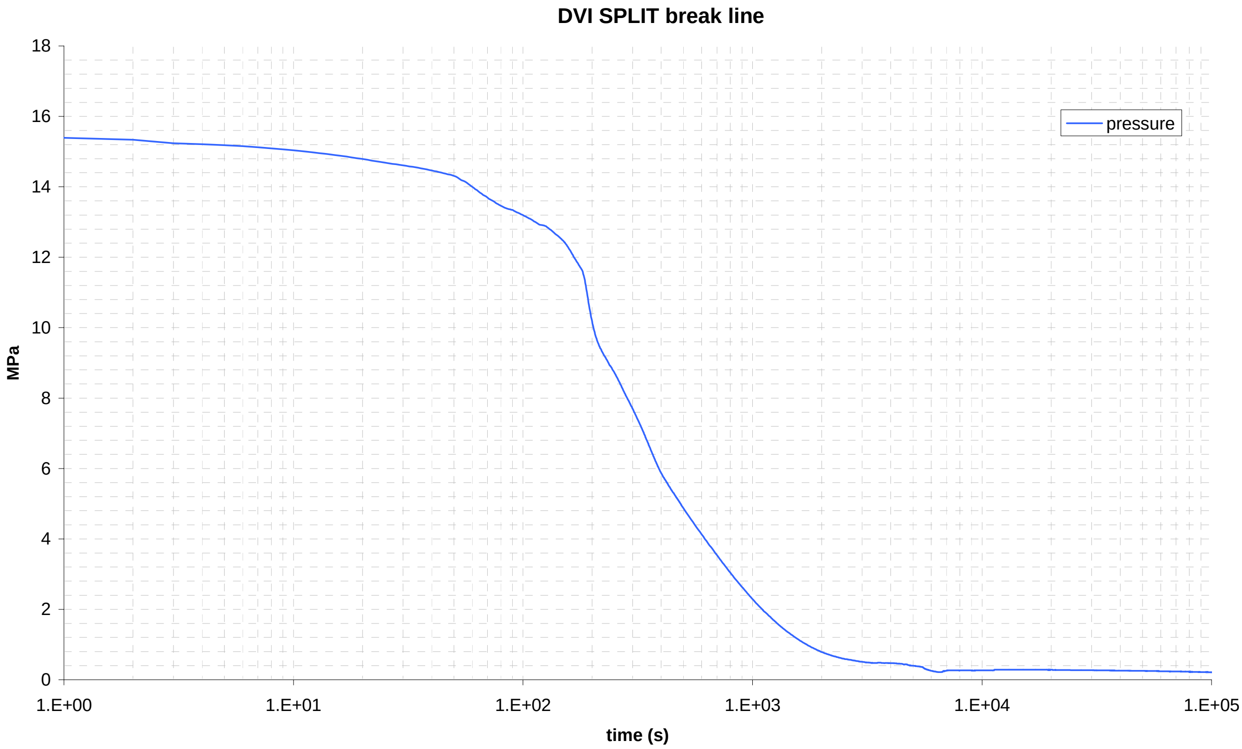

Fig. A2.4 Pressure transient (DVI SPLIT break line)

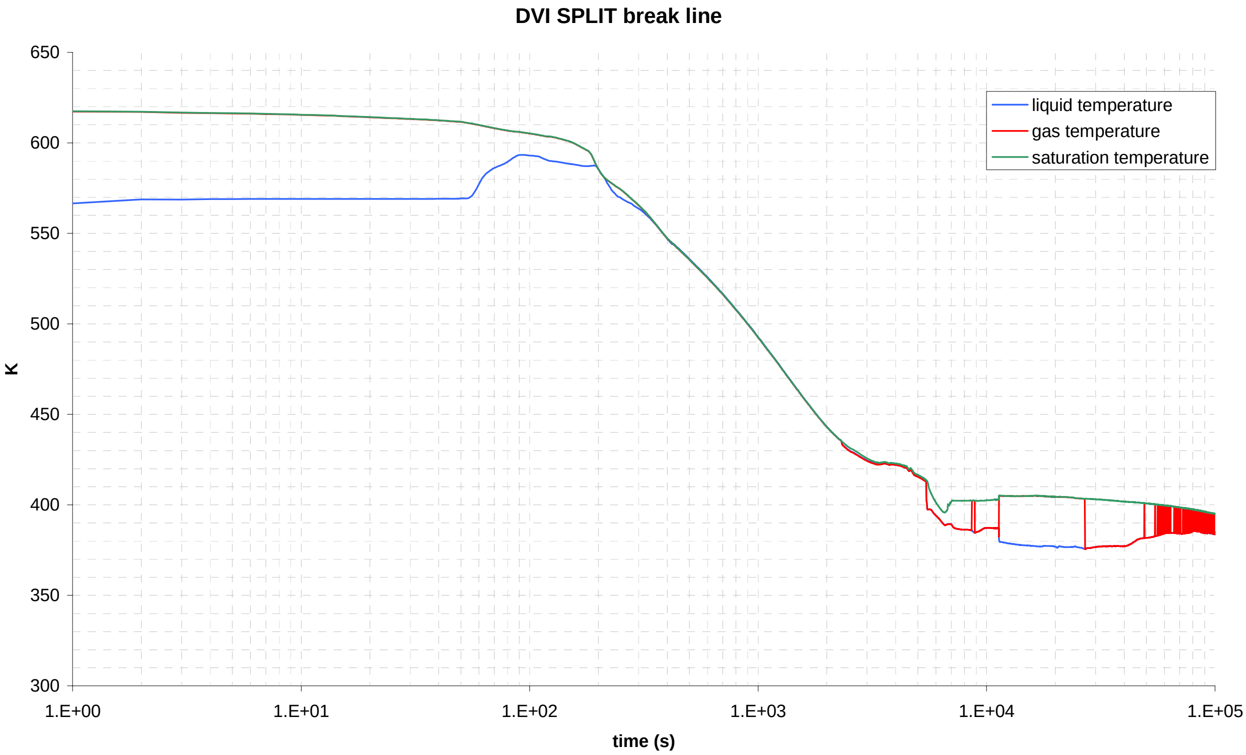

Fig. A2.5 Temperature history (DVI SPLIT break line)

DVI SPLIT break line		MIN	MAX
void fraction		0.0000	0.9994
volume equilibrium quality		-0.9012	0.9975
mass flow rate	kg/s	-0.1308	1.3328
liquid velocity	m/s	-4.0312	12.0997
gas velocity	m/s	-13.5510	154.1660
liquid temperature	K	375.5650	593.3750
gas temperature	K	375.5650	618.6600
pressure	Mpa	0.2102	15.6391

Table A.2 Range of main two-phase flow variables

3. ADS lines (DVI SPLIT Break line)

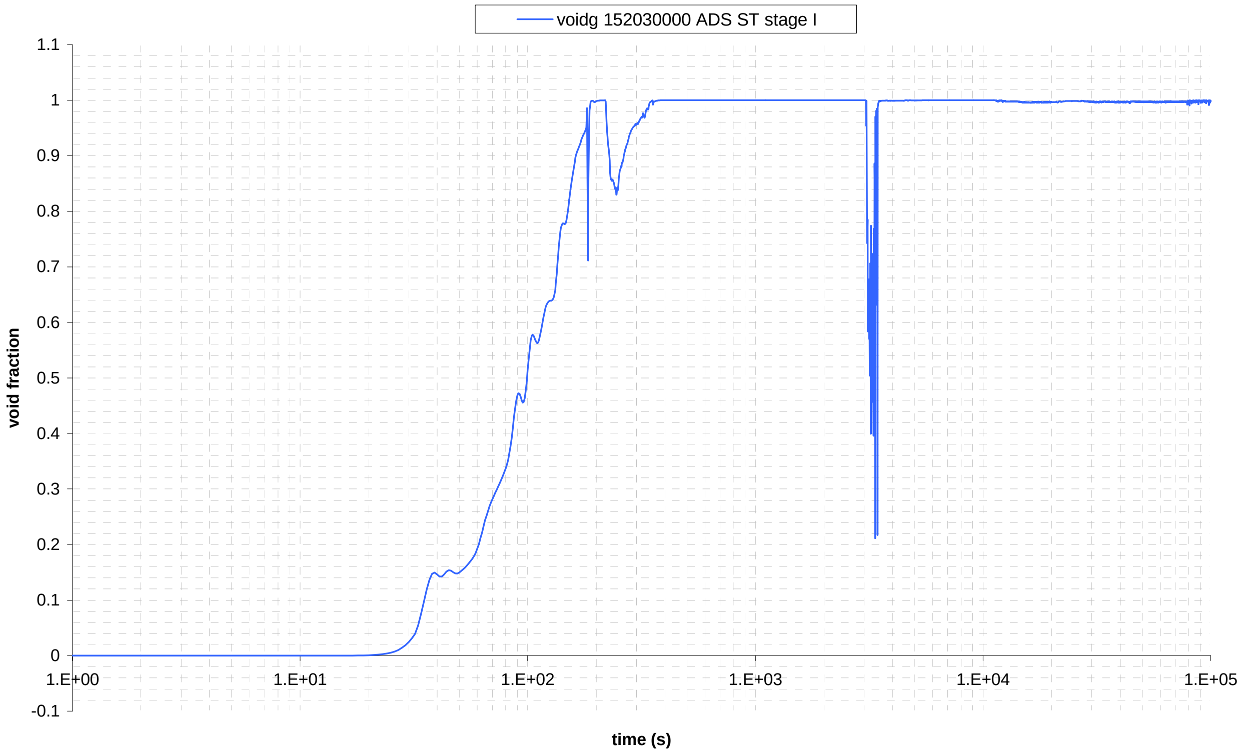

Fig. A3.1 Void fraction

DVI DEG break		Volume	MIN	MAX
ADS DT stage I	Void Fraction	142080000	0.8111	1.0000
ADS ST stage I	*Plot*			
ADS DT stage II	Void Fraction	132020000	0.0986	1.0000
ADS ST stage II	Void Fraction	135020000	0.0000	1.0000
ADS DT stage I	Mass Flow (kg/s)	143000000	-0.0160	1.8389
ADS DT stage II	Mass Flow (kg/s)	144000000	-0.0097	0.0153
ADS ST stage I	Mass Flow (kg/s)	153000000	-0.1311	0.9082
ADS ST stage II	Mass Flow (kg/s)	154000000	-0.0021	0.0079

Table A3 Void fraction and mass flow rate range

FLOW REGIMES: *DVI DEG line– Upstream – Downstream*

Time	675010	677010	677030	677050	677070	677090	678010
0	BBY	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR
1	BBY	ANM	ANM	ANM	ANM	ANM	ANM
2	HST	ANM	ANM	ANM	ANM	ANM	HST
7	HST	ANM	HST	HST	HST	HST	HST
54	HST	HST	HST	HST	HST	HST	HST
56	HST	HST	HST	HST	HST	HST	CHF MPR
184	HST	HST	HST	HST	HST	HST	HST
185	BBY	HST	HST	HST	HST	HST	HST
437	BBY	BBY	HST	HST	HST	HST	HST
454	BBY	SLG	HST	HST	HST	HST	HST
487	BBY	ANM	HST	HST	HST	HST	HST
488	HST	ANM	HST	HST	HST	HST	HST
490	SLG	ANM	HST	HST	HST	HST	HST
810	SLG	ANM	HST	HST	HST	HST	HST
1020	CHF MPR	ANM	HST	HST	HST	HST	HST
1390	HST	ANM	HST	HST	HST	HST	HST
1850	HST	HST	HST	HST	HST	HST	HST
1860	HST	CHF MPR	CHF MPR	CHF MPR	HST	HST	HST
1910	HST	CHF MPR	CHF MPR	CHF MPR	CHF MPR	HST	HST
1920	HST	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR	HST
1940	HST	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR
2090	HST	CHF MPR	CHF MPR	CHF MPR	CHF MPR	HST	HST
2180	HST	HST	HST	HST	HST	HST	HST
2190	BBY	HST	HST	HST	HST	HST	HST
2200	BBY	BBY	HST	HST	HST	HST	HST
2210	BBY	HST	HST	HST	HST	HST	HST
2220	BBY	BBY	HST	HST	HST	HST	HST
2230	BBY	HST	HST	HST	HST	HST	HST
6690	BBY	BBY	HST	HST	HST	HST	HST
25790	BBY	HST	HST	HST	HST	HST	HST
99990	HST	HST	HST	HST	HST	HST	HST

DVI SPLIT line – Usptream - Downstream

Time	665010	667010	667050	667090	667140	668010
0	BBY	HST	HST	HST	HST	HST
192	BBY	ANM	ANM	ANM	ANM	ANM
334	BBY	ANM	ANM	ANM	ANM	HST
337	BBY	ANM	HST	HST	ANM	HST
432	BBY	ANM	HST	HST	HST	HST
452	HST/BBY	ANM	HST	HST	HST	HST
1740	HST	ANM	HST	HST	HST	HST
1750	HST	HST	HST	HST	HST	HST
1760	HST	ANM	HST	HST	HST	HST
2460	HST	HST	HST	HST	HST	HST
2750	HST	HST	HST	HST	HST	CHF MPR
2810	HST	HST	HST	HST	HST	HST
2990	HST	HST	HST	HST		CHF MPR
3070	HST	HST	HST	HST	CHF MPR/HST	HST
4600	HST	HST	HST	HST	HST	HST
4780	HST	HST	HST	HST	HST	CHF MPR/HST
5410	HST	HST	HST	HST	CHF MPR/HST	CHF MPR/HST
5450	HST	HST	HST	HST	HST	HST
5480	BBY	HST	HST	HST	HST	HST
6200	BBY	BBY	HST	HST	HST	HST
6440	BBY	HST/BBY	HST	HST	HST	HST
6550	BBY	HST/BBY	HST	HST	BBY	HST
6580	BBY	HST/BBY	HST	HST	HST	HST
6910	HST	HST/BBY	HST	HST	HST	HST
6920	BBY	HST/BBY	HST	HST	HST	HST
7020	HST	HST/BBY	HST	HST	HST	HST
8890	BBY	BBY	HST	HST	HST	HST
9810	HST	HST	HST	HST	HST	HST
9820	HST	HST	HST	HST	BBY	HST
9850	HST	BBY	HST	HST	BBY	HST
9880	HST	BBY	HST	HST	HST/BBY	HST
10700	HST	BBY	HST	HST	BBY	HST
10710	HST	BBY	HST	BBY	BBY	HST
10740	HST	BBY	HST	HST	BBY	HST
10900	HST	BBY	HST	BBY	BBY	HST
10940	HST	BBY	BBY/HST	BBY	BBY	HST
10980	HST	BBY	BBY/HST	BBY	HST	HST
11010	HST	BBY	BBY/HST	HST	HST	HST
11160	HST	BBY	HST	HST	HST	HST
11300	HST	HST	HST	HST	HST	HST
26890	BBY	BBY	HST	HST	HST	HST
99990	HST/HST	HST/HST	HST	HST	HST	HST

4 SPES3, 90, EBT break

EBT DEG break line

UPSTREAM	MOTOR VALVE	DOWNSTRAM	NOZZLE
652010000 (MIS)	653000000	654010000 654020000 654030000 (MIS) 654040000 654050000 654060000 654070000	655010000

UPSTREAM

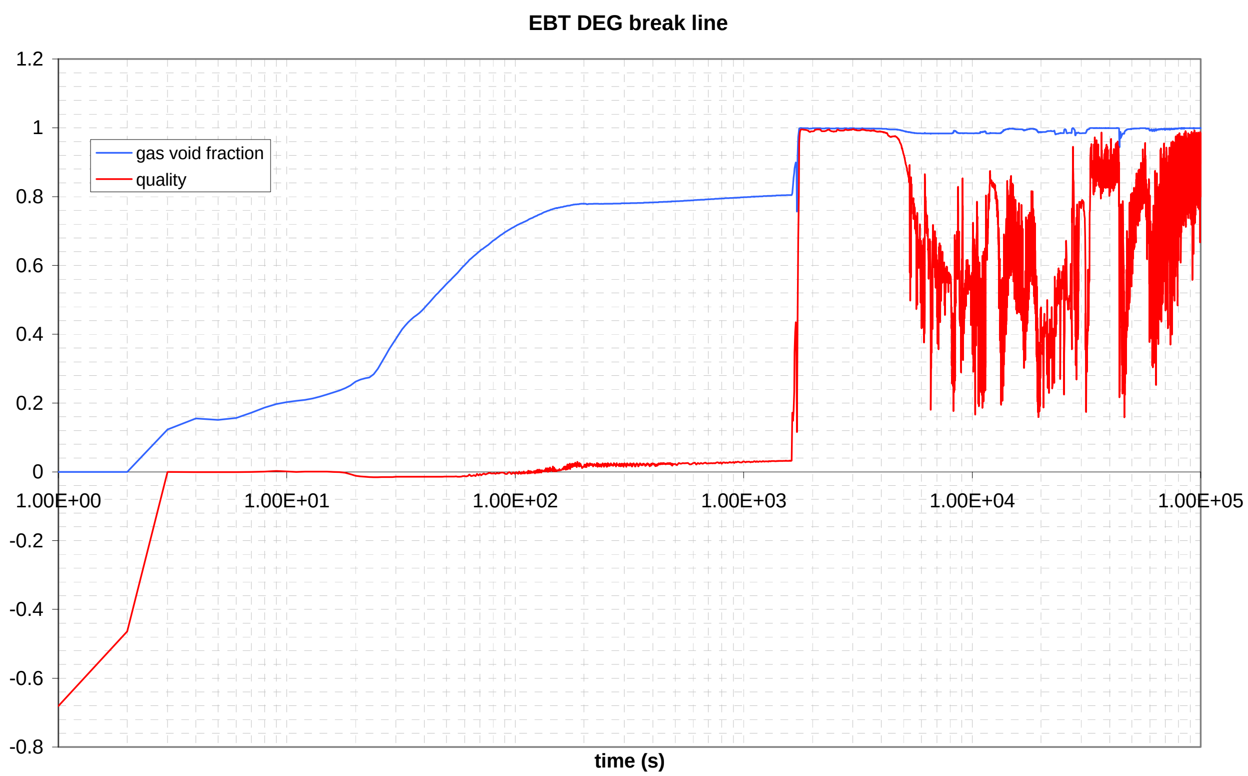

Fig. A4.1 Gas void fraction and quality history (EBT DEG break line)

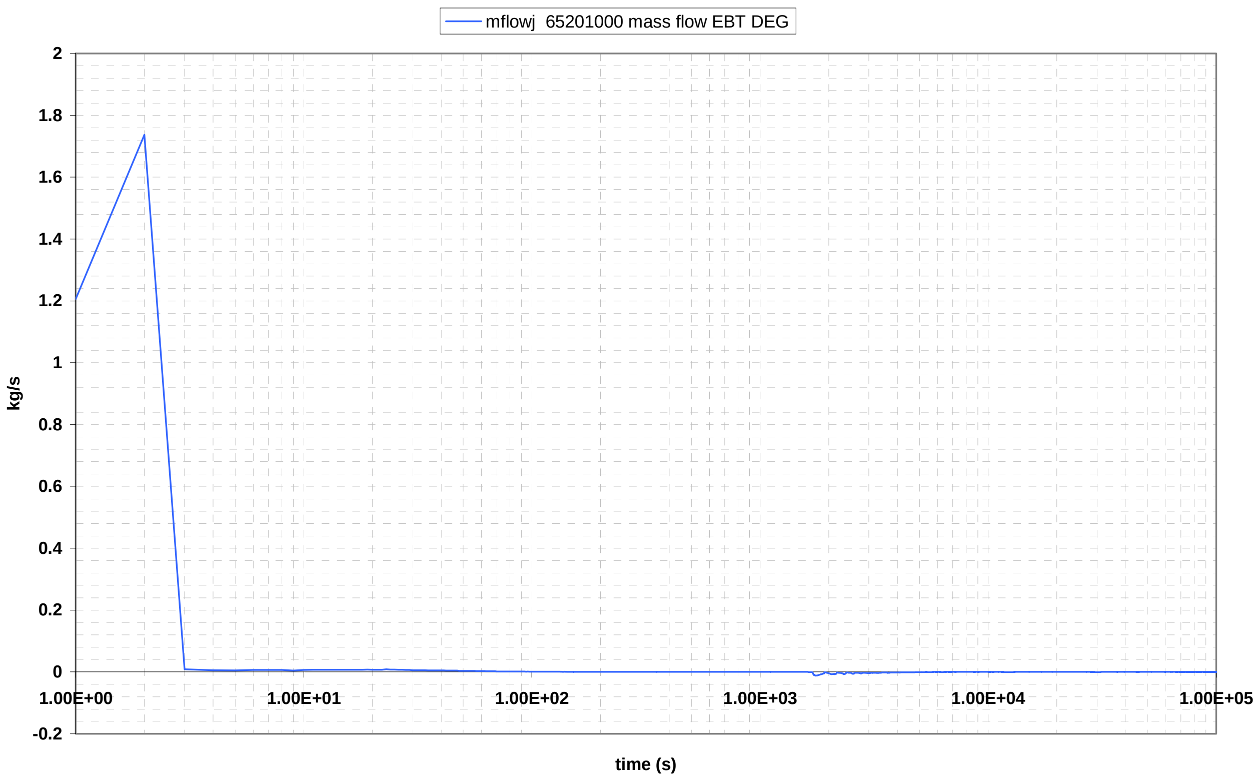

Fig. A4. 2 Mass flow Transient (EBT DEG break Line)

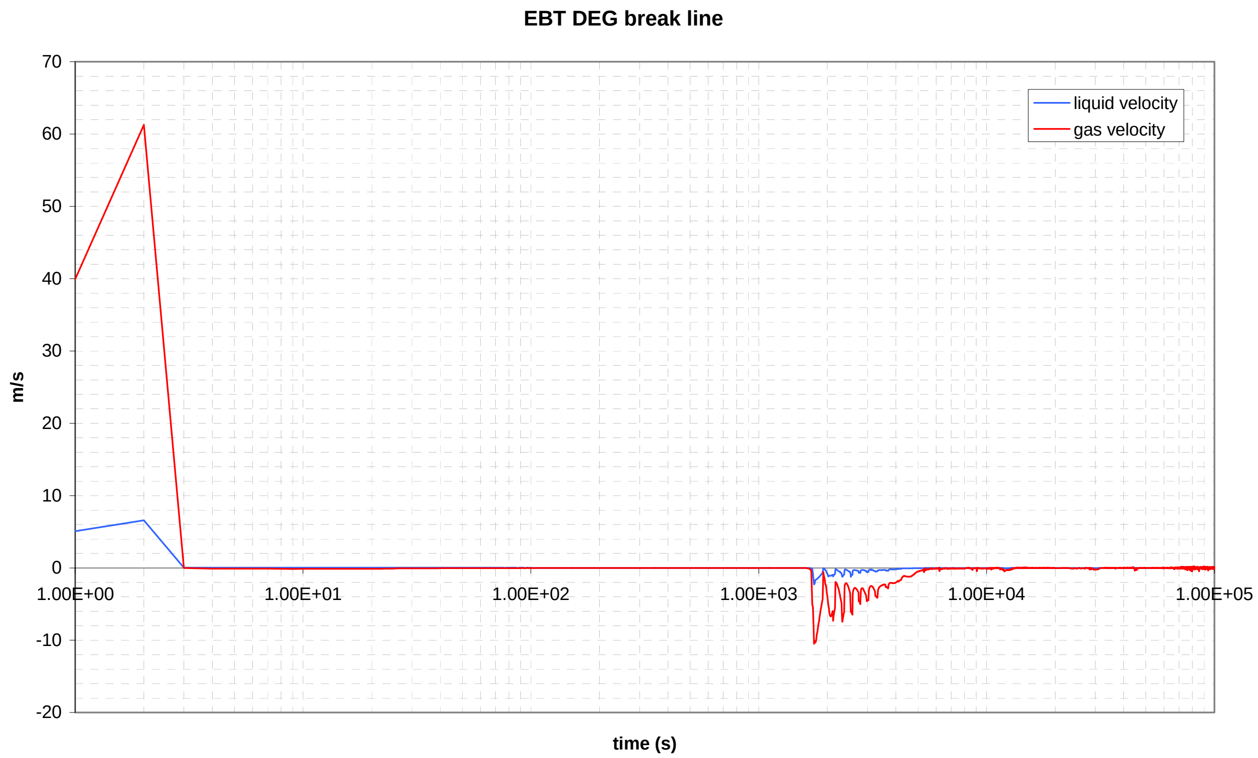

Fig. A4. 3 Liquid and gas velocities (EBT DEG break Line)

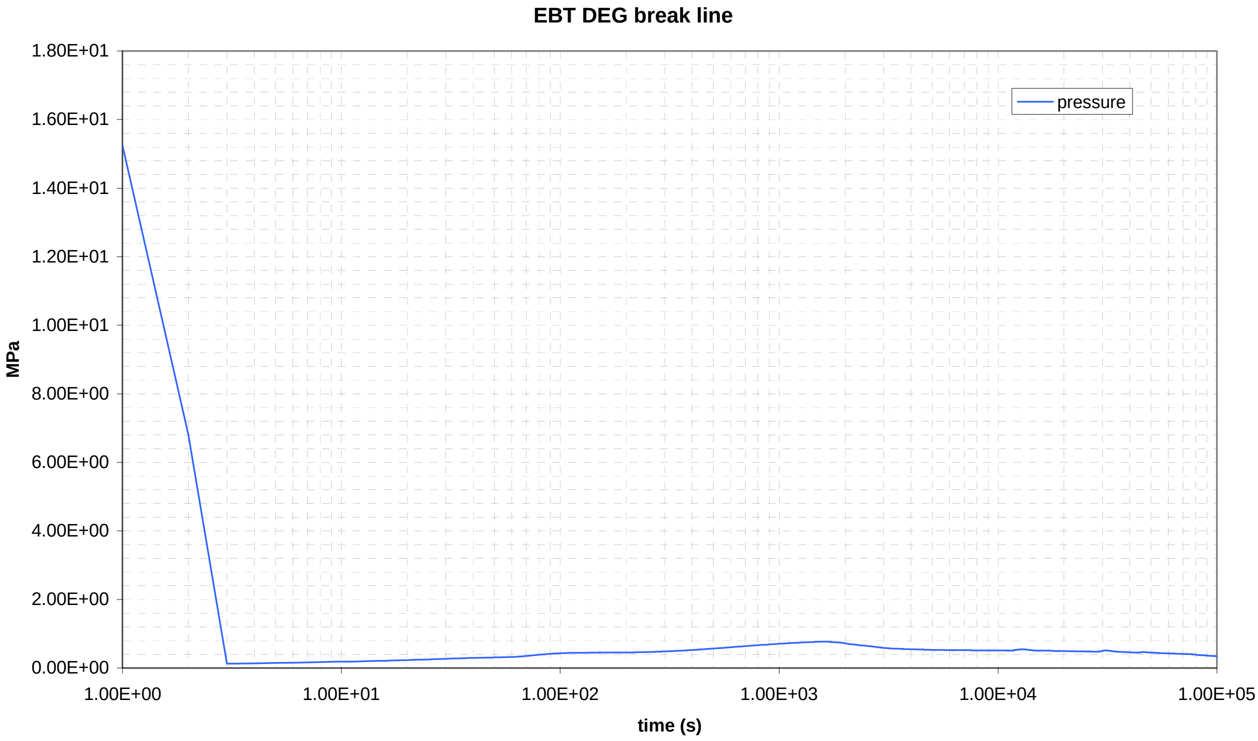

Fig. A4. 4 Pressure transien (EBT DEG break Line)

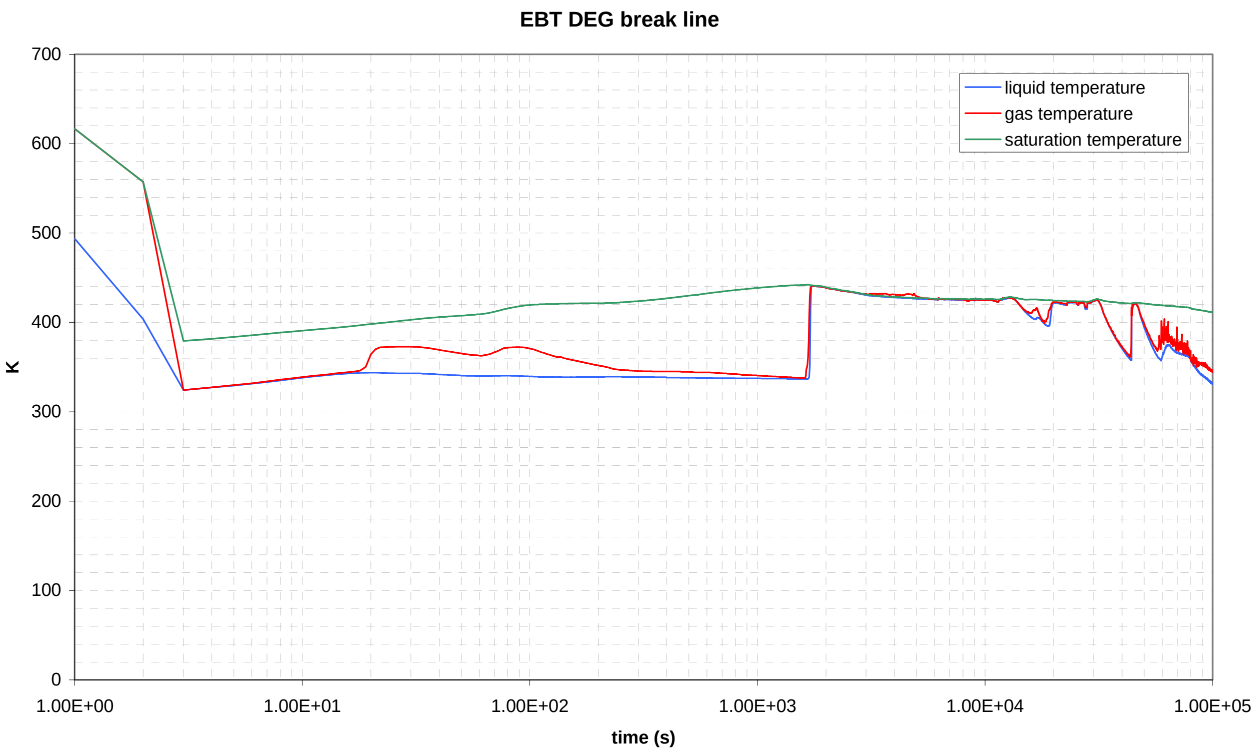

Fig. A4. 5 Temperature history (EBT DEG break Line)

DVI DEG break line		**MIN**	**MAX**
void fraction		0.0000	0.9997
volume equilibrium quality		-1.4991	0.9964
Mass flow rate	kg/s	-0.0122	1.7372
Liquid velocity	m/s	-2.2831	6.5990
gas velocity	m/s	-10.4934	61.2530
Liquid temperature	K	314.0290	493.8590
gas temperature	K	324.3550	618.0670
pressure	Mpa	0.1257	15.5245

Table A4: Range of main two-phase flow variables

5. EBT SPLIT break line

UPSTREAM	MOTOR VALVE	DOWNSTREAM	NOZZLE
622010000 (MIS)	643000000	644010000 644020000 644030000 (MIS) 644040000 644050000 644060000 644070000	645010000

UPSTREAM

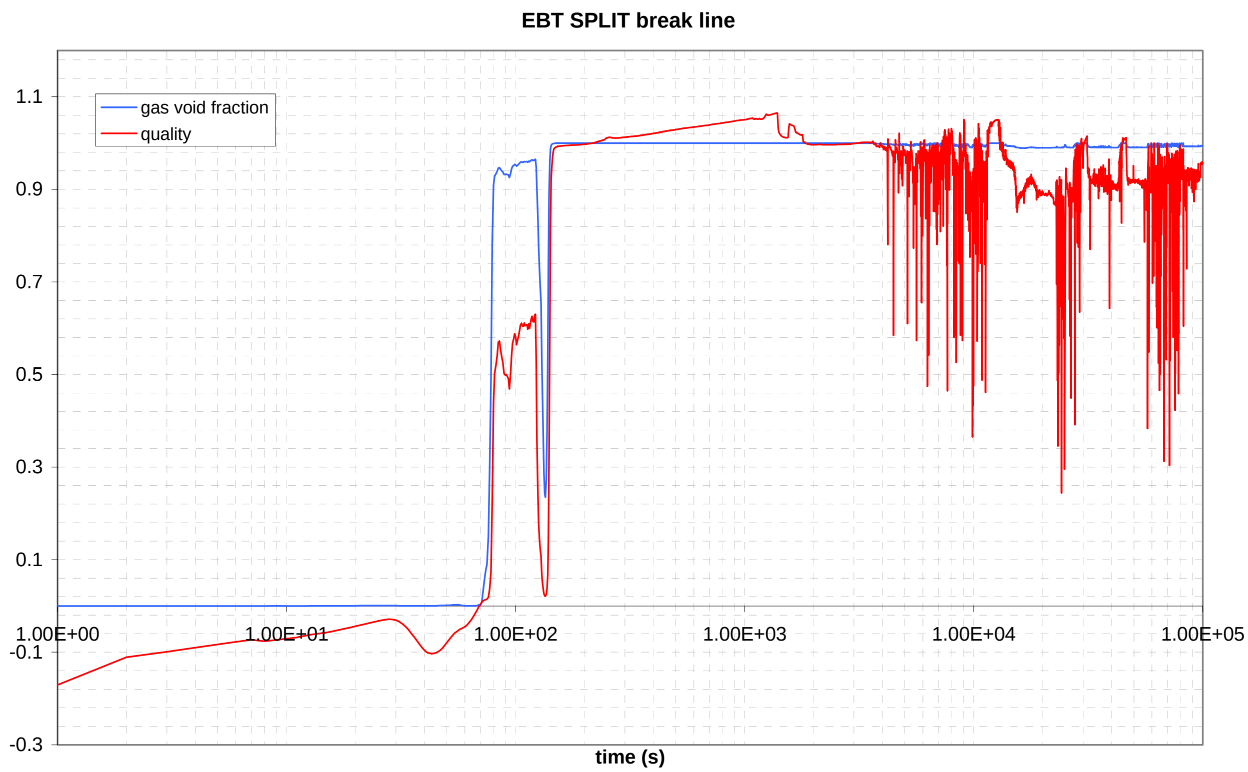

Fig. A5.1 Gas void fraction and quality history (EBT SPLIT brak line)

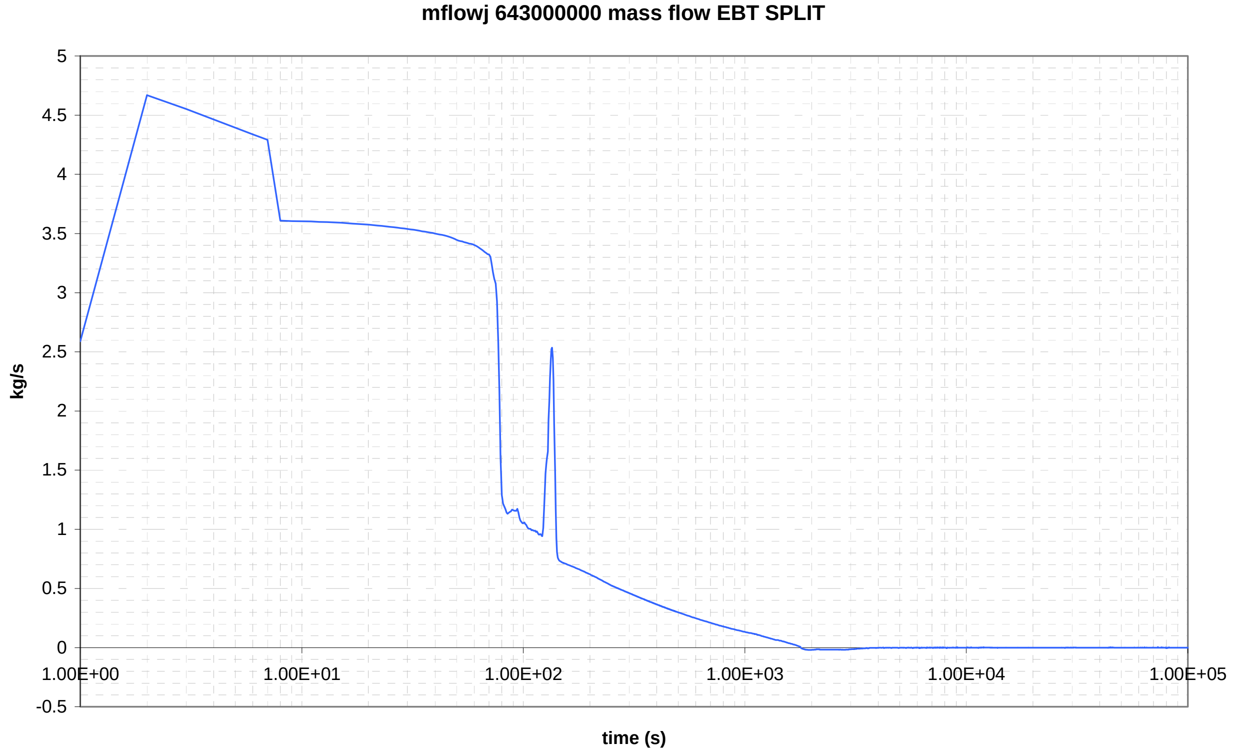

Fig. A5.2 Mass flow history (EBT SPLIT brak line)

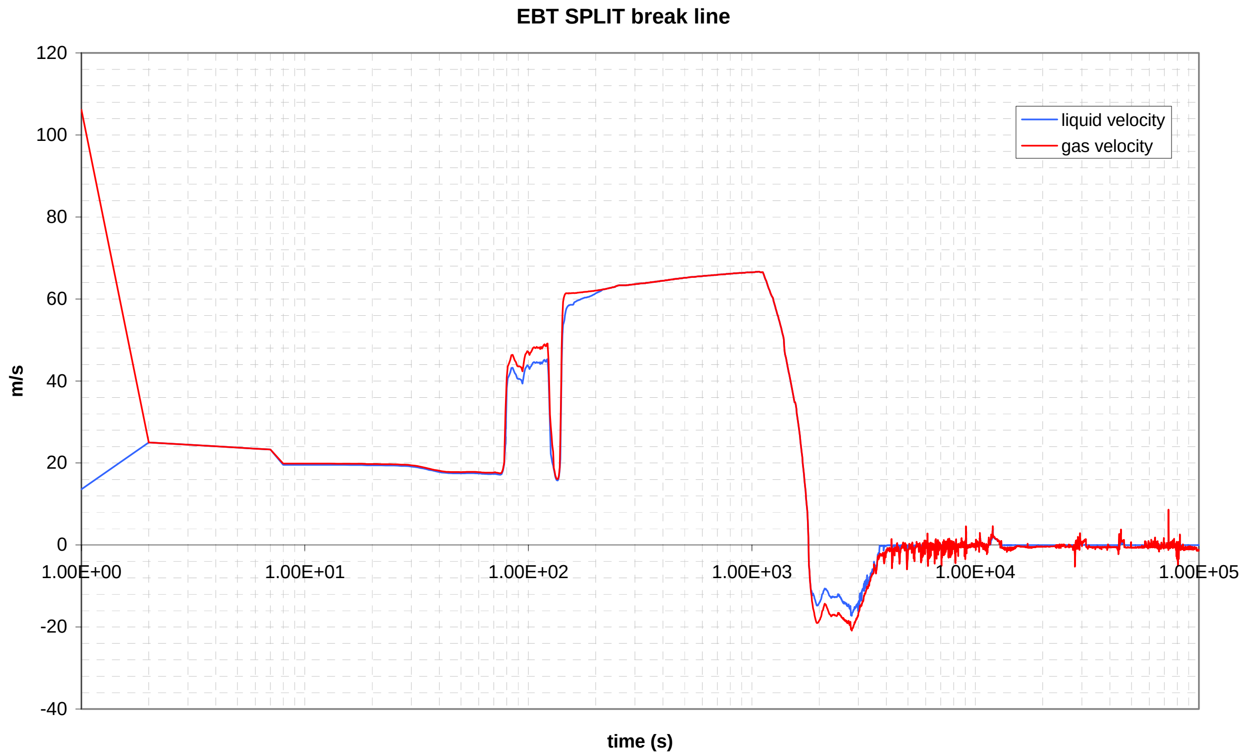

Fig. A5.3 Liquid and gas velocity history (EBT SPLIT break line)

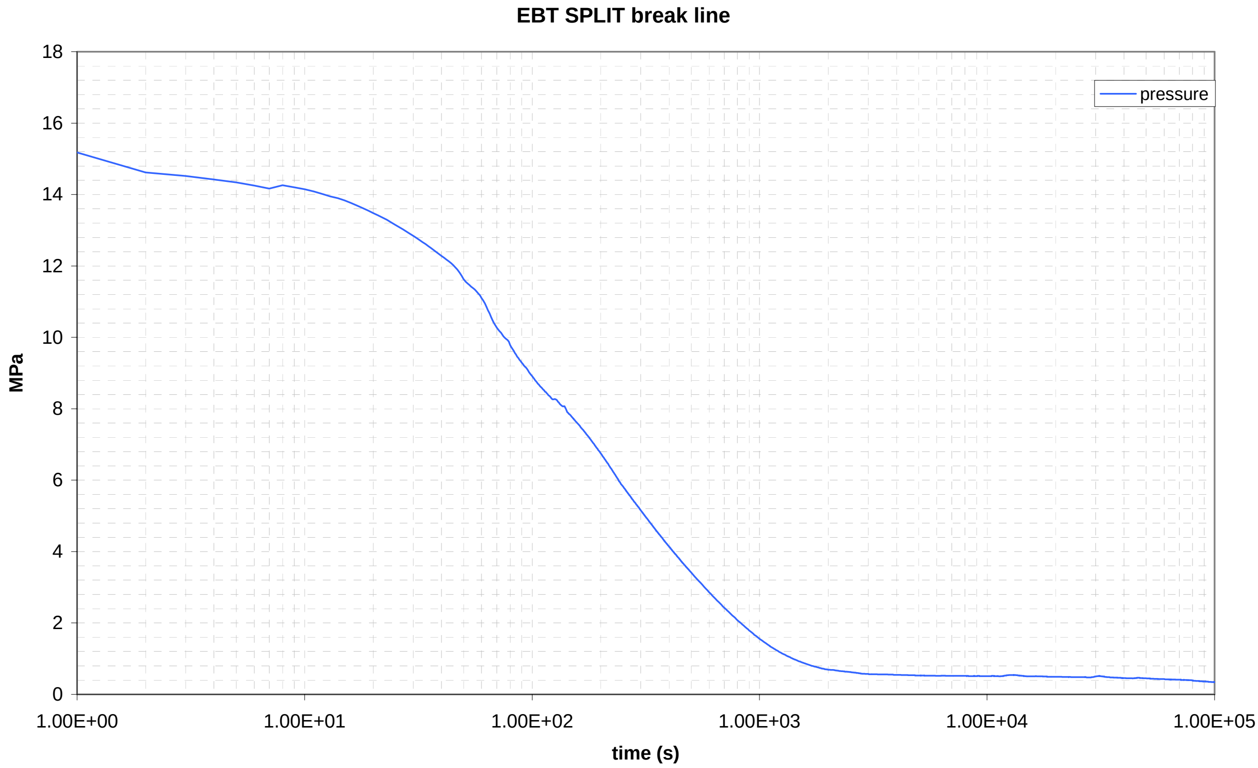

Fig. A5.4 Pressure history (EBT SPLIT break line)

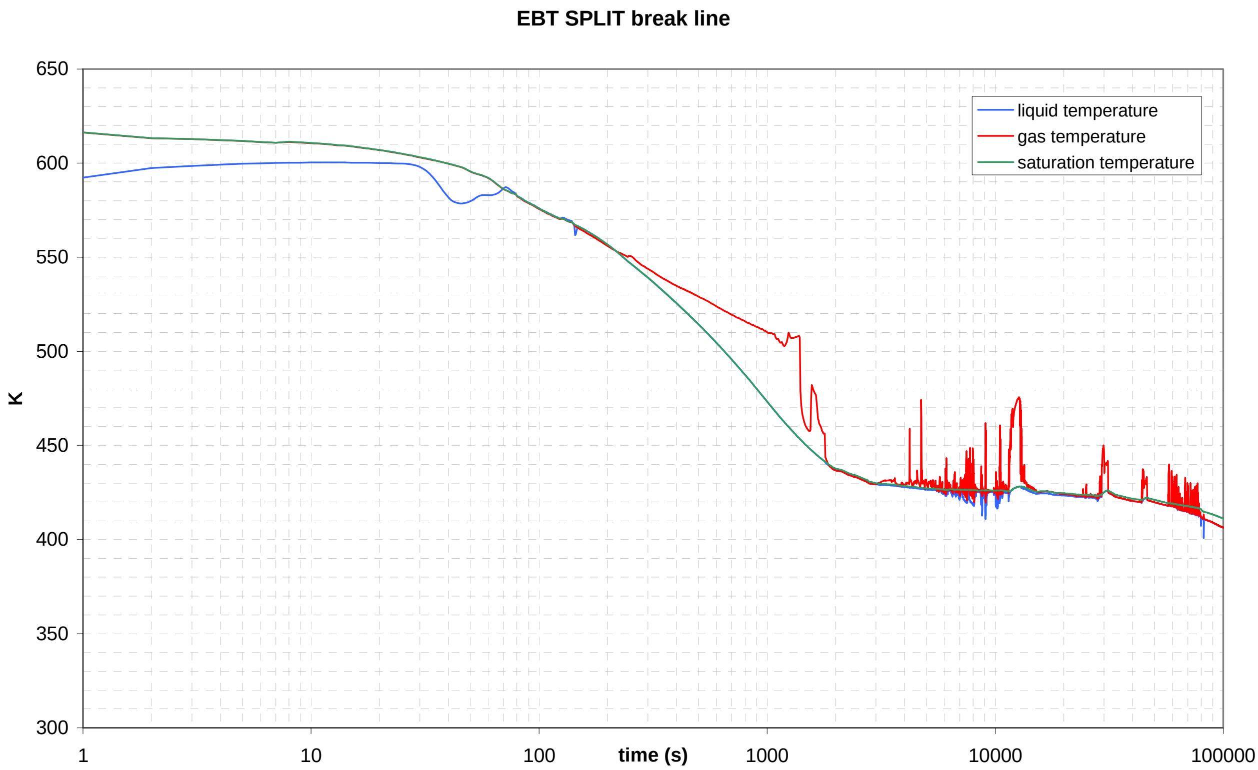

Fig. A5.5 Temperature history (EBT SPLIT break line)

EBT SPLIT break line		MIN	MAX
void fraction		0.0000	1.0000
volume equilibrium quality		-1.4991	1.0651
mass flow rate	kg/s	-0.0202	4.6686
liquid velocity	m/s	-17.2207	66.6764
gas velocity	m/s	-20.8762	106.1670
liquid temperature	K	314.0370	600.3600
gas temperature	K	406.3700	618.0670
Pressure	Mpa	0.3417	15.5245

Table A5: Main Tho phase flow variables

ADS lines flow during the EBT SPLIT break line

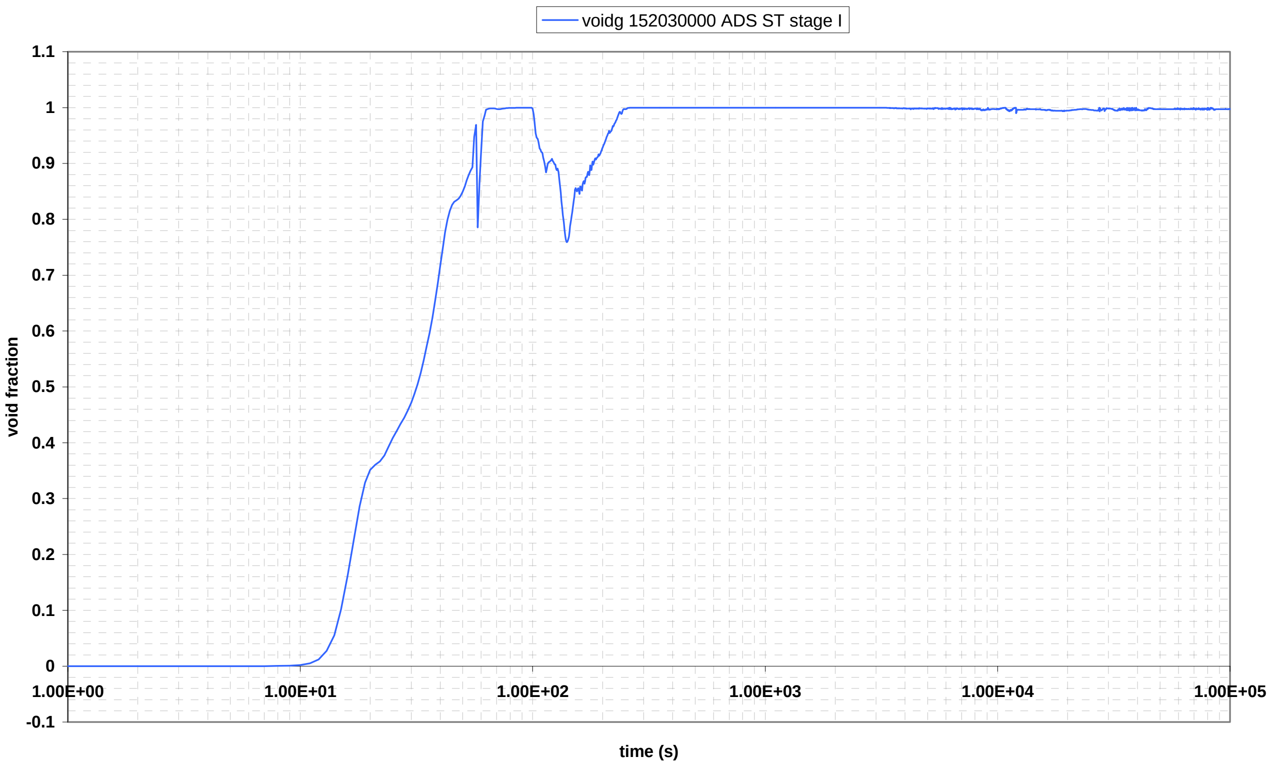

Fig. A5.6 Void fraction into ADS line

EBT DEG break		Volume	MIN	MAX
ADS DT stage I	Void Fraction	1.42E+08	0.7260	1.0000
ADS DT stage II	Void Fraction	1.32E+08	0.1098	1.0000
ADS ST stage I	*Plot*			
ADS ST stage II	Void Fraction	1.35E+08	0.0000	1.0000
ADS DT stage I	Mass Flow	1.43E+08	-0.0036	1.9801
ADS DT stage II	Mass Flow	1.44E+08	-0.0209	0.0145
ADS ST stage I	Mass Flow	1.53E+08	-0.0024	0.9577
ADS ST stage II	Mass Flow	1.54E+08	-0.0067	0.0109

Table A5.2 Void fraction and mass flow into ADS line

FLOW REGIMES (ADS line): *EBT DEG line – Usptream - Downstream*

Time	652010000	654010000	654030000	654070000	655010000
0	BBY	CHF MPR	CHF MPR	CHF MPR	CHF MPR
2	BBY	ANM	ANM	ANM	ANM
1700	HST	HST	HST	HST	ANM
1720	HST	SLG	HST	HST	ANM
2040	HST	HST	HST	HST	HST
2310	HST	HST	HST	HST	CHF MPR
2370	HST	HST	HST	HST	HST
3240	HST	HST	HST	HST	CHF MPR
3620	HST	HST	HST	HST	HST
3640	HST	HST	HST	HST	CHF MPR
99990	HST	HST	HST	HST	HST

EBT SPLIT line – Usptream - Downstream

Time	622010000	644010000	644030000	644070000	645010000
0	BBY	CHF MPR	CHF MPR	CHF MPR	CHF MPR
78	BBY	ANM	ANM	ANM	ANM
79	SLG	ANM	ANM	ANM	ANM
125	ANM	ANM	ANM	ANM	ANM
130	SLG	ANM	ANM	ANM	ANM
137	BBY	ANM	ANM	ANM	ANM
139	SLG	ANM	ANM	ANM	ANM
159	ANM	ANM	ANM	ANM	ANM
550	CHF MPR	ANM	ANM	ANM	ANM
850	CHF MPR	ANM	ANM	ANM	HST
910	CHF MPR	CHF MPR	ANM	ANM	HST
1150	CHF MPR	CHF MPR	CHF MPR	CHF MPR	HST
1620	CHF MPR	CHF MPR	HST	HST	HST
1790	CHF MPR	HST	HST	HST	HST
1820	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR
1830	HST	HST	CHF MPR	CHF MPR	CHF MPR
2470	HST	HST	HST	HST	HST
3870	HST	HST	HST	HST	CHF MPR
6190	HST	HST	HST	HST	HST
6200	HST	HST	HST	HST	CHF MPR
7500	HST	HST	HST	HST	HST
8050	HST	HST/ CHF MPR	HST	HST	HST
8070	CHF MPR	HST/ CHF MPR	HST	HST	HST
10830	HST	HST	HST	HST	HST
10840	HST	HST	HST	HST	CHF MPR
99990	HST	HST	HST	HST	HST

6. SPES91, ADS DEG break line

ADS DEG break line

UPSTREAM	MOTOR VALVE	DOWNSTRAM	NOZZLE
126010000 (MIS)	127000000	128010000 128020000 128030000 128040000 (MIS) 128050000	129010000

UPSTREAM

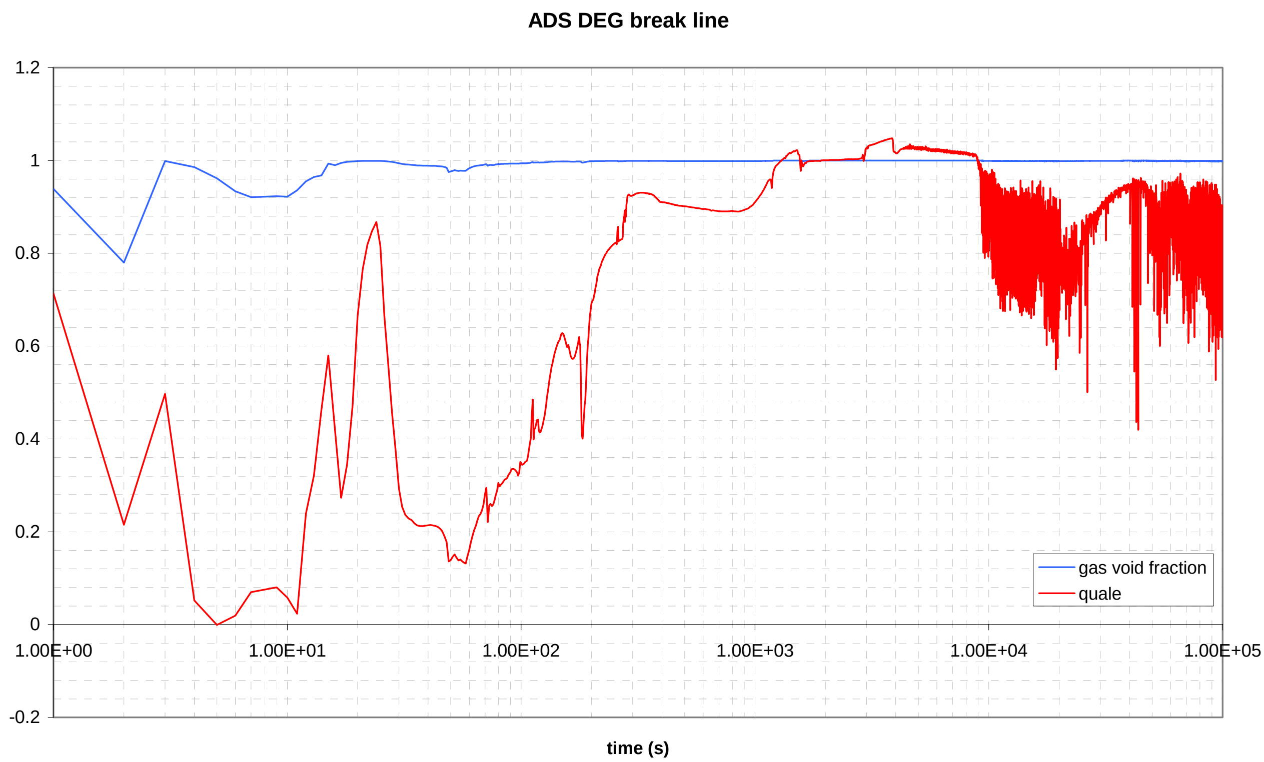

Fig. A6.1 Gas void fration and quality history (ADS DEG break line)

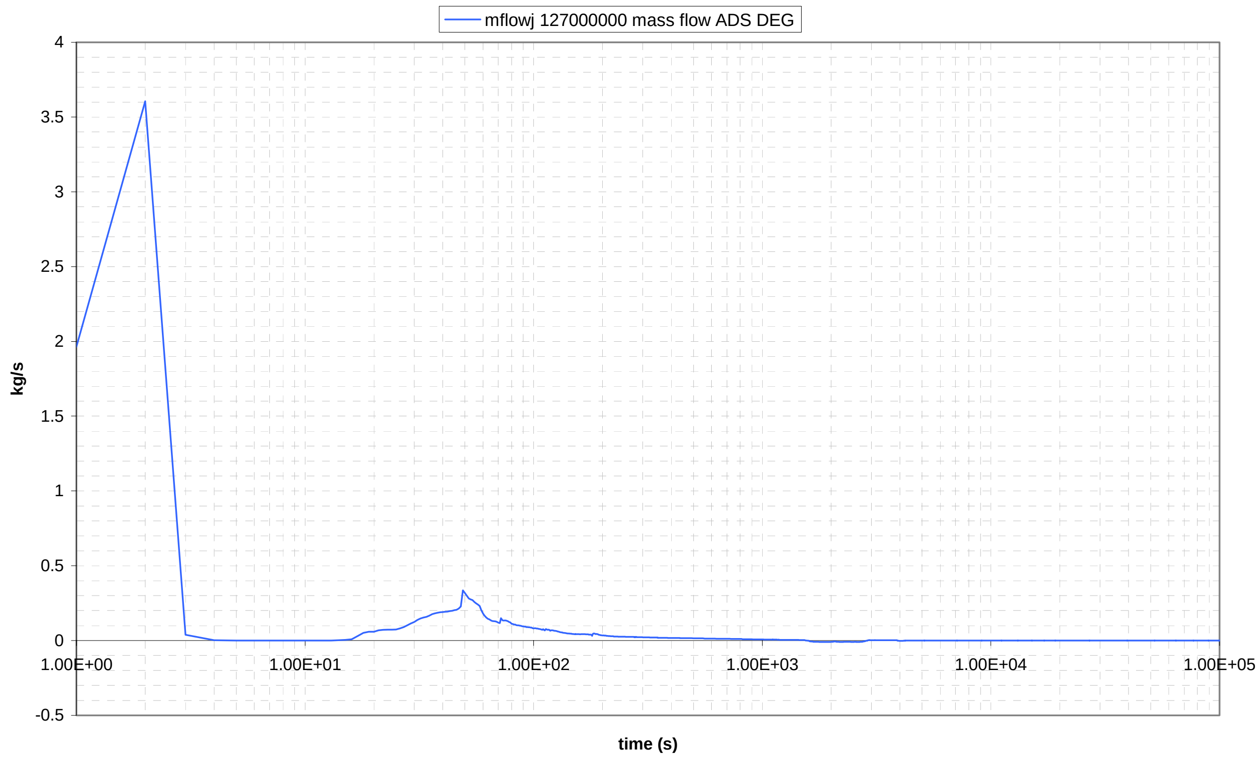

Fig. A6.2 mass flow history (ADS break line)

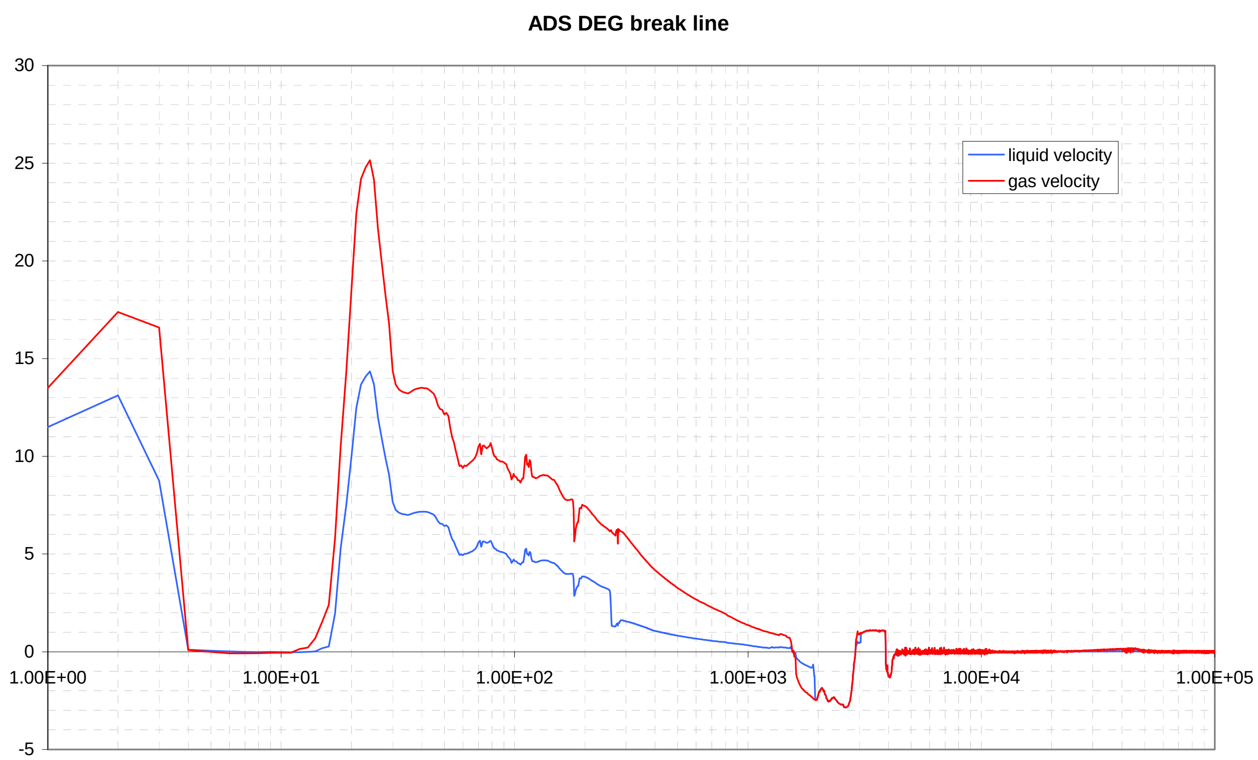

Fig. A6.3 Liquid and gas velocity history (ADS break line)

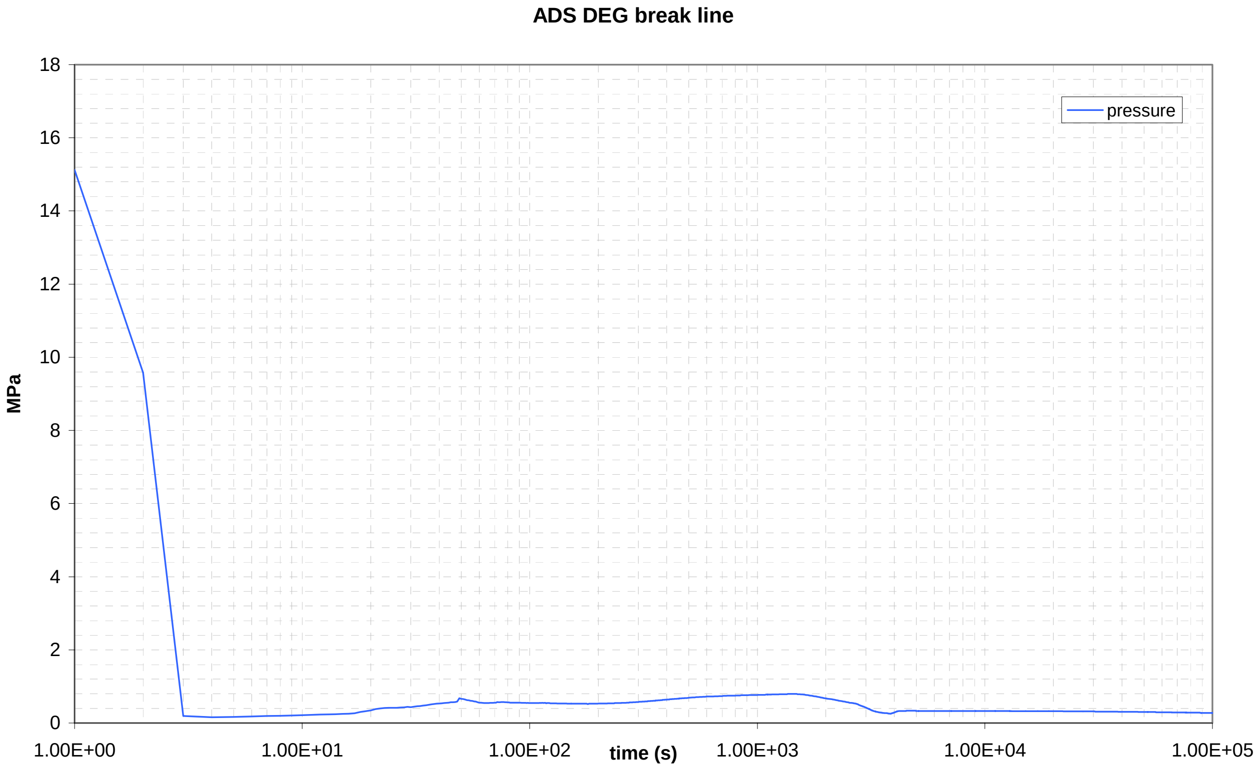

Fig. A6.4 Pressure history (ADS break line)

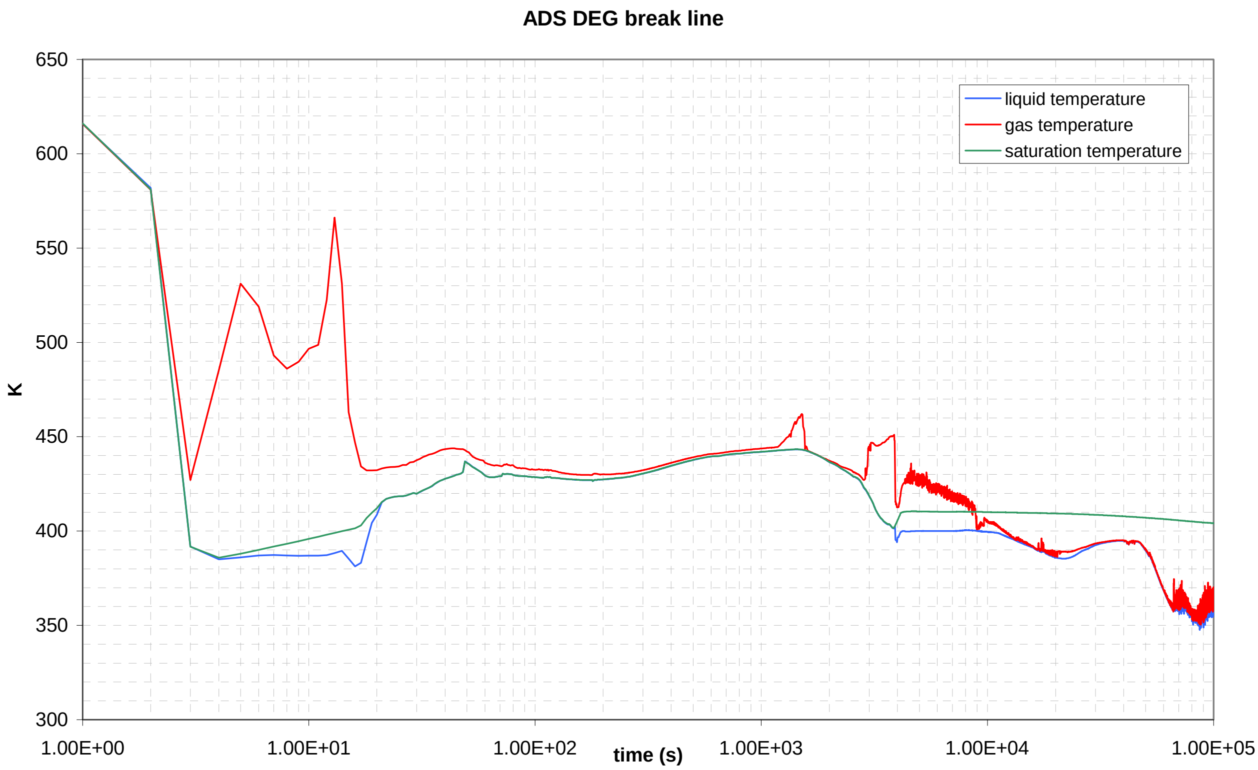

Fig. A6.5 Temperature history (ADS break line)

DVI DEG break line	MIN	MAX

void fraction		0.0008	1.0000
volume equilibrium quality		0.0000	0.0000
mass flow rate	kg/s	-0.0102	3.6046
liquid velocity	m/s	-2.8502	14.3460
gas velocity	m/s	-2.8502	25.1588
liquid temperature	K	347.6950	615.9080
gas temperature	K	350.4220	617.9740
Pressure	Mpa	0.1563	15.5067

Table A6: Main two phase flow range variable

7. ADS SPLIT break line

UPSTREAM	MOTOR VALVE	DOWNSTREAM	NOZZLE
157010000 (MIS)	158000000	133010000 133020000 133030000 133040000 (MIS) 133050000 133060000 133070000	159010000

UPSTREAM

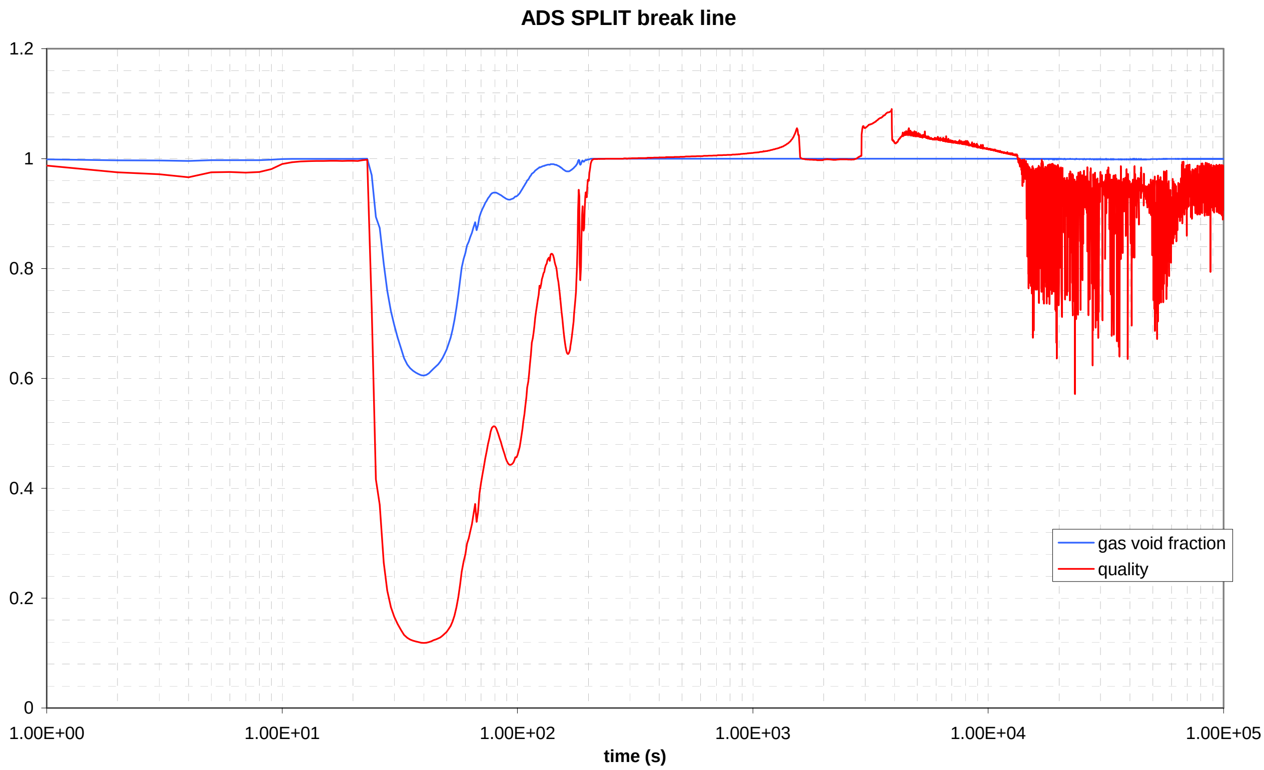

Fig. A7.1 Gas void fraction and quality (ADS SPLIT break line)

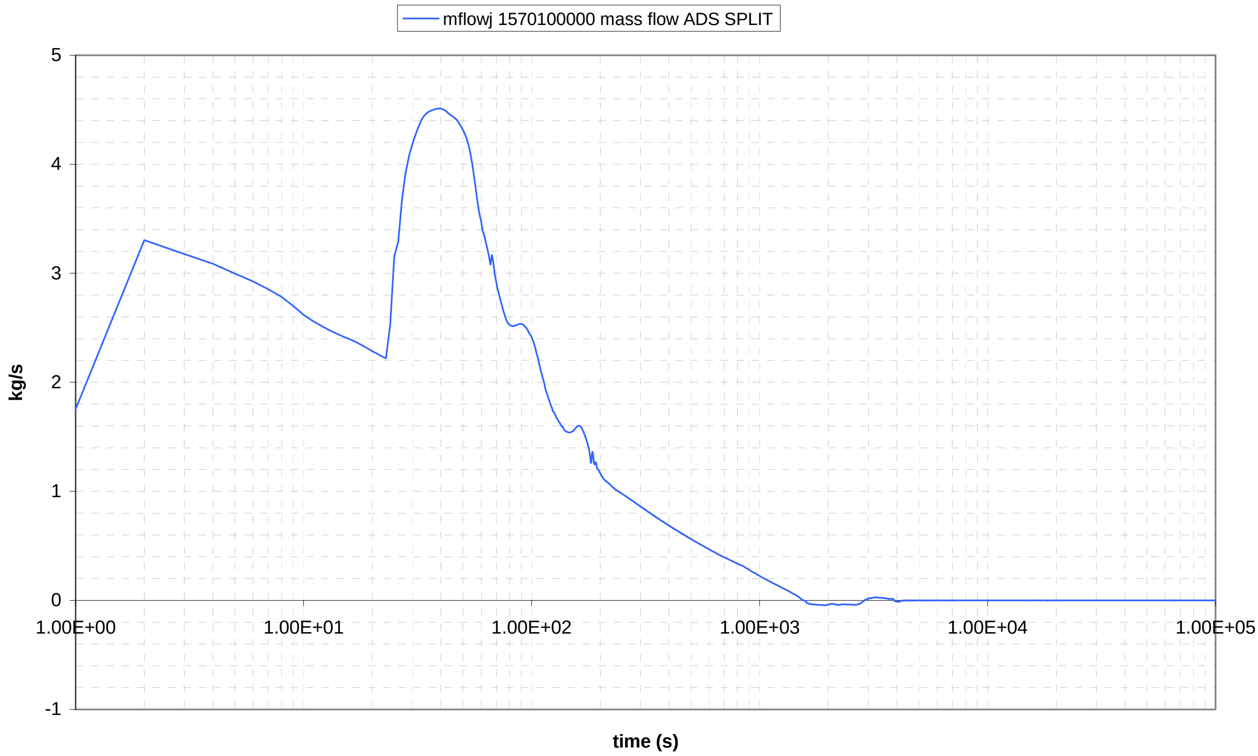

Fig. A7.2 mass flow history (ADS SPLIT break line)

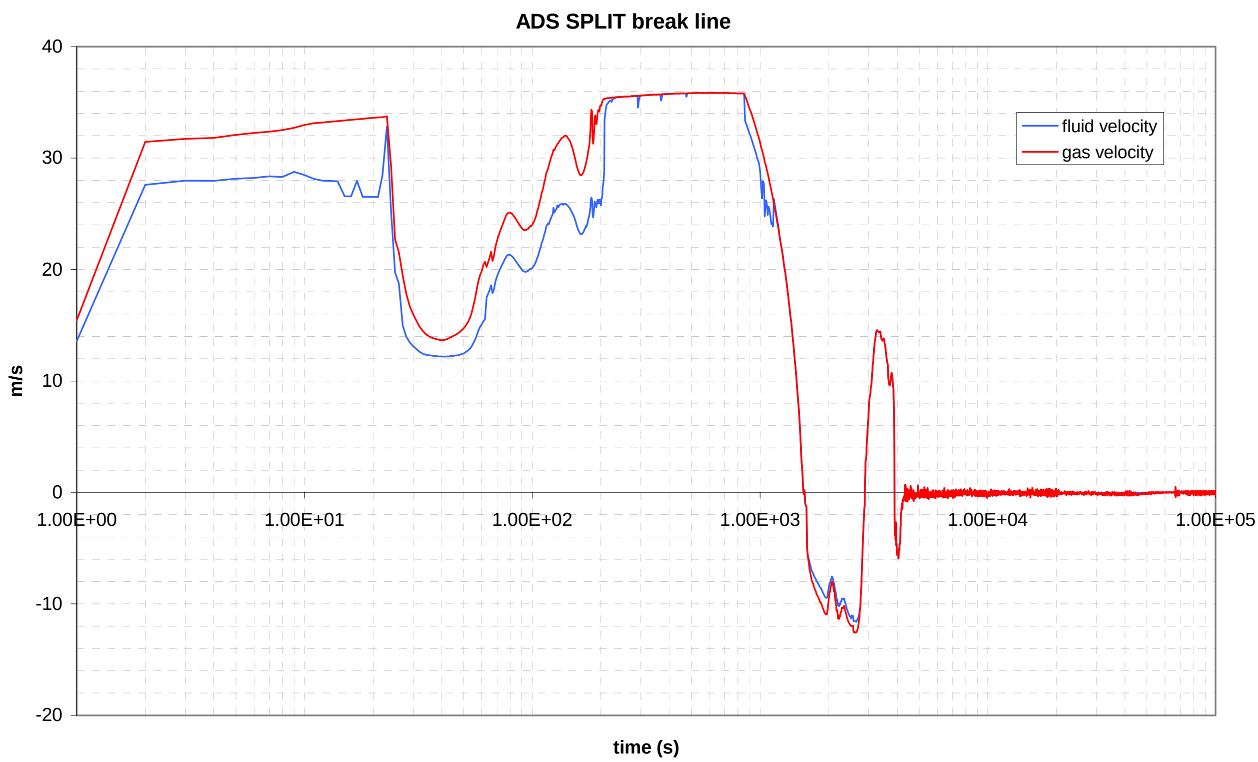

Fig. A7.3 liquid and gas velocity history (ADS SPLIT break line)

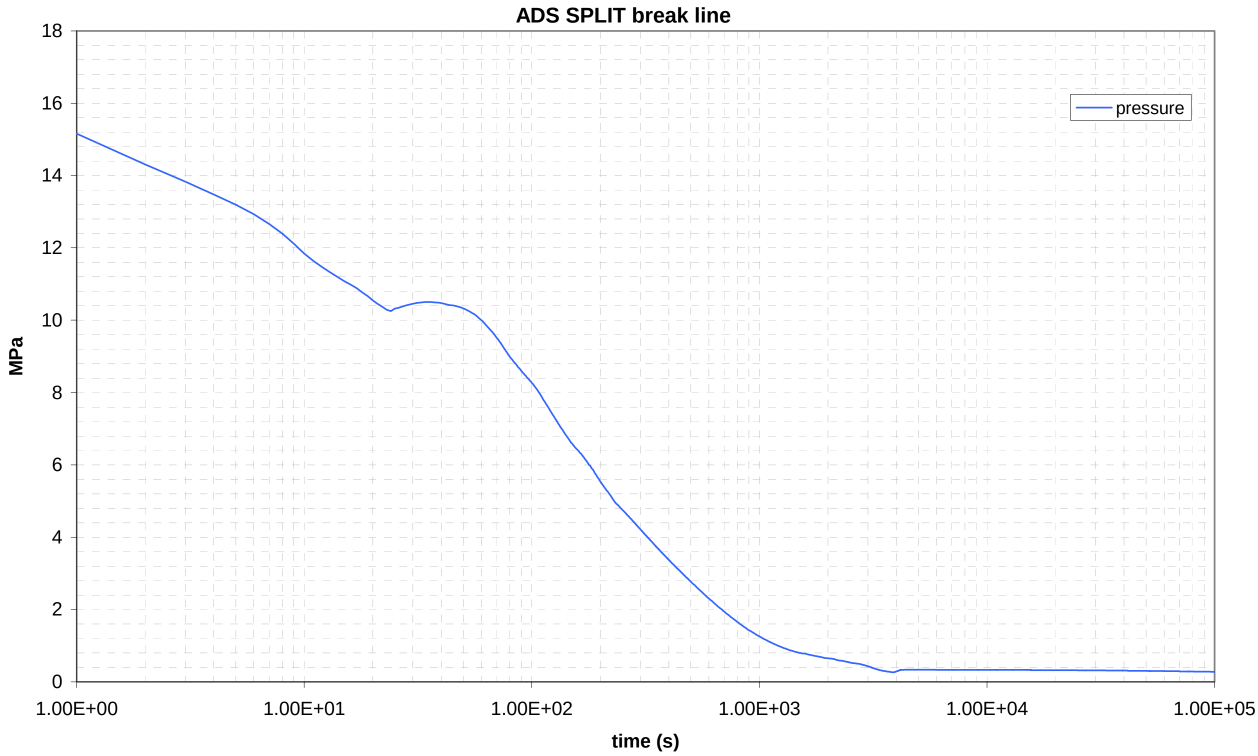

Fig. A7.4 Pressure history (ADS SPLIT break line)

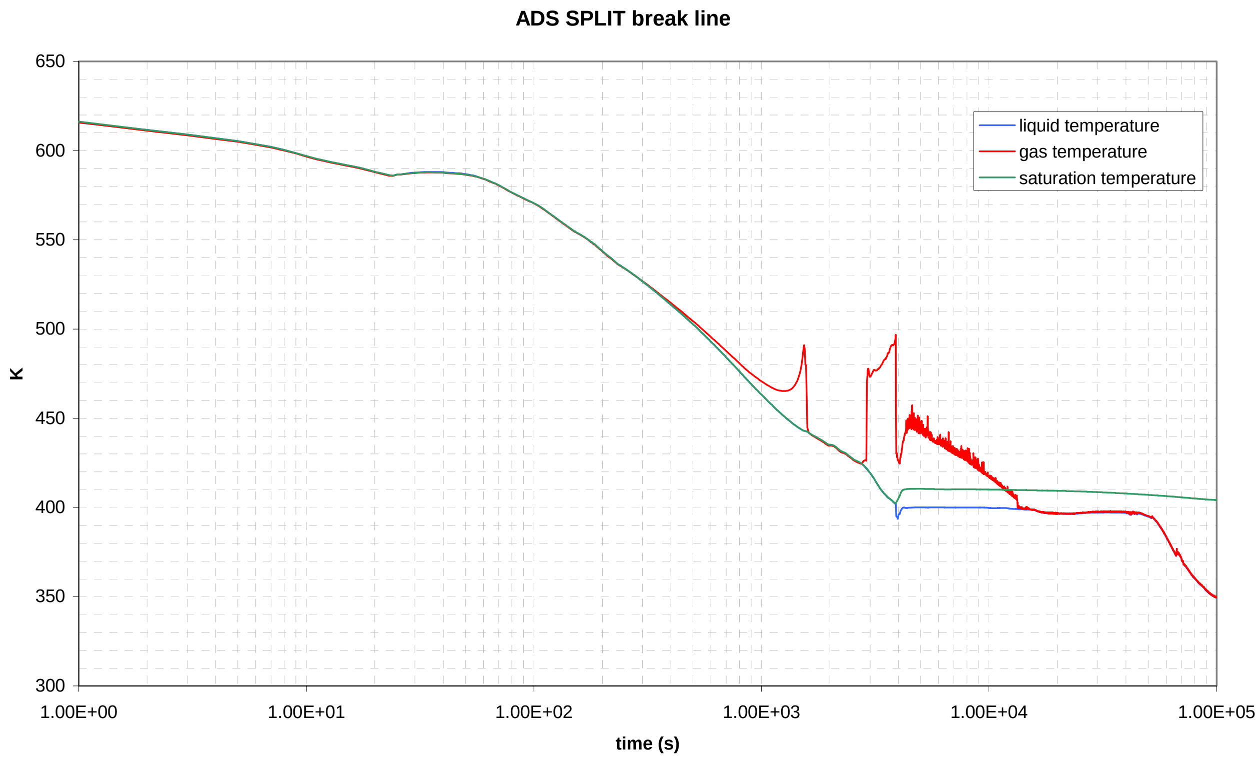

Fig. A7.5 Temperature history (ADS SPLIT break line)

DVI SPLIT break line		MIN	MAX
void fraction		0.0424	1.0000
volume equilibrium quality		-0.0560	1.0905
mass flow rate	kg/s	-0.0442	4.5107
liquid velocity	m/s	-11.6084	35.8412
gas velocity	m/s	-12.5918	35.8412
liquid temperature	K	349.4430	615.6810
gas temperature	K	349.5890	617.9750
pressure	Mpa	0.2640	15.5067

Table A.7: Main two phase flow range variables

ADS lines

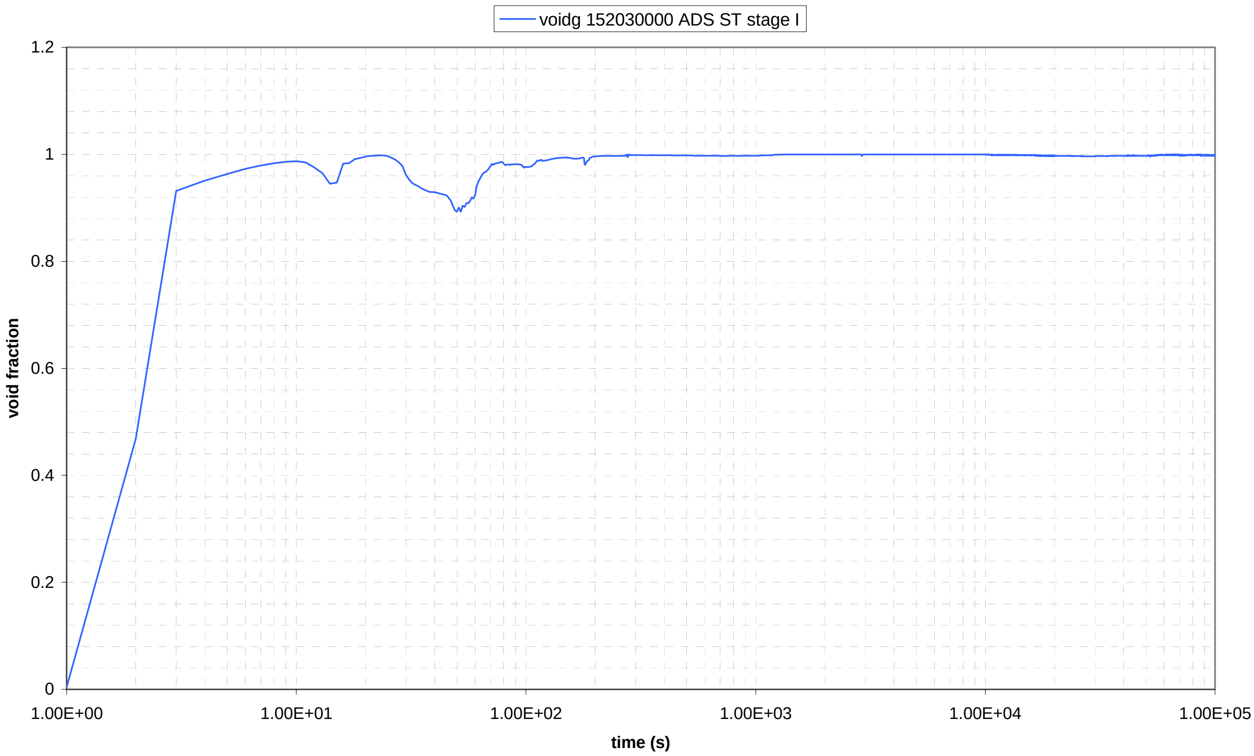

Fig. A7.6 Void Fraction into ADS line during ADS DEG line break

ADS DEG break		Volume	MIN	MAX
ADS DT stage I	Void Fraction	142080000	0.3793	1.0000
ADS DT stage II	Void Fraction	132020000	0.0845	1.0000
ADS ST stage I	*Plot*			
ADS ST stage II	Void Fraction	135020000	0.0000	1.0000
ADS DT stage I	Mass Flow	143000000	-0.0111	3.1324
ADS DT stage II	Mass Flow	144000000	0.0000	0.0000
ADS ST stage I	Mass Flow	153000000	-0.2696	0.0102
ADS ST stage II	Mass Flow	154000000	0.0000	0.0000

Table A7.2 Void fraction and mass flow range

FLOW REGIMES : ***ADS DEG Line – Upstream – Downtream***

Time	126010000	128010000	128040000	128050000	129010000
0	BBY	CHF MPR	CHF MPR	CHF MPR	CHF MPR
1	ANM	ANM	ANM	ANM	ANM
2	SLG	ANM	ANM	ANM	ANM
2120	HST	HST	HST	HST	HST
2130	CHF MPR	CHF MPR	HST	HST	HST
2220	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR
2250	CHF MPR	CHF MPR	HST	HST	HST
2260	CHF MPR	CHF MPR	CHF MPR	HST	HST
2880	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR
2890	HST	CHF MPR	CHF MPR	CHF MPR	CHF MPR
2900	HST	HST	CHF MPR	CHF MPR	CHF MPR
2910	HST	HST	CHF MPR	CHF MPR	CHF MPR
2920	HST	HST	HST	HST/ CHF MPR	CHF MPR
2930	HST	HST	HST	HST/ CHF MPR	HST
2950	HST	HST	HST	HST/ CHF MPR	CHF MPR
3040	HST	HST	CHF MPR	HST/ CHF MPR	CHF MPR
3770	CHF MPR	CHF MPR	CHF MPR	HST/ CHF MPR	CHF MPR
3910	CHF MPR	CHF MPR	CHF MPR	HST/ CHF MPR	HST/ CHF MPR
8810	CHF MPR	CHF MPR	CHF MPR	CHF MPR	HST/ CHF MPR
8820	CHF MPR	HST	CHF MPR	CHF MPR	HST/ CHF MPR
8830	HST	HST	CHF MPR	CHF MPR	HST/ CHF MPR
8840	CHF MPR	HST	CHF MPR	CHF MPR	HST/ CHF MPR
9860	HST	HST	CHF MPR	CHF MPR	HST/ CHF MPR
10490	HST	HST	CHF MPR	CHF MPR	HST/ CHF MPR
10500	HST	HST	HST	CHF MPR	HST/ CHF MPR
10510	HST	HST	CHF MPR	CHF MPR	HST/ CHF MPR
10750	HST	HST	HST	CHF MPR	HST/ CHF MPR
10890	HST	HST	HST	HST/ CHF MPR	HST/ CHF MPR
11250	HST	HST	HST	HST	HST/ CHF MPR
99990	HST	HST	HST	HST	HST

ADS SPLIT Line – Upstream – Downtream

Time	157010000	133010000	133040000	133070000	159010000
0	HST	CHF MPR	CHF MPR	CHF MPR	CHF MPR
1	HST	ANM	ANM	ANM	ANM
	ANM	ANM	ANM	ANM	ANM
22	ANM	ANM	ANM	ANM	ANM
23	CHF MPR	ANM	ANM	ANM	ANM
27	ANM	ANM	ANM	ANM	ANM
57	SLG	ANM	ANM	ANM	ANM
207	ANM	ANM	ANM	ANM	ANM
333	CHF MPR	ANM	ANM	ANM	ANM
550	CHF MPR	ANM	ANM	ANM	HST
1140	CHF MPR	ANM	HST	HST	HST
1520	CHF MPR	HST	HST	HST	HST
1550	CHF MPR	HST	HST	HST	CHF MPR
1560	HST	HST	HST	HST	CHF MPR
1570	CHF MPR	HST	HST	CHF MPR	CHF MPR
1580	HST	HST	CHF MPR	CHF MPR	CHF MPR
1590	HST	HST	CHF MPR	HST	HST
2130	HST	HST	HST	HST	HST
2140	HST	CHF MPR	HST	HST	HST
2740	HST	CHF MPR	CHF MPR	CHF MPR	CHF MPR
3890	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR
3960	CHF MPR	CHF MPR	CHF MPR	HST	HST
13290	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR
15420	HST	HST	CHF MPR	CHF MPR	CHF MPR
15430	HST	HST	HST	CHF MPR	CHF MPR
15660	HST	HST	CHF MPR	CHF MPR	CHF MPR
15840	HST	HST	HST	CHF MPR	CHF MPR
16270	HST	HST	HST	HST	CHF MPR
16710	HST	HST	HST	HST	HST/ CHF MPR
99990	HST	HST	HST	HST	HST

8. SPES3 91, SL DEG break

SL DEG break line

UPSTREAM	MOTOR VALVE	DOWNSTRAM	NOZZLE
570010000 (MIS)	571000000	572010000 572020000 572030000 (MIS) 572040000 572050000	573010000

UPSTREAM

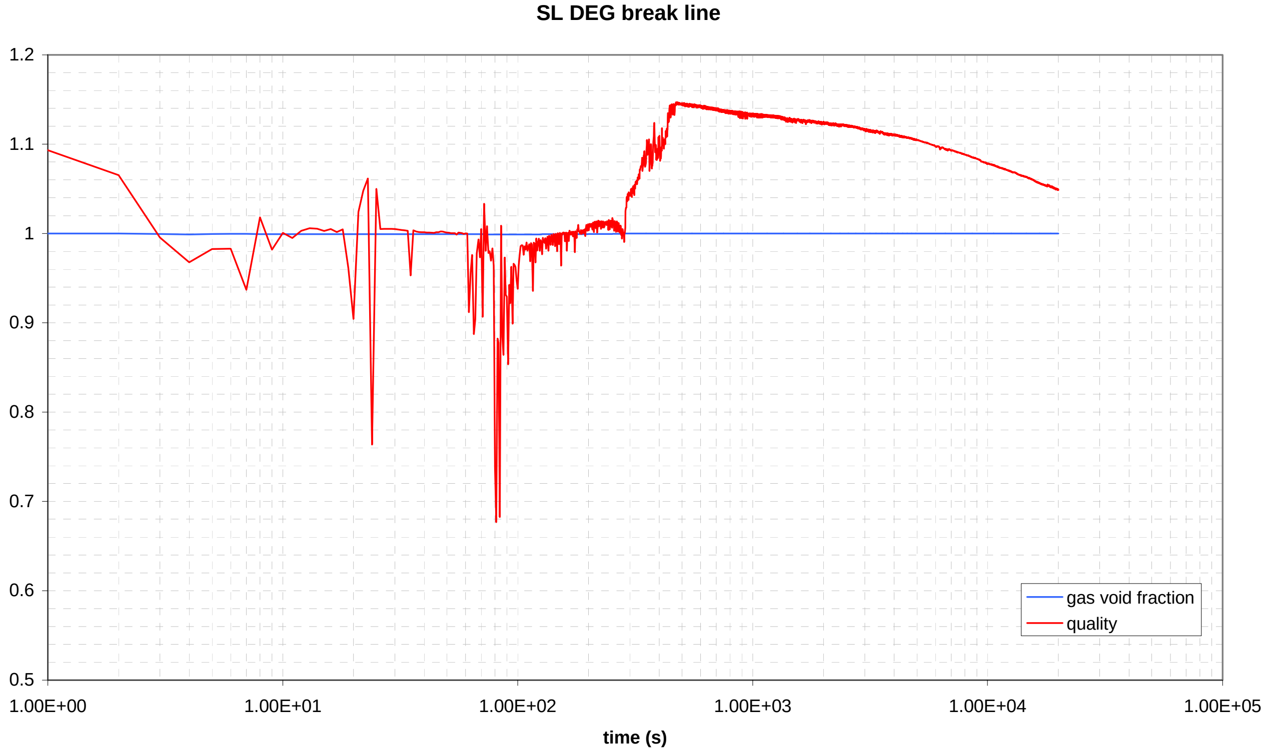

Fig. A8.1 Gas void fraction and quality history (SL DEG Break line)

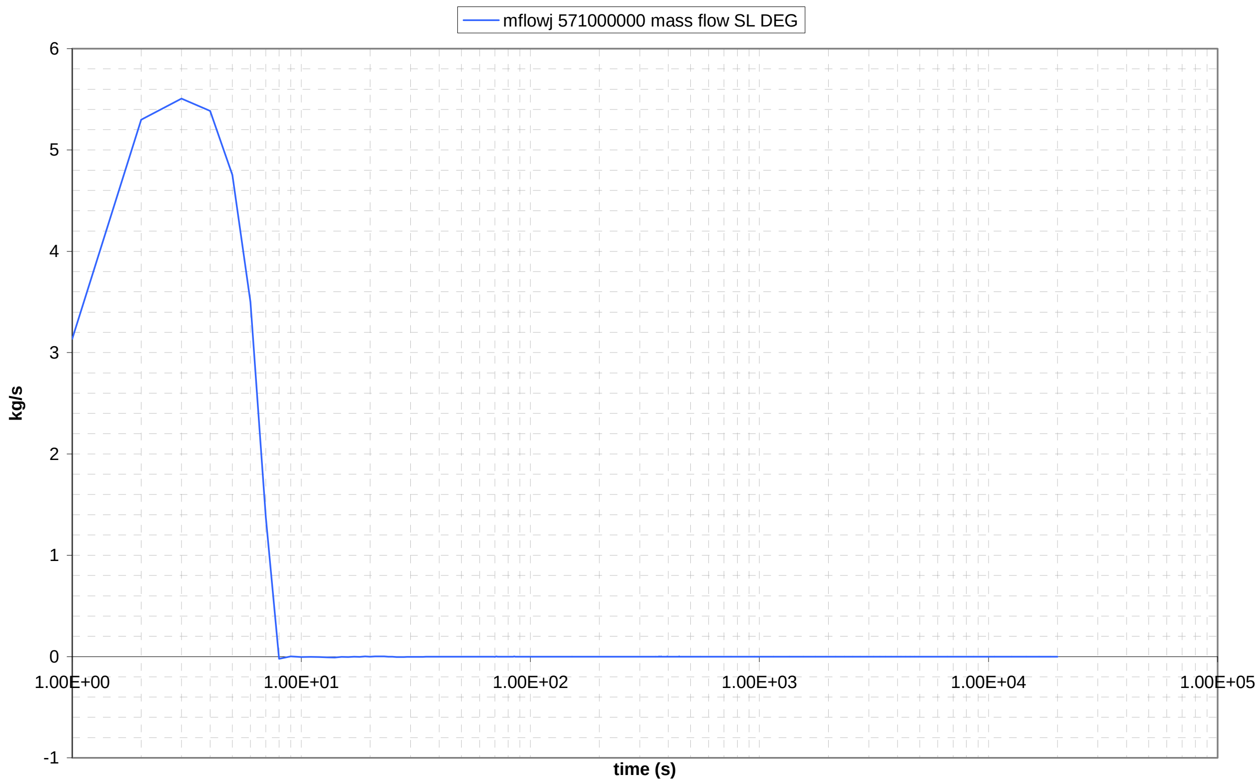

Fig. A8.2 Mass flow history (SL DEG Break line)

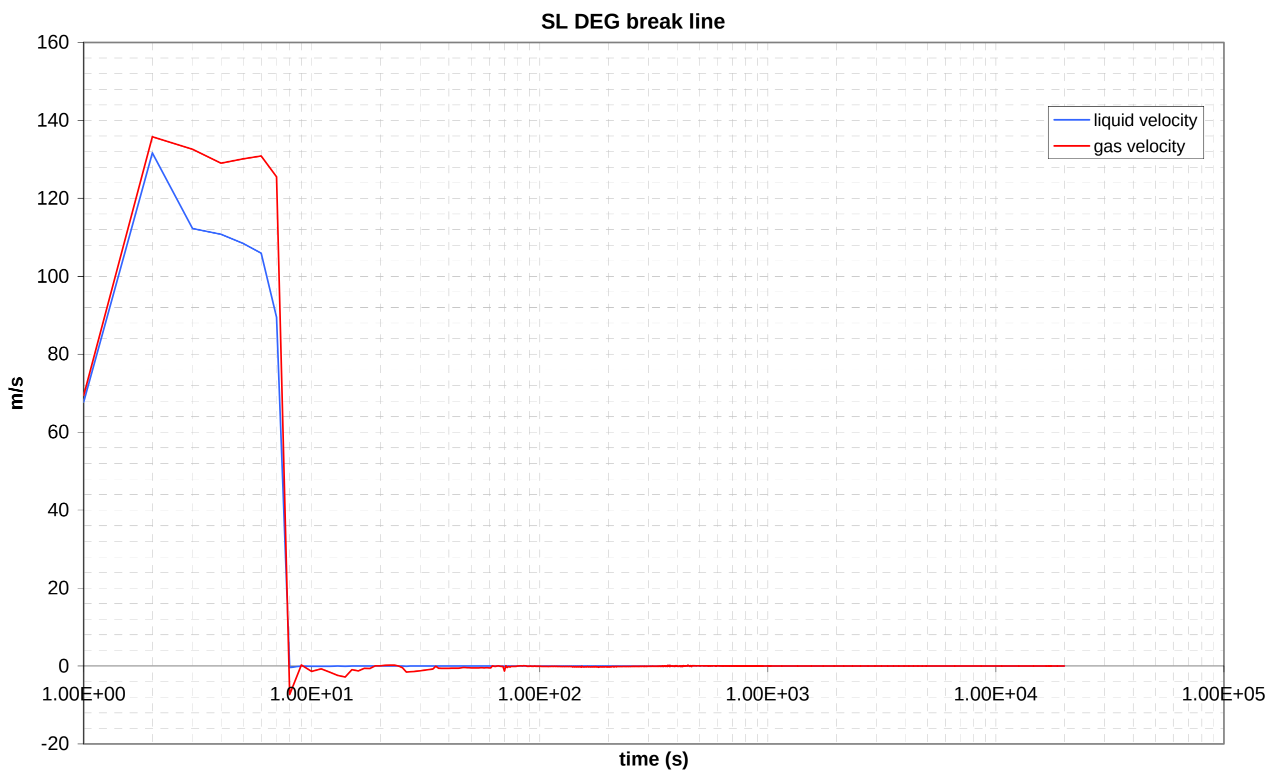

Fig. A8.3 Liquid and gas velocity history (SL DEG Break line)

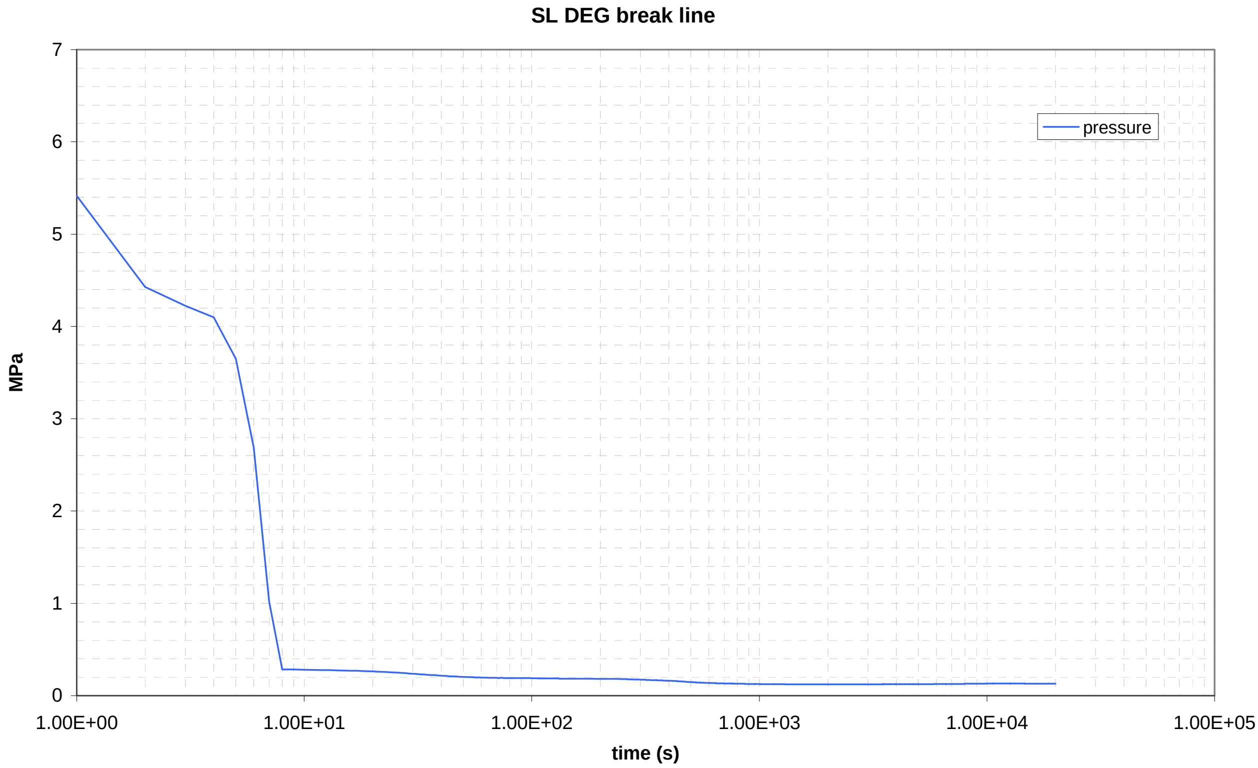

Fig. A8.4 Pressure history (SL DEG Break line)

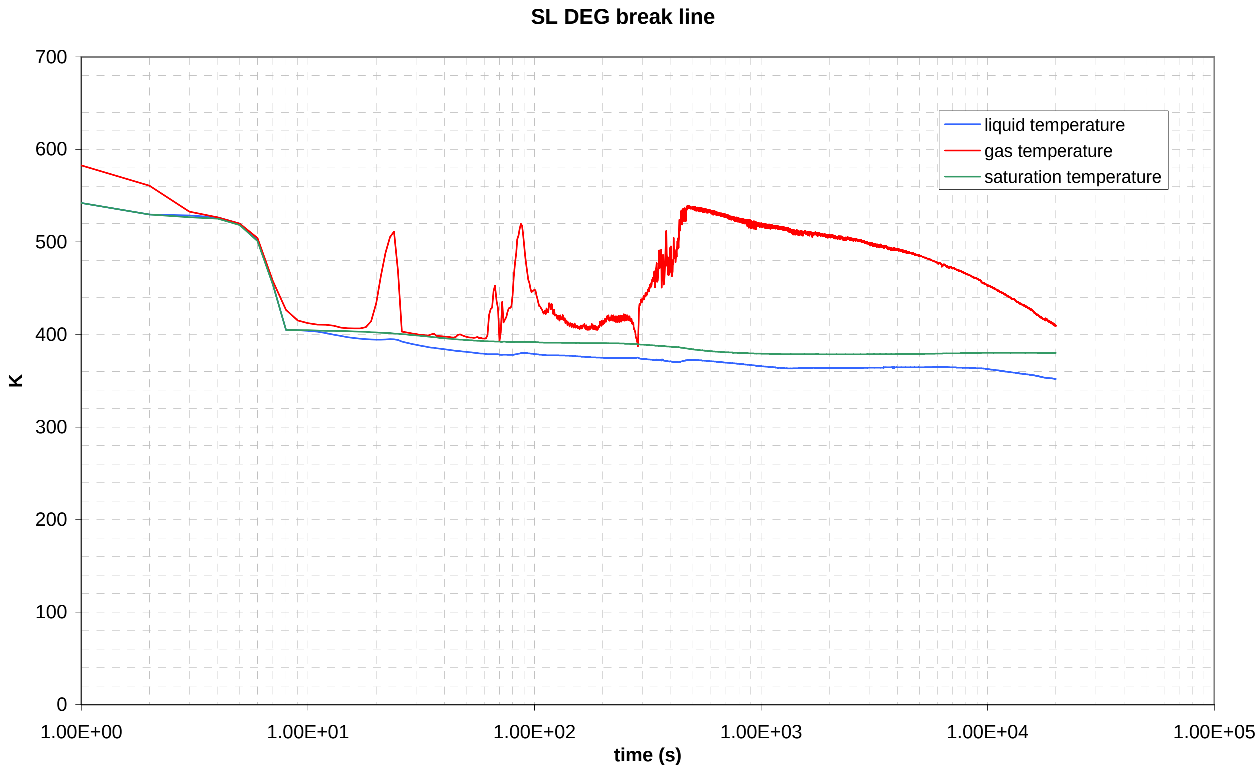

Fig. A8.5 Temperature history (SL DEG Break line)

SL DEG break line	MIN	MAX

void fraction		0.9990	1.0000
volume equilibrium quality		0.6767	1.1471
mass flow rate	kg/s	-0.0212	5.5071
liquid velocity	m/s	-0.4145	131.6760
gas velocity	m/s	-7.3419	135.8310
liquid temperature	K	363.3310	546.7500
gas temperature	K	387.1220	582.7480
pressure	MPa	0.1224	5.8197

Table 8.1: Main two phase flow range variables

9. SL SPLIT break line

UPSTREAM	MOTOR VALVE	DOWNSTRAM	NOZZLE
575010000	576000000	577010000 577020000 577030000 577040000 (MIS) 577050000 577060000	578010000

UPSTREAM

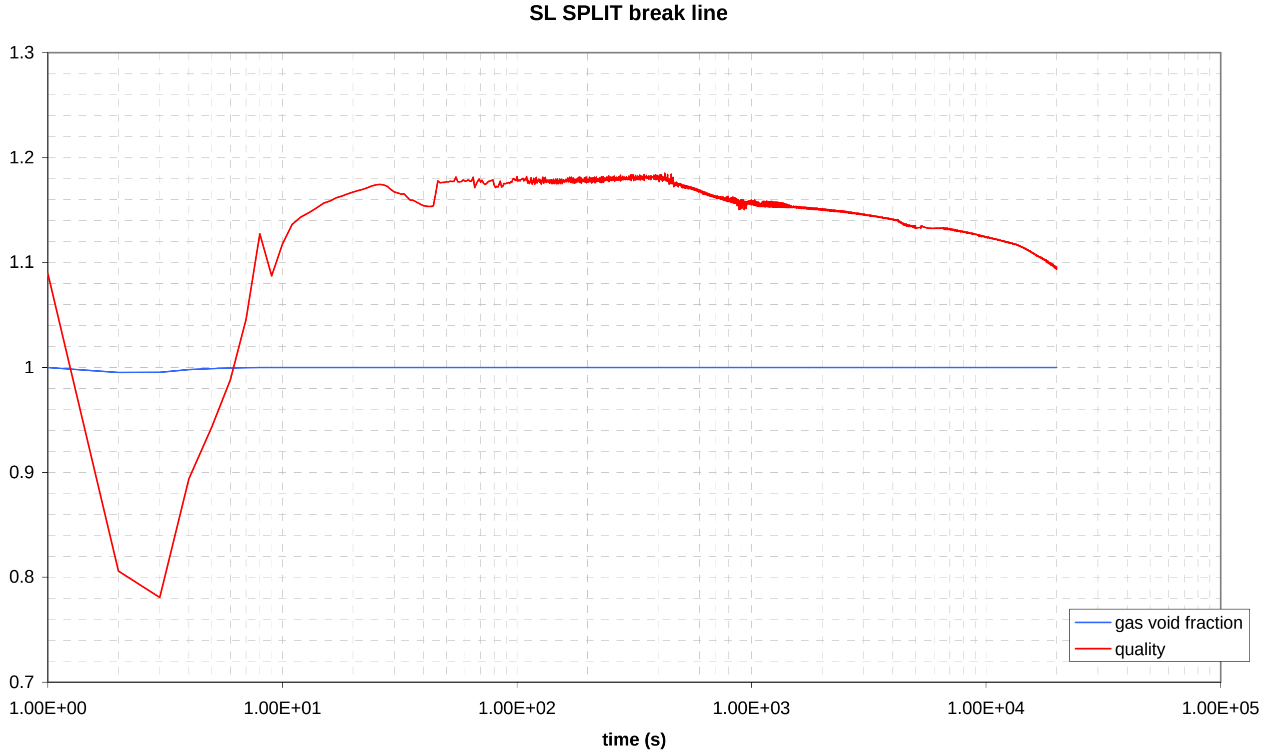

Fig. 9.1 Gas void fraction and quality history (SL SPLIT break line)

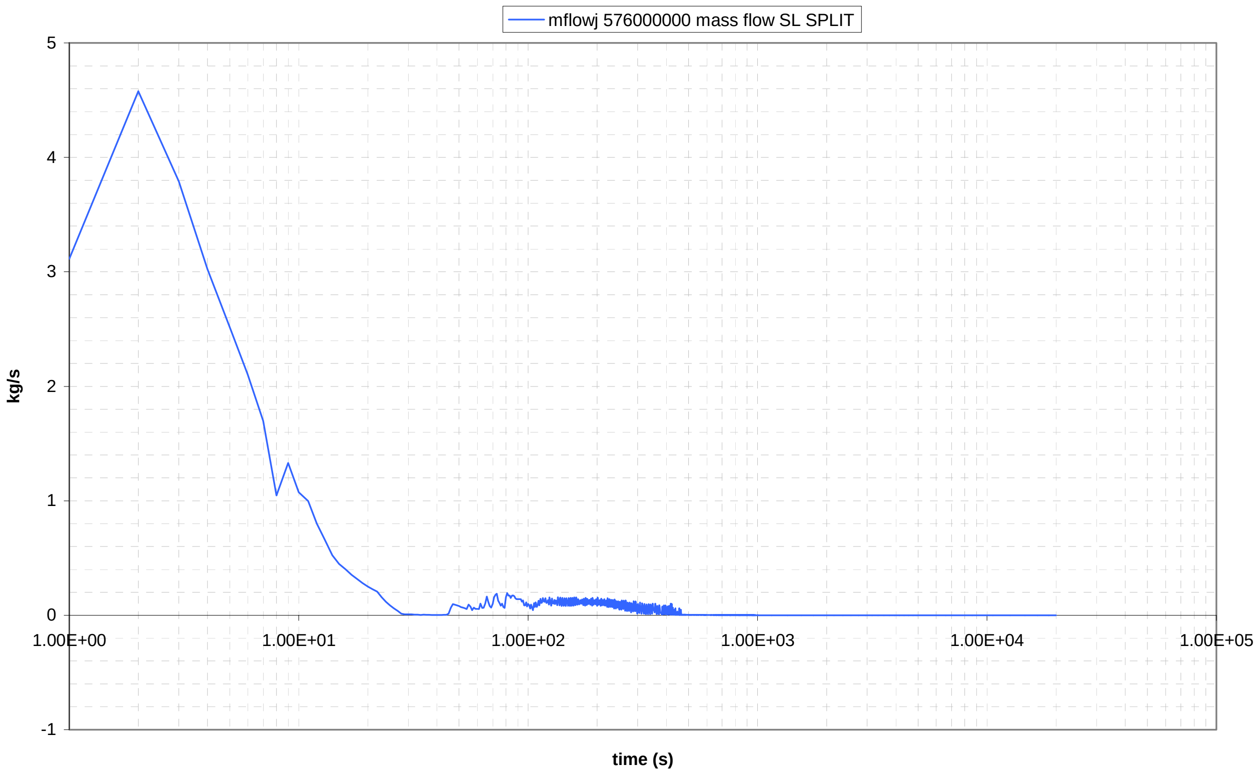

Fig. 9.2 Mass flow history (SL SPLIT break line)

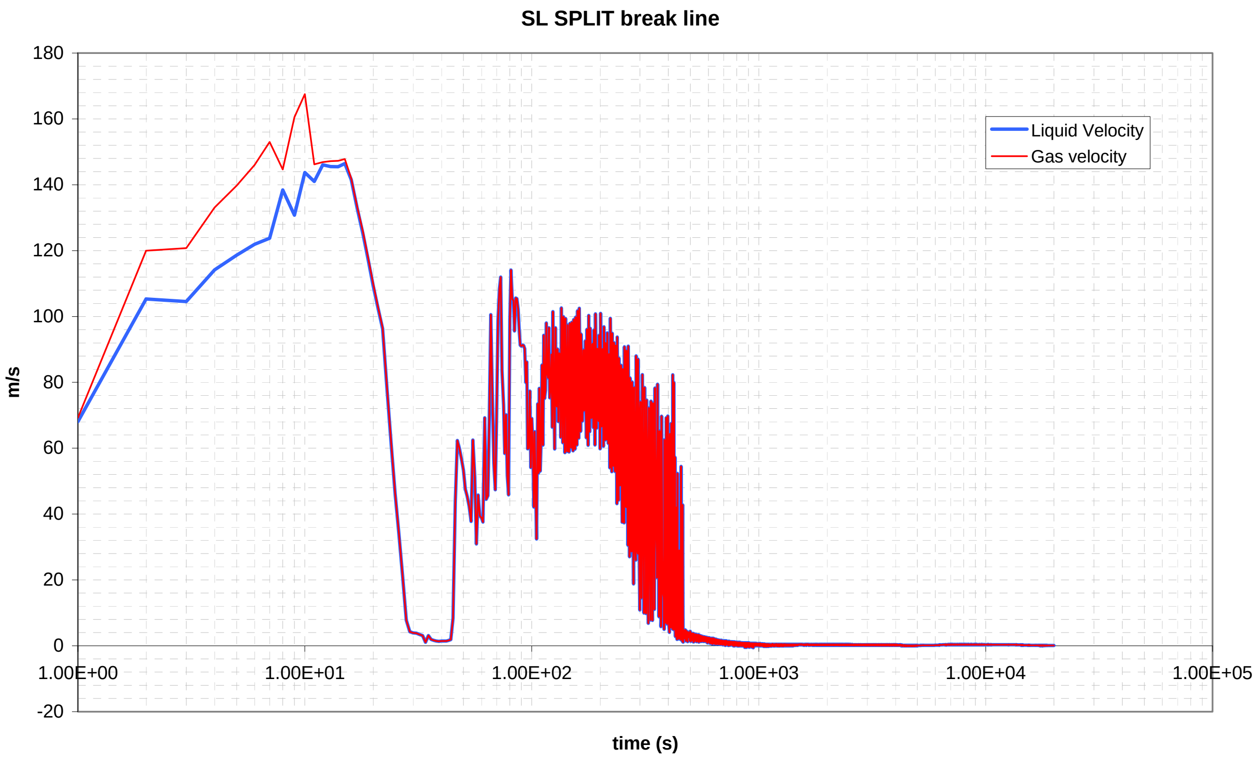

Fig. 9.3 Liquid and gas flow history (SL SPLIT break line)

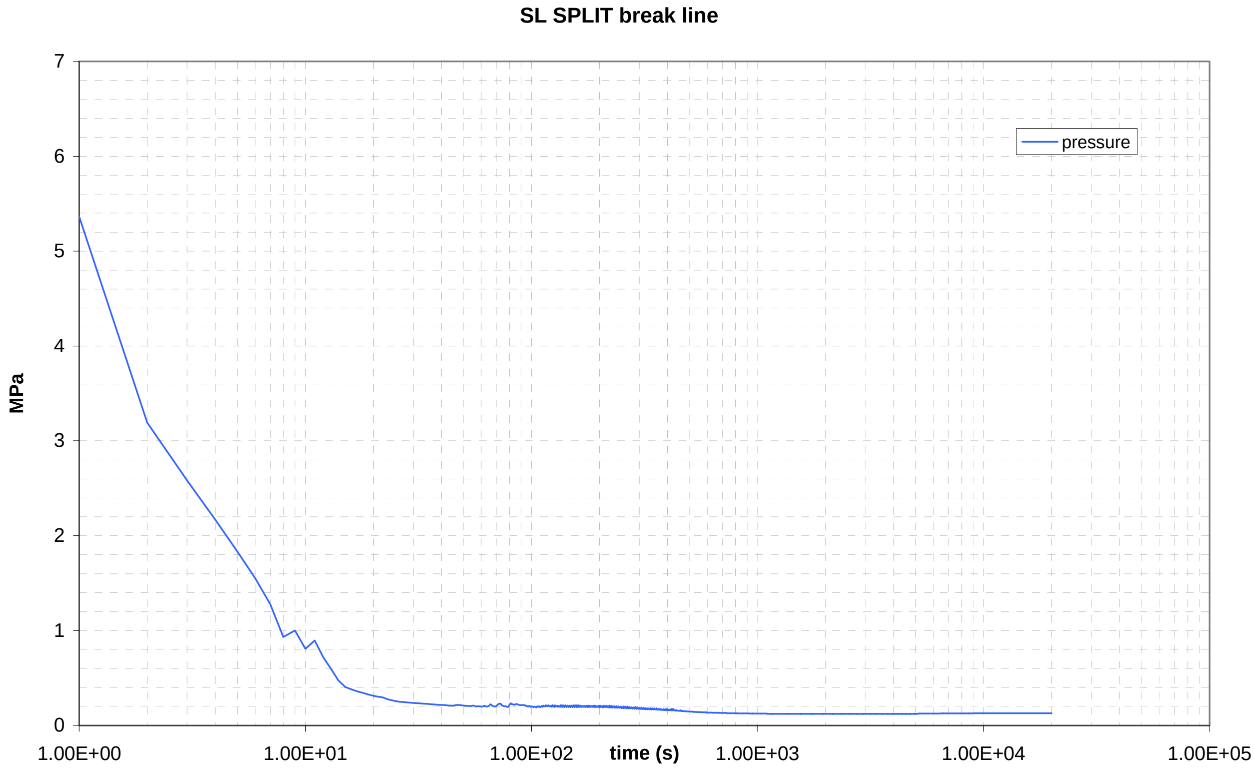

Fig. 9.4 Pressure history (SL SPLIT break line)

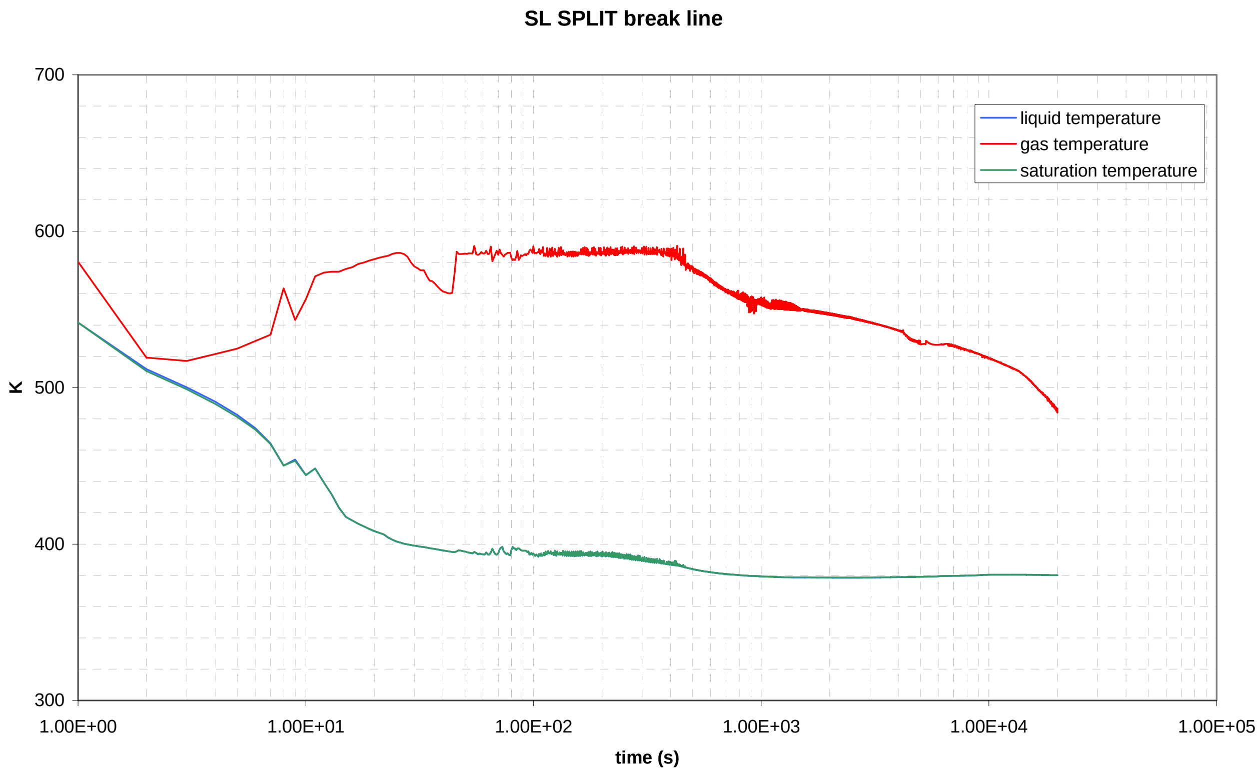

Fig. 9.5 Temperature history (SL SPLIT break line)

void fraction		0.9950	1.0000
volume equilibrium quality		0.7808	1.1852
mass flow rate	kg/s	-0.0005	4.5788
liquid velocity	m/s	-0.5612	146.4540
gas velocity	m/s	-0.5612	167.5600
liquid temperature	K	378.4970	546.8500
gas temperature	K	517.0160	590.6430
pressure	Mpa	0.1224	5.8335

Table A9 : Main two phase flow range variables

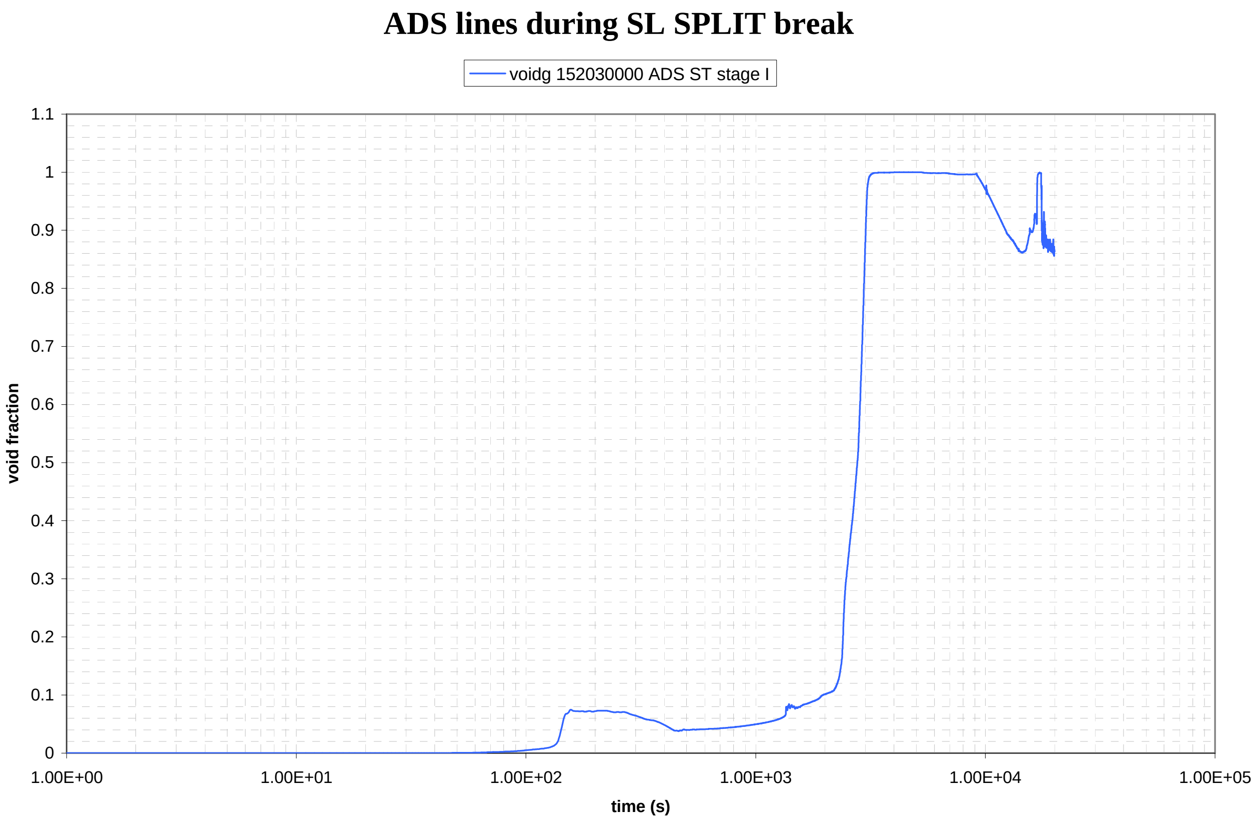

Fig. 9.6 Void fraction history (SL SPLIT break line)

SL DEG break		Volume	MIN	MAX
ADS DT stage I	Void Fraction	142080000	0.8110	1.0000
ADS DT stage II	Void Fraction	132020000	0.8105	1.0000
ADS ST stage I	*Plot*			
ADS ST stage II	Void Fraction	135020000	0.0000	0.9992
ADS DT stage I	Mass Flow	143000000	0.0000	0.0000
ADS DT stage II	Mass Flow	144000000	0.0000	0.0000
ADS ST stage I	Mass Flow	153000000	0.0000	0.0000
ADS ST stage II	Mass Flow	154000000	0.0000	0.0000

FLOW REGIMES: *SL DEG line – Upstream – Downstream*

Time	570010000	572010000	572030000	572050000	573010000
0	HST	CHF MPR	CHF MPR	CHF MPR	CHF MPR
1	CHF MPR	CHF MPR	ANM	ANM	ANM
2	CHF MPR	CHF MPR	ANM	ANM	ANM
7	ANM	ANM	ANM	ANM	ANM
69	HST	HST	HST	HST	HST
73	HST	HST	HST	HST	CHF MPR
152	HST	HST	HST	HST	HST
153	HST	HST	HST	HST	HST
179	HST	HST	HST	HST	HST/ CHF MPR
260	HST	HST	HST	HST	CHF MPR
274	HST	CHF MPR	HST	HST	CHF MPR
304	HST	CHF MPR	HST	CHF MPR	CHF MPR
334	HST	CHF MPR	CHF MPR	CHF MPR	CHF MPR
335	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR
337	HST	CHF MPR	CHF MPR	CHF MPR	CHF MPR
344	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR
345	HST	CHF MPR	CHF MPR	CHF MPR	CHF MPR
19180	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR
19520	CHF MPR	HST	CHF MPR	CHF MPR	CHF MPR
19530	HST	HST	CHF MPR	CHF MPR	CHF MPR
19850	CHF MPR	HST	CHF MPR	CHF MPR	CHF MPR
19860	HST	HST	CHF MPR	CHF MPR	CHF MPR
19990	CHF MPR	HST	CHF MPR	CHF MPR	CHF MPR

SL SPLIT line – Upstream – Downstream

Time	575010000	577010000	577030000	577060000	578010000
0	HST	CHF MPR	CHF MPR	CHF MPR	CHF MPR
1	CHF MPR	CHF MPR	ANM	ANM	ANM
2	ANM	ANM	ANM	ANM	ANM
6	ANM	ANM	ANM	ANM	ANM
7	ANM	CHF MPR	ANM	ANM	ANM
8	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR
9	CHF MPR	CHF MPR	CHF MPR	CHF MPR	ANM
19	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR
26	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR
27	HST	CHF MPR	CHF MPR	CHF MPR	CHF MPR
19990	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR

10 SPES 92, FL DEG break

FL DEG break line

UPSTREAM	MOTOR VALVE	DOWNSTRAM	NOZZLE
560010000 (MIS)	561000000	562010000 562020000 562030000 562040000 562050000 562060000 562070000 562080000 (MIS) 562090000 562100000 562110000	563010000

UPSTREAM

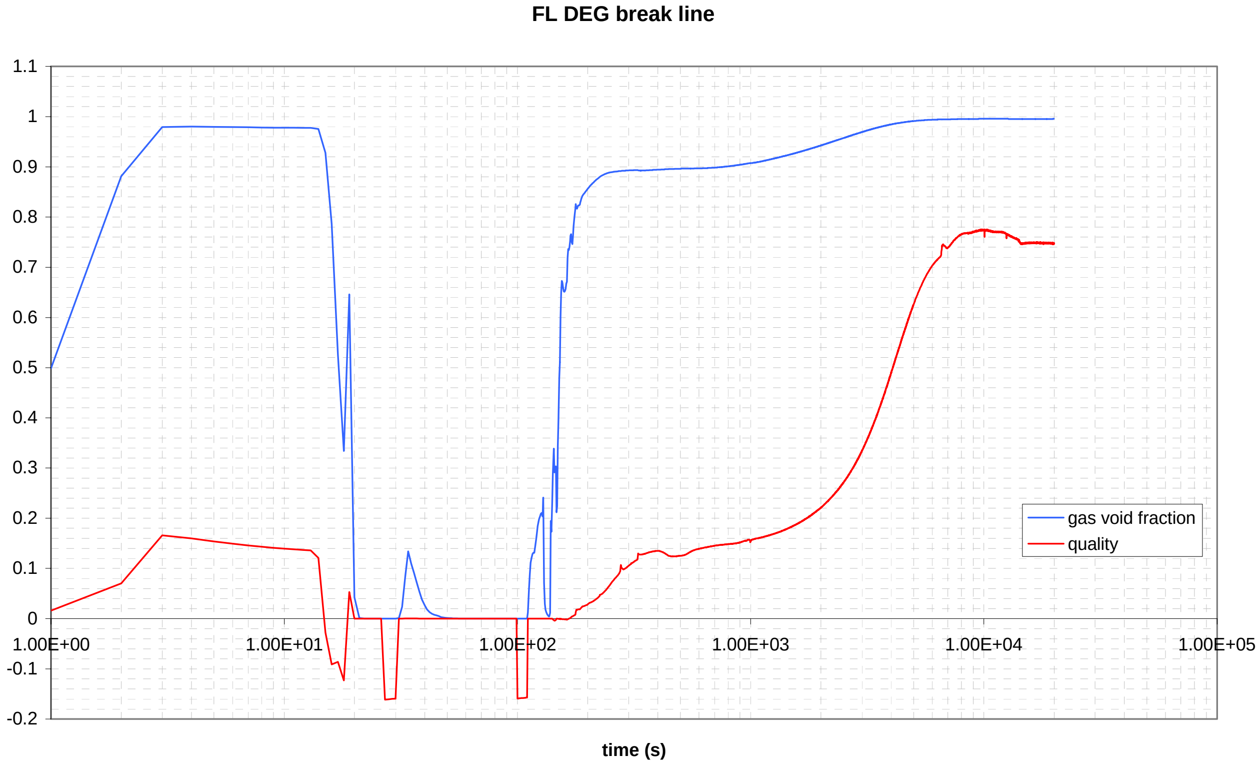

Fig. 10.1 Void fraction and quality history (FL DEG break line)

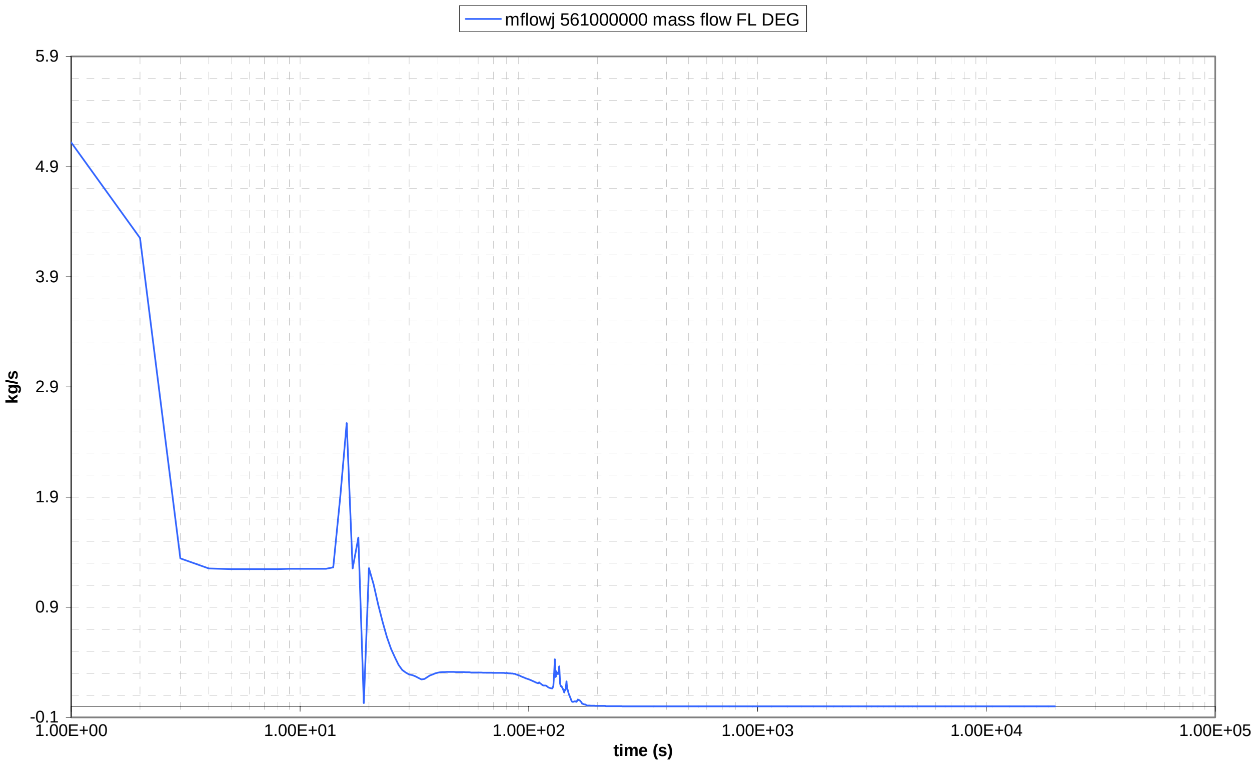

Fig. 10.2 Mass flow history (FL DEG break line)

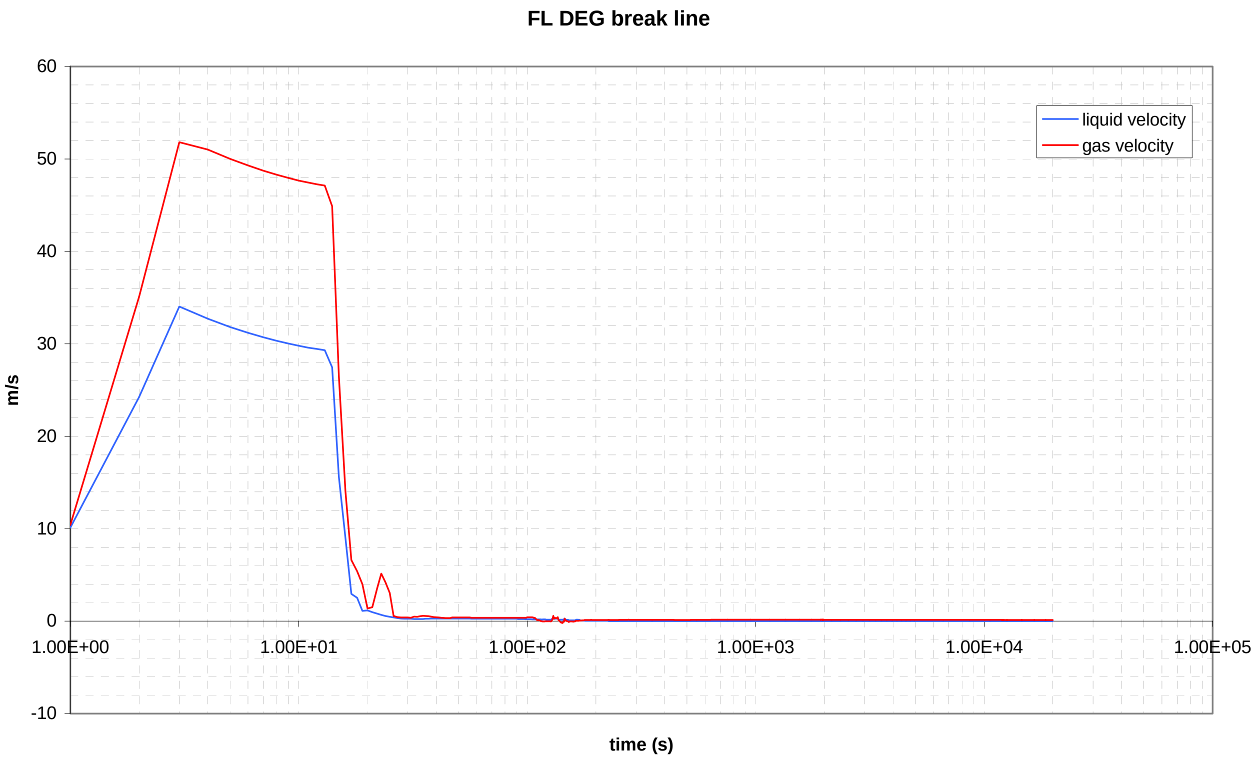

Fig. 10.3 Liquid and gas velocity history (FL DEG break line)

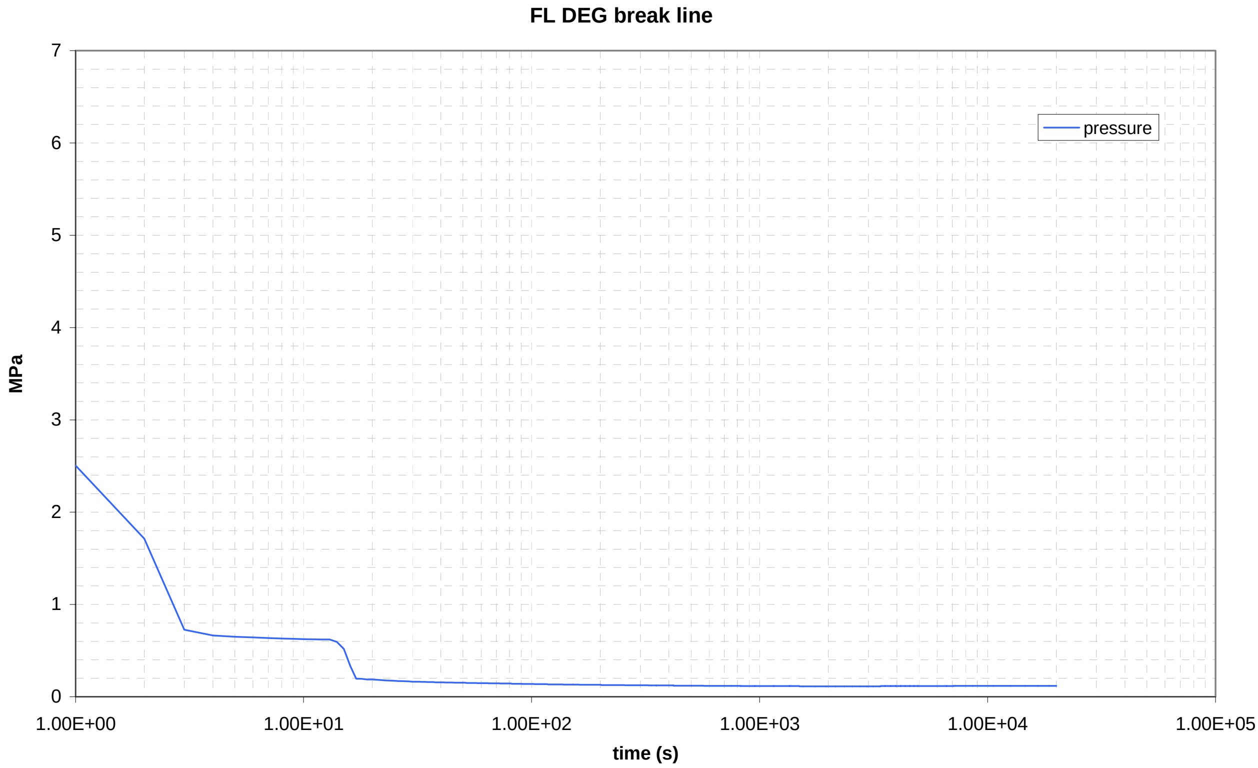

Fig. 10.4 Pressure history (FL DEG break line)

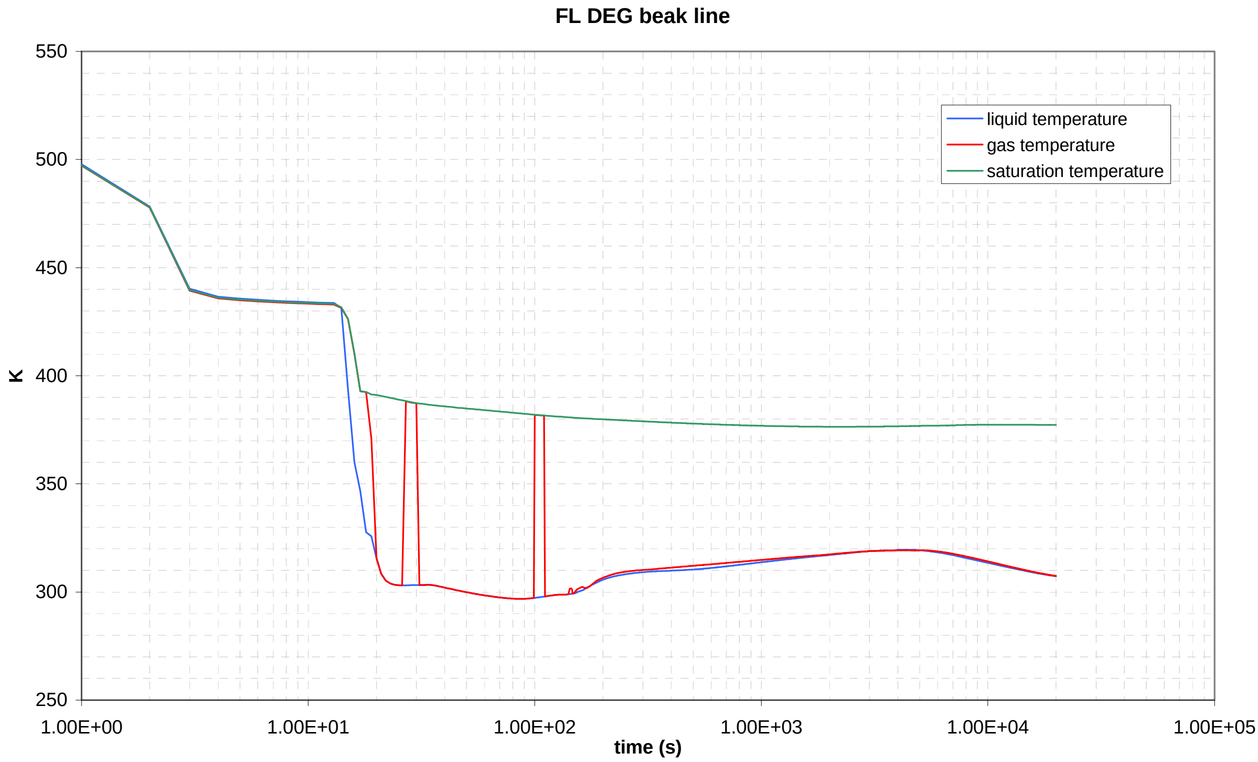

Fig. 10.5 Temperature history (FL DEG break line)

FL DEG break line	MIN	MAX

void fraction		0.0000	0.9813
volume equilibrium quality		-0.2799	0.4441
mass flow rate	kg/s	0.0000	5.1198
liquid velocity	m/s	0.0000	34.0266
gas velocity	m/s	-0.1924	51.8101
liquid temperature	K	296.7980	497.8300
gas temperature	K	296.7980	551.0530
pressure	Mpa	0.1137	6.2161

Table A10: Main two phase flow variable ranges

11. FL SPLIT break line

UPSTREAM	MOTOR VALVE	DOWNSTRAM	NOZZLE
565010000 (MIS)	566000000	567010000 567020000 567030000 567040000 567050000 567060000 567070000 567080000 (MIS) 567090000 567100000 567110000	568010000

UPSTREAM

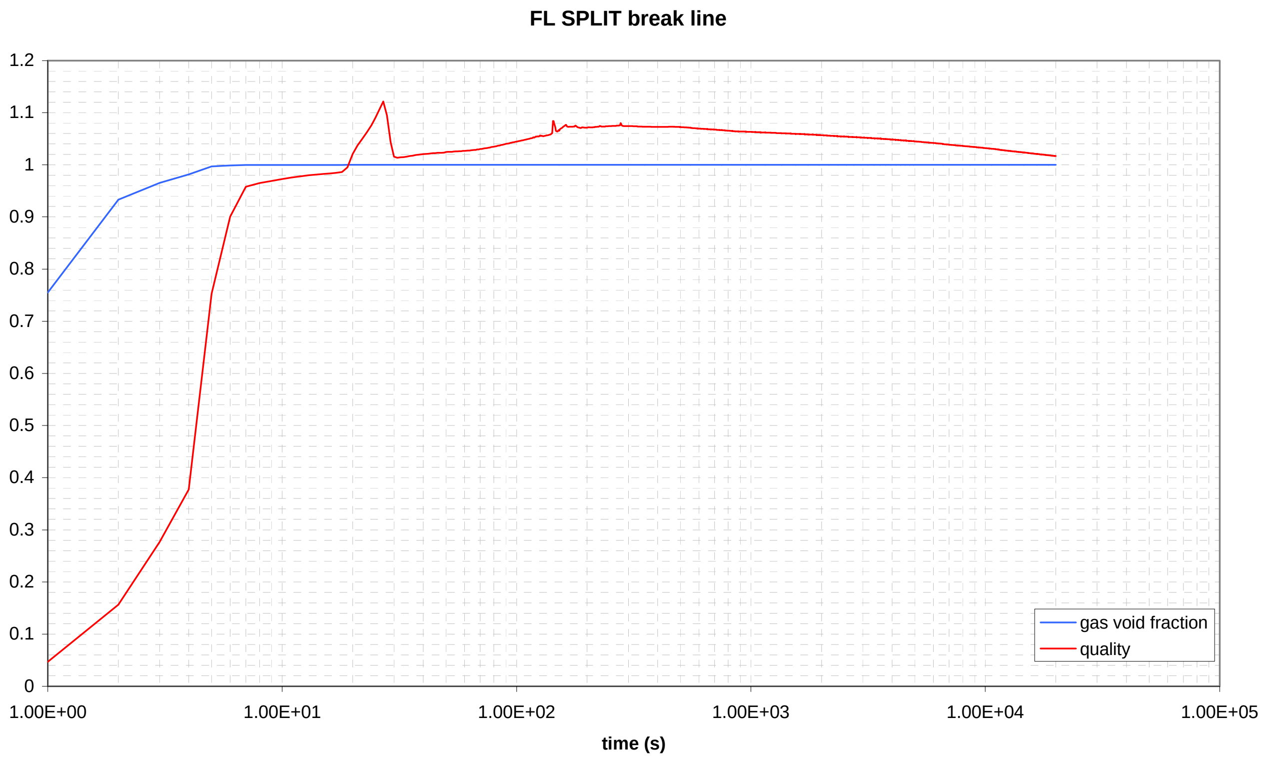

Fig. A11.1 Void fraction and quality history (FL SPLIT break line)

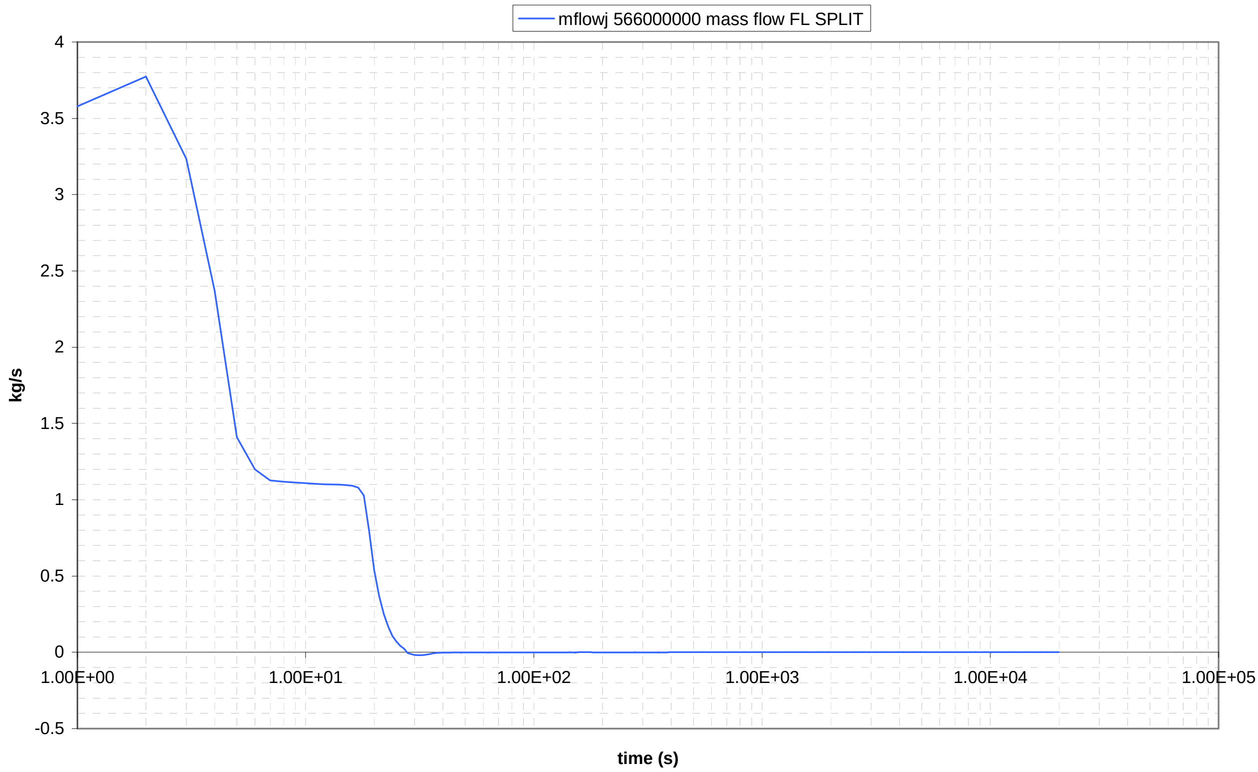

Fig. A11.2 Mass flow history (FL SPLIT break line)

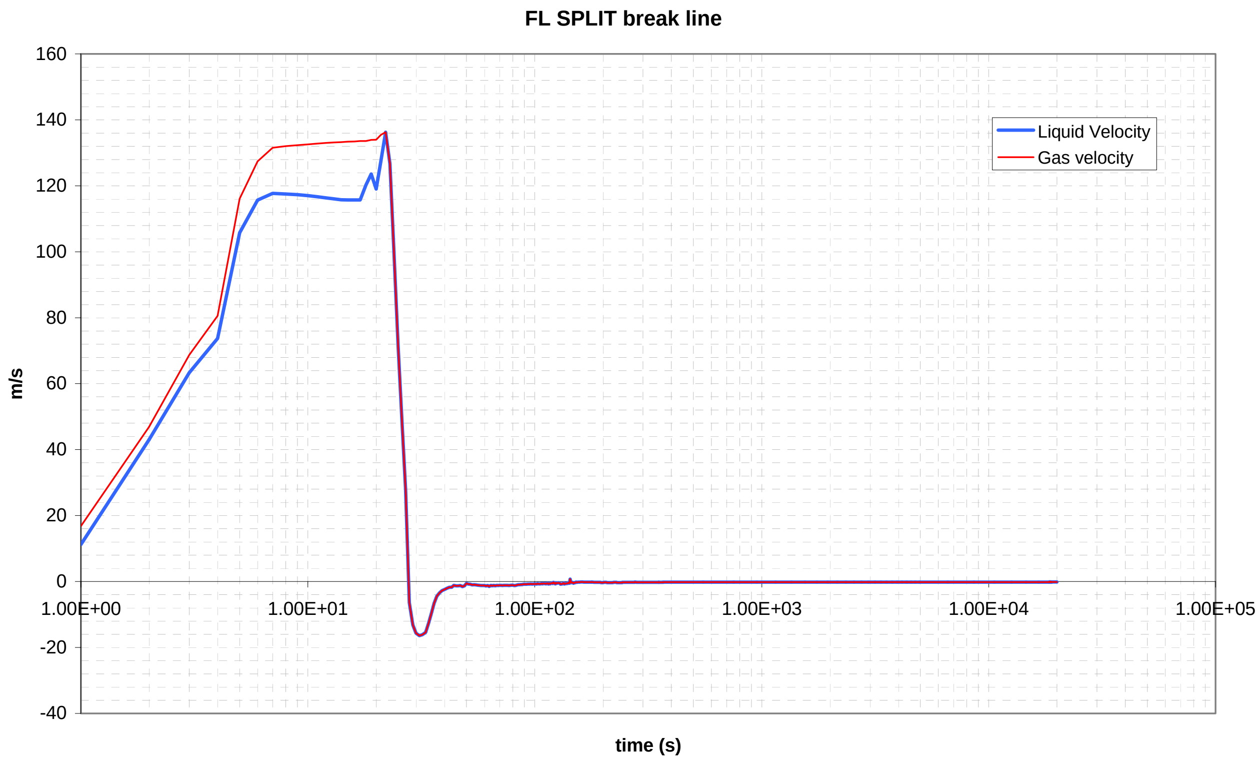

Fig. A11.3 Liquid angìd gas velocity history (FL SPLIT break line)

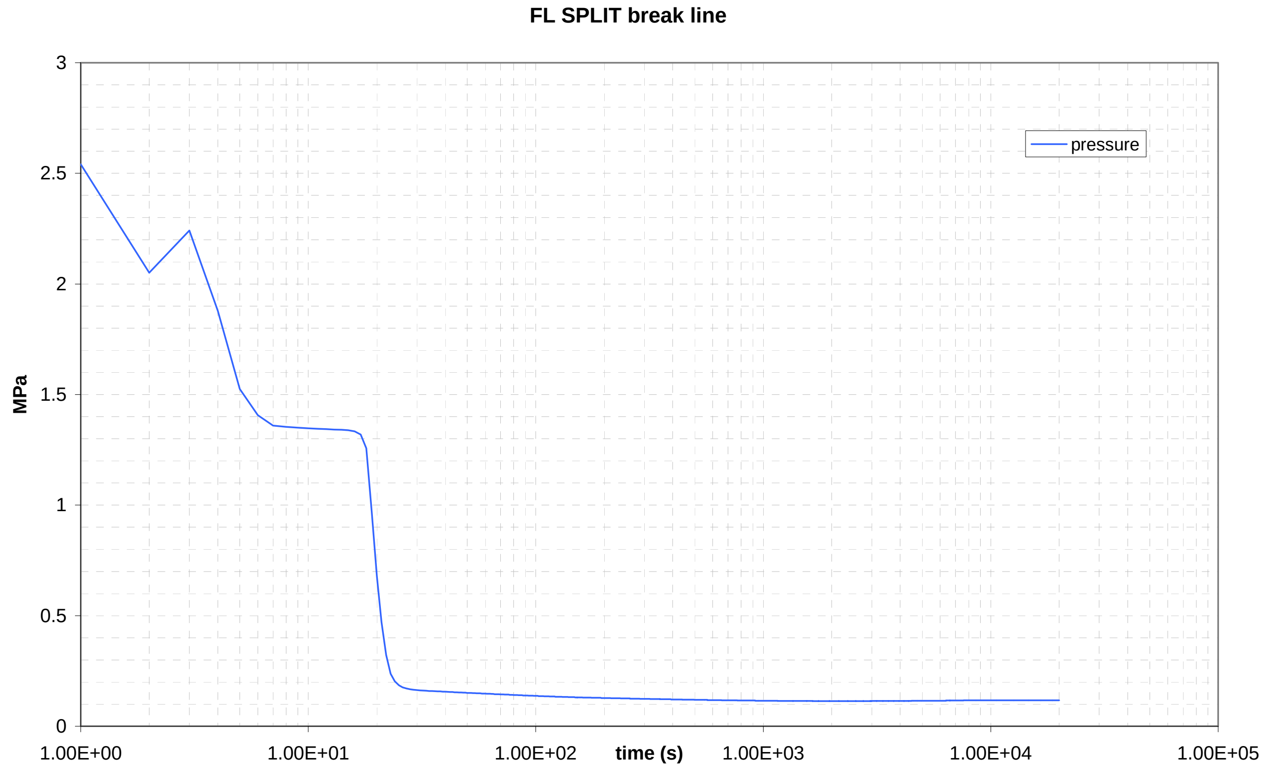

Fig. A11.4 Pressure history (FL SPLIT break line)

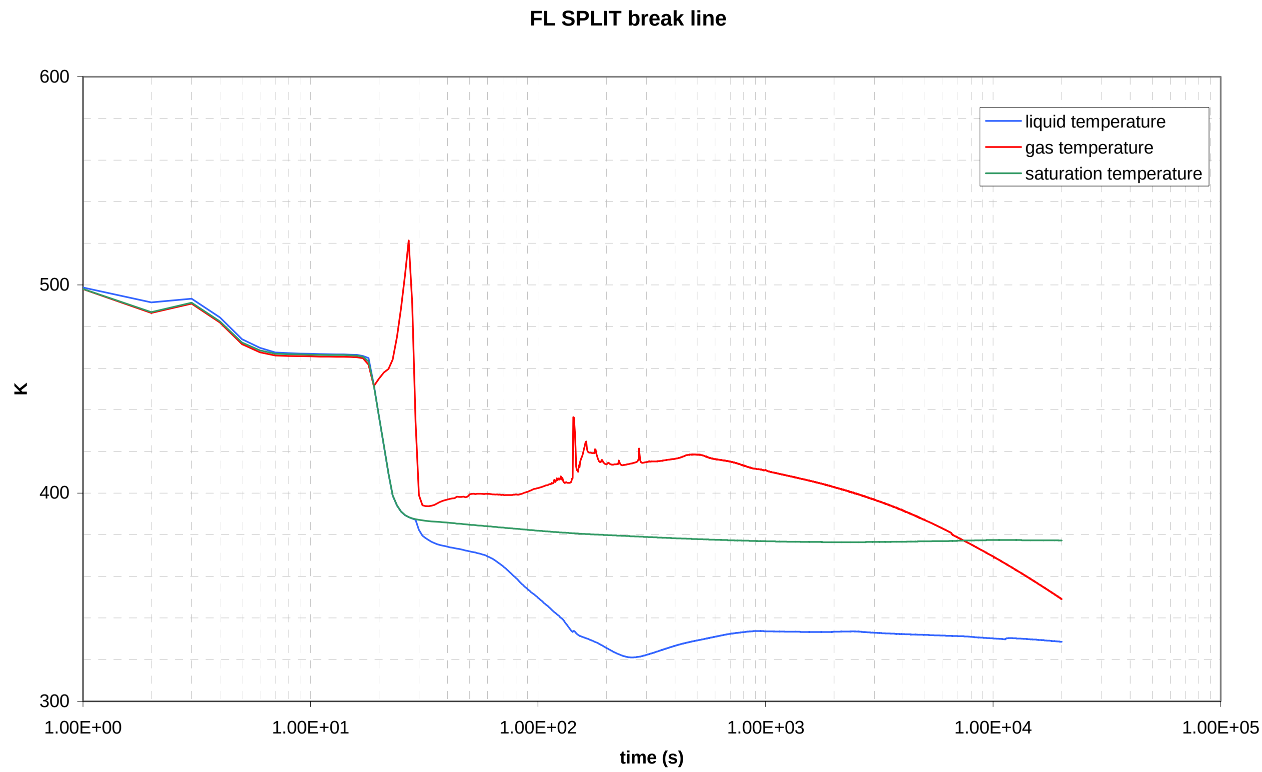

Fig. A11.5 Temperature history (FL SPLIT break line)

FL SPLIT break line	MIN MAX

void fraction		0.0000	1.0000
volume equilibrium quality		-0.2799	1.1217
mass flow rate	kg/s	-0.0192	3.7740
liquid velocity	m/s	-16.3977	136.2470
gas velocity	m/s	-16.3977	136.2470
liquid temperature	K	321.0650	498.7680
gas temperature	K	393.0600	551.0490
pressure	Mpa	0.1137	6.2157

Table A11: Main two phase flow variable ranges

ADS lines flow during FL Split break line

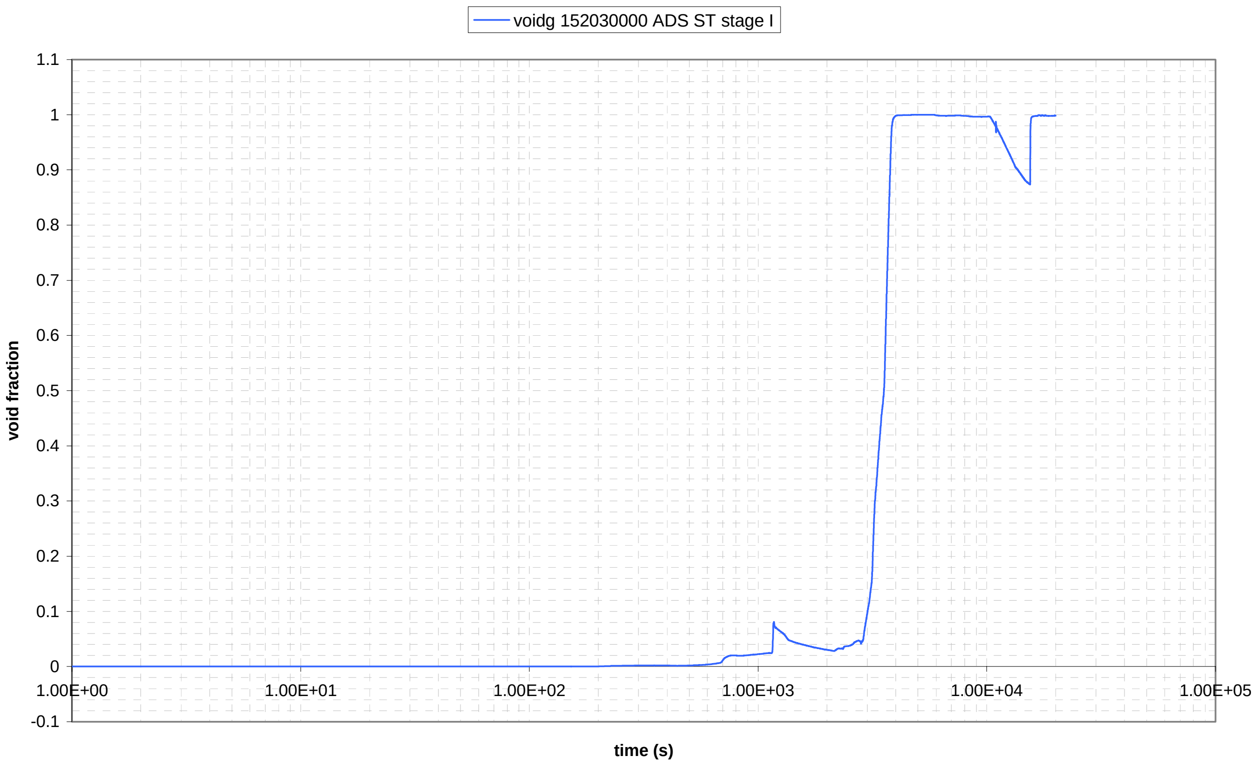

Fig. A11 void fraction ADS line

FL DEG break		**Volume**	**MIN**	**MAX**
ADS DT stage I	Void Fraction	142080000	0.7516	1.0000
ADS DT stage II	Void Fraction	132020000	0.7484	1.0000
ADS ST stage I	*Plot*			
ADS ST stage II	Void Fraction	135020000	0.0000	0.8031
ADS DT stage I	Mass Flow	143000000	0.0000	0.0000
ADS DT stage II	Mass Flow	144000000	0.0000	0.0000
ADS ST stage I	Mass Flow	153000000	0.0000	0.0000
ADS ST stage II	Mass Flow	154000000	0.0000	0.0000

FLOW REGIMES: ***FL DEG break – Upstream – Downstream***

Time	560010000	562010000	562080000	562110000	563010000
0	BBY	CHF MPR	CHF MPR	CHF MPR	CHF MPR
1	BBY	ANM	ANM	ANM	ANM
2	ANM	ANM	ANM	ANM	ANM
10	ANM	ANM	ANM	ANM	ANM
14	ANM	ANM	ANM	ANM	HST
15	ANM	ANM	HST	HST	HST
20	HST	HST	HST	HST	HST
32	BBY	HST	HST	HST	HST
44	HST	HST	HST	HST	HST
111	BBY	HST	HST	HST	HST
133	HST	HST	HST	HST	HST
134	BBY	HST	HST	HST	HST
135	HST	HST	HST	HST	HST
138	BBY	HST	HST	HST	HST
19990	HST	HST	HST	HST	HST

FL SPLIT break – Upstream – Downstream

Time	565010000	567010000	567080000	567110000	568010000
0	BBY	CHF MPR	HST	CHF MPR	CHF MPR
1	SLG	ANM	ANM	ANM	ANM
2	ANM	ANM	ANM	ANM	ANM
15	ANM	ANM	ANM	ANM	ANM
17	ANM	CHF MPR	ANM	ANM	ANM
18	CHF MPR	CHF MPR	ANM	ANM	ANM
20	CHF MPR	CHF MPR	CHF MPR	ANM	ANM
22	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR
23	CHF MPR	CHF MPR	CHF MPR	CHF MPR	HST
24	CHF MPR	CHF MPR	CHF MPR	HST	HST
19990	CHF MPR	CHF MPR	CHF MPR	CHF MPR	CHF MPR