

DEVELOPMENT OF COMPUTER PROGRAM
FOR FIRE SUPPRESSANT FLUID FLOW

FINAL TECHNICAL REPORT
VOLUME II
INPUT MANUAL FOR THE PROGRAM
EXPERIMENTAL DATA
ASSESSMENT OF THE PROGRAM

by

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It is noted that the present computer program was developed from a base computer program, RELAPS/MOD3, developed originally at the Idaho National Engineering Laboratory for nuclear reactor safety analysis under the sponsorship of the U.S. Nuclear Regulatory Commission.

ABSTRACT

A computer program has been developed for predicting the hydraulic performance of delivery systems of fire-suppressant fluids. The program was developed under the Next Generation Fire Suppression Technology Program being managed by the National Institute of Standards and Technology.

The program is based on a one-dimensional, two-fluid model of two-phase flow. In this model, separate conservation equations are written for the liquid and gas phases for mass, momentum and energy. Constitutive relationships are specified for interphase transport of mass, momentum and energy. Heat transfer between the fluid and passive structures such as pipe walls can be modeled. The program also contains built-in models for wall friction and two-phase critical flow. The transport of non-condensable gas in the system, namely the Nitrogen fill gas, as well as the Nitrogen released from solution during agent discharge, is modeled via separate mass conservation equations, with constitutive relations to specify the rate of gas release. The conservation equations are solved using a semi-implicit numerical method, with user-supplied boundary and initial conditions.

The program was deliberately made flexible in terms of types of fluids and piping layout. The current version of the program allows the user to select any one of five fluids – water, Halon-1301, CO₂, HFC-227ea or HFC-125. Modules are available in the program with which the user can model a delivery system, including one or more supply tanks and a combination of piping networks. The user can also model valves in the system, with specified valve opening times if needed.

The suppressant discharge is a highly transient process, generally lasting less than a second to few seconds. The program was benchmarked against transient experimental data available in the literature, as well as experiments conducted as a part of this project, on the discharge of HFC-227ea and HFC-125 in a specially prepared discharge loop. The present experiments lasted between 1.5 to 6 seconds. In addition to transient system pressure at various points, these experiments also measured critical parameters, such as the transient mass discharge history, fluid temperature and the void fraction near the exit. These are first dynamic measurements of mass flow rate, fluid temperatures and void fraction during suppression discharge. This allowed a more comprehensive assessment of the computer program than possible with previously available experimental data. The results of the assessment showed that the program is capable of predicting the performance of various delivery systems with several fluids.

This report is prepared in two volumes. First volume provides a detailed description of the experimental work and discussion of the results. It also includes a brief description of the theory and numerical solution method, instructions for installation on a personal computer with the WINDOWS operating system, and instructions on preparation of the input needed to describe the system being analyzed. Volume II of the report consists of three appendices: a) an input manual for the computer program, b) information on the experimental data, and c) comparison of the present data to predictions of the computer program.

INTRODUCTION

Included here in Volume II is substantial information in regards to “experimental data” and “code assessment.” Also included in this volume is an “input manual” for the computer program prepared in this project.

Appendix A contains the input manual for the computer program developed in the present work.

Appendix B presents the experimental data obtained at the Lehigh University test facility. Experimental data for a total of 21 test runs are provided.

Appendix C presents comparisons of code predictions with the data from 18 experimental runs shown in Appendix B.

APPENDIX A

INPUT MANUAL FOR THE COMPUTER PROGRAM FSP

FSP

VERSION 1.0

**A COMPUTER PROGRAM FOR PREDICTING PERFORMANCE OF
FIRE-SUPPRESSANT FLUID DELIVERY SYSTEMS**

APPENDIX A

USER INPUT MANUAL

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ACKNOWLEDGEMENTS

This computer program, FSP, was developed under the Next Generation Fire Suppression Technology Program (NGP) managed by the National Institute of Standards and Technology (NIST). Dr. Richard Gann and Dr. William Grosshandler of NIST provided valuable guidance during program development. Dr. Jiann Yang of NIST provided needed information on fluid properties. Their support is gratefully acknowledged.

It is noted that this program was developed from a base computer program, RELAP5/MOD3, developed originally at the Idaho National Engineering Laboratory for nuclear reactor safety analysis under the sponsorship of the U.S. Nuclear Regulatory Commission.

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INTRODUCTION

FSP is a modular computer program, in the sense that the user describes a problem using a set of modules (or components). This description of the problem is contained in an 'input file' created by the user. The purpose of this manual is to describe how the user can create this input file.

The discussion below provides some basic introductory information. It describes the data deck organization and data card requirements for the problems modeled by the FSP code. Subsequent sections contain descriptions of the various components available in FSP with which the user can set up an input model.

Control Format

Input is described in terms of an input file, developed by the user, whose name is restricted to 8 characters or less, with an extension 'i'. The FSP code will generate an output file and a restart file with the same filename, but with extensions 'o' and 'r' respectively. The input file consists of a set of input records or cards, where an input record or card is an 80-character record. Usually, this 80-character record is one line of the input file. The word 'card' is a holdover from the times when punched cards were used to enter input data. In this manual, the word 'card' simply means an input record, generally occupying one line of the input file. The program attempts to read a 96-character record. If the actual input record is smaller, blank characters are added to the end of the input record to extend it to 96 characters. Each 96-character input record, preceded by a sequential card number starting at one and incrementing by one, is printed as the first part of a problem output. Only the first 80 characters are used for input; the additional 16 columns are for use with editors or utility programs such as UPDATE. Most interactive editors allow the input of at least 80 character records.

With many terminals allowing only 80 characters per line, it is convenient to limit the data record to 72 characters so that the data and editor supplied line numbers fit on one line (eight columns for line number and separator, 72 columns of data). Some editors provide for the optional storing of editor line numbers following the data portion of the record. If the data field is 72 columns, these editors may store the line numbers in columns 73 to 80. These line numbers will be processed as input, since the program uses the first 80 characters. To avoid this, either request the editor to store line numbers starting at character position 81, put a terminating character before the line number, or don't store the line numbers. The line numbers, if saved, are listed in the output echo of the input data.

If the UPDATE program is used to maintain the input deck, the update command must be used to specify that the card data are 80 columns instead of the default of 72.

Data Deck Organization

A problem input deck consists of at least one title card, optional comment cards, data cards, and a terminator card. A list of these input cards is printed at the beginning of each problem in the output file. The order of the title, data, and comment cards is not critical except that only the

last title card and, in the case of data cards having duplicate data card numbers, only the last data card is used. It is recommended that for a base deck, the title card be first, followed by data cards in card number order. Comment cards should be used freely to document the input. For parameter studies and for temporary changes, a new title card with the inserted, modified, and deleted data cards and identifying comment cards should be placed just ahead of the terminating card. In this manner, a base deck is maintained, yet changes are easily made.

When card format punctuation errors, such as an alphanumeric character in numeric fields are detected, a line containing a caret (^) located under the character causing the error and a message giving the card column of the error are printed. An error flag is set such that input processing continues, but the problem is terminated at the end of input processing. A standard error message (error message preceded by *****) is printed if a card error is found. Usually a card error will cause additional error comments to be printed during further input processing when the program attempts to process the erroneous data.

Title Card

A title card must be entered for each problem. A title card is identified by an equal sign (=) as the first nonblank character. The title (remainder of the title card) is printed as the second line of the first page following the list of input data. If more than one title card is entered, the last one entered is used.

Comment Cards

An asterisk (*) or a dollar sign (\$) appearing as the first nonblank character identifies the card as a comment card. Blank cards are treated as comment cards. The only processing of comment cards is the printing of their contents. Comment cards may be placed anywhere in the input deck except before continuation cards.

Data Cards

Data cards may contain varying numbers of fields that may be integer, real (floating point), or alphanumeric. Blanks preceding and following fields are ignored. The first field on a data card is a card identification number that must be an unsigned integer. The value for this number depends upon the data being entered and will be defined for each type. If the first field has an error or is not an integer, an error flag is set. Consequently, data on the card are not used, and the card is identified by the card sequence number in the list of unused data cards. After each card number and the accompanying data are read, the card number is compared to previously entered card numbers. If a matching card number is found, the data entered on the previous card are replaced by data from the current card. If the card being processed contains only a card number, the card number and data from the last previous card with that card number are deleted. Deleting a nonexistent card is not considered an error. If a card causes replacement or deletion of data, a statement is printed indicating that the card is a replacement card. Comment information may follow the data fields on any data card by beginning the comment with an asterisk (*) or dollar (\$) sign.

A numeric field must begin with either a digit (0 through 9), a sign (+ or -), or a decimal point (.). A comma or blank (with one exception, subsequently noted) terminates the numeric field. The numeric field has a number part and optionally an exponent part. A numeric field without a decimal point or an exponent is an integer field; a number with either a decimal point, an exponent, or both is a real field. A real number without a decimal point (i.e., with an exponent) is assumed to have a decimal point immediately in front of the first digit. The exponent part denotes the power of ten to be applied to the number part of the field. The exponent part has an E or D, a sign (+ or -), or both followed by a number giving the power of ten. These rules for real numbers are identical to those for entering data in FORTRAN E or F fields except that no blanks (with one exception) are allowed between characters to allow real data written by FORTRAN programs to be read. The exception is that a blank following an E or D denoting an exponent is treated as a plus sign. Acceptable ways of entering real numbers, all corresponding to the quantity 12.45, are illustrated by the following six fields: 12.45, +12.45, 0.1245+2, 1.245+1, 1.245e 1, 1.245d+1.

Alphanumeric fields have three forms. The most common alphanumeric form is a field that begins with a letter and terminates with a blank, a comma, or the end of the card. After the first alphabetic character, any characters except commas and blanks are allowed. The second form is a series of characters delimited by quotes (``) or apostrophes ('). Either a quote or an apostrophe initiates the field, and the same character terminates the field. The delimiters are not part of the alphanumeric word. If the delimiter character is also a desired character within the field, two adjacent delimiting characters are treated as a character in the field. The third alphanumeric form is entered as nHz, where n is the number of characters in the field, and the field starts at the first column to the right of H and extends for n columns. With the exception of the delimiters (even these can be entered if entered in pairs), the last two alphanumeric forms can include any desired characters. In all cases, the maximum number of alphanumeric characters that can be stored in a word is eight. If the number of characters is less than eight, the word is left justified and padded to the right with blanks. If more than eight characters are entered, the field generates as many words as needed to store the field, eight characters per word, and the last word is padded with blanks as needed. Regardless of the alphanumeric type, at least one blank or comma must separate the field from the next field.

Note that the CDC-7600-6600 class of computers stores ten characters per word, while most other computers (e.g., CRAY, Cyber 205, and IBM) hold only eight characters per word. All alphanumeric words required by the FSP code, such as component types, system names, or processing options, have thus been limited to eight characters. It is recommended that the user limit all other one-word alphanumeric quantities to eight characters so that input decks can be easily used on all computer versions. Examples of such input are alphanumeric names entered to aid identification of components in output edits.

Continuation Cards

A continuation card, indicated by a plus sign (+) as the first nonblank character on a card, may follow a data card or another continuation card. Fields on each card must be complete, that is, a field may not start on one card and be continued on the next card. The data card and each continuation card may have a comment field starting with an asterisk (*) or dollar (\$) sign. No card number field is entered on the continuation card, since continuation cards merely extend the

amount of information that can be entered under one card number. Deleting a card deletes the data card and any associated continuation cards.

Terminator Cards

The input data are terminated by a card with a slash or a period. The slash and period cards have a slash (/) and a period (.), respectively, as the first nonblank character. Comments may follow the slash and period on these cards. When a slash card is used as the problem terminator, the list of card numbers and associated data used in a problem is passed to the next problem. Cards entered for the next problem are added to the passed list or act as replacement cards, depending on the card number. The resulting input is the same as if all previous slash cards were removed from the input data up to the last period card or the beginning of the input data. When a period card is used as the problem terminator, all previous input is erased before the input to the next problem is processed.

Sequential Expansion Format

Several different types of input are specified in sequential expansion format. This format consists of sets of data, each set containing one or more data items followed by an integer. The data items are the parameters to be expanded, and the integer is the termination point for the expansion. The expansion begins at one more than the termination point of the previous set and continues to the termination point of the current set. For the first set, the expansion begins at one. The termination points are generally volume, junction, or mesh point numbers, and always form a strictly increasing sequence. The input description will indicate the number of words per set (always at least two) and the last terminating point. The terminating point of the last expansion set must equal the last terminating point. Two examples are given. For the volume flow areas in a pipe component, the format is two words per set in sequential expansion format for *nv* sets. Using the number of volumes in the pipe (*nv*) as 10, the volume flow areas could be entered as:
0010101 0.01,10.

In this case, the volume flow areas for volumes 1 through 10 have the value of 0.01. The second example shows how the pipe volume friction data could be input. The input consists of three words per set for *nv* sets. The three words designate the wall roughness, hydraulic diameter (input of zero causes the code to calculate it), and volume number. Possible data might be:

```
0010801 1.0-6,0,8 1.0-3,0,9  
0010802 1.0-6,0,10
```

Here, volumes 1 through 8 and 10 have the same values, and volume 9 has a different value.

Upper/Lower Case Sensitivity

Historically, computer systems allowed only upper case alphabetic characters. Now, many systems have upper and lower case alphabetic characters, and some applications are case sensitive, others are not. The FSP code was developed under the UNIX operating system, where the required input must be in lower case. At installations with both upper and lower case

capability, there are utilities and editors that can easily switch alphabetic characters to the desired case. It is expected that many users of FSP will use typical PC operating systems, such as WINDOWS, which are not case sensitive. Nevertheless, for ease of portability of the input decks, it is recommended that users stick with lower case alphabetic characters.

Data Card Requirements

In the following description of the data cards, the card number is given with a descriptive title of the data contained on the card. Next, an explanation is given of any variable data that are included in the card number. Then, the order of the data, the type, and the description of the data item are given. The type is indicated by A for alphanumeric, I for integer, and R for real.

Card 100, Problem Type and Option

This card is always required.

W1(A) Problem type. One of the following can be entered: NEW, RESTART, or STRIP.

NEW specifies a new simulation problem. RESTART specifies continuation from some point in a previous problem using information from the RSTPLT file. STRIP specifies that data are to be extracted (stripped) from the RSTPLT file, for example for creating plots, and only the data specified are written to the STRIP file.

Most users will use NEW and that is the recommended option. The RESTART option will not be necessary for most users because typical problems will be relatively small. Hence it is easier to start a problem over from the beginning rather than to attempt to restart it from an intermediate time. The STRIP option is no longer necessary. It was intended for stripping needed output variables from the Restart file, for plotting, etc. In the current method of running FSP, an alternate procedure has been developed, whereby the user lists the desired plot variables in a file with extension 'inp' (example *filename.inp*) and then runs the program *Rstrip*.

W2(A) Problem option. This word is needed if W1 is NEW or RESTART and is optional if W1 is STRIP. If NEW or RESTART is entered, enter either STDY-ST or TRANSNT to specify the type of simulation. Note the cautions in the discussion below under Card 103 when the problem option is changed from STDY-ST to TRANSNT or vice versa. Users should normally use the TRANSNT option.

Card 101, Input Check or Run Option

This card is optional for all types.

W1(A) Option. Enter either INP-CHK or RUN; if this card is omitted, RUN is assumed. If INP-CHK is entered, the problem execution stops at the end of input processing; if RUN is entered, the problem is executed if no input errors are detected.

Card 102, Units Selection

This card is optional for all problem types. If the card is omitted, SI units are assumed for both input and output. If the card is used, enter either SI or BRITISH for each word. SI units used are the basic units, kg, m, s, and the basic combined units such as $\text{Pa} = \text{kg.m/s}^2.\text{m}^2$. British units are a mixture of lb (mass), ft, and s primarily, but pressure is in lbf/in^2 (lbf is pounds force), heat energy is in Btu, and power is in MW. Thermal conductivity and heat transfer units use s, not h.

W1(A) Input units.

W2(A) Output units. If this word is missing, SI units are assumed for output.

Card 103, Restart Input File Control Card

This card is not allowed for problem type NEW and is required for other problem types (W1 of Card 100). When the problem option (W2 on Card 100) is the same as the problem being restarted, the steady-state or transient is continued, and data on the RSTPLT file up to the point of restart are saved. If the restart continues from the point the previous problem terminated, restart and plot information is added to the end of the previous RSTPLT file. If the restart is prior to the termination point of the previous simulation, restart and plot data after the point of restart are overwritten by new results. A copy should be saved if RSTPLT files from each simulation are needed. If the problem options are different, data up to the point of restart are not saved, problem advancement time is reset to zero, and the RSTPLT file will contain information as if this problem type were NEW.

Some cautions should be observed when the problem advancement time is changed by changing the problem option from STDY-ST to TRANSNT, or vice versa, or the problem advancement time is reset through W1 on Card 200. Either or both of these could be specified at restart. When the advancement time is changed, the user is responsible for ensuring that models involving problem time will operate as intended. Affected models include trips using advancement time, control systems using time as an operand (does not include differentiation or integration with respect to time), and table lookup and interpolation using time as the independent variable. If necessary, trips, control systems, general tables, time-dependent volumes, junctions, and pump speed tables can all be reentered at restart. With normal modeling practices, little use of modeling features involving advancement time is needed for runs to steady state and accordingly little effort should be needed in switching from STDY-ST to TRANSNT. Because of the frequent use of time in logic to initiate failures, as part of safety systems, and used in establishing the delay times allowed in most table lookup and interpolation tables, required changes to a transient run may be extensive.

The program does make a change to delay control components when the advancement time is changed. The delay control component operates by maintaining a tabular past history of the delayed functions and using table lookup and interpolating to evaluate the delayed function. The

table consists of pairs of time values and the delayed function. When the problem time is changed, the time values in the history table and the time value to store the next point in the table are modified by adding the difference of the new advancement time and the old advancement time. The modified history table is as if the problem being restarted was run with the new advancement time. This may not be the desired change, and, in that case, the user can reenter the delay component.

W1(I) Restart number. This must be a number printed in one of the restart print messages (in the OUTPUT file) and whose associated restart information is stored in the RSTPLT file. If the problem type (W1 on Card 100) is STRIP, this number must be 0.

W2(A) Compress flag. This optional flag indicates whether the restart-plot file is written in a noncompressed or compressed format. If the word is not entered or if NCMRESS is entered, the restart plot file is assumed to be in noncompressed format. If CMPRESS is entered, the restart plot file is assumed to be in compressed format. This word is usually not needed.

W3-7(A) Restart plot file name. This optional alphanumeric entry can be used to enter the file name of the restart plot file. Up to forty characters may be entered as one alphanumeric field. (The code internally treats the field as up to five eight-character words.) The default file name for the restart plot file is rstplt. This may be overridden on Unix machines by using the -r option on the command line. Either the default name, the name from the command field, or the name from this field on a previous case may be overridden by this field. This word is usually not needed.

Card 104, Restart-Plot File Control Card

This card can be entered for NEW, RESTART, and STRIP options. For the strip option, this card controls the strip file, and the NONE option is not allowed. If this card is omitted, the restart-plot file is rewound at the end of the problem, but no further action is taken. The user may need to provide system control cards to dispose of the file. To prevent the restart-plot file from being written, a card with NONE must be entered. This card is usually not needed.

W1(A) Action. This word may not be blank. If the card is NONE, no restart-plot file is written. If this word is NCMRESS, the restart-plot file is written in noncompressed format. If this word is CMPRESS, the file is written in compressed mode. The NCMRESS and CMPRESS options may be entered only in NEW problems. In RESTART problems, this information is entered on the 103 card. For STRIP problems, the NONE option is not allowed.

W2-6(A) Restart plot file name. This optional alphanumeric entry can be used to enter the file name of the restart plot file. Up to forty characters may be entered as one alphanumeric field. (The code internally treats the field as up to five eight-character words.) The default file name for the restart plot file is rstplt. This may be overridden on Unix machines by using the -r option on the command line. Either the default name, the name from the command field, or the name from this field on a previous case may be overridden by this field. This information can be

entered only on NEW problems; in RESTART problems, this information may be entered on the 103 card.

Card 105, CPU Time Remaining and the Diagnostic Edit Card

This feature is not necessary for most users. It is not required.

Card 106, Noncondensable Dissolved Gas Release Parameters

This card is required for all calculations. It provides the needed parameters for the dissolved gas release model. Note that only SI units are accepted for this Card. This restriction applies only to this card. For other input, the units should be as defined by the user in Card 103.

W1(R) Release coefficient, Γ_0 , in the gas release model ($\text{kg}/\text{m}^3\text{-s}$). Typical values range between 1000 and 5000. This parameter determines the rate of gas release. Larger the value of this parameter, the higher the gas release rate.

W2(R) Critical radius for growth of nitrogen bubbles (m). Typical values range between $7.5\text{E-}09$ to $1.0\text{E}08$. This parameter determines the pressure at which gas will begin to be released. The smaller the critical radius, the lower the pressure at which gas release will be initiated.

W3(R) Initial system fill pressure (Pa). This is the pressure at which the supply vessel has reached equilibrium after being filled with the fire suppressant-liquid and the propellant gas (nitrogen).

W4(R) Initial system fill temperature (K). This is the temperature corresponding to the pressure in W3.

Card 110, Noncondensable Gas Species

This card is required for all calculations that use noncondensable gas.

W1-WN(A) Noncondensable gas type. Enter any number of words (maximum 5) of the following noncondensable gas types: argon, helium, hydrogen, nitrogen, xenon, krypton, air, or sf6. Typically, 'nitrogen' is the only noncondensable gas type in fire-suppressant delivery systems.

Card 115, Initial Mass Fraction for Each Noncondensable Gas Type

Skip this card if only one noncondensable gas type is used (for example, nitrogen). Card 115 is related to Card 110. This card is required if Card 110 is entered, unless only one species is entered on Card 110 and then the mass fraction is set to 1.0. The number of words on Card 115

must equal the number of words on Card 110. The sum of the mass fractions on each card must sum to one. The mass fractions on these cards are default values and are used for initial conditions of active volumes and for values of time-dependent volumes unless mass fractions are entered in the hydrodynamic component data. This card cannot be entered on a RESTART problem.

W1-WN(R) Mass fraction for each noncondensable gas type.

Cards 120 through 129, Hydrodynamic System Control and Fluid Type

Independent hydrodynamic systems can be described by the hydrodynamic component input. The term independent hydrodynamic systems means that there is no possibility of flow between the independent systems. A typical example would be the primary and secondary systems in a reactor where heat flows from the primary system to the secondary system in the steam generator but there is no fluid connection. If a tube rupture were modeled, the two systems would no longer be independent. Input processing lists an elevation for each volume in each independent hydrodynamic system and includes a check on elevation closure for each loop within a system. A reference volume is established for each system through input or default.

The processing for elevation changes and checks on proper loop closure is extended for moving problems. An elevation change in a volume is the component on the fixed z axis of a movement from one face of the volume to the opposite face. In a fixed problem, the only body force is gravity along the negative z axis. With translational and rotational movement, additional body forces with components in all three directions are possible. Analogous to elevations changes, the components along each fixed axis due to the face to face movements along each coordinate direction in a volume are required. In moving problems, the loop closure test and associated edited output is done for all three fixed axes.

These cards are optional for each system but these cards will be needed for most moving problems. If not entered for a system, that system contains H₂O as the fluid unless a different fluid is specified in hydrodynamic component data, and the lowest numbered volume in each system is the reference volume.

Additionally, the reference volume has a default elevation of zero for fixed problems and position coordinates of zero for a moving problem. These cards should not be entered in a RESTART problem. In fixed problems, the ability of entering a reference elevation is only a user convenience to perhaps facilitate checking edited elevation data against facility drawings. In moving problems, the information is used in computing rotation effects. The specification of the position coordinates of the reference volume implies an origin, and using volume input information, the position coordinates of each volume in the system. The rotation is assumed to be about the origin implied by the position of the reference volume. The position coordinates of each volume are updated each time step and the position data can be plotted or printed in minor edits. The effects of translation are included when computing forces on the fluid within a volume but are not included in the computation of position coordinates. Thus during rotation and translation, the coordinates may change but the magnitude of the position vector remains constant.

W1(I) Reference volume number. This must be a volume in the hydrodynamic system.

W2(R) Reference elevation of the volume center relative to a fixed z axis (m, ft).

W3(A) Fluid type. Enter H2O, Halon, CO2, R125 or R227ea. Note that entering Halon will activate properties for Halon-1301.

W4(A) Optional alphanumeric name of system used in output editing. *NONE* is used if this word not entered.

Cards 201 through 299, Time Step Control

At least one card of this series is required for NEW problems. If this series is entered for RESTART problems, it replaces the series from the problem being restarted. This series is not used for other problem types. Card numbers need not be consecutive.

W1(R) Time end for this set (s). This quantity must increase with increasing card number.

W2(R) Minimum time step (s). This quantity should be a positive number $< 1.0E-6$. If a larger number is entered, it is reset to $1.0E-6$.

W3(R) Maximum time step (s). This quantity is also called the requested time step. In transient problems (Word 2 = TRANSNT for Card 100), the user should be careful not to make this too large for the first time step.

W4(I) Control option (see Section 8.2 for a discussion of this input). This word has the packed format ssdt. It is not necessary to input leading zeros. For most applications, it is recommended that this word be entered as 00003. A further explanation of the various options is provided below.

The digits ss, that represent a number from 0 through 15, are used to control the printed content of the major edits. The number is treated as a four-bit binary number. If no bits are set (i.e., the number is 0), all the standard major printed output is given. If the first bit from the right is set (i.e., ss=1 if the other bits are not set), the heat structure temperature block is omitted. If the second bit from the right is set (i.e., ss=2 if the other bits are not set), the second portion of the junction block is omitted. If the third bit from the right is set (i.e., ss=4 if the other bits are not set), the third and fourth portions of the volume block is omitted. If the fourth bit from the right is set (i.e., ss=8 if the other bits are not set), the statistics block is omitted.

The digit d, which represents a number from 0 through 7, can be used to obtain extra output at every hydrodynamic time step. The number is treated as a three-bit binary number. If no bits are set (i.e., the number is 0), the standard output at the requested frequency using the maximum time step is obtained (see words 5 and 6 of this card). If the number is nonzero, output is obtained at each successful time step; and the bits indicate which output is obtained. If the first bit from the right is set (i.e., d=1 if the other bits are not set), major edits are obtained every successful time step. If the second bit from the right is set (i.e., d=2 if the other bits are not set), minor edits are obtained every successful time step. If the third bit from the right is set (i.e., d=4

if the other bits are not set), plot records are written every successful time step. These options should be used carefully, since considerable output can be generated.

The digits tt , that represent a number from 0 through 31, are used to control the time step. The number is treated as a four-bit binary number. The effect of no bits being set, i.e., 0 being entered, and the effect of each bit are first described followed by the recommended combination of bits. If no bits are set (i.e., the number is 0), no error estimate time step control is used, and the maximum time step is attempted for both hydrodynamic and heat structure advancement. The hydrodynamic time step, however, is reduced to the material Courant limit and further to the minimum time step for causes such as water property failures. If the first bit from the right is set (i.e., $tt=1$ if no other bits are set), the hydrodynamics advancement, in addition to the time step control when no bits are set, uses a mass error analysis to control the time step between the minimum and maximum time step. If the second bit from the right is set (i.e., $tt=2$ if the other bits are not set), the heat conduction/transfer time step is the same as the hydrodynamic time step; if the second bit from the right is not set, the heat conduction/transfer time step uses the maximum time step. If the third bit from the right is set (i.e., $tt=4$ if the other bits are not set), the heat conduction/transfer and hydrodynamics are coupled implicitly; if the third bit from the right is not set, the heat conduction/transfer and hydrodynamic advancements are done separately and the information between the models is coupled explicitly. If the fourth bit from the right is set (i.e., $tt=8$ if the other bits are not set), the nearly-implicit scheme is used to advance the hydrodynamics; if the fourth bit from the right is not set, the semi-implicit scheme is used to advance the hydrodynamics. If the fifth bit from the right is set (i.e., $tt=16$ if the other bits are not set), the test for convergence of a steady-state calculation is not made; if the fifth bit from the right is not set, the test for convergence of a steady-state calculation is made. We recommend not using tt equal to 0 except for special testing situations. The use of tt equal to 1 is possible if the maximum time step is kept sufficiently small to ensure that the explicit connection between the heat conduction/transfer and hydrodynamics calculations remains stable. If there is any doubt, use tt equal to or greater than 3 (sets first bit and second bit). Using tt equal to 3 or 11 specifies the semi-implicit or the nearly implicit advancement scheme, respectively, with both schemes using time step control, the heat conduction and hydrodynamics use the same time step, and the heat conduction/transfer and hydrodynamics are advanced separately. Using tt equal to 7 or 15 specifies the same features as tt equal to 3 or 11 and, in addition, specifies the implicit advancement of the heat conduction/transfer with the hydrodynamics. We recommend the nearly implicit scheme during a steady-state and/or self-initialization case problem where the time step is limited by the material Courant limit. The nearly implicit scheme can also be used during slower phases of a transient problem, though we advise the user that the answers may change somewhat from the semi-implicit scheme answers (depending on the time step size). (The nearly implicit advancement scheme is still under development; most of the verification and assessment for the code has been done with the semi-implicit advancement scheme.) We did not recommend use of the implicit coupling of the heat conduction/transfer and hydrodynamics in prior versions since the implicit coupling was only partially implemented. With the implicit coupling now complete, we encourage the use of tt equal to 7 or 15. When using the implicit coupling, the heat conduction time step must be the same as the hydrodynamic time step. This requirement is currently not enforced by the coding. In steady-state calculations, setting the fifth bit (adding 16) for the early part of the run can ensure the calculation runs to a user-specified time; then, setting the fifth bit off can allow the steady-state convergence to test control the termination of the problem.

W5(I) Minor edit and plot frequency. This is the number of maximum or requested time advances per minor edit and write of plot information. Essentially, this controls the frequency at which plot variables are stored in the Restart file. Typically, if the requested (maximum) time step is 0.001 second, plot variables will be stored every 0.01 second if this number is entered as 10. If the word is entered as 100, plot variables will be stored every 0.1 second. This is up to the user, depending on the degree of accuracy desired in plotting. The user should balance the accuracy needed with the amount of information stored (which directly affects the size of the Restart file) over the course of the calculation.

W6(I) Major edit frequency. This is the number of requested time advances per major edit. Usually, major edits are not necessary since most of the output information needed can be obtained via plots. Hence, a few major edits over the course of the calculation will suffice. Thus if a calculation is for a period of 5 seconds, and the requested (maximum) time step is 0.001 seconds, entering 1000 for this quantity will produce a major edit every 1 second, resulting in 5 major edits over the course of the calculation. This is typically all that would be required.

W7(I) Restart frequency. This is the number of requested time advances per write of restart information in the Restart file. This is the file which will be used to access the output of the code calculation. The Restart file needs to be written at least once, at the end of the calculation. Hence, if the requested time step is 0.001, and the course of the calculation is 5 seconds, a restart frequency of 5000 will ensure that a Restart file will be available at the calculation end time of 5 seconds.

CARDS 301 THROUGH 399, MINOR EDIT REQUESTS

These cards are optional for NEW and RESTART problems, are required for a REEDIT problem, and are not allowed for PLOT and STRIP problems. These cards are only needed if the user wants to see certain variables printed in the output file at the frequency specified on the Time Step Control Cards (Cards 201 through 299). If these cards are not present, no minor edits are printed. If these cards are present, minor edits are generated, and the order of the printed quantities is given by the card number of the request card. One request is entered per card, and the card numbers need not be consecutive. For RESTART problems, if these cards are entered, all the cards from the previous problem are deleted.

In most calculations, the user will probably want to see plots rather than hard copy output. Hence these cards need not be present in the '.i' file. Note that when plots are required, these variables can be requested via the '.inp' file, using the variable names and the parameter number as specified below.

W1(A) Variable code (alphanumeric).

W2(I) Parameter (numeric).

Words 1 and 2 form the variable request code pair. The quantities that can be edited and the input required are listed below. The list below is a subset of a larger set of variables that the user can access. Only the subset is shown here because these variables are the most likely variables that a user may want to plot in typical fire-suppression system analyses.

General Quantities

DT	The current time step (s). The parameter is 0.
EMASS	Estimate of mass error in all the systems (kg, lb). The parameter is zero.
NULL	Specifies null field. Allowed only on trip cards. The parameter is zero.
TIME	Time (s). The parameter is zero. This request cannot be used for minor edit requests. It is used in Trip cards (cards 401-599 or 601-799).
TIMEOF	Time of trip occurring (s). The parameter is the trip number. This request is allowed only on trip cards.
TMASS	Total mass of liquid, steam, and noncondensables in all the systems (kg, lb). The parameter is zero.

Component Quantities

The quantities listed below are unique to certain components; for example, a valve area can only be requested for a valve component. The parameter is the component number, i.e., the three-digit number ccc used in the input cards.

VLVAREA	This is the ratio of the current valve physical area to the junction area. The junction area is the fully open valve physical area for the smooth area option and the minimum of the two connecting volumes for the abrupt area change.
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Volume Quantities

For most of the following variable codes, the parameter is the volume number, i.e., the nine-digit number ccnn0000 printed in the major edit. The parameter is ccc010000 for a single volume; ccc010000 for a time-dependent volume; ccnn0000 for a volume in a pipe component ($0 < nn < 100$); and ccc010000 for the volume in a branch. Some of the quantities are associated with the coordinate directions in the volume, and these quantities are computed for each coordinate direction in use. The parameter for the coordinate direction-related quantities is the volume number plus F, where F is described below. The quantities requiring the volume number plus F are so identified.

Every volume has at least one coordinate direction, and some volumes may have up to three orthogonal coordinate directions. Each coordinate has an inlet face and an outlet face. Faces are numbered 1 through 6, where faces 1 and 2 are the inlet and outlet faces associated with coordinate 1 (or x), respectively, faces 3 and 4 are inlet and outlet faces associated with coordinate 2 (or y), and faces 5 and 6 are inlet and outlet faces associated with coordinate 3 (or z). All volumes use coordinate 1. The quantity F to be added to the volume number to form the

parameter used with coordinate direction related quantities is 0 or the face number. When F is 0 (i.e., just the volume number), 1, or 2, the volume velocity is for coordinate 1. When F is 3 or 4, the volume velocity is for coordinate 2, and when F is 5 or 6, the volume velocity is for coordinate 3. For the underlined quantities followed by an asterisk in the list below, the coordinate-dependent quantities for coordinate 1 are automatically written to the restart-plot records using the parameter with F equal to 0. The other coordinate-dependent quantities can be written to the plot records using the 208 card series. Input checks are made to ensure the parameter specifies a volume coordinate direction that is in use.

Code Quantity

AVOL Area of the volume (m^2 , ft^2); the parameter is the volume number plus F.
 CSUBPF Liquid specific heat at bulk conditions (J/Kg-K, BTU/lbm-F)
 CSUBPG Vapor specific heat at bulk conditions (J/Kg-K, BTU/lbm-F)
 ENTHN Enthalpy of released nitrogen (J/Kg, BTU/lbm).
 ENTHSO Enthalpy of dissolved nitrogen (J/Kg, BTU/lbm).
 GAMMAI Vapor generation rate in the bulk per unit volume ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$).
 GAMMAN Noncondensable generation rate per unit volume (kg/m^3 , lbm/ft^3).
 GAMMAS Negative of nitrogen gas release rate per unit volume (kg/m^3 , lbm/ft^3).
 HVMIX Enthalpy of the liquid and vapor (J/kg, Btu/lb).
 P Volume pressure (Pa, $lb \cdot f/in^2$).
 PPS Vapor partial pressure (Pa, $lb \cdot f/in^2$).
 Q Total volume heat source from the wall (W, Btu/s).
 QUALA Volume noncondensable mass fraction.
 QUALE Volume equilibrium quality. The quality uses phasic enthalpies, with the mixture enthalpy calculated using the flow quality.
 QUALS Volume static quality.
 RHO Total density (kg/m^3 , lb/ft^3).
 RHOF Liquid density (kg/m^3 , lb/ft^3).
 RHOG Vapor density (kg/m^3 , lb/ft^3).
 RHOM Total density for the mass error check (kg/m^3 , lb/ft^3).
 SATHF Liquid specific enthalpy at saturation conditions using partial pressure of vapor (J/kg, Btu/lb).
 SATHG Steam specific enthalpy at saturation conditions using partial pressure of vapor (J/kg, Btu/lb).
 SATTEMP Volume saturation temperature based on the partial pressure of vapor (K, °F).
 SIGMA Surface tension (J/m², Btu/ft²).
 SOLUTE Solute concentration, i.e., dissolved gas concentration in liquid (kg/m^3 , lb/ft^3).
 SOUNDE Volume sonic velocity (m/s, ft/s).
 TEMPF Volume liquid temperature (K, °F).
 TEMPG Volume vapor temperature (K, °F).
 THCONF Liquid thermal conductivity (W/m.K, Btu/s.ft. °F).
 THCONG Vapor thermal conductivity (W/m.K, Btu/s.ft. °F).
 TIENGV Total internal energy (of both phases and noncondensables) in volume (J, Btu).
 TMASSV Total mass (includes both phases and noncondensables) in volume (kg, lb).
 TSATT Saturation temperature corresponding to total pressure (K, °F).

UF Liquid specific internal energy (J/kg, Btu/lb).
 UG Vapor specific internal energy (J/kg, Btu/lb).
 VAPGEN Total volume vapor generation rate per unit volume (kg/m³. s, lb/ft³. s).
 VELF* Volume oriented liquid velocity (m/s, ft/s); the parameter is the volume number plus F.
 VELG* Volume oriented vapor velocity (m/s, ft/s); the parameter is the volume number plus F.
 VISCF Liquid viscosity (kg/m.s, lb/ft.s).
 VISCG Vapor viscosity (kg/m.s, lb/ft.s).
 VOIDF Volume liquid fraction.
 VOIDG Volume vapor fraction (void fraction).
 VOIDLA Void above the level.
 VOIDLB Void below the level.
 VOLLEV Location of the level inside the volume (m, ft).
 VVOL Volume of the volume (m³ , ft³).

Junction Quantities

For the following variable request codes, the parameter is the junction number, i.e., the nine-digit number ccnn0000 printed in the major edit. The parameter is ccc000000 for a single junction; ccc000000 for a time-dependent junction; cccmm0000 for a junction in a pipe component (0 < mm < 99); cccmm0000 for a junction in a branch.

Code Quantity

FLENTJ Total enthalpy flow in junction (includes both phases and noncondensables) (J/s, Btu/s).
 MFLOWJ Combined liquid and vapor flow rate (kg/s, lb/s).
 QUALAJ Junction noncondensable mass fraction.
 RHOFJ Junction liquid density (kg/m³ , lb/ft³).
 RHOGJ Junction vapor density (kg/m³ , lb/ft³).
 SONICJ Junction sound speed (m/s, ft/s).
 UFJ Junction liquid specific internal energy (J/kg, Btu/lb).
 UGJ Junction vapor specific internal energy (J/kg, Btu/lb).
 VELFJ Junction liquid velocity (m/s, ft/s).
 VELGJ Junction vapor velocity (m/s, ft/s).
 VOIDFJ Junction liquid fraction.
 VOIDGJ Junction vapor fraction (void fraction).
 XEJ Junction equilibrium quality.

Control System Quantities

The parameter is the control component number, i.e., the three-digit number, ccc, or the four-digit number, cccc, used in the input cards.

CNTRLVAR Control component number.

CARDS 400 THROUGH 799, TRIP INPUT DATA

These cards are optional for NEW and RESTART type problems and are not used for other problem types. Two different card series are available for entering trip data, but only one series type may be used in a problem. Card numbers 401 through 799 allow 199 variable trips and 199 logical trips.

Cards 401 through 599

Each card defines a logical statement or trip condition concerned with the quantities being advanced in time. A trip is false or not set if the trip condition is not met, and true if it is met. On restart, new trips can be introduced, old trips can be deleted, and a new trip with the same number as an old trip replaces the old trip.

The variable codes and parameters are the same as described for minor edits, NULL is allowed for the right side when only a comparison to the constant is desired. The variable code TIMEOF, with the parameter set to the trip number, indicates the time at which the trip was last set. If the trip goes false, TIMEOF is set to -1.0.

W1(A) Variable code. On RESTART problems, this word can also contain DISCARD or RESET. DISCARD deletes the trip; RESET sets the trip to false. If DISCARD or RESET are entered, no further words are entered on the card.

W2(I) Parameter.

W3(A) Relationship. This may be either EQ, NE, GT, GE, LT, or LE, where the symbols have the standard FORTRAN meaning. Do not enter periods as part of the designator. For example, use GE rather than .GE. to specify greater than or equal to.

W4(A) Variable code.

W5(I) Parameter.

W6(R) Additive constant.

W7(A) Latch indicator. If L, the trip once set true remains true, even if the condition later is not met. If N, the trip is tested each time advancement.

W8(R) Timeof quantity (s). This word is optional. If it is not entered, the trip is initialized as false and the associated TIMEOF quantity is set to -1.0. If -1.0 is entered, the trip is initialized as false. If zero or a positive number is entered for TIMEOF, the trip is initialized as true.

TIMEOF must not be greater than zero for NEW problems and must not be greater than the time of restart for RESTART problems.

The logical statement is "Does the quantity given by Words 1 and 2 have the relationship given by Word 3 with the quantity given by Words 4 and 5 plus Word 6?" If the relationship is false, the trip is false or not set. If the relationship is true, the trip is true or set. The TIMEOF variable is -1.0 if the trip is false.

If the trip is true, this variable is the time the trip was last set true. A latched trip is never reset, so the trip time never changes once it changes from -1.0. For the nonlatched trips, the trip time when set remains constant until the trip condition becomes false and then the trip time is -1.0

again. If the trip condition becomes true again, the process is repeated. For trips such as a time test, L should be used to eliminate repeated testing, although no error or difference in results will occur if N is used.

Cards 601 through 799 or 20610010 through 20620000, Logical Trip Cards

These cards are not needed unless some control logic is desired, usually not the case in most fire-suppressant fluid discharge problems. If these cards are entered, at least one of the variable trip cards must have been entered. Each card defines a logical relationship with the trips defined on these cards or on the variable trip cards.

W1(I) Trip number. The absolute value of this number must be one of the trip numbers defined by the variable or logical trip cards. A negative trip number indicates that the complement of the trip is to be used in the test.

W2(A) Operator. The operator may be AND, OR, or XOR. For RESTART problems, this quantity may also contain DISCARD or RESET. DISCARD deletes the trip and RESET sets the trip to false. If DISCARD or RESET are entered, no further words are entered on the card and Word 1 (W1) may be zero.

W3(I) Trip number. This is similar to Word 1 (W1).

W4(A) Latch indicator. If L, the trip when set remains set. If N, the trip is tested each time advancement.

W5(R) Timeof quantity (s). This word is optional. If not entered, the trip is initialized as false, and the associated TIMEOF quantity is set to -1.0. If -1.0 is entered, the trip is initialized as false. If zero or a positive number is entered for TIMEOF, the trip is initialized as true. TIMEOF must not be greater than zero for NEW problems and must not be greater than the time of restart for RESTART problems.

The trip condition is given by the result of the following logical expression:

CONDITION OF TRIP IN W1 OPERATOR CONDITION OF TRIP IN W3.

CARDS CCCXXNN, HYDRODYNAMIC COMPONENTS

These cards are required for NEW type problems and may be entered for RESTART problems. Hydrodynamic systems are described in a NEW problem. In a RESTART problem, the hydrodynamic systems may be modified by deleting, adding, or replacing components. The resultant problem must describe at least two volumes and one junction. The hydrodynamic card numbers are divided into fields, where ccc is the component number (the component numbers need not be consecutive), xx is the card type, and nn is the card number within type. When a range is indicated, the numbers need not be consecutive.

Card ccc0000, Component Name and Type

This card is required for each component.

W1(A) Component name. Use a name descriptive of the component's use in system. A limit of 10 characters is allowed for CDC-7600 computers, and a limit of 8 characters is allowed for most other computers, e.g., CRAY, Cyber-205, and IBM computers. There is no limit on PCs, but it is suggested that users restrict this to 8 characters.

W2(A) Component type. Enter one of the following component types, SNGLVOL, TMDPVOL, SNGLJUN, TMDPJUN, PIPE, BRANCH, VALVE, or the command DELETE. The command DELETE is allowed only in RESTART problems, and the component number must be an existing component at the time of restart. The DELETE command deletes the component. The remaining cards for each component depend on the type of component.

Single-Volume Component

A single-volume component is indicated by SNGLVOL on Card ccc0000. The junction connection code determines the placement of the volume within the system. More than one junction may be connected to an inlet or outlet. If an end has no junctions, that end is considered a closed end. Normally, only a branch has more than one junction connected to a volume end. For major edits, minor edits, and plot variables, the volume in the single volume component is numbered as ccc010000.

Cards ccc0101 through ccc0109, Single Volume X-Coordinate Volume Data

This card (or cards) is required for a single volume component. The nine words can be entered on one or more cards, and the card numbers need not be consecutive.

W1(R) Volume flow area (m², ft²).

W2(R) Length of volume (m, ft).

W3(R) Volume of volume (m³, ft³). The program requires that the volume equals the volume flow area times the length ($W3=W1*W2$). At least two of the three quantities, W1, W2, and W3, must be nonzero. If one of the quantities is zero, it will be computed from the other two. If none of the words are zero, the volume must equal the area times the length within a relative error of 0.000001.

W4(R) Azimuthal angle (degrees). The absolute value of this angle must be <360 degrees and is defined as a positional quantity. This quantity is not used in the calculation but is specified for possible automated drawing of nodalization diagrams.

W5(R) Inclination angle (degrees). The absolute value of this angle must be <90 degrees. The angle 0 degrees is horizontal; and positive angles have an upward inclination, i.e., the inlet is at the lowest elevation. This angle is used in the interphase drag calculation.

W6(R) Elevation change (m, ft). A positive value is an increase in elevation. The absolute value of this quantity must be less than or equal to the volume length. If the vertical angle orientation is zero, this quantity must be zero. If the vertical angle is nonzero, this quantity must also be nonzero and have the same sign. When the absolute value of the elevation angle determined by the ratio of the elevation change (this word 6) and the volume length (word 2) is less than or

equal to 45 degrees, the horizontal flow regime map is used. When the ratio is greater than 45 degrees, the vertical flow regime map is used.

W7(R) Wall roughness (m, ft).

W8(R) Hydraulic diameter (m, ft). This should be computed from $4.0 * (\text{volume flow area}) / (\text{wetted perimeter})$. If zero, the hydraulic diameter is computed from $2.0 * (\text{volume flow area} / p) ** 0.5$. A check is made to ensure the pipe roughness is less than half the hydraulic diameter. See word 1 for volume flow area.

W9(I) Volume control flags. This word has the packed format tlpvbf. It is not necessary to input leading zeros. Volume flags consist of scaler oriented and coordinate direction oriented flags. Only one value for a scaler oriented flag is entered per volume but up to three coordinate oriented flags can be entered for a volume, one for each coordinate direction. At present, the f flag is the only coordinate direction oriented flag. This word enters the scaler oriented flags and the x-coordinate flag.

The digit t specifies whether the thermal front tracking model is to be used; t=0 specifies that the front tracking model is not to be used for the volume, and t=1 specifies that the front tracking model is to be used for the volume. Use t=0.

The digit l specifies whether the mixture level tracking model is to be used; l=0 specifies that the level model not be used for the volume, and l=1 specifies that the level model be used for the volume. Use l=0.

The digit p specifies whether the water packing scheme is to be used. p=0 specifies that the water packing scheme is to be used for the volume, and p=1 specifies that the water packing scheme is not to be used for the volume. The water packing scheme is recommended when modeling a pressurizer. Use p=0.

The digit v specifies whether the vertical stratification model is to be used. v=0 specifies that the vertical stratification model is to be used for the volume, and v=1 specifies that the vertical stratification model is not to be used for the volume. The vertical stratification model is recommended when modeling a pressurizer. Use v=0.

The digit b specifies the interphase friction that is used. b=0 means that the pipe interphase friction model will be applied, b=1 means that the rod bundle interphase friction model will be applied, and b=2 means that the narrow channel model will be applied. Use b=0.

The digit f specifies whether wall friction is to be computed. f=0 specifies that wall friction effects are to be computed along the x coordinate of the volume, and f=1 specifies that wall friction effects are not to be computed along the x coordinate. Use f=0, unless a sensitivity study is being conducted to see the effect of no wall friction.

The digit e specifies if nonequilibrium or equilibrium is to be used. e=0 specifies that a nonequilibrium (unequal temperature) calculation is to be used, and e=1 specifies that an equilibrium (equal temperature) calculation is to be used. Equilibrium volumes should not be connected to nonequilibrium volumes. The equilibrium option is provided only for comparison with other codes. Use e=0.

Cards ccc0181 through ccc0189, Single-Volume Y-Coordinate Volume Data

These cards are optional. These cards are used when the user specifies the y-direction connection with the crossflow model.

W1(R) Area of the volume (m²).

W2(R) Length of the crossflow volume (m).

W3(R) Roughness.

W4(R) Hydraulic diameter (m).

W5(I) Volume control flags. This word has the general packed format tlpvbf, but this word is limited to 00000f0 since it only enters the coordinate oriented flags for the y direction. The digit f specifies whether wall friction is to be computed. f=0 specifies that wall friction effects are to be computed along the y coordinate direction in the volume, and f=1 specifies that wall friction effects are not to be computed along the y coordinate direction.

W6(R) This word is not used. Enter 0.

W7(R) This word is not used. Enter 0.

W8(R) This word is the position change in the z fixed (vertical) direction as the flow passes from the y inlet face to the y outlet face (m, ft). This quantity affects problems if connections are made to the y faces.

Cards ccc0191 through ccc0199, Single-Volume Z-Coordinate Volume Data

These cards are optional. These cards are used when the user specifies the z-direction connection with the crossflow model.

W1(R) Area of the volume (m²).

W2(R) Length of the crossflow volume (m).

W3(R) Roughness.

W4(R) Hydraulic diameter (m).

W5(I) Volume control flags. This word has the general packed format tlpvbf, but this word is limited to 00000f0 since it only enters the coordinate oriented flags for the z direction. The digit f specifies whether wall friction is to be computed. f=0 specifies that wall friction effects are to be computed along the z coordinate direction in the volume, and f=1 specifies that wall friction effects are not to be computed along the z coordinate direction.

W6(R) This word is not used. Enter 0.

W7(R) This word is not used. Enter 0.

W8(R) This word is the position change in the z fixed (vertical) direction as the flow passes from the z inlet face to the z outlet face (m, ft). This quantity affects problems if connections are made to the z faces.

Card ccc0200, Single-Volume Initial Conditions

This card is required for a single volume.

W1(I) Control word. This word has the packed format ebt. It is not necessary to input leading zeros.

The digit e specifies the fluid. e =0 is the default fluid that is set for the hydrodynamic system by Cards 120 through 129. If Cards 120 through 129 are not entered and all control words use the

default $e=0$, then H₂O is assumed as the fluid. Always use $e=0$ and Cards 120-129 to specify the default fluid.

The digit b specifies whether solute (dissolved gas) is present or not. The digit $b=0$ specifies that the volume fluid does not contain solute; $b=1$ specifies that a solute concentration in Kg/Kg (which may be zero) is being entered after the other required thermodynamic information.

The digit t specifies how the following words are to be used to determine the initial thermodynamic state. Entering $t=0$ through 3 specifies only one component (vapor/liquid). Entering $t=4$ through 6 allows the specification of two components (vapor/liquid and noncondensable gas).

If $t=0$, the next four words are interpreted as pressure (Pa, lb f/in²), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), and vapor void fraction; these quantities will be interpreted as nonequilibrium or equilibrium conditions depending on the volume control flag. If equilibrium, the static quality is checked; but only the pressure and internal energies are used to define the thermodynamic state.

If $t=1$, the next two words are interpreted as temperature (K, o F) and quality in equilibrium condition.

If $t=2$, the next two words are interpreted as pressure (Pa, lb f/in²) and quality in equilibrium condition.

If $t=3$, the next two words are interpreted as pressure (Pa, lb f/in²) and temperature (K, o F) in equilibrium condition. The following options are used for input of noncondensable states only. In all cases, the criteria used for determining the range of values for quality are $1.0E-9 < \text{quality} < 0.99999999$, two phase conditions, and $\text{quality} < 1.0 E-9$ or $\text{quality} > 0.99999999$, single phase.

Noncondensable options are as follows:

If $t=4$, the next three words are interpreted as pressure (Pa, lb f/in²), temperature (K, o F), and equilibrium quality. Using this input option with quality 0.0 and <1.0 , saturated noncondensables will result. Also, the temperature is restricted to be less than the saturation temperature at the input pressure. Setting quality to 0.0 is used as a flag that will initialize the volume to all noncondensable (dry noncondensable) with no temperature restrictions. Quality is reset to 1.0 using this dry noncondensable option.

If $t=5$, the next three words are interpreted as temperature (K, o F), equilibrium quality, and noncondensable quality. Both the equilibrium and noncondensable qualities are restricted to be between $1.0 E-9$ and 0.99999999 . Little experience has been obtained using this option, and it has not been checked out.

If $t=6$, the next five words are interpreted as pressure (Pa, lb f/in²), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), vapor void fraction, and noncondensable quality. The combinations of vapor void fraction and noncondensable quality must be thermodynamically consistent. If noncondensable quality is set to 0.0, noncondensables are not present and the input processing branches to that type of processing. If noncondensables are present and noncondensable quality is greater than 0.0, then the vapor void fraction must not be 0.0. If the noncondensable quality is set to 1.0 (pure noncondensable), then the vapor void fraction must also be 1.0. When both the vapor void fraction and the noncondensable quality are set to 1.0, the volume temperature is calculated from the noncondensable energy equation using the input vapor specific internal energy.

W2-W7(R) Quantities as described under Word1 (W1). Depending on the control word, two through five quantities may be required. Enter only the minimum number required. If entered, solute concentration (Kg/Kg) follows the last required word for thermodynamic conditions.

Time-Dependent Volume Component

This component is indicated by TMDPVOL on card ccc0000. For major edits, minor edits, and plot variables, the volume in the time-dependent volume component is numbered as ccc01000.

Cards ccc0101 through ccc0109, Time-Dependent Volume Geometry Cards

This card (or cards) is required for a time-dependent volume component. The nine words can be entered on one or more cards, and the card numbers need not be consecutive.

W1(R) Volume flow area (m², ft²).

W2(R) Length of volume (m, ft).

W3(R) Volume of volume (m³, ft³). The program requires that the volume equals the volume flow area times the length ($W3=W1*W2$). At least two of the three quantities, W1, W2, and W3, must be nonzero. If one of the quantities is zero, it will be computed from the other two. If none of the words are zero, the volume must equal the area times the length within a relative error of 0.000001.

W4(R) Azimuthal angle (degrees). The absolute value of this angle must be < 360 degrees. This quantity is not used in the calculation but is specified for possible automated drawing of nodalization diagrams.

W5(R) Inclination angle (degrees). The absolute value of this angle must be < 90 degrees. The angle 0 degrees is horizontal, and positive angles have an upward inclination, i.e., the inlet is at the lowest elevation. This angle is used in the interphase drag calculation.

W6(R) Elevation change (m, ft). A positive value is an increase in elevation. The absolute value of this quantity must be less than or equal to the volume length. If the vertical angle orientation is zero, this quantity must be zero. If the vertical angle is nonzero, this quantity must also be nonzero and have the same sign. As with the other components, this word 6 is compared to the volume length (word 2) to determine if the horizontal or vertical flow regime map is used. This is not important for this component, since the correlations that depend on the flow regime maps are not needed for this component. The volume conditions are prescribed through input cards ccc0201-ccc0299.

W7(R) Wall roughness (m, ft).

W8(R) Hydraulic diameter (m, ft). This should be computed from $4*(\text{volume flow area})/(\text{wetted perimeter})$. If zero, the hydraulic diameter is computed from $2.0*(\text{volume flow area}/p)**0.5$. A check is made to ensure the pipe roughness is less than half the hydraulic diameter. See word 1 for the volume flow area.

W9(I) Volume control flags. This word has the packed format tlpvbf. It is not necessary to input leading zeros. Volume flags consist of scaler oriented and coordinate direction oriented flags.

Only one value for a scaler oriented flag is entered per volume but up to three coordinate oriented flags can be entered for a volume, one for each coordinate direction. At present, the f flag is the only coordinate direction oriented flag. This word enters the scaler oriented flags and the x coordinate flag. The time dependent component uses only the e digit and y and z coordinate data are not read.

The digit t is not used and must be entered as zero (t=0). The thermal stratification model

is not used in a time dependent volume.

The digit l is not used and must be entered as zero (l=0). The level tracking model is not used in a time dependent volume.

The digit p is not used and should be input as zero (p=0). The major edit will show p=1.

This digit v is not used and should be input as zero (v=0). The major edit will show v=1.

The digit b specifies the interphase friction that is used. b=0 means that the pipe interphase friction model will be applied, and b=1 means that the rod bundle interphase friction model will be applied. The interphase friction models are not used for time-dependent volumes, so either b=0 or b=1 can be inputted and the output will show the digit entered. Use b=0.

The digit f specifies whether wall friction is to be computed. f=0 specifies that wall friction effects are to be computed for the volume, and f=1 specifies that wall friction effects are not to be computed for the volume. The wall friction model is not used for time-dependent volumes, so either f=0 or f=1 can be inputted and the output will show the digit entered. Use f=0.

The digit e specifies if nonequilibrium or equilibrium is to be used. e=0 specifies that a nonequilibrium (unequal temperature calculation is to be used, and e=1 specifies that an equilibrium (equal temperature) calculation is to be used. Equilibrium volumes should not be connected to nonequilibrium volumes. The equilibrium option is provided only for comparison to other codes. The nonequilibrium and equilibrium options are not used for time-dependent volumes, so either e=0 or e=1 can be used. Use e=0.

Card ccc0200, Time-Dependent Volume Data Control Word

This card is required for a time-dependent volume.

W1(I) Control word for time-dependent data on ccc02nn cards. This word has the packed format ebt. It is not necessary to input leading zeros.

The digit e specifies the fluid. e =0 is the default fluid that is set for the hydrodynamic system by Cards 120 through 129. If Cards 120 through 129 are not entered and all control words use the default e =0, then H₂O is assumed as the fluid. Always use e=0 and Cards 120-129 to specify the default fluid.

The digit b specifies whether solute (dissolved gas) is present or not. The digit b=0 specifies that the volume fluid does not contain solute; b=1 specifies that a solute concentration (which may be zero) is being entered after the other required thermodynamic information.

The digit t specifies how the words of the time-dependent volume data in Cards ccc0201 through ccc0299 are to be used to determine the initial thermodynamic state. Entering t=0 through 3 specifies only one component (vapor/liquid). Entering t=4 through 6 allows the specification of two components (vapor/liquid and noncondensable gas). With options 4 through 6, Card 110 defining components of the noncondensable gas must be entered and mass fractions of the components are entered on Card ccc0301, if entered, or are taken from the default data on Card 115.

If t=0, the second, third, fourth, and fifth words of the time-dependent volume data on Cards ccc0201 through ccc0299 are interpreted as pressure (Pa, lb f/in²), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), and vapor void fraction; these quantities will be interpreted as nonequilibrium or equilibrium conditions depending on the volume control flag. If equilibrium, the static quality is checked, but only the pressure and

internal energies are used to define the thermodynamic state. Enter only the minimum number of words required. If entered, solute concentration follows the last required word for thermodynamic conditions.

If $t=1$, the second and third words of the time-dependent volume data on Cards ccc0201 through ccc0299 are interpreted as temperature (K, o F) and quality in equilibrium condition. Enter only the minimum number of words required. If entered, solute concentration follows the last required word for thermodynamic conditions.

If $t=2$, the second and third words of the time-dependent volume data on Cards ccc0201 through ccc0299 are interpreted as pressure (Pa, lb f/in²) and quality in equilibrium condition. Enter only the minimum number of words required. If entered, solute concentration follows the last required word for thermodynamic conditions.

If $t=3$, the second and third words of the time-dependent volume data on Cards ccc0201 through ccc0299 are interpreted as pressure (Pa, lb f/in²) and temperature (K, o F) in equilibrium conditions. Enter only the minimum number of words required. If entered, solute concentration follows the last required word for thermodynamic conditions.

The following options are used for input of noncondensable states only. In all cases, the criteria used for determining the range of values for quality are $1.0E-9 < \text{quality} < 0.99999999$, two-phase conditions, and $\text{quality} < 1.0E-9$ or $\text{quality} > 0.99999999$, single-phase.

Noncondensable options are as follows:

If $t=4$, the second, third, and fourth words of the time-dependent data on Cards ccc0201 through ccc0299 are interpreted as pressure (Pa, lb f/in²), temperature (K, o F), and equilibrium quality. Using this input option with $\text{quality} > 0.0$ and < 1.0 , saturated noncondensables will result. Also, the temperature is restricted to be less than the saturation temperature at the input pressure. Setting quality to 0.0 is used as a flag that will initialize the volume to all noncondensable (dry noncondensable) with no temperature restrictions. Quality is reset to 1.0 using this dry noncondensable option. Enter only the minimum number of words required. If entered, solute concentration follows the last required word for thermodynamic conditions.

If $t=5$, the second, third, and fourth words of the time-dependent data on Cards ccc0201 through ccc0299 are interpreted as temperature (K, o F), equilibrium quality, and noncondensable quality. Both the equilibrium and noncondensable qualities are restricted to be between $1.0E-9$ and 0.99999999 . Enter only the minimum number of words required. If entered, solute concentration follows the last required word for thermodynamic conditions. Little experience has been obtained using this option, and it has not been checked out.

If $t=6$, the second, third, fourth, fifth, and sixth words of the time-dependent data on Cards ccc0201 through ccc0299 are interpreted as pressure (Pa, lb f/in²), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), vapor void fraction, and noncondensable quality. The combinations of vapor void fraction and noncondensable quality must be thermodynamically consistent. If noncondensable quality is set to 0.0, noncondensables are not present, and the input processing branches to that type of processing. If noncondensables are present (noncondensable quality greater than 0.0), then the vapor void fraction must not be 0.0. If the noncondensable quality is set to 1.0 (pure noncondensable), then the vapor void fraction must also be 1.0. When both the vapor void fraction and the noncondensable quality are set to 1.0, the volume temperature is calculated from the noncondensable energy equation using the input vapor specific internal energy. Enter only the minimum number of words required. If entered, solute concentration follows the last required word for thermodynamic conditions.

W2(I) Table trip number. This word is optional. If missing or zero and Word 3 is missing, no trip is used, and the time argument is the advancement time. If nonzero and Word 3 is missing, this number is the trip number, and the time argument is -1.0 if the trip is false, and the advancement time minus the trip time if the trip is true.

W3(A) Alphanumeric part of variable request code. This quantity is optional. If not present, time is the search argument. If present, this word and the next are a variable request code that specifies the search argument for the table lookup and interpolation. If the trip number is zero, the specified argument is used. If the trip number is nonzero, -1.0E+75 is used if the trip is false, and the specified argument is used if the trip is true. TIME can be selected, but note that the trip logic is different than if this word were omitted.

W4(I) Numeric part of variable request code. This is assumed zero if missing.

Cards ccc0201 through ccc0299, Time-Dependent Volume Data Cards

These cards are required for time-dependent volume components. A set of data is made up of the search variable (e.g., time) followed by the required data indicated by control word 1 in Card cc0200. The card numbers need not be consecutive, but the value of the search variable in a succeeding set must be equal to or greater than the value in the previous set. One or more sets of data, up to 5000 sets, are allowed. Enter only the minimum number of words required. If entered, solute concentration follows the last required word for thermodynamic conditions. Linear interpolation is used if the search argument lies between the search variable entries. End-point values are used if the argument lies outside the table values. Only one set is needed if constant values are desired, and computer time is reduced when only one set is entered. Step changes can be accommodated by entering the two adjacent sets with the same search variable values or an extremely small difference between them. Given two identical argument values, the set selected will be the closest to the previous argument value. Sets may be entered one or more per card and may be split across cards. The total number of words must be a multiple of the set size. Inputting time-dependent volume tables where the search variable is a thermodynamic variable from some other component can run into difficulties if the component numbering is such that the time-dependent volume is initialized before the component providing the needed search variable. A reliable fix for this is to make the search variable a control system output in the desired units, while the thermodynamic variable is the control system input in code internal (SI) units. The control system initial value can be set to the desired initial value of the search variable, and this will be used by the time-dependent table.

W1(R) Search variable (e.g., time).

W2-W7(R) Quantities as described under word 1 in Card 200. Depending on the control word, two through five quantities may be required. If entered, solute concentration follows the last required word for thermodynamic conditions.

As described above, sets may be entered one or more per card.

Single-Junction Component

A single-junction component is indicated by SNGLJUN on card ccc0000. For major edits, minor edits, and plot variables, the junction in the single junction component is numbered ccc000000.

Cards ccc0101 through ccc0109, Single-Junction Geometry Cards

This card (or cards) is required for single-junction components.

W1(I) From connection code to a component. This refers to the component from which the junction coordinate direction originates. For connecting to a time-dependent volume, the connection code is ccc000000, where ccc is the component number of the time-dependent volume. An old or an expanded format can be used to connect all other volumes. In the old format, use ccc000000 if the connection is to the inlet side of the component and use ccc010000 if the connection is to the outlet side of the component. In the expanded format, the connection code is cccvv000n, where cc is the component number, vv is the volume number, and n indicates the face number. A nonzero n specifies the expanded format. The number n equal to 1 and 2 specifies the inlet and outlet faces, respectively, for the volume's coordinate direction. The number n equal to 3 through 6 specifies crossflow. The number n equal to 3 and 4 would specify inlet and outlet faces for the second coordinate direction; n equal to 5 and 6 would do the same for the third coordinate direction.

W2(I) To connection code to a component. This refers to the component at which the junction coordinate direction ends. See the description for W1 above.

W3(R) Junction area (m², ft²). If zero, the area is set to the minimum volume flow area of the adjoining volumes. For abrupt area changes, the junction area must be equal to or smaller than the minimum of the adjoining volume areas. For smooth area changes, there are no restrictions.

W4(R) Forward flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero. Note: a variable loss coefficient may be specified. See Section below.

W5(R) Reverse flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative. Note: a variable loss coefficient may be specified. See Section below.

W6(I) Junction control flags. This word has the packed format efvcahs. It is not necessary to input leading zeros. The digit e specifies the modified PV term in the energy equations. e=0 means that the modified PV term will not be applied, and e=1 means that it will be applied. Use e=0.

The digit f specifies CCFL options. f=0 means that the CCFL model will not be applied, and f=1 means that it will be applied. Use f=0.

The digit v specifies horizontal stratification entrainment/ pullthrough options. This model is for junctions connected to a horizontal volume. v=0 means the model is not applied; v=1 means an upward-oriented junction; v=2 means a downward-oriented junction; and v=3 means a centrally (side) located junction. Use v=0.

The digit c specifies choking options. c=0 means that the choking model will be applied, and c=1 means that the choking model will not be applied. Generally do not allow choking at interior junctions where choking is not expected. Hence use c=0 only at exit junctions from the supply vessel, or at the exit of the system. Use c=1 at all other junctions.

The digit a specifies area change options. a=0 means either a smooth area change or no area change, and a=1 means an abrupt area change.

The digit h specifies nonhomogeneous or homogeneous. h=0 specifies the nonhomogeneous (two velocity momentum equations) option, and h=2 specifies the homogeneous (single velocity momentum equation) option. For the homogeneous option (h=2), the major edit printout will show a 1. Use h=0 unless conducting a sensitivity study to examine effect of homogeneous flow conditions.

The digit s specifies momentum flux options. s=0 uses momentum flux in both the to volume and the from volume. s=1 uses momentum flux in the from volume, but not in the to volume. s=2 uses momentum flux in the to volume, but not in the from volume; s=3 does not use momentum flux in either the to or the from volume. Use s=0.

W7(R) Subcooled discharge coefficient. This quantity is applied only to subcooled liquid choked flow calculations. The quantity must be >0.0 and <2.0. If missing, it is set to 1.0.

W8(R) Two-phase discharge coefficient. This quantity is applied only to two-phase choked flow calculations. The quantity must be >0.0 and <2.0. If missing, it is set to 1.0.

W9(R) Superheated discharge coefficient. This quantity is applied only to superheated vapor choked flow calculations. The quantity must be >0.0 and <2.0. If missing, it is set to 1.0.

Card ccc0110, Single-Junction Diameter and CCFL Data Card

This card is optional. The defaults indicated for each word are used if the card is not entered. If this card is being used to specify only the junction hydraulic diameter for the interphase drag calculation (i.e., f=0 in Word 6 of Cards ccc0101-ccc0109), then, the diameter should be entered in Word 1 and any allowable values should be entered in Words 2 through 4 (will not be used). If this card is being used for the CCFL model (i.e., f=1 in Word 6 of Cards ccc0101-ccc0109), then enter all four words for the appropriate CCFL model if values different from the default values are desired. In analysis of fire-suppressant fluid discharge systems, the CCFL condition will not be encountered. Hence, if this card is being entered, the allowable values can be entered, as shown below, for the CCFL data, which will not be used in any case.

W1(R) Junction hydraulic diameter, D_j (m, ft). This quantity is the junction hydraulic diameter used in the CCFL correlation equation and interphase drag and must be >0. This number should be computed from 4.0*(junction area)/(wetted perimeter). If zero is entered or if the default is used, the junction diameter is computed from 2.0*(junction area/p)**0.5. See Word 3 of Cards ccc0101-ccc0109 for the junction area.

W2(R) Flooding correlation form, b. Enter a number between 0 and 1.

W3(R) Gas intercept, c. Enter a number greater than 0. The default value is 1.

W4(R) Slope, m. Enter a number greater than 0. The default value is 1.

Card ccc0111, Single-Junction Form Loss Data Card

This card is optional. The user-specified form loss is given in Words 4 and 5 of Card ccc0101 if this card is not entered. If this card is entered, the form loss coefficient is calculated from

$$K_f = A_f + B_f(\text{Re})^{-c_f}$$

$$K_r = A_r + B_r(\text{Re})^{-\text{cr}}$$

where K_f and K_r are the forward and reverse form loss coefficient. A_f and A_r are the Words 4 and 5 of Card ccc0101. Re is the Reynolds number based on mixture fluid properties. If this card is being used for the form loss calculation, then enter all four words for the appropriate expression.

W1(R) $B_f (>0)$. This quantity must be greater than or equal to zero.

W2(R) $\text{cf} (>0)$. This quantity must be greater than or equal to zero.

W3(R) $B_r (>0)$. This quantity must be greater than or equal to zero.

W4(R) $\text{cr} (>0)$. This quantity must be greater than or equal to zero.

Card ccc0201, Single-Junction Initial Conditions

This card is required for single-junction components.

W1(I) Control word. If zero, the next two words are velocities; if one, the next two words are mass flows.

W2(R) Initial liquid velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on the control word.

W3(R) Initial vapor velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on the control word.

W4(R) Interface velocity (m/s, ft/s). Enter zero.

Time-Dependent Junction Component

This component is indicated by TMDPJUN on Card ccc0000. For major edits, minor edits, and plot variables, the junction in the time-dependent junction component is numbered as ccc000000.

Card ccc0101, Time-Dependent Junction Geometry Card

This card is required for time-dependent junction components.

W1(I) From connection code to a component. This refers to the component from which the junction coordinate direction originates. For connecting to a time dependent volume, the connection code is ccc000000, where ccc is the component number of the time dependent volume. An old or an expanded format can be used to connect all other volumes. In the old format, use ccc000000 if the connection is to the inlet side of the component and use ccc010000 if the connection is to the outlet side of the volume. In the expanded format, the connection code is cccvv000n, where ccc is the component number, vv is the volume number, and n indicates the face number. A nonzero n specifies the expanded format. The number n equal to 1 and 2 specifies the inlet and outlet faces respectively or the volume's coordinate direction. The number n equal to 3 through 6 specifies crossflow. The number n equal to 3 and 4 would specify inlet

and outlet faces for the second coordinate direction; n equal to 5 and 6 would do the same for the third coordinate direction.

W2(I) To connection code to a component. This refers to the component at which the junction coordinate direction ends. See the description for W1 above.

W3(R) Junction area (m², ft²). If zero, the area is set to the minimum flow area of the adjoining volumes. There are no junction area restrictions for time dependent junctions.

Card ccc0200, Time-Dependent Junction Data Control Word

This card is optional. If this card is missing, the second and third words of the time-dependent data are assumed to be velocities.

W1(I) Control word. If zero, the second and third words of the time-dependent junction data in Cards ccc0201 through ccc0299 are velocities. If one, the second and third words of the time-dependent junction data in Cards ccc0201 through ccc0299 are mass flows. In both cases, the fourth word is interface velocity and should be entered as zero.

W2(I) Table trip number. This word is optional. If missing or zero and Word 3 is missing, no trip is used, and the time argument is the advancement time. If nonzero and Word 3 is missing, this number is the trip number and the time argument is -1.0 if the trip is false, and the advancement time minus the trip time if the trip is true.

W3(A) Alphanumeric part of variable request code. This quantity is optional. If present, this word and the next are a variable request code that specifies the search argument for the table lookup and interpolation. If the trip number is zero, the specified argument is always used. If the trip number is nonzero, -1.0E75 is used if the trip is false, and the specified argument is used if the trip is true. TIME can be selected, but note that the trip logic is different than if this word is omitted.

W4(I) Numeric part of variable request code. This is assumed zero if missing.

Cards ccc0201 through ccc0299, Time-Dependent Junction Data Cards

These cards are required for time-dependent junction components. A set of data consists of the search variable (e.g., time) followed by the required data indicated by control word 1 on card ccc0200. The card numbers need not be consecutive, but the value of the search variable in a succeeding set must be equal to or greater than the value in the previous set. One or more sets of data up to 5000 sets may be entered. Zero may be entered for a velocity or flow if the phase or material is not present. The interpolation and card formats for the time-dependent data are identical to that in Cards ccc0201- ccc0209 (Time-Dependent Volume Data Cards). When doing a single phase problem and entering velocities here, the same value should be entered for both liquid and vapor velocities. If entering mass flows, the correct value should be entered for either liquid or vapor (whichever single phase is being modeled) and the other entry should be zero. If the user wants to specify the vapor void fraction as a function of time in the time-dependent volume, and the total mass flow as a function of time in the time-dependent junction, then both the phasic (gas and liquid) mass flow rates must be calculated and entered in these cards.

W1(R) Search variable (e.g., time).

W2(R) Liquid velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on control word 1 on card ccc0200.

W3(R) Vapor velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on control word 1 on card ccc0200.

W4(R) Interface velocity (m/s, ft/s). Enter zero.

As described above, sets may be entered one or more per card.

Pipe Component

A pipe component is indicated by PIPE on Card ccc0000. More than one junction may be connected to the inlet or outlet. If an end has no junctions, that end is considered a closed end. For major edits, minor edits, and plot variables, the volumes in the pipe component are numbered as cccnn0000, where nn is the volume number (greater than 00 and less than 100). The junctions in the pipe component are numbered as cccmm0000, where mm is the junction number (greater than 00 and less than 99). The input for a pipe or annulus component assumes that the pipe has at least two volumes with one junction separating the two volumes. It is possible to input a one-volume pipe or annulus. In order to implement this special case, the user must set the number of volumes and the volume number on the volume cards to one. In addition, the user should not input any of the junction cards. The volumes in a pipe are usually considered one-dimensional components and flow in the volumes is along the x-coordinate. Cross flow junctions can connect the pipe volumes in the y and z-coordinate directions using a form of the momentum equation that does not include momentum flux terms. Optional input may be added that allow the full one-dimensional momentum equations to be used in the y- and z- coordinate directions.

Card ccc0001, Pipe Information Card

This card is required for pipe components.

W1(I) Number of volumes, nv. nv must be greater than zero and less than 100. The number of associated junctions internal to the pipe is nv-1. The outer junctions are described by other components.

Cards ccc0101 through ccc0199, Pipe X-Coordinate Volume Flow Areas

The format is two words per set in sequential expansion format for nv sets. These cards are required, and the card numbers need not be consecutive. The words for one set are

W1(R) Volume flow area (m², ft²).

W2(I) Volume number.

Cards ccc1601 through ccc1699, Pipe Y-Coordinate Volume Flow Areas

The format is two words per set in sequential expansion format for nv sets. These cards are optional and if entered activate the y-coordinate for each volume and allow the full one-dimensional momentum equations to be used in connections to the y faces. The card numbers need not be consecutive. The words for one set are:

W1(R) Volume flow area (m² , ft²).
W2(I) Volume number.

Cards ccc1701 through ccc1799, Pipe Z-Coordinate Volume Flow Areas

The format is two words per set in sequential expansion format for nv sets. These cards are optional and if entered activate the z-coordinate for each volume and allow the full one-dimensional momentum equations to be used in connections to the z faces. The card numbers need not be consecutive. The words for one set are:

W1(R) Volume flow area (m² , ft²).
W2(I) Volume number.

Cards ccc0201 through ccc0299, Pipe Junction Flow Areas

These cards are optional, and, if entered, the card numbers need not be consecutive. The format is two words per set in sequential expansion format for $nv-1$ sets.

W1(R) Internal junction flow area (m² , ft²). If cards are missing or a word is zero, the junction flow area is set to the minimum area of the adjoining volumes. For abrupt area changes, the junction area must be equal to or less than the minimum of the adjacent volume areas. There is no restriction for smooth area changes.
W2(I) Junction number.

Cards ccc0301 through ccc0399, Pipe X-Coordinate Volume Lengths

These cards are required for pipe components. The format is two words per set in sequential expansion format for nv sets. Card numbers need not be consecutive.

W1(R) Pipe volume length (m, ft).
W2(I) Volume number.

Cards ccc1801 through ccc1899, Pipe Y-Coordinate Volume Lengths

These cards are optional and if entered activate the y-coordinate for each volume and allow the full one-dimensional momentum equation for connections to the y faces. The format is two words per set in sequential expansion format for nv sets. Card numbers need not be consecutive.

W1(R) Pipe volume length (m, ft).
W2(I) Volume number.

Cards ccc1901 through ccc1999, Pipe Z-Coordinate Volume Lengths

These cards are optional and if entered activate the z-coordinate for each volume and allow the full one-dimensional momentum equation for connections to the z faces. The format is two words per set in sequential expansion format for nv sets. Card numbers need not be consecutive.

W1(R) Pipe volume length (m, ft).
W2(I) Volume number.

Cards ccc0401 through ccc0499, Pipe Volume Volumes

The format is two words per set in sequential expansion format for nv sets. Card numbers need not be consecutive.

W1(R) Volume (m^3 , ft^3). If these cards are missing, volumes equal to zero are assumed. The code requires that each volume equal the flow area times length. For any volume, at least two of the three quantities, area, length, or volume, must be nonzero. If one of the quantities is zero, it will be computed from the other two. If none of the quantities are zero, the volume must equal the area times the length within a relative error of 0.000001.

W2(I) Volume number.

Cards ccc0501 through ccc0599, Pipe Volume Azimuthal Angles

These cards are optional, and, if not entered, the angles are set to zero. The format is two words per set in sequential expansion format for nv sets, and card numbers need not be consecutive.

W1(R) Azimuthal angle (degrees). The absolute value of the angle must be < 360 degrees.
W2(I) Volume number.

Cards ccc0601 through ccc0699, Pipe Volume Vertical Angles

These cards are required for pipe components. The format is two words per set in sequential expansion format for nv sets, and card numbers need not be consecutive.

W1(R) Vertical angle (degrees). The absolute value of the angle must be less than or equal to 90

degrees. This angle is used in the interphase drag calculation.
W2(I) Volume number.

Cards ccc0701 through ccc0799, Pipe X-Coordinate Elevation Changes

These cards are optional. If these cards are missing, the coordinate changes or elevation changes are computed from the x-coordinate volume length and a rotation matrix computed from the angle information. If these cards are entered, the entered data becomes the x-coordinate change or elevation change data. Two formats entering one or three coordinate changes per volume are provided. The card format is two or four words per set in sequential expansion format up to *nv* sets, and card numbers need not be consecutive.

One Coordinate Change Per Volume Format:

W1(R) Elevation change. This is the coordinate change along the fixed z-axis due to the traverse from inlet to outlet along the local x-coordinate, Δ_{zx} (m, ft). A positive value is an increase in elevation. The magnitude must be equal to or less than the volume length. When the absolute value of the elevation angle determined by the ratio of the elevation change (this word) and the volume length is less than or equal to 45 degrees, the horizontal flow regime map is used; when the ratio is greater than 45 degrees, the vertical flow regime map is used.

W2(I) Volume number.

Three Coordinate Changes Per Volume Format:

W1(R) Coordinate change along the fixed x-axis due to traverse from inlet to outlet along the local x-coordinate, Δ_{xx} , (m, ft).

W2(R) Coordinate change along the fixed y-axis due to traverse from inlet to outlet along the local x-coordinate, Δ_{yx} , (m, ft).

W3(R) Coordinate change along the fixed z-axis due to traverse from inlet to outlet along the local x-coordinate, Δ_{zx} , (m, ft).

W4(I) Volume number.

Cards ccc2101 through ccc2199, Pipe Y-Coordinate Elevation Changes

These cards are optional. If these cards are missing, the coordinate changes are computed from the y- coordinate volume length and a rotation matrix computed from the angle information. If these cards are entered, the entered data overwrites the previously computed coordinate change data. The card format is four words per set in sequential expansion format up to *nv* sets, and card numbers need not be consecutive.

W1(R) Coordinate change along fixed x-axis due to traverse from inlet to outlet along the local y- coordinate, Δ_{xy} (m, ft).

W2(R) Coordinate change along fixed y-axis due to traverse from inlet to outlet along the local y- coordinate, Δ_{yy} (m, ft).

W3(R) Coordinate change along fixed z-axis due to traverse from inlet to outlet along the local y- coordinate, Δ_{zy} (m, ft).

W4(I) Volume number.

Cards ccc2201 through ccc2299, Pipe Z-Coordinate Elevation Changes

These cards are optional. If these cards are missing, the coordinate changes are computed from the z- coordinate volume length and a rotation matrix computed from the angle information. If these cards are entered, the entered data overwrites the previously computed coordinate change data. The card format is four words per set in sequential expansion format up to nv sets, and card numbers need not be consecutive.

W1(R) Coordinate change along fixed x-axis due to traverse from inlet to outlet along the local z- coordinate, Δ_{xz} (m, ft).

W2(R) Coordinate change along fixed y-axis due to traverse from inlet to outlet along the local z- coordinate, Δ_{yz} (m, ft).

W3(R) Coordinate change along fixed z-axis due to traverse from inlet to outlet along the local z- coordinate, Δ_{zz} (m, ft).

W4(I) Volume number.

Cards ccc0801 through ccc0899, Pipe Volume X-Coordinate Friction Data

These cards are required for pipe components. The card format is three words per set for nv sets, and card numbers need not be consecutive.

W1(R) Wall roughness (m, ft).

W2(R) Hydraulic diameter (m, ft). This should be computed from $4.0 * (\text{volume flow area}) / (\text{wetted perimeter})$. If zero, the hydraulic diameter is computed from $2.0 * (\text{volume flow area} / p) ** 0.5$. A check is made to ensure that the roughness is less than half the hydraulic diameter. See Word 1 on Cards ccc0101-ccc0109 for the volume flow area.

W3(I) Volume number.

Cards ccc2301 through ccc2399, Pipe Volume Y-Coordinate Friction Data

These cards are optional and may be entered if volume flow area or volume length data was entered for the y-coordinate. If the cards are not entered, the wall roughness defaults to zero and the default hydraulic diameter is computed as if zero was entered in Word 2. The format for these cards is the same as for the friction data for the x-coordinate.

Cards ccc2401 through ccc2499, Pipe Volume Z-Coordinate Friction Data

These cards are optional and may be entered if volume flow area or volume length data was entered for the z-coordinate. If the cards are not entered, the wall roughness defaults to zero and

the default hydraulic diameter is computed as if zero was entered in Word 2. The format for these cards is the same as for the friction data for the x-coordinate.

Cards ccc0901 through ccc0999, Pipe Junction Loss Coefficients

These cards are optional and if missing, the energy loss coefficients are set to zero. The card format is three words per set in sequential expansion format for nv-1 sets, and card numbers need not be consecutive.

W1(R) Forward flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero. Note: a variable loss coefficient may be specified. See Section below.

W2(R) Reverse flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative. Note: a variable loss coefficient may be specified. See Section below.

W3(I) Junction number.

Cards ccc1001 through ccc1099, Pipe Volume X-Coordinate Control Flags

These cards are required for pipe volumes. The card format is two words per set in sequential expansion format for nv sets, and card numbers need not be consecutive.

W1(I) Volume control flags. This word has the packed format tlpvbf. It is not necessary to input leading zeros. See discussion under Word 9 of Single Volume X-Coordinate Volume Data Card.

W2(I) Volume number.

Cards ccc2701 through ccc2799, Pipe Y-Coordinate Control Flags

W1(I) Volume control flags. This word has the general packed format tlpvbf, but this word is limited to 00000f0 since it only enters the coordinate oriented flags for the y direction. See discussion under Word 5 of Single Volume Y-Coordinate Volume Data Card.

W2(I) Volume number.

Cards ccc2801 through ccc2899, Pipe Z-Coordinate Control Flags

W1(I) Volume control flags. This word has the general packed format tlpvbf, but this word is limited to 00000f0 since it only enters the coordinate oriented flags for the z direction. See discussion under Word 5 of Single Volume Z-Coordinate Volume Data Card.

W2(I) Volume number.

Cards ccc1101 through ccc1199, Pipe Junction Control Flags

These cards are required for pipe components. The card format is two words per set in sequential expansion format for nv-1 sets, and card numbers need not be consecutive.

W1(I) Junction control flags. This word has the packed format efvcahs. It is not necessary to input leading zeros. See discussion under Word 6 of Single Junction Geometry Card.

W2(I) Junction number.

Cards ccc1201 through ccc1299, Pipe Volume Initial Conditions

These cards are required for pipe components. The card format is seven words per set in sequential expansion format for nv sets, and card numbers need not be consecutive.

W1(I) Control word. This word has the packed format ebt. It is not necessary to input leading zeros.

The digit e specifies the fluid. e=0 is the default fluid that is set for the hydrodynamic system by Cards 120 through 129. If Cards 120 through 129 are not entered and all control words use the default e=0, then H₂O is assumed as the fluid. Always use e=0 and Cards 120-129 to specify the default fluid.

The digit b specifies whether solute (dissolved gas) is present or not. The digit b=0 specifies that the volume fluid does not contain solute; b=1 specifies that a solute concentration in Kg/Kg (which may be zero) is being entered after the other required thermodynamic information.

The digit t specifies how the following words are to be used to determine the initial thermodynamic state. Entering t=0 through 3 specifies only one component (vapor/liquid).

Entering t=4 through 6 allows the specification of two components (vapor/liquid and noncondensable gas).

If t=0, the next four words are interpreted as pressure (Pa, lb f/in²), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), and vapor void fraction; these quantities will be interpreted as nonequilibrium or equilibrium conditions depending on the volume control flag. If equilibrium, the static quality is checked; but only the pressure and internal energies are used to define the thermodynamic state.

If t=1, the next two words are interpreted as temperature (K, o F) and quality in equilibrium condition.

If t=2, the next two words are interpreted as pressure (Pa, lb f/in²) and quality in equilibrium condition.

If t=3, the next two words are interpreted as pressure (Pa, lb f/in²) and temperature (K, o F) in equilibrium condition. The following options are used for input of noncondensable states only. In all cases, the criteria used for determining the range of values for quality are $1.0E-9 < \text{quality} < 0.99999999$, two phase conditions, and $\text{quality} < 1.0 E-9$ or $\text{quality} > 0.99999999$, single phase.

Noncondensable options are as follows:

If t=4, the next three words are interpreted as pressure (Pa, lb f/in²), temperature (K, o F), and equilibrium quality. Using this input option with quality 0.0 and <1.0, saturated noncondensables will result. Also, the temperature is restricted to be less than the saturation temperature at the input pressure. Setting quality to 0.0 is used as a flag that will initialize the volume to all noncondensable (dry noncondensable) with no temperature restrictions. Quality is reset to 1.0 using this dry noncondensable option.

If $t=5$, the next three words are interpreted as temperature (K, o F), equilibrium quality, and noncondensable quality. Both the equilibrium and noncondensable qualities are restricted to be between $1.0 \text{ E-}9$ and 0.99999999 . Little experience has been obtained using this option, and it has not been checked out.

If $t=6$, the next five words are interpreted as pressure (Pa, lb f /in 2), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), vapor void fraction, and noncondensable quality. The combinations of vapor void fraction and noncondensable quality must be thermodynamically consistent. If noncondensable quality is set to 0.0, noncondensables are not present and the input processing branches to that type of processing. If noncondensables are present and noncondensable quality is greater than 0.0, then the vapor void fraction must not be 0.0. If the noncondensable quality is set to 1.0 (pure noncondensable), then the vapor void fraction must also be 1.0. When both the vapor void fraction and the noncondensable quality are set to 1.0, the volume temperature is calculated from the noncondensable energy equation using the input vapor specific internal energy.

W2-W6(R) Quantities as described under Word 1. Five quantities must be entered, and zeros should be entered for unused quantities. If any control word (Word 1) indicates that solute is present, Cards ccc2001 through ccc2099 must be entered to define the initial solute concentrations. Solute concentrations are not entered in Words 2 through 6.

W7(I) Volume number.

Cards ccc2001 through ccc2099, Pipe Initial Solute (Dissolved Gas) Concentrations

These cards are required only if solute is specified in one of the control words (Word 1) in Cards ccc1201 through ccc1299. The card format is two words per set in sequential expansion format for nv sets. Solute concentrations must be entered for each volume, and zero should be entered for those volumes whose associated control word did not specify solute.

W1(R) Solute concentration. (Kg/Kg, lbm/lbm).

W2(I) Volume number.

Card ccc1300, Pipe Junction Conditions Control Words

This card is optional, and, if missing, velocities are assumed on Cards ccc1301 through ccc1399.

W1(I) Control word. If zero, the first and second words of each set on Cards ccc1301 through ccc1399 are velocities. If one, the first and second words of each set on Cards ccc1301 through ccc1399 are mass flows.

Cards cc1301 through ccc1399, Pipe Junction Initial Conditions

W1(R) Initial liquid velocity or mass flow (velocity in m/s, ft/s or mass flow in kg/s, lb/s).

W2(R) Initial vapor velocity or mass flow (velocity in m/s, ft/s or mass flow in kg/s, lb/s).

W3(R) Interface velocity (m/s, ft/s). Enter zero.

W4(I) Junction number.

Cards ccc1401 through ccc1499, Pipe Junction Diameter and CCFL Data Cards

This card is optional. The defaults indicated for each word are used if the card is not entered. If this card is being used to specify only the junction hydraulic diameter for the interphase drag calculation (i.e., $f=0$ in Cards ccc1101-ccc1199), then, the diameter should be entered in Word 1 and any allowable values should be entered in Words 2 through 4 (will not be used). If this card is being used for the CCFL model (i.e., $f=1$ in Cards ccc1101-ccc1199), then enter all four words for the appropriate CCFL model if values different from the default values are desired. In analysis of fire-suppressant fluid discharge systems, the CCFL condition will not be encountered. Hence, if this card is being entered, the allowable values can be entered, as shown below, for the CCFL data, which will not be used in any case.

W1(R) Junction hydraulic diameter, D_j (m, ft). This quantity is the junction hydraulic diameter used in the CCFL correlation equation and interphase drag and must be >0 . This number should be computed from $4.0 \cdot (\text{junction area}) / (\text{wetted perimeter})$. If zero is entered or if the default is used, the junction diameter is computed from $2.0 \cdot (\text{junction area}/p)^{0.5}$. See Word 3 of Cards ccc0101-ccc0109 for the junction area.

W2(R) Flooding correlation form, b . Enter a number between 0 and 1.

W3(R) Gas intercept, c . Enter a number greater than 0. The default value is 1.

W4(R) Slope, m . Enter a number greater than 0. The default value is 1.

W5(I) Junction number.

Card ccc3001 through ccc3099, Pipe Junction Form Loss Data Card

This card is optional. The user-specified form loss is given in Cards ccc0901 through ccc0999 if this card is not entered. If this card is entered, the form loss coefficient is calculated from

$$K_f = A_f + B_f(\text{Re})^{-cf}$$

$$K_r = A_r + B_r(\text{Re})^{-cr}$$

where K_f and K_r are the forward and reverse form loss coefficient. A_f and A_r are the Words 4 and 5 of Card ccc0101. Re is the Reynolds number based on mixture fluid properties. If this card is being used for the form loss calculation, then enter all four words for the appropriate expression.

W1(R) $B_f (>0)$. This quantity must be greater than or equal to zero.

W2(R) $cf (>0)$. This quantity must be greater than or equal to zero.

W3(R) $B_r (>0)$. This quantity must be greater than or equal to zero.

W4(R) $cr (>0)$. This quantity must be greater than or equal to zero.

W5(I) Junction number.

Branch Component

A branch component is indicated by BRANCH on Card ccc0000. In junction references using the old format, the code for the component inlet is ccc000000 and the code for the component outlet is ccc010000. In the junction references using the expanded format, the connection code is cccvv00n, where ccc is the component number, vv is the volume number, and n is the face number. More than one junction may be connected to the inlet or outlet. If an end has no junctions, that end is considered a closed end. Normally, only a branch has more than one junction connected to a volume end. Multiple junctions may connect to the ends of pipes and single volumes, except that a warning message is issued even though the connections are handled correctly. Limiting multiple connections to branch components allows the warning message to indicate probable input error. If more than one junction is connected on one end of a branch, each junction should be modeled as an abrupt area change. For major edits, minor edits, and plot variables, the volume in the branch component is numbered as ccc010000. The junctions associated with the branch component are numbered as cccmm0000, where mm is the junction number (greater than 00 and less than 10).

Card ccc0001, Branch Information Card

This card is required for branch components.

W1(I) Number of junctions, nj. nj is the number of junctions described in the input data for this component and must be equal to or greater than zero and less than ten. For BRANCH components, not all junctions connecting to the branch need be described with this component input, and NJ is not necessarily the total number of junctions connecting to the branch. Junctions described in single junctions, time dependent junctions and other branches can be connected to this branch.

W2(I) Initial condition control. This word is optional and, if missing, the junction initial velocities in the first and second words on Cards cccn201 are assumed to be velocities. If zero, velocities are assumed; if nonzero, mass flows are assumed.

Cards ccc0101 through ccc0109, Branch X-Coordinate Volume Data

This card (or cards) is required for branch components. The nine words can be entered on one or more cards, and the card numbers need not be consecutive.

W1(R) Volume flow area (m², ft²).

W2(R) Length of volume (m, ft).

W3(R) Volume of volume (m³, ft³). The code requires that the volume equals the volume flow area times the length ($W3=W1*W2$). At least two of the three quantities, W1, W2, and W3, must be nonzero. If one of the quantities is zero, it will be computed from the other two. If none of the words are zero, the volume must equal the area times the length within a relative error of 0.000001.

W4(R) Azimuthal angle (degrees). The absolute value of this angle must be <360 degrees. This quantity is not used in the calculation but is specified for possible automated drawing of nodalization diagrams.

W5(R) Inclination angle (degrees). The absolute value of this angle must be <90 degrees. The angle 0 degrees is horizontal, and positive angles have an upward inclination, i.e., the inlet is at the lowest elevation. This angle is used in the interphase drag calculation.

W6(R) Elevation change (m, ft). A positive value is an increase in elevation. The absolute value of this quantity must be less than or equal to the volume length. If the vertical angle orientation is zero, this quantity must be zero. If the vertical angle is nonzero, this quantity must also be nonzero and have the same sign. When the absolute value of the elevation angle determined by the ratio of the elevation change (this Word 6) and the volume length (Word 2) is less than or equal to 45 degrees, the horizontal flow regime map is used. When the ratio is greater than 45 degrees, the vertical flow regime map is used.

W7(R) Wall roughness (m, ft).

W8(R) Hydraulic diameter (m, ft). This should be computed from $4.0 \cdot (\text{volume flow area}) / (\text{wetted perimeter})$. If zero, the hydraulic diameter is computed from $2.0 \cdot (\text{volume flow area} / p) \cdot 0.5$. A check is made that the pipe roughness is less than half the hydraulic diameter. See Word 1 for the volume flow area.

W9(I) Volume control flags. This word has the packed format tlpvbf. It is not necessary to input leading zeros. Volume flags consist of scaler oriented and coordinate direction oriented flags. Only one value for a scaler oriented flag is entered per volume but up to three coordinate oriented flags can be entered for a volume, one for each coordinate direction. At present, the f flag is the only coordinate direction oriented flag. This word enters the scaler oriented flags and the x-coordinate flag.

The digit t specifies whether the thermal front tracking model is to be used; $t=0$ specifies that the front tracking model is not to be used for the volume, and $t=1$ specifies that the front tracking model is to be used for the volume. Use $t=0$.

The digit l specifies whether the mixture level tracking model is to be used; $l=0$ specifies that the level model not be used for the volume, and $l=1$ specifies that the level model be used for the volume. Use $l=0$.

The digit p specifies whether the water packing scheme is to be used. $p=0$ specifies that the water packing scheme is to be used for the volume, and $p=1$ specifies that the water packing scheme is not to be used for the volume. The water packing scheme is recommended when modeling a pressurizer. Use $p=0$.

The digit v specifies whether the vertical stratification model is to be used. $v=0$ specifies that the vertical stratification model is to be used for the volume, and $v=1$ specifies that the vertical stratification model is not to be used for the volume. The vertical stratification model is recommended when modeling a pressurizer. Use $v=0$.

The digit b specifies the interphase friction that is used. $b=0$ means that the pipe interphase friction model will be applied, $b=1$ means that the rod bundle interphase friction model will be applied, and $b=2$ means that the narrow channel model will be applied. Use $b=0$.

The digit f specifies whether wall friction is to be computed. $f=0$ specifies that wall friction effects are to be computed along the x coordinate of the volume, and $f=1$ specifies that wall friction effects are not to be computed along the x coordinate. Use $f=0$, unless a sensitivity study is being conducted to see the effect of no wall friction.

The digit e specifies if nonequilibrium or equilibrium is to be used. $e=0$ specifies that a

nonequilibrium (unequal temperature) calculation is to be used, and $e=1$ specifies that an equilibrium (equal temperature) calculation is to be used. Equilibrium volumes should not be connected to nonequilibrium volumes. The equilibrium option is provided only for comparison with other codes. Use $e=0$.

Cards ccc0181 through ccc0189, Branch Y- Coordinate Volume Data

These cards are optional for BRANCH components. These cards are used when the user specifies the y-direction connection with the crossflow model.

W1(R) Area of the volume (m²).

W2(R) Length of the crossflow volume (m).

W3(R) Roughness.

W4(R) Hydraulic diameter (m).

W5(I) Volume control flags. This word has the general packed format tlpvbf, but this word is limited to 00000f0 since it only enters the coordinate oriented flags for the y direction. The digit f specifies whether wall friction is to be computed. $f=0$ specifies that wall friction effects are to be computed along the y coordinate direction in the volume, and $f=1$ specifies that wall friction effects are not to be computed along the y coordinate direction.

W6(R) This word is not used. Enter 0.

W7(R) This word is not used. Enter 0.

W8(R) This word is the position change in the z fixed (vertical) direction as the flow passes from the y inlet face to the y outlet face (m, ft). This quantity affects problems if connections are made to the y faces.

Cards ccc0191 through ccc0199, Branch Z- Coordinate Volume Data

These cards are optional for BRANCH components. These cards are used when the user specifies the z-direction connection with the crossflow model.

W1(R) Area of the volume (m²).

W2(R) Length of the crossflow volume (m).

W3(R) Roughness.

W4(R) Hydraulic diameter (m).

W5(I) Volume control flags. This word has the general packed format tlpvbf, but this word is limited to 00000f0 since it only enters the coordinate oriented flags for the z direction. The digit f specifies whether wall friction is to be computed. $f=0$ specifies that wall friction effects are to be computed along the z coordinate direction in the volume, and $f=1$ specifies that wall friction effects are not to be computed along the z coordinate direction.

W6(R) This word is not used. Enter 0.

W7(R) This word is not used. Enter 0.

W8(R) This word is the position change in the z fixed (vertical) direction as the flow passes from the z inlet face to the z outlet face (m, ft). This quantity affects problems if connections are made to the zfaces.

Card ccc0200, Branch Volume Initial Conditions

This card is required for branch components.

W1(I) Control word. This word has the packed format ebt. It is not necessary to input leading zeros.

The digit e specifies the fluid. e =0 is the default fluid that is set for the hydrodynamic system by Cards 120 through 129. If Cards 120 through 129 are not entered and all control words use the default e =0, then H₂O is assumed as the fluid. Always use e=0 and Cards 120-129 to specify the default fluid.

The digit b specifies whether solute (dissolved gas) is present or not. The digit b=0 specifies that the volume fluid does not contain solute; b=1 specifies that a solute concentration in Kg/Kg (which may be zero) is being entered after the other required thermodynamic information.

The digit t specifies how the following words are to be used to determine the initial thermodynamic state. Entering t=0 through 3 specifies only one component (vapor/liquid). Entering t=4 through 6 allows the specification of two components (vapor/liquid and noncondensable gas).

If t=0, the next four words are interpreted as pressure (Pa, lb f/in²), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), and vapor void fraction; these quantities will be interpreted as nonequilibrium or equilibrium conditions depending on the volume control flag. If equilibrium, the static quality is checked; but only the pressure and internal energies are used to define the thermodynamic state.

If t=1, the next two words are interpreted as temperature (K, o F) and quality in equilibrium condition.

If t=2, the next two words are interpreted as pressure (Pa, lb f/in²) and quality in equilibrium condition.

If t=3, the next two words are interpreted as pressure (Pa, lb f/in²) and temperature (K, o F) in equilibrium condition. The following options are used for input of noncondensable states only. In all cases, the criteria used for determining the range of values for quality are $1.0E-9 < \text{quality} < 0.99999999$, two phase conditions, and $\text{quality} < 1.0 E-9$ or $\text{quality} > 0.99999999$, single phase. Noncondensable options are as follows:

If t=4, the next three words are interpreted as pressure (Pa, lb f/in²), temperature (K, o F), and equilibrium quality. Using this input option with quality 0.0 and <1.0, saturated noncondensables will result. Also, the temperature is restricted to be less than the saturation temperature at the input pressure. Setting quality to 0.0 is used as a flag that will initialize the volume to all noncondensable (dry noncondensable) with no temperature restrictions. Quality is reset to 1.0 using this dry noncondensable option.

If t=5, the next three words are interpreted as temperature (K, o F), equilibrium quality, and noncondensable quality. Both the equilibrium and noncondensable qualities are restricted to be between $1.0 E-9$ and 0.99999999 . Little experience has been obtained using this option, and it has not been checked out.

If t=6, the next five words are interpreted as pressure (Pa, lb f/in²), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), vapor void fraction, and noncondensable quality. The combinations of vapor void fraction and noncondensable quality must be thermodynamically consistent. If noncondensable quality is set to 0.0, noncondensables are not present and the input processing branches to that type of processing. If noncondensables

are present and noncondensable quality is greater than 0.0, then the vapor void fraction must not be 0.0. If the noncondensable quality is set to 1.0 (pure noncondensable), then the vapor void fraction must also be 1.0. When both the vapor void fraction and the noncondensable quality are set to 1.0, the volume temperature is calculated from the noncondensable energy equation using the input vapor specific internal energy.

W2-W7(R) Quantities as described under Word1 (W1). Depending on the control word, two through five quantities may be required. Enter only the minimum number required. If entered, solute concentration, in Kg/Kg, follows the last required word for thermodynamic conditions.

Cards cccn101 through cccn109, Branch Junction Geometry Card

These cards are required if n_j is greater than zero. Cards with n equal to 1 through 9 are entered, one for each junction. For a BRANCH component, n need not be consecutive, but n_j cards must be entered. The card format for Words 1 through 6 is listed below and is identical to Words 1 through 6 on Card ccc0101 of the Single Junction Geometry Card, except that n instead of 0 is used in the fourth digit. Word 7 is not used for BRANCH components.

W1(I) From connection code to a component. This refers to the component from which the junction coordinate direction originates. For connecting to a time-dependent volume, the connection code is ccc000000, where ccc is the component number of the time-dependent volume. An old or an expanded format can be used to connect all other volumes. In the old format, use ccc000000 if the connections to the inlet side of the component and use ccc010000 if the connection is to the outlet side of the volume. In the expanded format, the connection code is cccvv000n, where ccc is the component number, vv is the volume number, and n indicates the face number. A nonzero n specifies the expanded format. The number n equal to 1 and 2 specifies the inlet and outlet faces respectively for the volume's coordinate direction. The number n equal to 3 through 6 specifies crossflow. The number n equal to 3 and 4 would specify inlet and outlet faces for the second coordinate direction; n equal to 5 and 6 would do the same for the third coordinate direction.

W2(I) To connection code to a component. This refers to the component at which the junction coordinate direction ends. See the description for W1 above.

W3(R) Junction area (m^2 , ft^2). If zero, the area is set to the minimum volume area of the adjoining volumes. For abrupt area changes, the junction area must be equal to or smaller than the minimum of the adjoining volume areas. For smooth area changes, there are no restrictions.

W4(R) Forward flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero.

W5(R) Reverse flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative.

W6(I) Junction control flags. This word has the packed format efvcahs. It is not necessary to input leading zeros.

The digit e specifies the modified PV term in the energy equations. $e=0$ means that the modified PV term will not be applied, and $e=1$ means that it will be applied. Use $e=0$.

The digit f specifies CCFL options. $f=0$ means that the CCFL model will not be applied, and $f=1$ means that it will be applied. Use $f=0$.

The digit v specifies horizontal stratification entrainment/ pullthrough options. This model is for junctions connected to a horizontal volume. v=0 means the model is not applied; v=1 means an upward-oriented junction; v=2 means a downward-oriented junction; and v=3 means a centrally (side) located junction. Use v=0 unless conducting sensitivity studies.

The digit c specifies choking options. c=0 means that the choking model will be applied, and c=1 means that the choking model will not be applied. Generally do not allow choking at interior junctions where choking is not expected. Hence use c=0 only at exit junctions from the supply vessel, or at the exit of the system. Use c=1 at all other junctions.

The digit a specifies area change options. a=0 means either a smooth area change or no area change, and a=1 means an abrupt area change.

The digit h specifies nonhomogeneous or homogeneous. h=0 specifies the nonhomogeneous (two velocity momentum equations) option, and h=2 specifies the homogeneous (single velocity momentum equation) option. For the homogeneous option (h=2), the major edit printout will show a 1. Use h=0 unless conducting a sensitivity study to examine effect of homogeneous flow conditions.

The digit s specifies momentum flux options. s=0 uses momentum flux in both the to volume and the from volume. s=1 uses momentum flux in the from volume, but not in the to volume. s=2 uses momentum flux in the to volume, but not in the from volume; s=3 does not use momentum flux in either the to or the from volume. Use s=0.

W7(R). Void fraction limit or Angle. Not needed for a BRANCH component.

Cards cccn110, Branch Junction Diameter and CCFL Data Cards

These cards are optional. The value n should follow the same approach as used in Cards ccn101-cccn109. The defaults indicated for each word are used if the card is not entered. If these cards are being used to specify only the junction hydraulic diameter for the interphase drag calculations (i.e., f=0 in Word 6 of Cards ccn101-cccn109), then the diameter should be entered in Word 1 and any allowable values should be entered in Words 2 through 4 (will not be used). If these cards are being used for the CCFL model (i.e., f=1 in Word 6 of Cards ccn101-cccn109), then enter all four words for the appropriate CCFL model if values different from the default values are desired.

W1(R) Junction hydraulic diameter, D_j (m, ft). This quantity is the junction hydraulic diameter used in the CCFL correlation equation and interphase drag and must be >0. This number should be computed from $4.0 * (\text{junction area}) / (\text{wetted perimeter})$. If zero is entered or if the default is used, the junction diameter is computed from $2.0 * (\text{junction area}/p) ** 0.5$. See Word 3 of Cards ccn101-cccn109 for the junction area.

W2(R) Flooding correlation form, b. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be >0 and <1. The default value is 0 (Wallis form).

W3(R) Gas intercept, c. This quantity is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be > 0. The default value is 1.

W4(R) Slope, m. This quantity is the slope used in the CCFL correlation and must be >0. The default value is 1.

Cards cccn112, Branch Junction Form Loss Data Card

These cards are optional. The user specified form loss is given in Words 4 and 5 of Cards cccn101- cccn109 if these cards are not entered. If these cards are entered, the form loss coefficient is calculated from

$$K_f = A_f + B_f(\text{Re})^{-c_f}$$

$$K_r = A_r + B_r(\text{Re})^{-c_r}$$

where K_f and K_r are the forward and reverse form loss coefficient. A_f and A_r are the Words 4 and 5 of Card ccc0101. Re is the Reynolds number based on mixture fluid properties. If this card is being used for the form loss calculation, then enter all four words for the appropriate expression.

W1(R) B_f (>0). This quantity must be greater than or equal to zero.

W2(R) c_f (>0). This quantity must be greater than or equal to zero.

W3(R) B_r (>0). This quantity must be greater than or equal to zero.

W4(R) c_r (>0). This quantity must be greater than or equal to zero.

Cards cccn201, Branch Junction Initial Conditions

These cards are required depending on the value of n_j as described for Cards cccn101-cccn109. The values of n should follow the same approach as used in Cards cccn101-cccn109.

W1(R) Initial liquid or mass flow (velocity in m/s, ft/s or mass flow in kg/s, lb/s).

W2(R) Initial vapor velocity or mass flow (velocity in m/s, ft/s or mass flow in kg/s, lb/s).

W3(R) Interface velocity (m/s, ft/s). Enter zero.

Valve Junction Component

A valve junction component is indicated by VALVE on Card ccc0000. For major edits, minor edits, and plot variables, the junction in the valve junction component is numbered ccc000000. A VALVE component is very similar to a single junction (SNGLJUN component), except that the area can be 0.0 if the valve is closed, or the area can vary with time if the valve is specified to open with a specified opening time. Only two types of valves are described here, a trip valve (TRPVLV) or a motor valve (MTRVLV). Other types exist and are allowed in the code, but these are the only types that are expected to be useful in modeling fire-suppressant fluid discharge systems.

Cards ccc0101 through ccc0109, Valve Junction Geometry Cards

This card (or cards) is required for valve junction components.

W1(I) From connection code to a component. This refers to the component from which the junction coordinate direction originates. For connecting to a time-dependent volume, the connection code is `ccc000000`, where `ccc` is the component number of the time-dependent volume. An old or an expanded format can be used to connect all other volumes. In the old format, use `ccc000000` if the connection is to the inlet side of the component and use `ccc010000` if the connection is to the outlet side of the volume. In the expanded format, the connection code is `cccvv000n`, where `ccc` is the component number, `vv` is the volume number, and `n` indicates the face number. A nonzero `n` specifies the expanded format. The number `n` equal to 1 and 2 specifies the inlet and outlet faces respectively for the volume's coordinate direction. The number `n` equal to 3 through 6 specifies crossflow. The number `n` equal to 3 and 4 would specify inlet and outlet faces for the second coordinate direction; `n` equal to 5 and 6 would do the same for the third coordinate direction.

W2(I) To connection code to a component. This refers to the component at which the junction coordinate direction ends. See the description for W1 above.

W3(R) Junction area (m^2 , ft^2). This quantity is the full open area of the valve. If this area is input as zero, the area is set to the minimum area of adjoining volumes. If nonzero, this area is used. When an abrupt area change model is specified, the area must be less than or equal to the minimum of the adjoining volume areas.

W4(R) Forward flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero.

W5(R) Reverse flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative.

W6(I) Junction control flags. This word has the packed format `efvcahs`. It is not necessary to input leading zeros.

The digit `e` specifies the modified PV term in the energy equations. `e=0` means that the modified PV term will not be applied, and `e=1` means that it will be applied. Use `e=0`.

The digit `f` specifies CCFL options. `f=0` means that the CCFL model will not be applied, and `f=1` means that it will be applied. Use `f=0`.

The digit `v` specifies horizontal stratification entrainment/ pullthrough options. This model is for junctions connected to a horizontal volume. `v=0` means the model is not applied; `v=1` means an upward-oriented junction; `v=2` means a downward-oriented junction; and `v=3` means a centrally (side) located junction. Use `v=0` unless conducting sensitivity studies.

The digit `c` specifies choking options. `c=0` means that the choking model will be applied, and `c=1` means that the choking model will not be applied. Generally do not allow choking at interior junctions where choking is not expected. Hence use `c=0` only at exit junctions from the supply vessel, or at the exit of the system. Use `c=1` at all other junctions.

The digit `a` specifies area change options. `a=0` means either a smooth area change or no area change, and `a=1` means an abrupt area change. For a motor valve, either option may be used. For a motor valve, if the smooth area change option is used, then a Cv table must be provided; or, if no Cv table is provided, then the abrupt area change option must be used. For all other valve types the abrupt area change option must be used.

The digit `h` specifies nonhomogeneous or homogeneous. `h=0` specifies the nonhomogeneous (two velocity momentum equations) option, and `h=2` specifies the homogeneous (single velocity momentum equation) option. For the homogeneous option (`h=2`), the major edit printout will

show a 1. Use h=0 unless conducting a sensitivity study to examine effect of homogeneous flow conditions.

The digit s specifies momentum flux options. s=0 uses momentum flux in both the to volume and the from volume. s=1 uses momentum flux in the from volume, but not in the to volume. s=2 uses momentum flux in the to volume, but not in the from volume; s=3 does not use momentum flux in either the to or the from volume. Use s=0.

W7(R) Subcooled discharge coefficient. This quantity is applied only to subcooled choked flow calculations. The quantity must be >0 and <2.0. If missing, it is set to 1.0.

W8(R) Two phase discharge coefficient. This quantity is applied only to two-phase choked flow calculations. The quantity must be >0 or <2.0. If missing, it is set to 1.0.

W9(R) Superheated discharge coefficient. This quantity is applied only to superheated choked flow calculations. The quantity must be >0 and <2.0. If missing, it is set to 1.0.

Card ccc0110, Valve Junction Diameter and CCFL Data Card

This card is optional. The defaults indicated for each word are used if the card is not entered. If this card is being used to specify the junction hydraulic diameter for the interphase drag calculation (i.e., f=0 in Word 6 of Cards ccc0101-ccc0109), then the diameter should be entered in Word 1 and any allowable values should be entered in Words 2 through (will not be used). If this card is being used for the CCFL model (i.e., f=1 in Word 6 of Cards ccc0101-ccc0109), then enter all four words for the appropriate CCFL model if values different from the default values are used.

W1(R) Junction hydraulic diameter, D_j (m, ft). This is the junction hydraulic diameter used in the CCFL correlation equation and interphase drag and must be >0. This number should be computed from $4.0 * (\text{junction area}) / (\text{wetted perimeter})$. If a zero is entered or if the default is used, the junction diameter is computed from $2.0 * (\text{junction area}/p)^{0.5}$. See Word 3 of Cards ccc0101-ccc0109 for the junction area.

W2(R) Flooding correlation form, b. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be >0 and < 1. The default value is 0 (Wallis form).

W3(R) Gas intercept, c. This is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be >0. The default value is 1.

W4(R) Slope, m. This is the slope used in the CCFL correlation and must be >0. The default value is 1.

Card ccc0111, Valve Junction Form Loss Data Card

This card is optional. The user specified form loss is given in Words 4 and 5 of Card ccc0101 if this card is not entered. If this card is entered, the form loss coefficient is calculated from

$$K_f = A_f + B_f(\text{Re})^{-c_f}$$

$$K_r = A_r + B_r(\text{Re})^{-c_r}$$

where K_f and K_r are the forward and reverse form loss coefficient. A_f and A_r are the Words 4 and 5 of Card ccc0101. Re is the Reynolds number based on mixture fluid properties. If this card is being used for the form loss calculation, then enter all four words for the appropriate expression.

W1(R) $B_f (>0)$. This quantity must be greater than or equal to zero.

W2(R) $cf (>0)$. This quantity must be greater than or equal to zero.

W3(R) $B_r (>0)$. This quantity must be greater than or equal to zero.

W4(R) $cr (>0)$. This quantity must be greater than or equal to zero.

Card ccc0201, Valve Junction Initial Conditions

This card is required for valve junction components.

W1(I) Control word. If zero, the next two words are velocities; if one, the next two words are mass flows.

W2(R) Initial liquid velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on the control word.

W3(R) Initial vapor velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on the control word.

W4(R) Interface velocity (m/s, ft/s). Enter zero.

Card ccc0300, Valve Type Card

This card is required to specify the valve type.

W1(A) Valve type. This word must contain one of the following: TRPVLV for a trip valve, MTRVLV for a motor valve. Most users will use this component to model the discharge junction at the outlet of the suppressant supply tank. Typically TRPVLV can be used to simulate an instantaneous opening to the fully open area, and MTRVLV can be used if the user wants to specify a time period (such as 10 or 20 ms) for the valve to achieve a fully open position. Other valve types are not recommended at this time.

Cards ccc0301 through ccc0399, Valve Data and Initial Conditions

These cards are required for valve junction components. Although six different types of valves are allowed, only two are recommended for use at this time. The following words may be placed on one or more cards, and the card numbers need not be consecutive. The card format of these cards depends on the valve type.

Trip Valve.

This behaves as an on, off switch. When the valve is tripped it goes from fully closed to fully open (or vice versa) over one time step. The valve is tripped using a trip as specified in Cards 400-799.

W1(I) Trip number. This must be a valid trip number. If the trip is false, the valve is closed; if the trip is true, the valve is open.

Motor Valve.

This behaves realistically in that the valve area varies as a function of time by either of two models specified by the user. The user must also select the model for valve hydrodynamic losses by specifying either the smooth or the abrupt area change model. If the smooth area change model is selected, a table of flow coefficients must also be input as described in Cards ccc0400 through ccc0499, CSUBV Table Section. If the abrupt area change model is selected, a flow coefficient table cannot be used.

W1(I) Open trip number.

W2(I) Close trip number. Both the open and close trip numbers must be valid trips. When both trips are false, the valve remains at its current position. When one of the trips is true, the valve opens or closes depending on which trip is true. The transient will be terminated if both trips are true at the same time.

W3(R) Valve change rate (s^{-1}). If Word 5 is not entered, this quantity is the rate of change of the normalized valve area as the valve opens or closes. If Word 5 is entered, this quantity is the rate of change of the normalized valve stem position. This word must be greater than zero.

W4(R) Initial position. This number is the initial normalized valve area or the initial normalized stem position depending on Word W5. This quantity must be between 0.0 and 1.0.

W5(I) Valve table number. If this word is omitted or input as zero, the valve area is determined by the valve change rate and the trips. If this word is input as nonzero, the valve stem position is determined by the valve change rate and the trips; and the valve area is determined from a general table containing normalized valve area versus normalized stem position. Input for general tables is discussed in Cards 202tttn, General Table Data. For this case, the normalized stem position is input as the argument value and the normalized valve area is input as the function value.

Cards ccc0400 through ccc0499, Valve CSUBV Table

The CSUBV table may be used for motor valves. If the CSUBV table is used, the smooth area change model must be specified on the valve junction geometry card (Card ccc0101 through ccc0109). If the smooth area change model is specified, a CSUBV table must be used. The CSUBV table contains forward and reverse flow coefficients as a function of normalized flow area or normalized stem position.

Cards ccc0400, Factors.

This card is optional. The factors apply to the flow area or the stem position and the flow coefficient entries in the CSUBV table.

W1(R) Normalized flow area or normalized stem position.

W2(R) Flow coefficient factor.

Cards ccc0401 through ccc0499, Table Entries.

The table is entered by using three-word sets. W1 is the flow area or stem position and must be normalized. The factor W1 on Card ccc0400 can be used to normalize the flow area or stem position. In either case, the implication is that if the valve is fully closed, the normalized term is zero. If the valve is fully open, the normalized term is one. Any value may be used for W1 that is between zero and one. The forward and reverse flow coefficients are W2 and W3, respectively. The code internally converts flow coefficients to energy loss coefficients by the formula $K = 2A_j^2 / (\rho * CSUBV^{**2})$, where ρ is density of water at 60° F (288.71 K), A_j is the fully open valve area, and CSUBV is the flow coefficient. On Card ccc0400, W2 may be used to modify the definition of CSUBV. A smooth area change must be specified in W6 on Card ccc0101 to use the CSUBV table. CSUBV is entered in British units only.

W1(R) Normalized flow area or normalized stem position.

W2(R) Forward CSUBV {gal/[min(lb f /in 2)**0.5]}. The CSUBV is input in British units only and is converted to SI units using 7.598055E-7 as the conversion factor.

W3(R) Reverse CSUBV {gal/[min(lb f /in 2)**0.5]}.

CARDS 202TTTNN, GENERAL TABLE DATA

These cards are used only in NEW or RESTART type problems and are required only if any input references general tables. ttt is the table number, and table references such as for power, heat transfer coefficients, and temperatures refer to this number. Data must be entered for each table that is referenced, but ttt need not be consecutive. Tables entered but not referenced are stored, and this is not considered an error. During RESTART, general tables may be added, existing tables may be deleted, or existing tables may be modified by entering new data.

Card 202ttt00, Table Type and Multiplier Data

W1(A) Table type. Enter POWER for power versus time; enter HTRNRATE for heat flux versus time; enter HTC-T for heat transfer coefficient versus time; enter HTC-TEMP for heat transfer coefficient versus temperature; enter TEMP for temperature versus time; enter REAC-T for reactivity versus time; enter NORMAREA for normalized area versus normalized stem position. In RESTART problems, DELETE can be entered to delete general table ttt. When a general table is used to define a FUNCTION type control system variable, table type REAC-T can be used to

prevent undesirable units conversion, since no British to SI units conversion is done for REAC-T entries.

The following two, three, or four words are optional and allow trips and factors or units changes to be applied to the table entries. If the factors are omitted, the data are used as entered. One multiplier is used for time, power, heat flux, heat transfer coefficient, normalized stem position, and normalized area; a multiplier and additive constant are used for temperature as $T = M \cdot TX + C$, where M is the multiplier, C is the additive constant, and TX is the temperature entered. The first one or two factors apply to the argument variable, time or temperature; one factor is applied if the argument is time, and two factors are used if the argument is temperature. The remaining one or two factors are used for the function, two factors being used if temperature is the function.

W2(I) Table trip number. This number is optional unless factors are entered. If missing or zero, no trip is used, and the time argument in the following table is the time supplied to the table for interpolation. If nonzero, the number is the trip number, and the time argument in the following table is -1.0 if the trip is false and the time supplied to the table minus the trip time if the trip is true. This field may be omitted if no factors are entered. This number must be zero or blank for tables that are not a function of time.

W3-W5(R) Factors. As described above, enter factors such that when applied to the table values entered, the resultant values have the appropriate units. For the NORMAREA table, the resultant values for both the normalized length and area must be >0 and <1.0 .

Cards 202ttt01 through 202ttt99, General Table Data

The card numbers need not be consecutive. The units given are the units required after the factors on Card 202ttt00 have been applied. Pairs of numbers are entered; the limit on the number of pairs is 99.

W1(R) Argument value (s, if time; K, o F, if temperature; dimensionless, if normalized stem position).

W2(R) Function value (W, MW, if power; K, o F, if temperature; W/m^2 , $Btu/s.ft^2$, if heat flux; $W/m^2.K$, $Btu/s.ft^2$, o F, if heat transfer coefficient; dollars, if reactivity; dimensionless, if normalized area).

The tables use linear interpolation for segments between table search argument values. For search arguments beyond the range of entered data, the end-point values are used.

CARDS 205CCCN OR 205CCCN, CONTROL SYSTEM INPUT DATA

These cards are used in NEW and RESTART problems if a control system is desired. They are also used to compute additional quantities from the normally computed quantities. These additional quantities can then be seen as output in major and minor edits and plots.

Two different card types are available for entering control system data, but only one type can be used in a problem. The digits ccc or cccc form the control variable number (i.e., control component number). The card format 205cccn allows 999 control variables, where ccc ranges from 001 through 999. The card format 205cccn allows 9999 control variables, where cccc ranges from 1 through 9999.

Card 20500000, Control Variable Card Type

If this card is omitted, card type 205cccn is used. If this card is entered, either card format can be selected. This card cannot be entered on RESTART problems if control components exist from the restart problem, in which case the card format from the restart problem must be used.

W1(I) Enter 999 to select the 205cccn format or 9999 (4095 also allowed) to select the 205cccn format.

Card 205ccc00 or 205cccc0, Control Component Type Card

W1(A) Alphanumeric name. Enter a name descriptive of the component. This name will appear in the printed output along with the component number. A limit of 10 characters is allowed for CDC 7600 computers, and a limit of 8 characters is allowed for most other computers.

W2(A) Control component type. Enter one of the component names, SUM, MULT, DIV, DIFFRENI, DIFFREND, INTEGRAL, FUNCTION, STDFNCTN, DELAY, TRIPUNIT, TRIPDLAY, POWERI, POWERR, POWERX, PROP-INT, LAG, LEAD-LAG, CONSTANT, or the command, DELETE. If DELETE is entered, enter any alphanumeric word in Word 1 and zeros in the remaining words. No other cards are needed when deleting a component.

W3(R) Scaling factor. For a CONSTANT component, this quantity is the constant value. No additional words are entered on this card, and Cards 205ccc01 through 205ccc09 or 205cccc1 through 205cccc9 are not entered.

W4(R) Initial value.

W5(I) Initial value flag. Zero means no initial condition calculation and W4 is used as the initial condition; one means compute initial condition.

W6(I) Limiter control. Enter zero, or omit this and the following words if no limits on the control variable are to be imposed. Enter 1 if only a minimum limit is to be imposed, 2 if only a maximum limit is to be imposed, and enter 3 if both minimum and maximum limits are to be imposed.

W7(R) Minimum or maximum value. This word is the minimum or maximum value if only one limit is to be imposed or is the minimum value if both limits are to be imposed.

W8(R) Maximum value. This word is used if both limits are to be imposed.

Cards 205ccc01 through 205ccc98 or 205cccc1 through 205cccc8, Control Component Data Cards

The format of these cards depends on the control component type. An equation is used to describe the processing by each component. The symbol Y represents the control variable defined by the component. The symbols A_j , $j=1,2,\dots,J$, represent constants defined by the control component input data. The variables V_j , $j=1,2,\dots,J$, represent any of the variables listed in the minor edit input description. Besides hydrodynamic component data, heat structure data, etc., any of the control variables including the variable being defined may be specified. The symbol S is the scale factor on Card 205ccc00 or 205cccc0. The variables V_j use the code's internal units (SI). To use British units, the user must convert from SI to British using the scale factor S and the constants A_j .

Sum-Difference Component

This component is indicated by SUM in Word 2 of Card 205ccc00 or 205cccc0. The sum-difference component is defined by

$$Y = S(A_0 + A_1 V_1 + A_2 V_2 + \dots + A_j V_j)$$

W1(R) Constant A_0 .

W2(R) Constant A_1 .

W3(A) Alphanumeric name of variable request code for V_1 .

W4(I) Integer name of the variable request code for V_1 . At least four words that define a constant and one product term must be entered. Additional sets of three words corresponding to Words 2 through 4 can be entered for additional product terms up to twenty product terms. One or more cards may be used as desired. Card numbers need not be strictly consecutive. The sign of A_j determines addition or subtraction of the product terms.

Multiplier Component

This component is indicated by MULT in Word 2 of Card 205ccc00 or 205cccc0. The multiplier component is defined by

$$Y = S V_1 V_2 \dots V_j.$$

W1(A) Alphanumeric name of the variable request code for V_1 .

W2(I) Integer name of the variable request code for V_1 . At least two words must be entered. Additional pairs of words can be entered on this or additional cards to define additional factors. Card numbers need not be strictly consecutive.

Divide Component

This component is indicated by DIV in Word 2 of Card 205ccc00 or 205cccc0. The divide component is defined by

$$Y = S/V1 \text{ or } Y = V2/V1$$

Specifying two words on the card indicates the first form, and specifying four words on the card indicates the second form. Execution will terminate if a divide by zero is attempted.

W1(A) Alphanumeric name of the variable request code for V 1 .

W2(I) Integer name of the variable request code for V 1 .

W3(A) Alphanumeric name of the variable request code for V 2 .

W4(I) Integer name of the variable request code for V 2 .

Differentiating Components

These components are indicated by DIFFRENI or DIFFREND in Word 2 of Card 205ccc00 or 205cccc0. The differentiating component is defined by

$$Y = S \, dV1/dt$$

This is evaluated by

$$Y = S*[2(V 1 - V 10)/\Delta t] - Y 0 \quad (\text{DIFFRENI})$$

$$Y = S*(V 1 - V 10)/\Delta t \quad (\text{DIFFREND})$$

where Δt is the time step, and $V 10$ and $Y 0$ are values at the beginning of the time step. The numerical approximations for the DIFFRENI and INTEGRAL components are exact inverses of each other. However, an exact initial value is required to use the DIFFRENI component, and erroneous results are obtained if an exact initial value is not furnished. The DIFFREND component uses a simple difference approximation that is less accurate and is not consistent with the integration approximation, but does not require an initial value. For these reasons, use of DIFFRENI is not recommended. Since differentiation, especially numerical differentiation, can introduce noise into the calculation, it should be avoided if possible. When using control components to solve differential equations, the equations can be arranged such that INTEGRAL components can handle all indicated derivatives except possibly those involving noncontrol variables.

W1(A) Alphanumeric name of variable request code for V 1 .

W2(I) Integer name of variable request code for V 1 .

Integrating Component

This component is indicated by INTEGRAL in Word 2 of Card 205ccc00 or 205cccc0. The integrating component is defined by

$$Y = S \int_0^t V1 \, dt$$

or, in Laplace notation,

$$Y(s) = S V1 (s) /s$$

This is evaluated by

$$Y = Y_0 + S*(V_1 + V_{10})*\Delta t/2$$

where Δt is the time step and Y_0 and V_{10} are values at the beginning of the time step.

W1(A) Alphanumeric name of the variable request code for V_1 .

W2(I) Integer name of the variable request code for V_1 .

Functional Component

This component is indicated by FUNCTION in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = S[\text{FUNCTION} (V_1)]$$

where FUNCTION is defined by a general table. This allows the use of any function that is conveniently defined by a table lookup and linear interpolation procedure. The function component can also be used to set limiting values.

W1(A) Alphanumeric name of the variable request code for V_1 .

W2(I) Integer name of the variable request code for V_1 .

W3(I) General table number of the function.

Standard Function Component

This component is indicated by STDFNCTN in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = S[\text{FNCTN} (V_1, V_2, \dots)]$$

where FNCTN is ABS (absolute value), SQRT (square root), EXP (e raised to power), LOG (natural logarithm), SIN (sine), COS (cosine), TAN (tangent), ATAN (arc tangent), MIN (minimum value), or MAX (maximum value). All function types except MIN and MAX must have only one argument; MIN and MAX function types must have at least two arguments and may have up to twenty arguments. If the control variable being defined also appears in the argument list of MIN or MAX, the old time value is used in the comparison.

W1(A) FNCTN.

W2(A) Alphanumeric name of the variable request code for V_1 .

W3(I) Integer name of the variable request code for V_1 .

Delay Component

This component is indicated by DELAY in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = S V1 (t - t_d)$$

where t is time and t_d is the delay time.

W1(A) Alphanumeric name of the variable request code for V1 .

W2(I) Integer name of the variable request code for V1 .

W3(R) Delay time, t_d (s).

W4(I) Number of hold positions. This quantity, h , must be > 0 and < 100 . This quantity determines the length of the table used to store past values of the quantity V 1 . The maximum number of time-function pairs that can be stored is $h+2$. The delay table time increment, d_{TM} , is $d_{TM} = t_d / h$. The delayed function is obtained by linear interpolation for V1 ($t - t_d$) using the stored past history. As the problem is advanced in time, new time values are added to the table. Once the table is filled, new values replace values that are older than the delay time. There are no restrictions on t_d or d_{TM} relative to the time steps on Cards 2nn. When a change in advancement time is made at a restart, the time values in this table are changed to have time values as if the problem in the restart had run to the new advancement time.

Unit Trip Component

This component is indicated by TRIPUNIT in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = S * U(\text{plus or minus } T1)$$

where U is 0.0 if the trip, $T1$, is false and is 1.0 if the trip is true. If the complement of $T1$ is specified, U is 1.0 if the trip is false and 0.0 if the trip is true.

W1(I) Trip number. A minus sign may prefix the trip number to indicate that the complement of the trip is to be used.

Trip Delay Component

This component is indicated by TRIPDLAY in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = S T_{rptim} (T1)$$

where T_{rptim} is the time the trip last turned true. If the trip is false, the value is -1.0; if the trip is true, the value is zero or a positive number.

W1(I) Trip number, T1 .

Integer Power Component

This component is indicated by POWERI in Word2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = S V1^I$$

W1(A) Alphanumeric name of the variable request code for V1 .

W2(I) Integer name of the variable request code for V1 .

W3(I) I.

Real Power Component

This component is indicated by POWERR in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = S V1^R$$

W1(A) Alphanumeric name of the variable request code for V1 .

W2(I) Integer name of the variable request code for V1 .

W3(R) R.

Variable Power Component

This component is indicated by POWERX in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = S V1^{V2}$$

W1(A) Alphanumeric name of the variable request code for V1 .

W2(I) Integer name of the variable request code for V1 .

W3(A) Alphanumeric name of the variable request code for V2 .

W4(I) Integer name of the variable request code for V2 .

Proportional-Integral Component

This component is indicated by PROP-INT in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = S [A1 V1 + A2 \int_0^t V1 dt]$$

or in Laplace transform notation,

$$Y(s) = S [A1 + A2/s] V1(s)$$

If the control variable is initialized,

$$Y(t_0) = S A1 V1(t_0)$$

If it is desired that the output quantity Y remain constant as long as the input quantity remains constant, V1 must initially be zero regardless of the initialization flag.

W1(R) A1 .

W2(R) A2 .

W3(A) Alphanumeric name of the variable request code for V1 .

W4(I) Integer name of the variable request code for V1 .

Lag Component

This component is indicated by LAG in Word 2 of Card 205ccc00 or 205cccc0. This component is defined by

$$Y = \int_0^t [(S V1 - Y) / A1] dt$$

or, in Laplace transform notation,

$$Y(s) = [S / (1 + A1 s)] V1(s)$$

If the control variable is initialized,

$$Y(t_0) = S V1(t_0).$$

If the initialization flag is set on and if the initial values of Y and V 1 satisfy a specified relationship, Y remains constant as long as V 1 retains its initial value.

W1(R) Lag time, A1 (s).

W2(A) Alphanumeric name of the variable request code for V1 .

W3(I) Integer name of the variable request code for V1 .

Lead-Lag Component

This component is indicated by LEAD-LAG in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = [A1 S V1 / A2] + \int_0^t [(S V1 - Y) / A2] dt$$

or, in Laplace transform notation,

$$Y(s) = S [(1 + A1 s) / (1 + A2 s)] V1(s)$$

If the control variable is initialized,

$$Y(t_0) = S V1(t_0).$$

If the initialization flag is set on and if the initial values of Y and V1 satisfy a specified relationship, Y remains constant as long as V 1 retains its initial value.

W1(R) Lead time, A1 (s).

W2(R) Lag time, A1 (s).

W3(A) Alphanumeric name of the variable request code for V1 .

W4(I) Integer name of the variable request code for V1 .

Constant Component

Cards 205ccc01 through 205ccc09 or 205cccc1 through 205cccc9 are not entered. The quantity in Word 3 of Card 205ccc00 or 205cccc0 is the constant value used for this component.

APPENDIX B

EXPERIMENTAL DATA FOR LEHIGH TESTS

This appendix contains the complete results of the experimental tests conducted at the Lehigh University facility. The next page is a chart of all of the experimental runs included in this appendix. The following information is provided in this section:

Runs #1-#7 (HFC-227ea) & #14-#17 (HFC-125) will contain the following:

- 1) A cover page describing the initial operating conditions and any necessary identification information of the experimental run.
- 2) A plot of the pressure histogram for the run including all of the output from the pressure transducers located throughout the system (this plot is similar to the example in figure 3.9).
- 3) A plot of the temperature histogram from the film thermocouples located in the source vessel, pipe position #1, #2, & #3. (These are similar to the plot presented in Vol. I, Fig. 3.17)
- 4) A plot of the temperature histogram from the 1/32" shielded thermocouples located in the source vessel and collection vessel. (This plot is similar to the plot presented in Vol. I, Fig. 3.18)
- 5) A plot of the void fraction histogram from the capacitance sensor located at the end of the pipe. (This plot is similar to the plot presented in Vol. I, Fig. 3.21)
- 6) A plot of the cumulative mass histogram from the differential pressure transducer located at the bottom of the source vessel. (This plot is similar to the plot presented in Vol. I, Fig. 3.28)

Runs #8-#10 will include the above six items along with the following:

- 7) A plot of the pressure drop across a capped tee in alternative piping configuration #1. ((This plot is similar to the plot presented in Vol. I, Fig. 3.13)
- 8) A plot of the pressure drop across a 90° elbow in alternative piping configuration #1. (This plot is similar to the plot presented in Vol. I, Fig. 3.13)
- 9) A plot of the pressure drop across a pipe union in alternative piping configuration #1. (This plot is similar to the plot presented in Vol. I, Fig. 3.13)

Runs #11-#13 will include parts 1-6 above along with the following:

- 7) A plot of the pressure drop across the top branch of a split tee in alternative piping configuration #2. (This plot is similar to the plot presented in Vol. I, Fig. 3.26)
- 8) A plot of the pressure drop across the bottom branch of a split tee in alternative piping configuration #2. ((This plot is similar to the plot presented in Vol. I, Fig. 3.26)

Runs #18-#21 will contain all of the following special plots listed below:

- 1) A cover page describing the initial operating conditions and any necessary identification information of the experimental run.
- 2) A plot of the pressure histogram for the run including all of the output from the pressure transducer located throughout the system. (This plot is similar to the plot presented in Vol. I, Fig. 3.9)
- 3) A plot of the temperature histogram from the film thermocouples located throughout the system. (This plot is similar to the plot presented in Vol. I, Fig. 3.17)
- 4) A plot of the temperature histogram from the 1/32" shielded thermocouples located in the source vessel and collection vessel (Run #18 only). (This plot is similar to the plot presented in Vol. I, Fig. 3.18)

- 5) A plot of the cumulative mass histogram from the differential pressure transducer located at the bottom of the source vessel (Run #18 only). (This plot is similar to the plot presented in Vol. I, Fig. 3.28)
- 6) A plot of the void fraction histogram from the capacitance sensor located at the end of the pipe (Run #19 only). (This plot is similar to the plot presented in Vol. I, Fig. 3.21)

Run #	Test Fluid	Piping Configuration	Fill Volume [mL]	Psvo [kPa]	Pcvo [kPa]	Temperature [°C]
1	HFC-227ea	Straight Pipe	3571	2125	10	32
2	HFC-227ea	Straight Pipe	2340	3235	635	33
3	HFC-227ea	Straight Pipe	2358	4180	720	32
4	HFC-227ea	Straight Pipe	2370	4195	525	29
5	HFC-227ea	Straight Pipe	2388	4220	720	31
6	HFC-227ea	Straight Pipe	2150	4910	715	31
7	HFC-227ea	Straight Pipe w/ Hotspot @ 55°C	2200	4230	710	27
8	HFC-227ea	Capped Tee (Config. #1)	3420	2120	125	21
9	HFC-227ea	Capped Tee (Config. #1)	2500	3915	575	24
10	HFC-227ea	Capped Tee (Config. #1)	2450	4910	615	25
11	HFC-227ea	Through Tee (Config. #2)	3507	2140	600	26
12	HFC-227ea	Through Tee (Config. #2)	2400	3935	655	24
13	HFC-227ea	Through Tee (Config. #2)	2460	4910	615	25
14	HFC-125	Straight Pipe	2900	2050	110	26
15	HFC-125	Straight Pipe	2363	3635	175	26
16	HFC-125	Straight Pipe	2400	4245	165	26
17	HFC-125	Straight Pipe	2467	5000	125	24
18	Water	Straight Pipe	3585	2875	120	28
19	Water	Straight Pipe	3100	4150	100	23
20	CO ₂	Straight Pipe	~1000	5215	100	20
21	CO ₂	Straight Pipe	~1000	5360	100	20

Run #1

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Straight Pipe

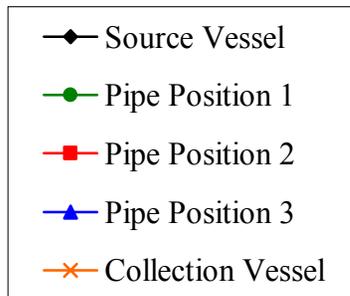
Source Vessel Initial Conditions: Fill Volume: 3571 milliliters
 Fluid Mass: 4.925 kg
 Pressure (Psvo): 2125 kPa
 Nitrogen Mass: 0.051 kg

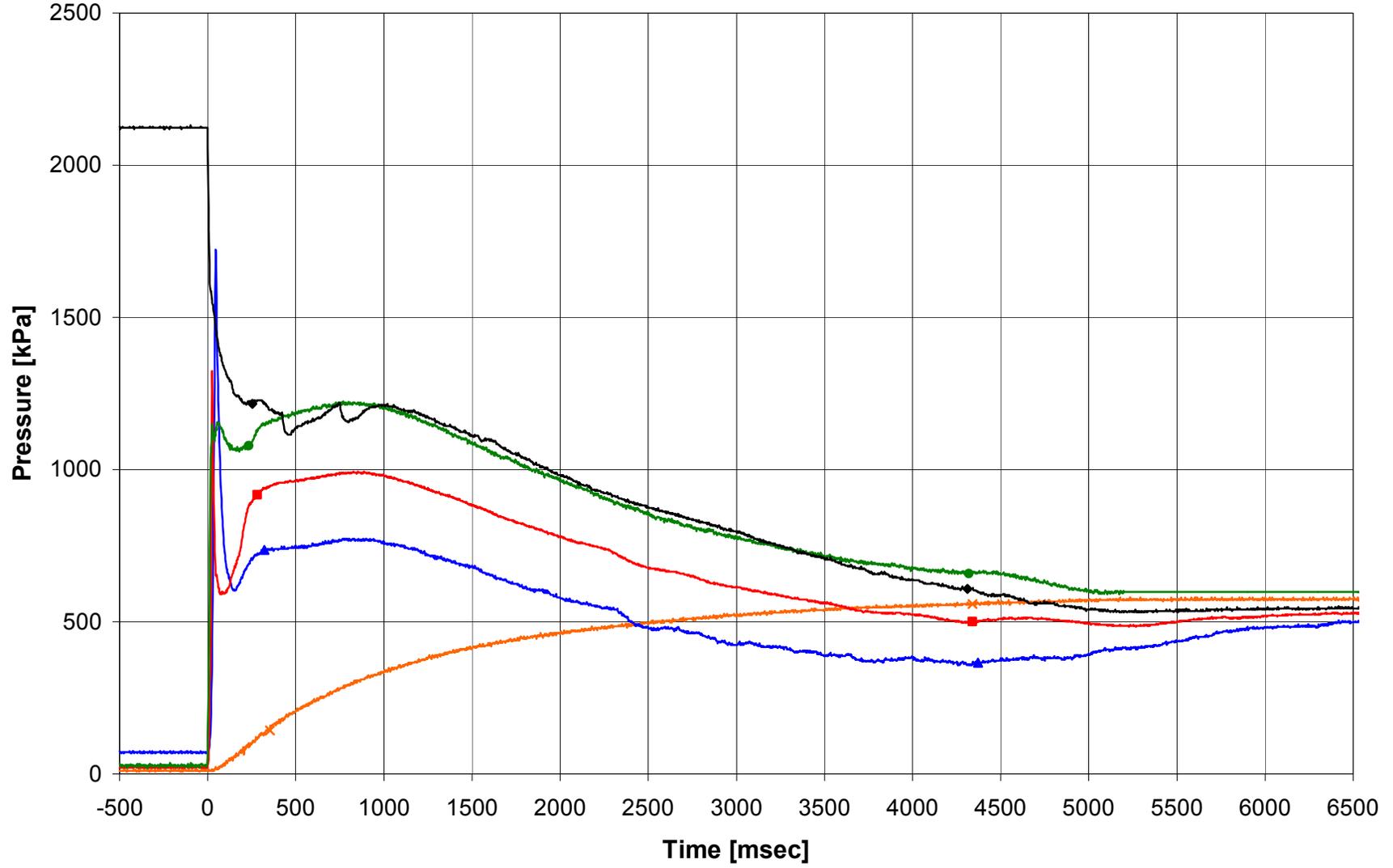
Initial Collection Vessel & Piping Pressure (Pcvo): 10 kPa

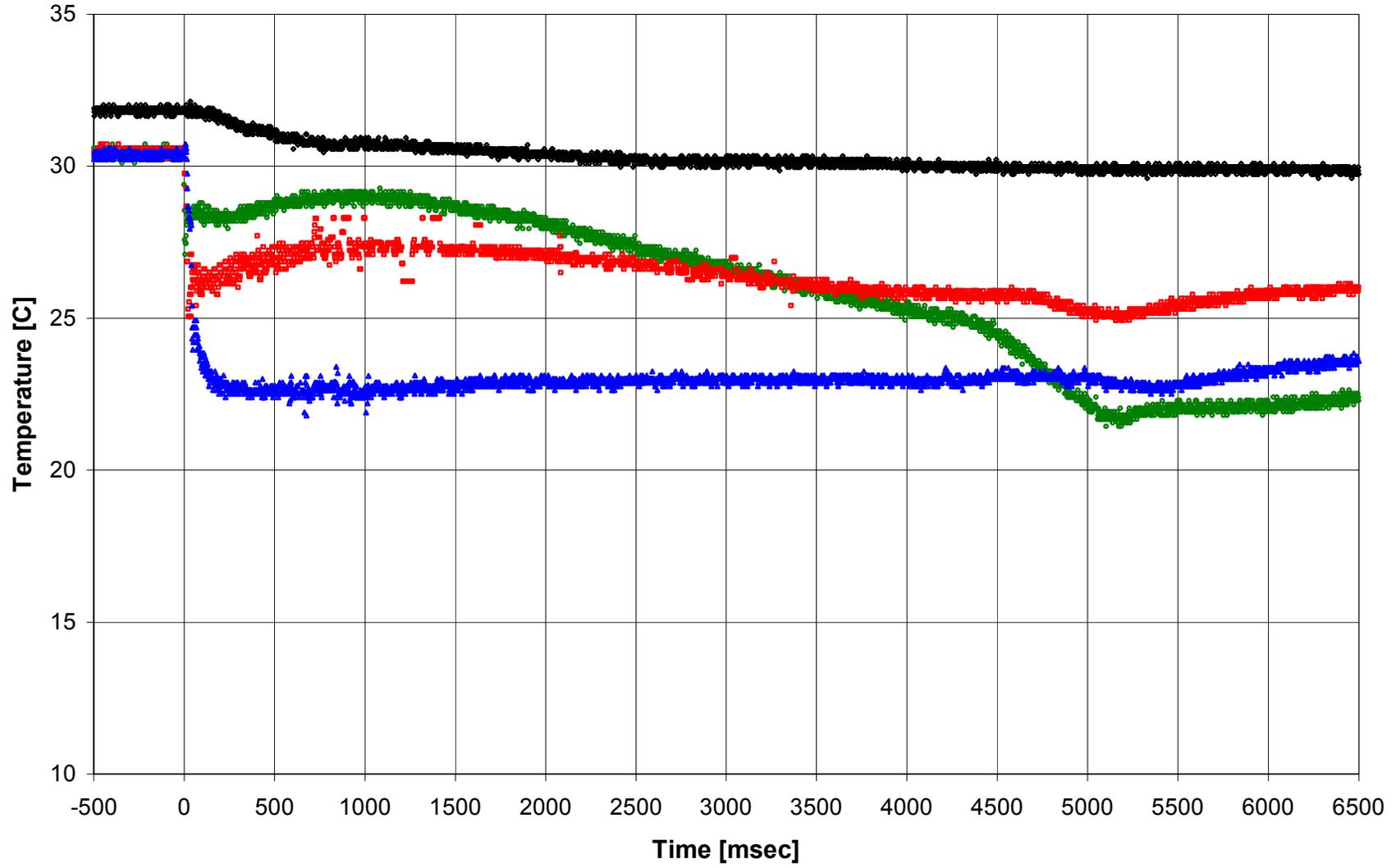
Initial System Temperature: 32° Celsius

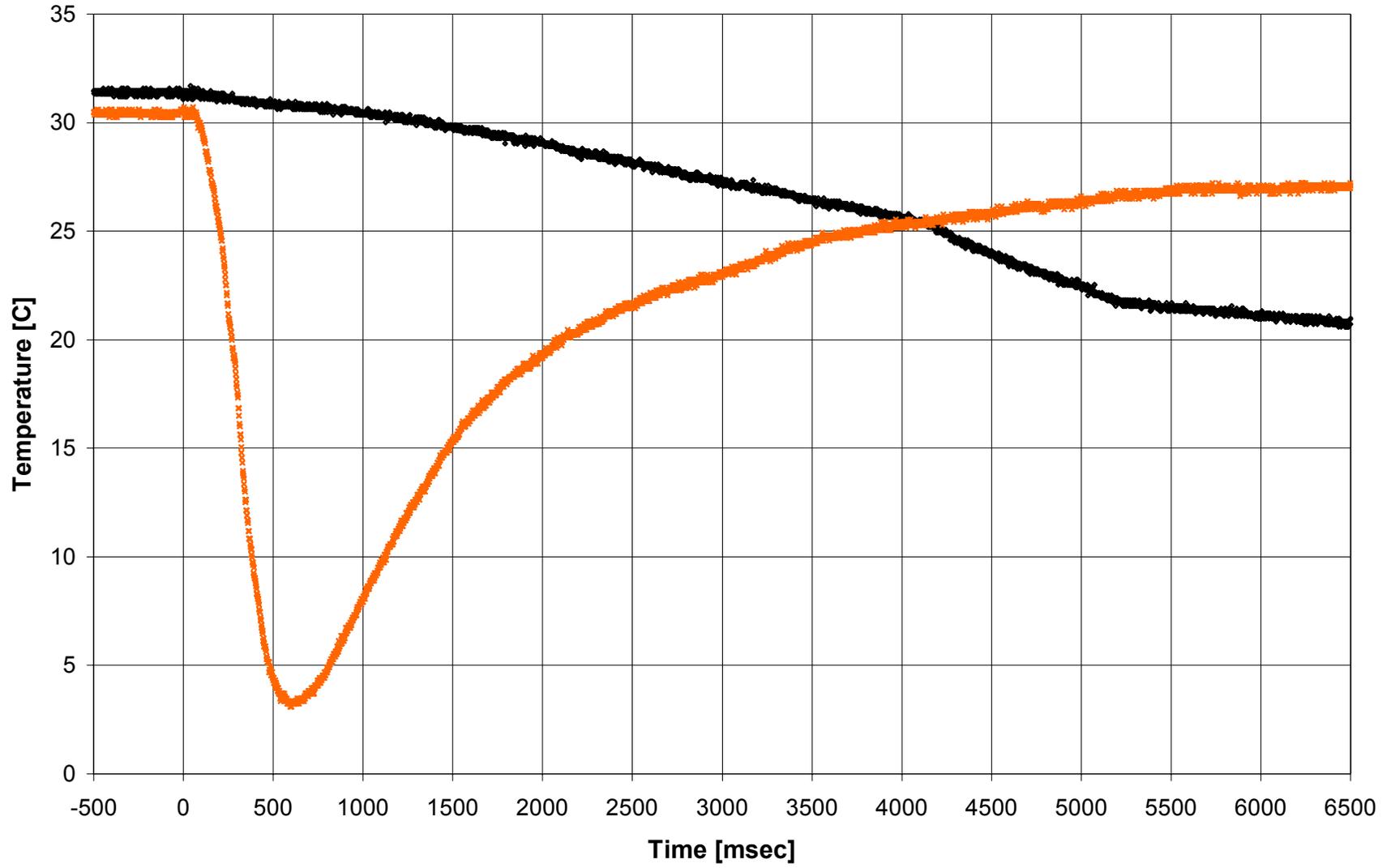
Completion Date: 7/12/99

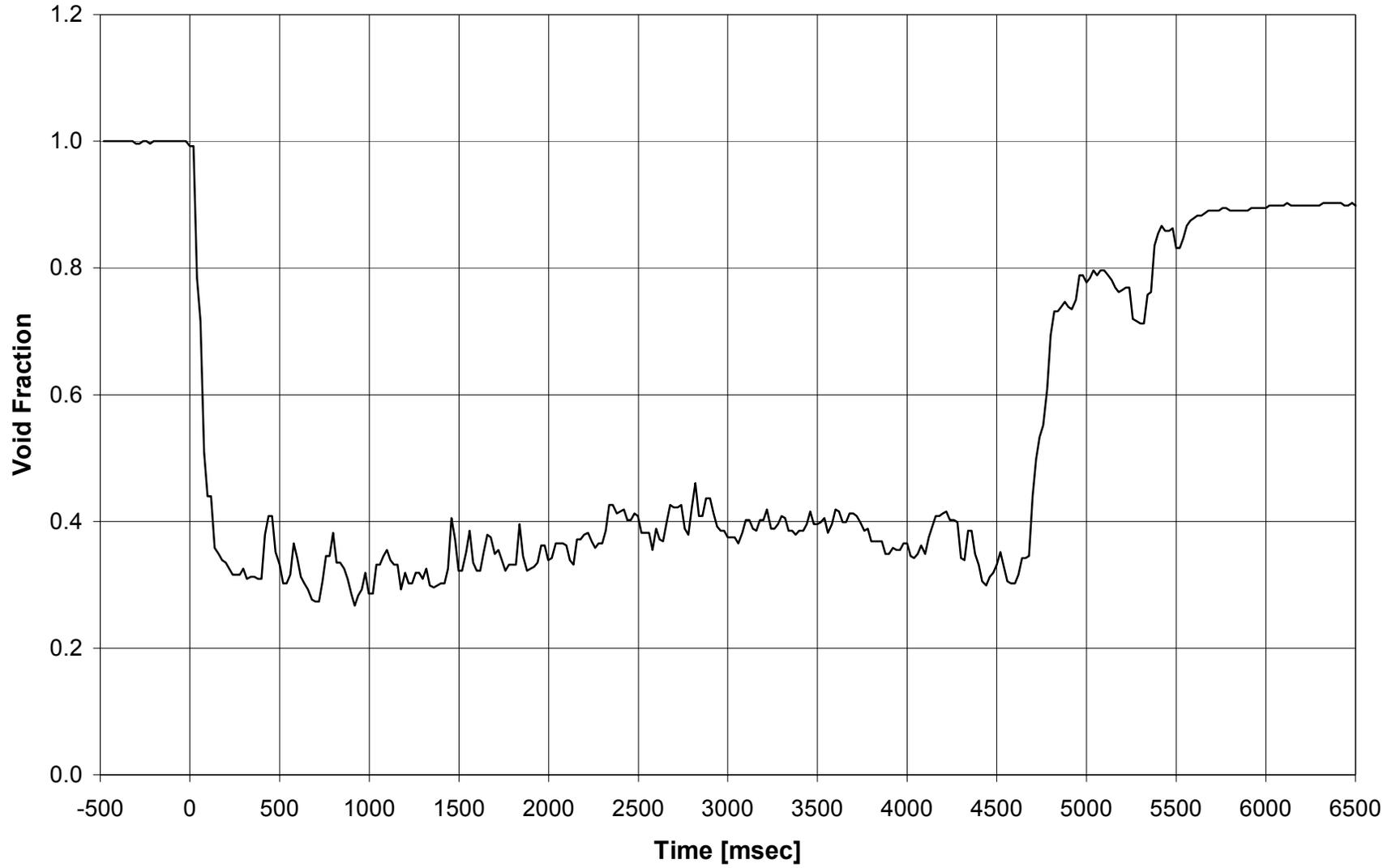
Legend

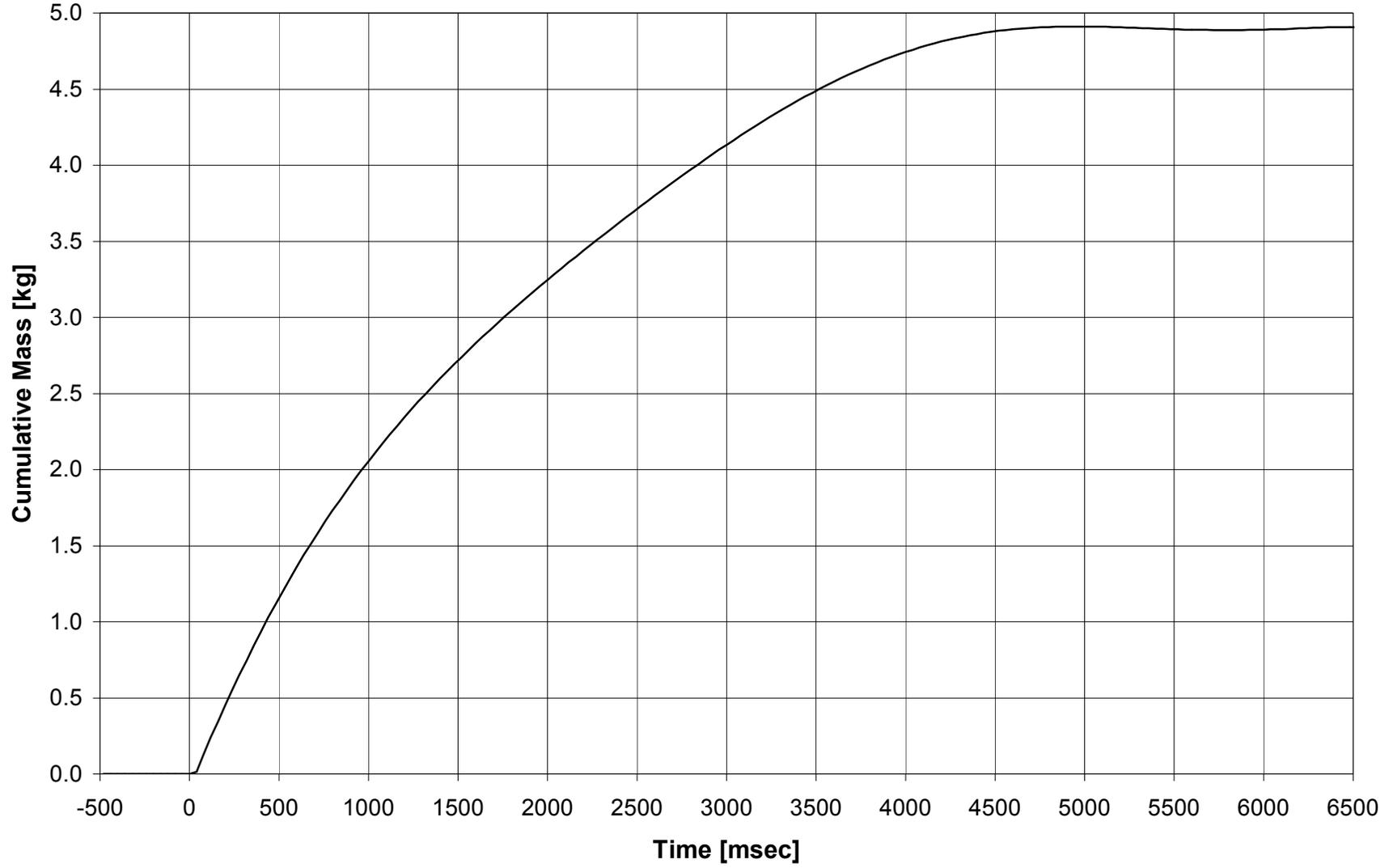












Run #2

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea) C₂HF₅ Pentafluoroethane
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Straight Pipe

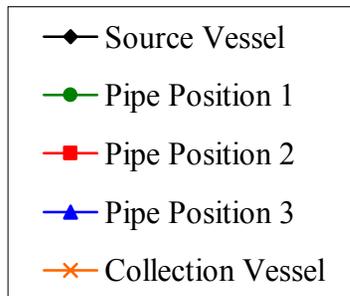
Source Vessel Initial Conditions: Fill Volume: 2340 milliliters
 Fluid Mass: 3.246 kg
 Pressure (P_{svo}): 3235 kPa
 Nitrogen Mass: 0.097 kg

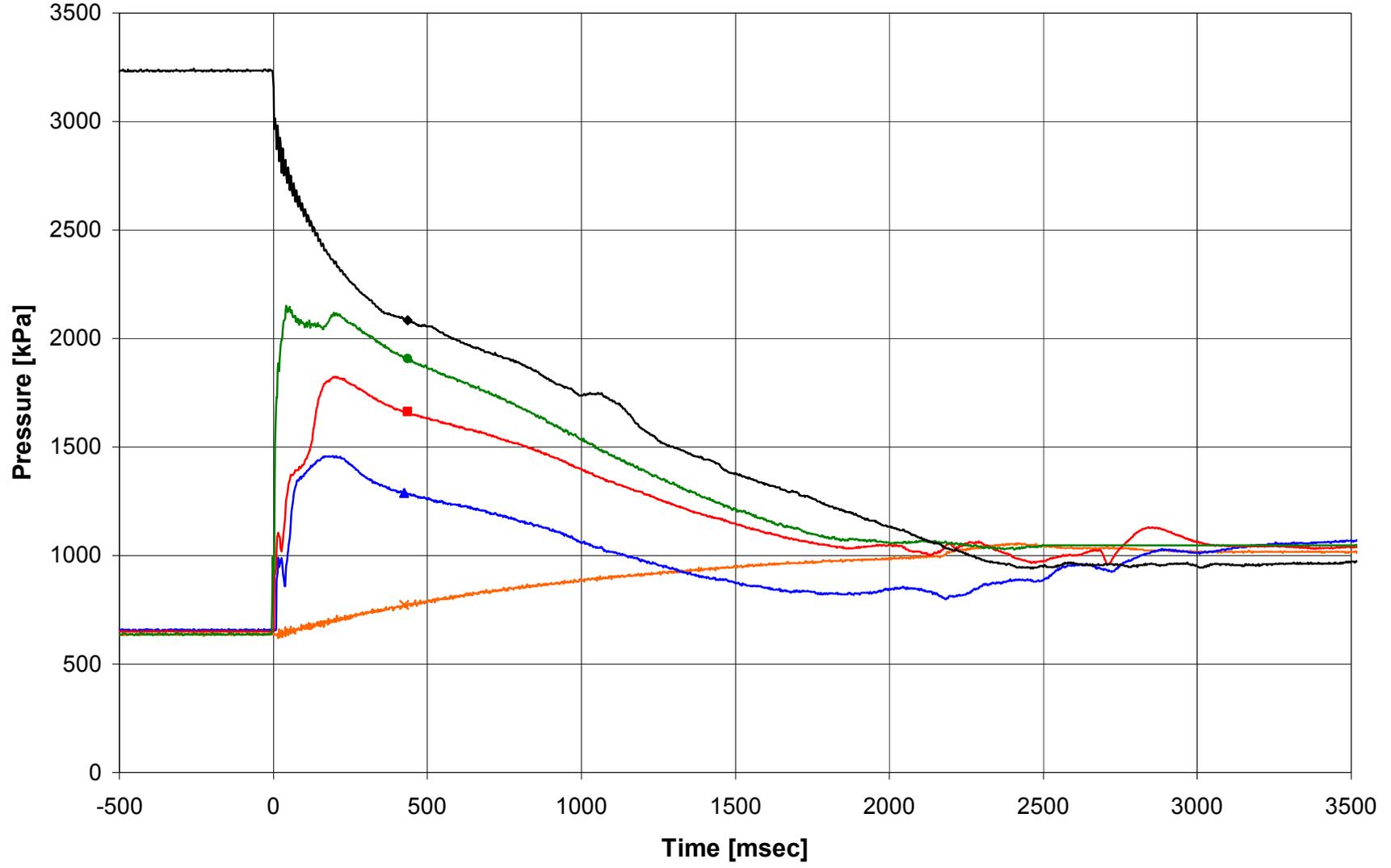
Initial Collection Vessel & Piping Pressure (P_{cvo}): 635 kPa

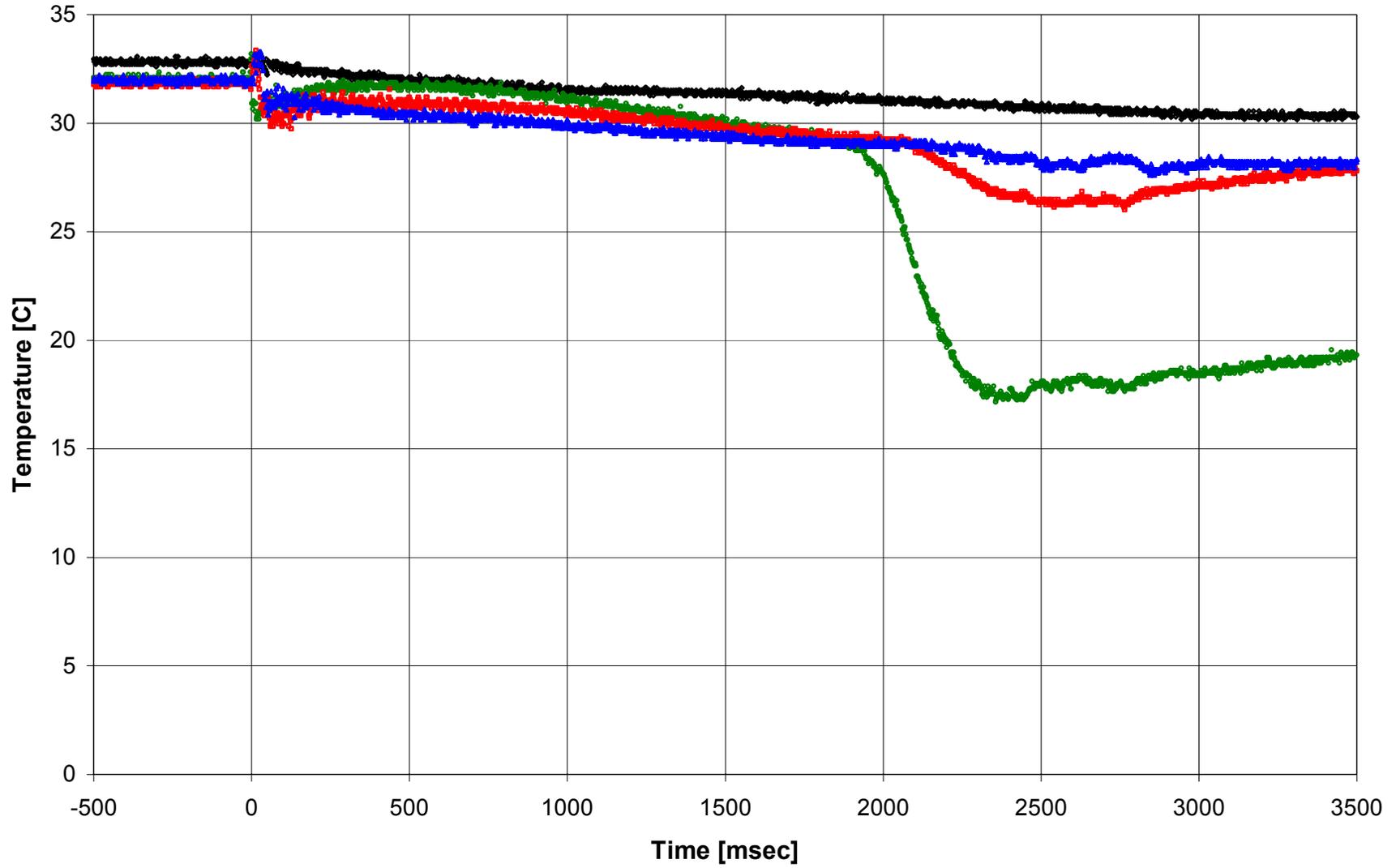
Initial System Temperature: 33° Celsius

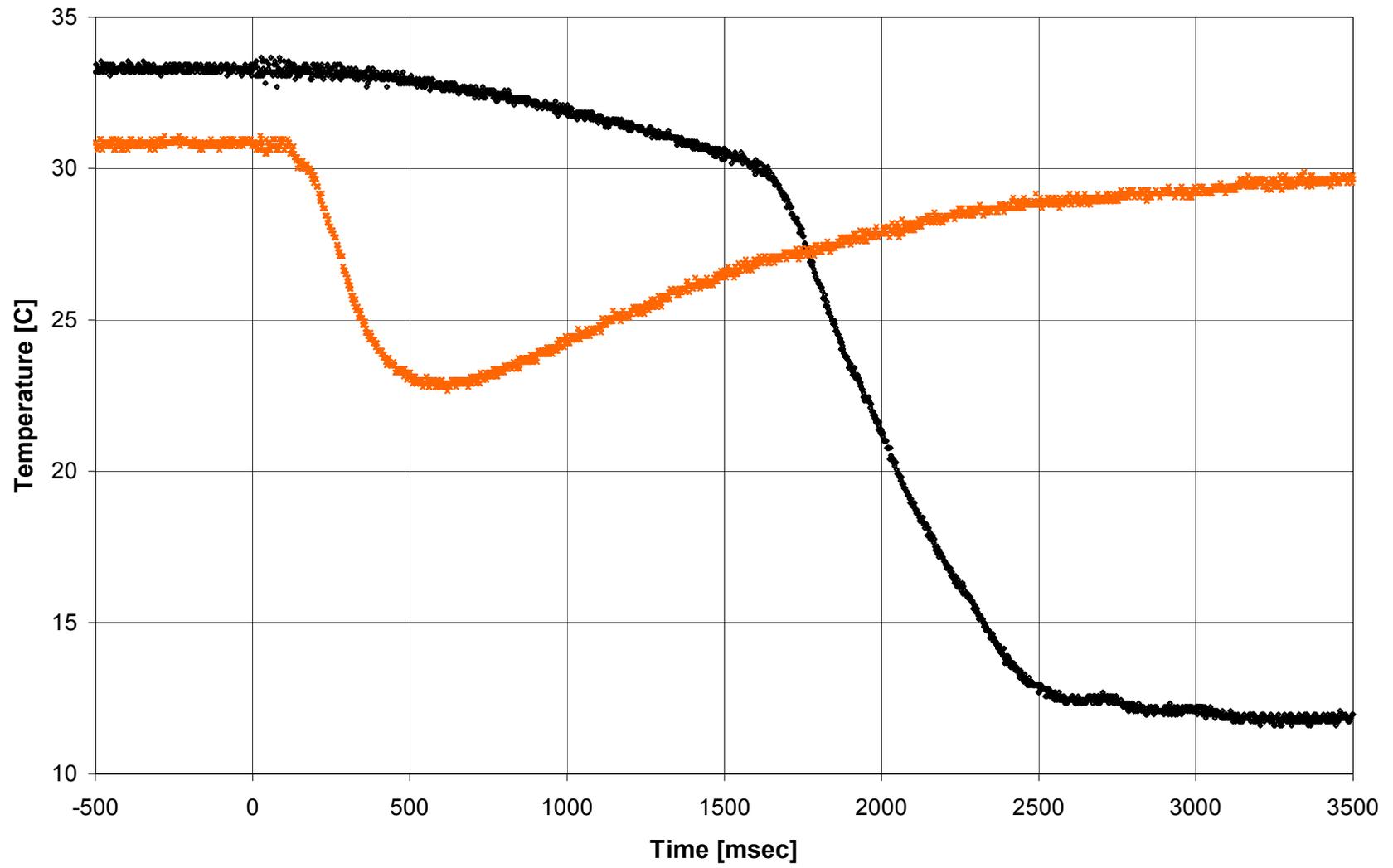
Completion Date: 8/12/99

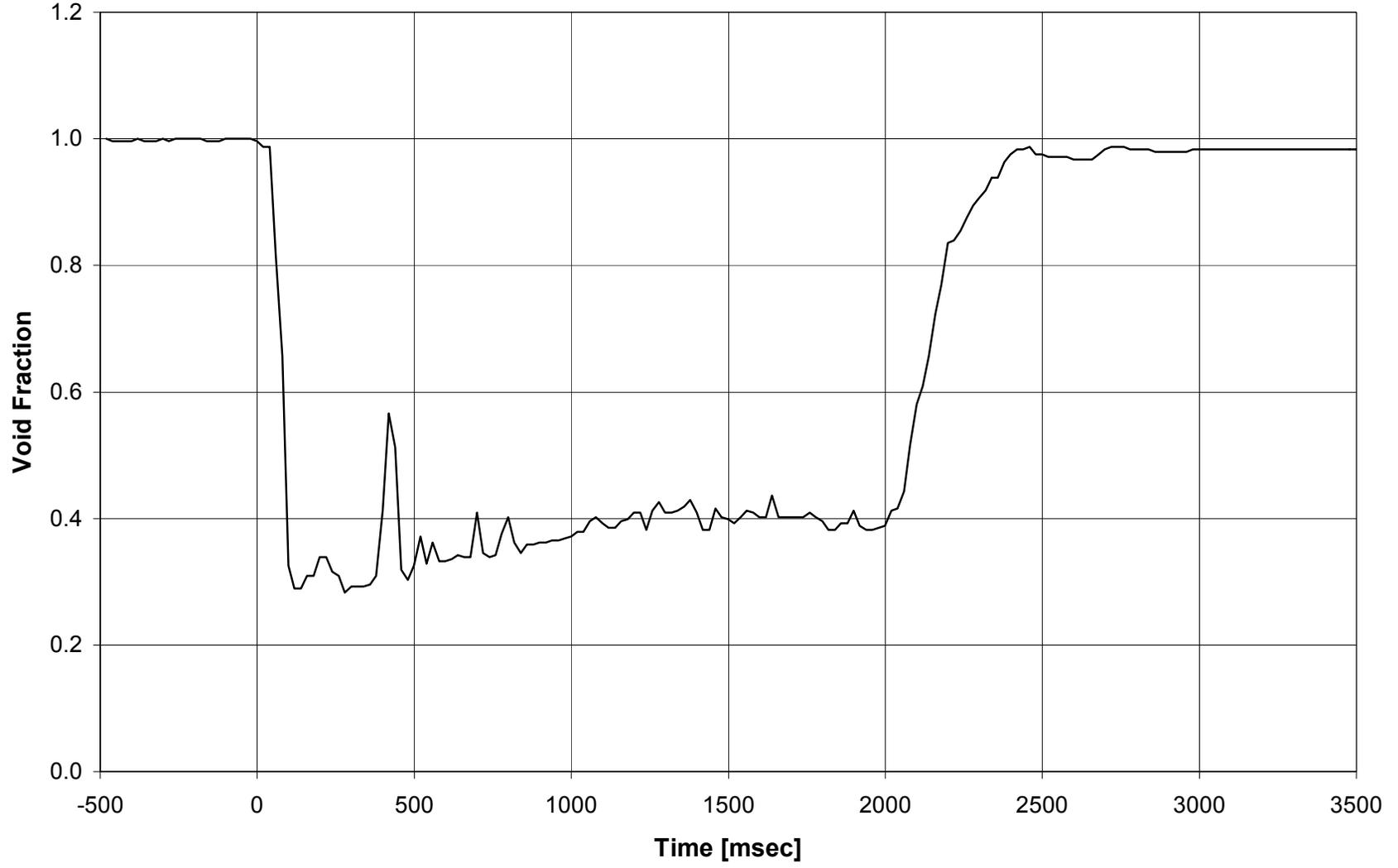
Legend

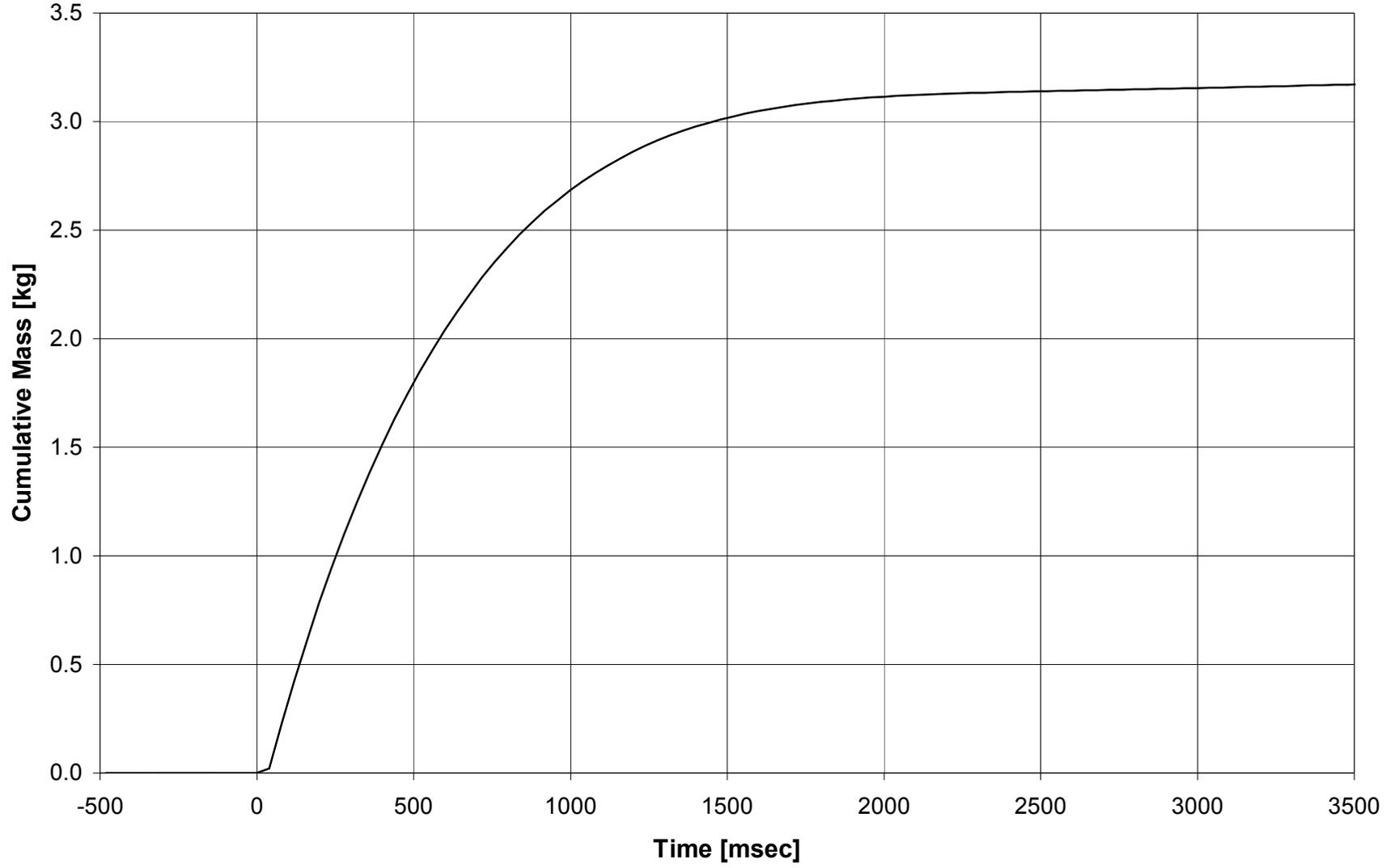












Run #3

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Straight Pipe

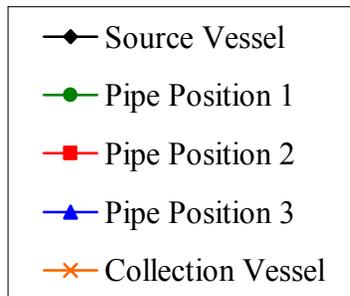
Source Vessel Initial Conditions: Fill Volume: 2358 milliliters
 Fluid Mass: 3.305 kg
 Pressure (Psvo): 4180 kPa
 Nitrogen Mass: 0.132 kg

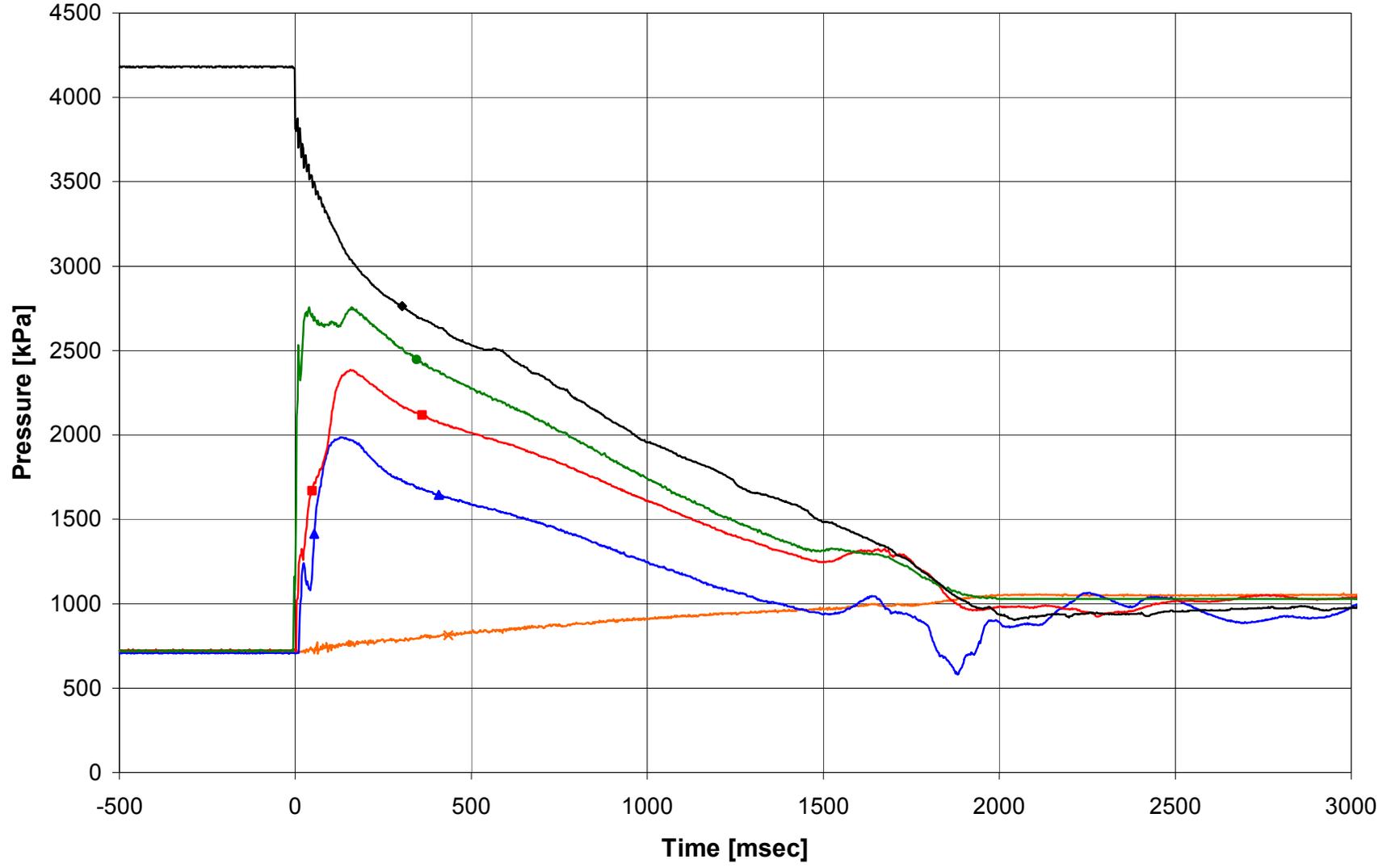
Initial Collection Vessel & Piping Pressure (Pcvo): 720 kPa

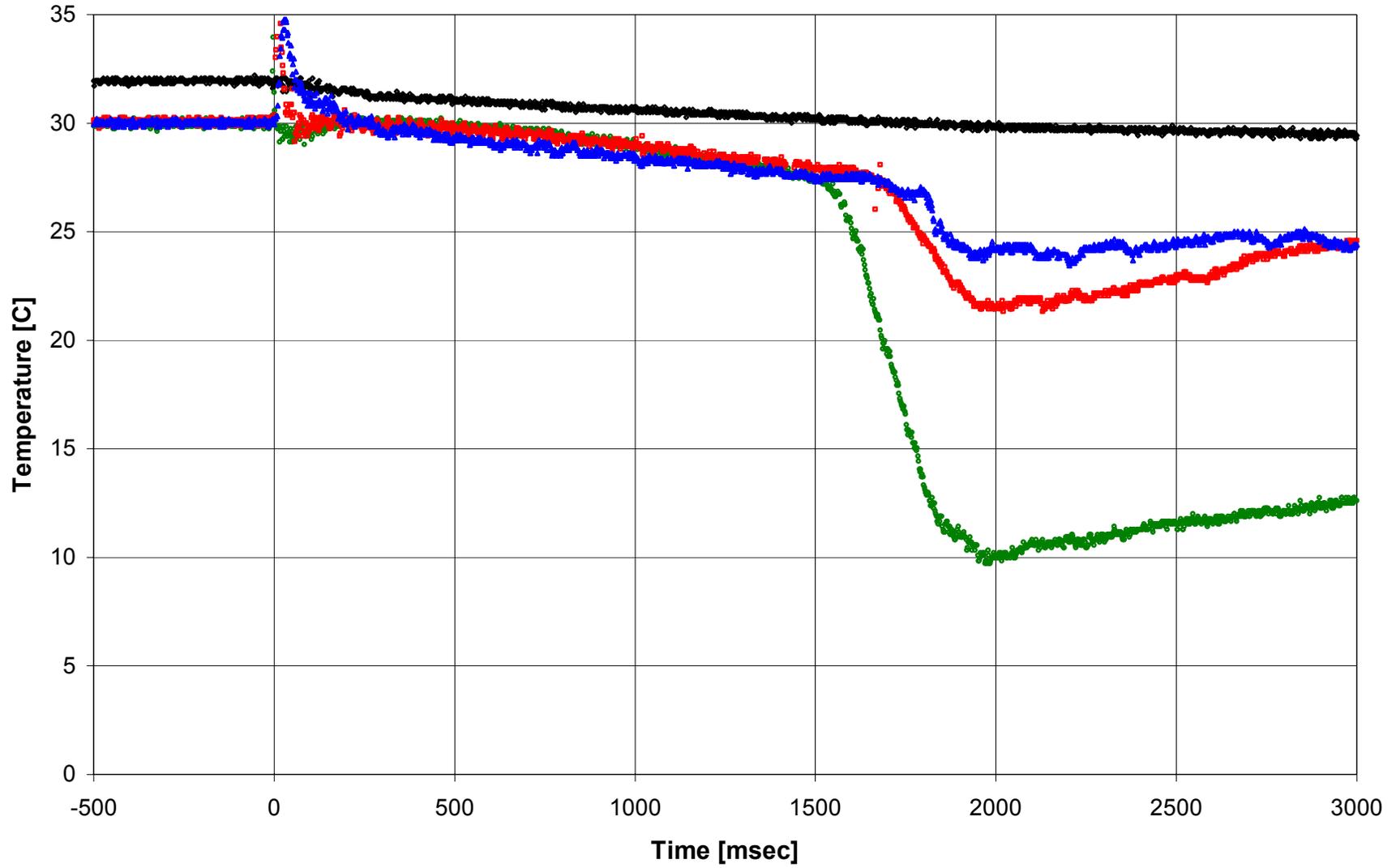
Initial System Temperature: 32° Celsius

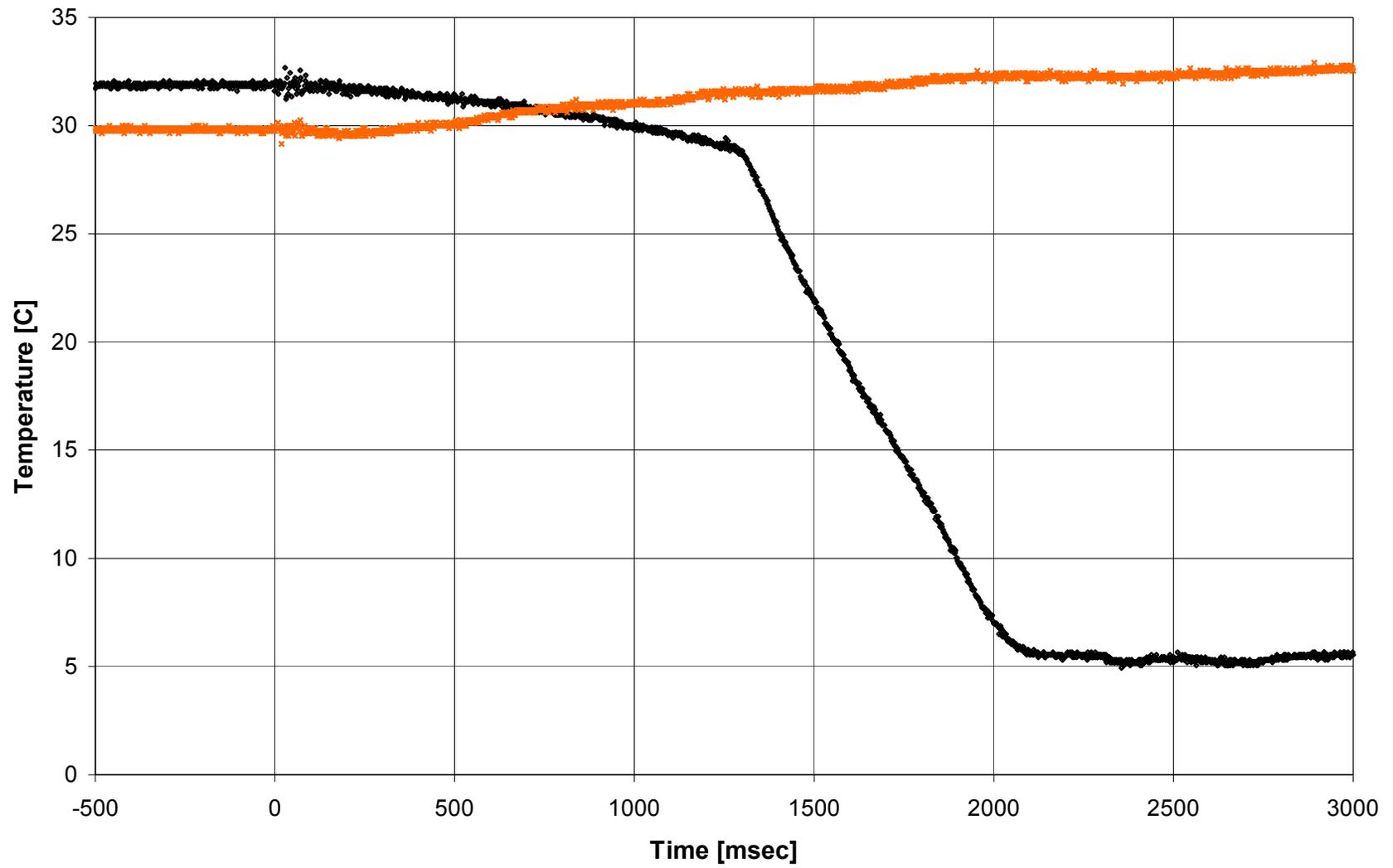
Completion Date: 7/19/99

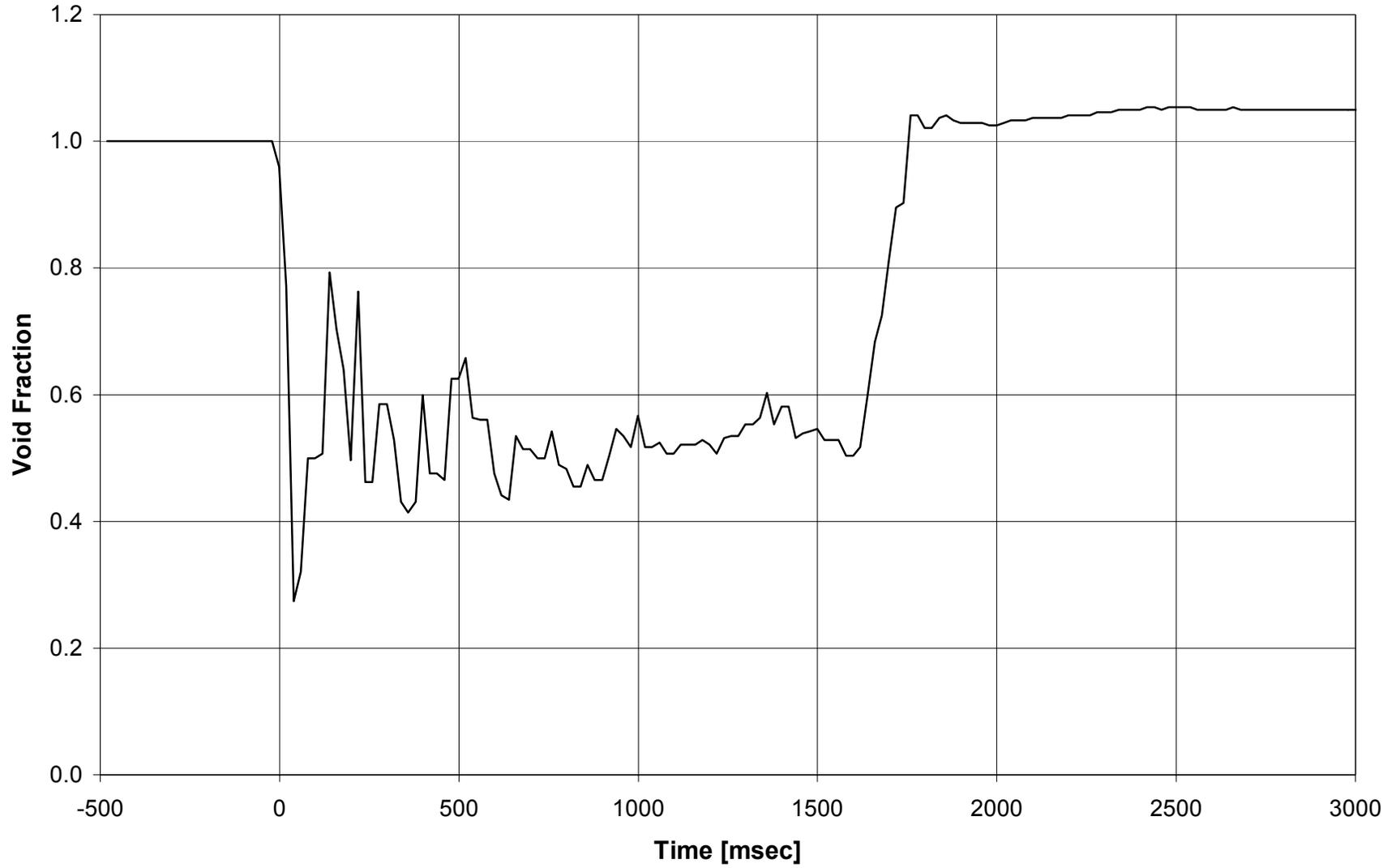
Legend

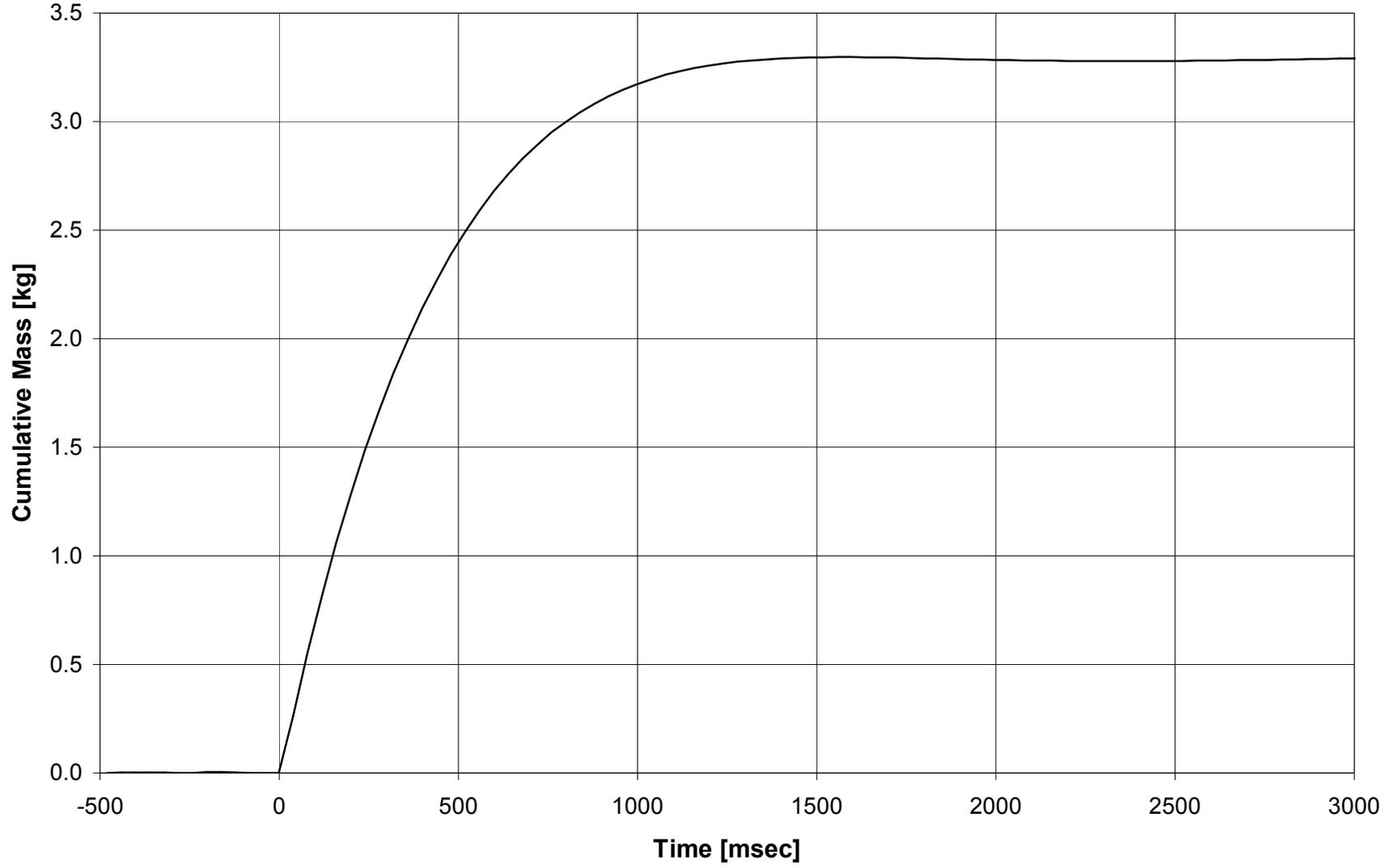












Run #4

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Straight Pipe

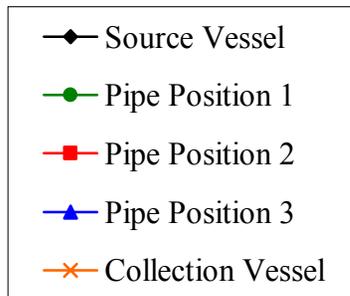
Source Vessel Initial Conditions: Fill Volume: 2370 milliliters
 Fluid Mass: 3.343 kg
 Pressure (Psvo): 4195 kPa
 Nitrogen Mass: 0.135 kg

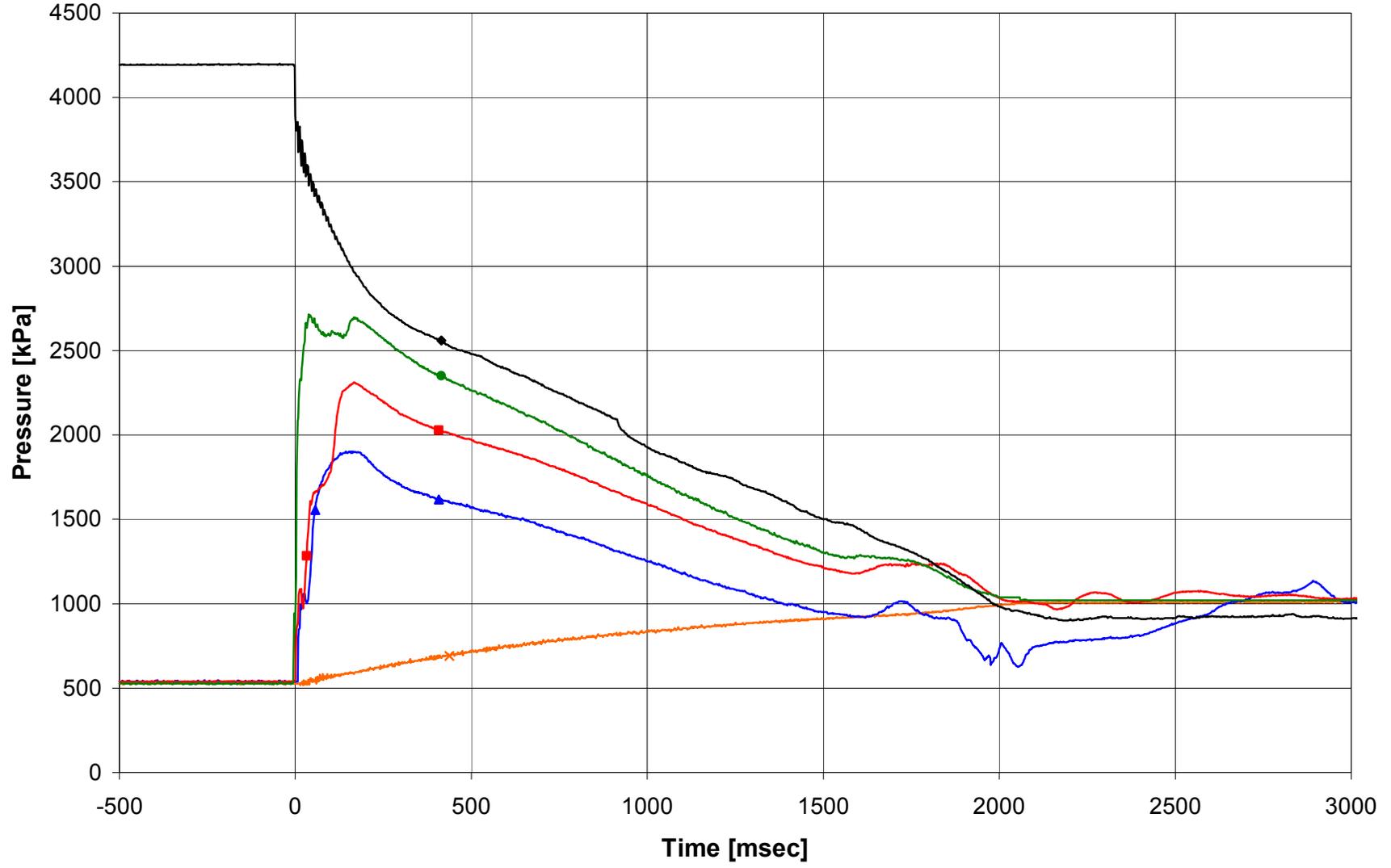
Initial Collection Vessel & Piping Pressure (Pcvo): 525 kPa

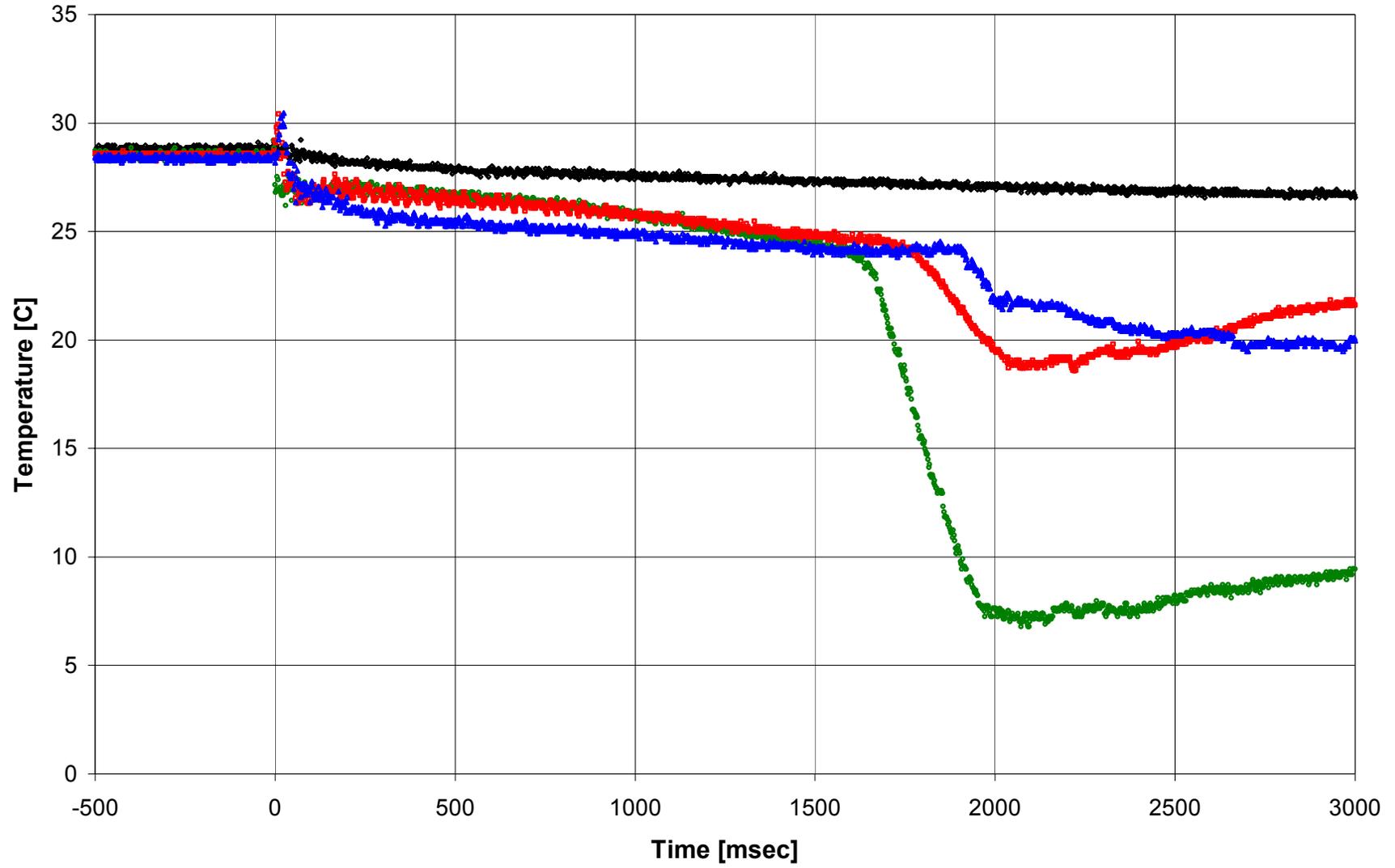
Initial System Temperature: 29° Celsius

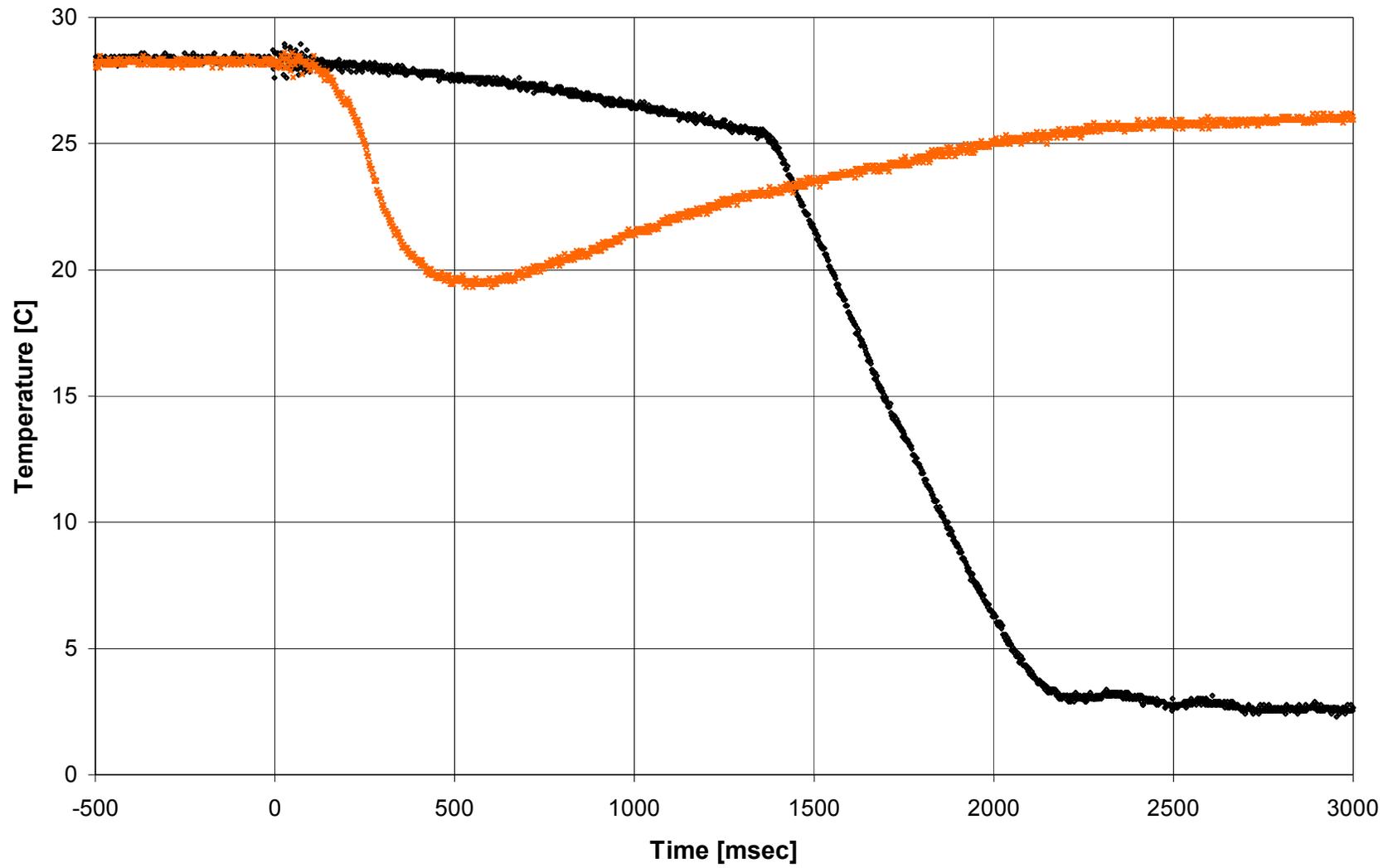
Completion Date: 7/21/99

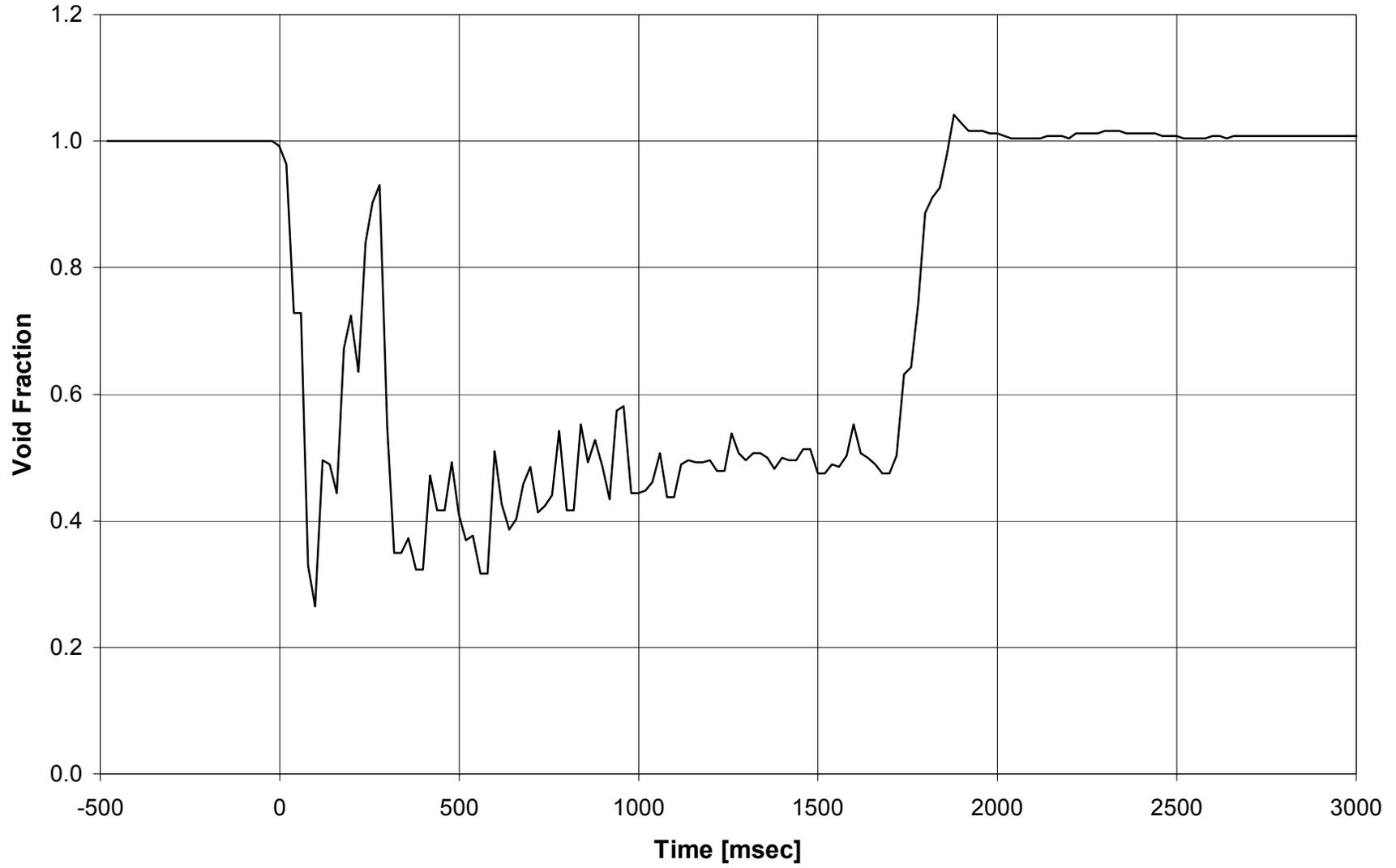
Legend

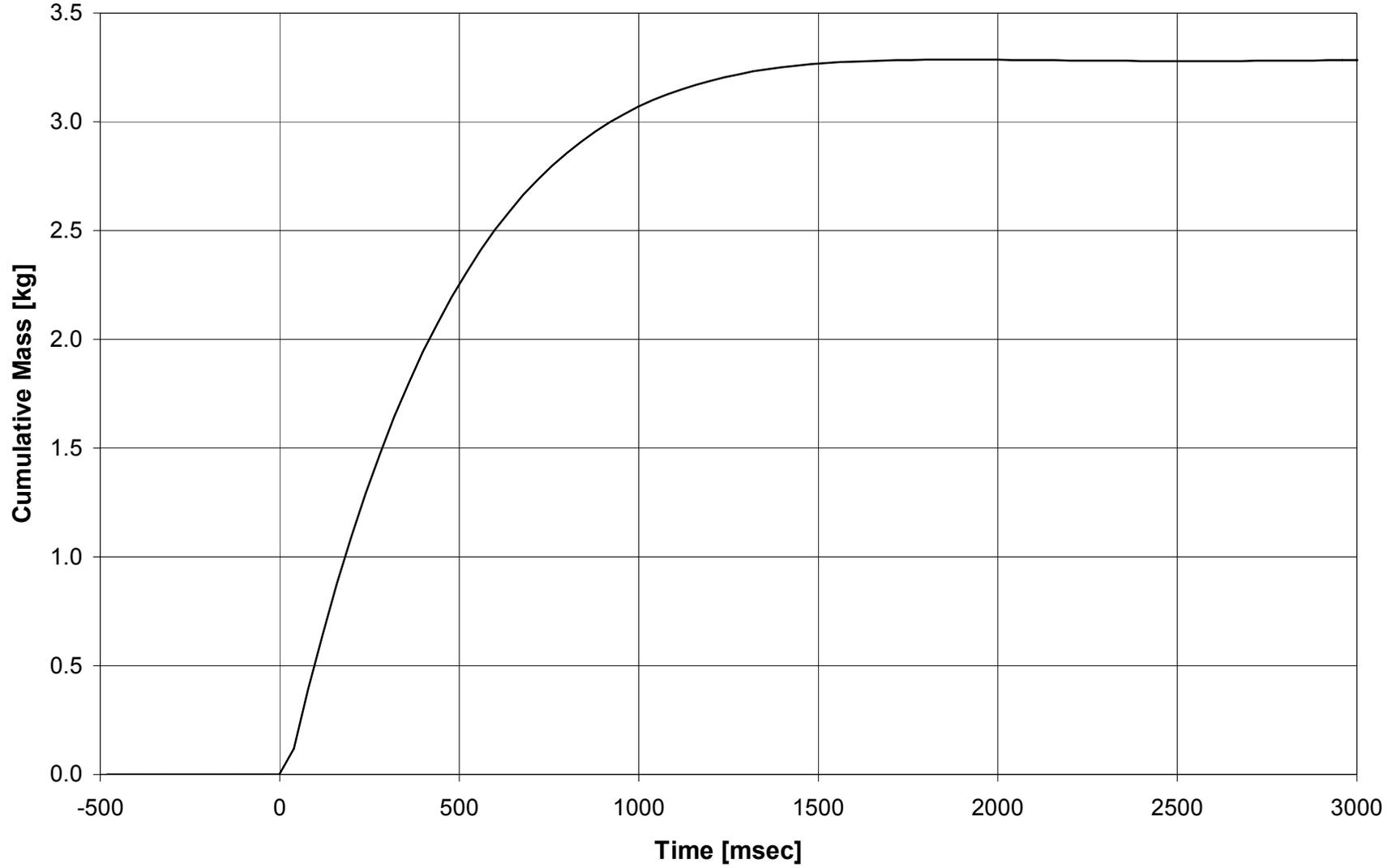












Run #5

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Straight Pipe

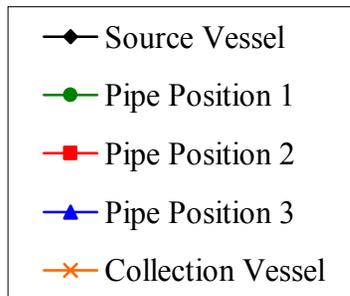
Source Vessel Initial Conditions: Fill Volume: 2388 milliliters
 Fluid Mass: 3.368 kg
 Pressure (Psvo): 4220 kPa
 Nitrogen Mass: 0.134 kg

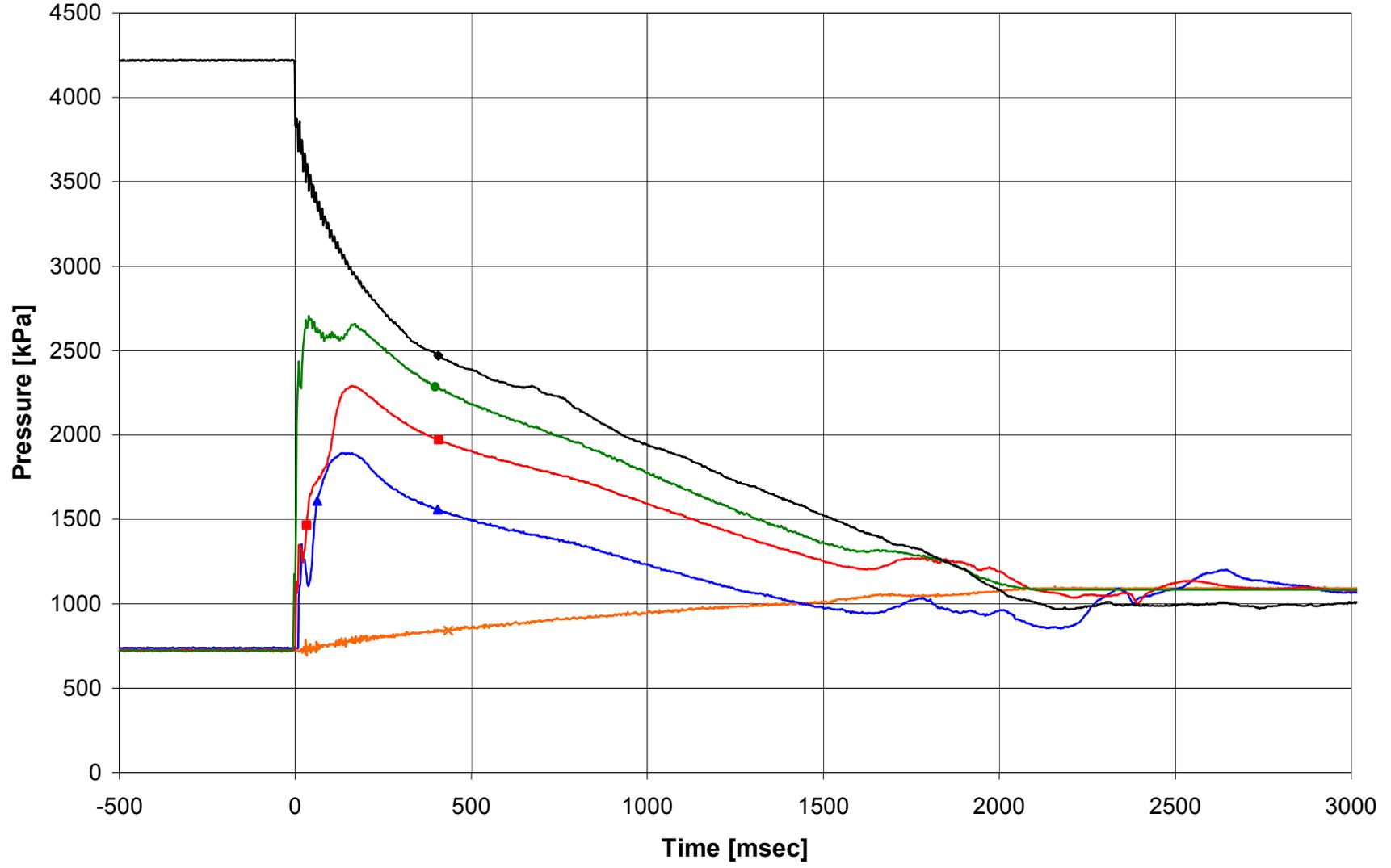
Initial Collection Vessel & Piping Pressure (Pcvo): 720 kPa

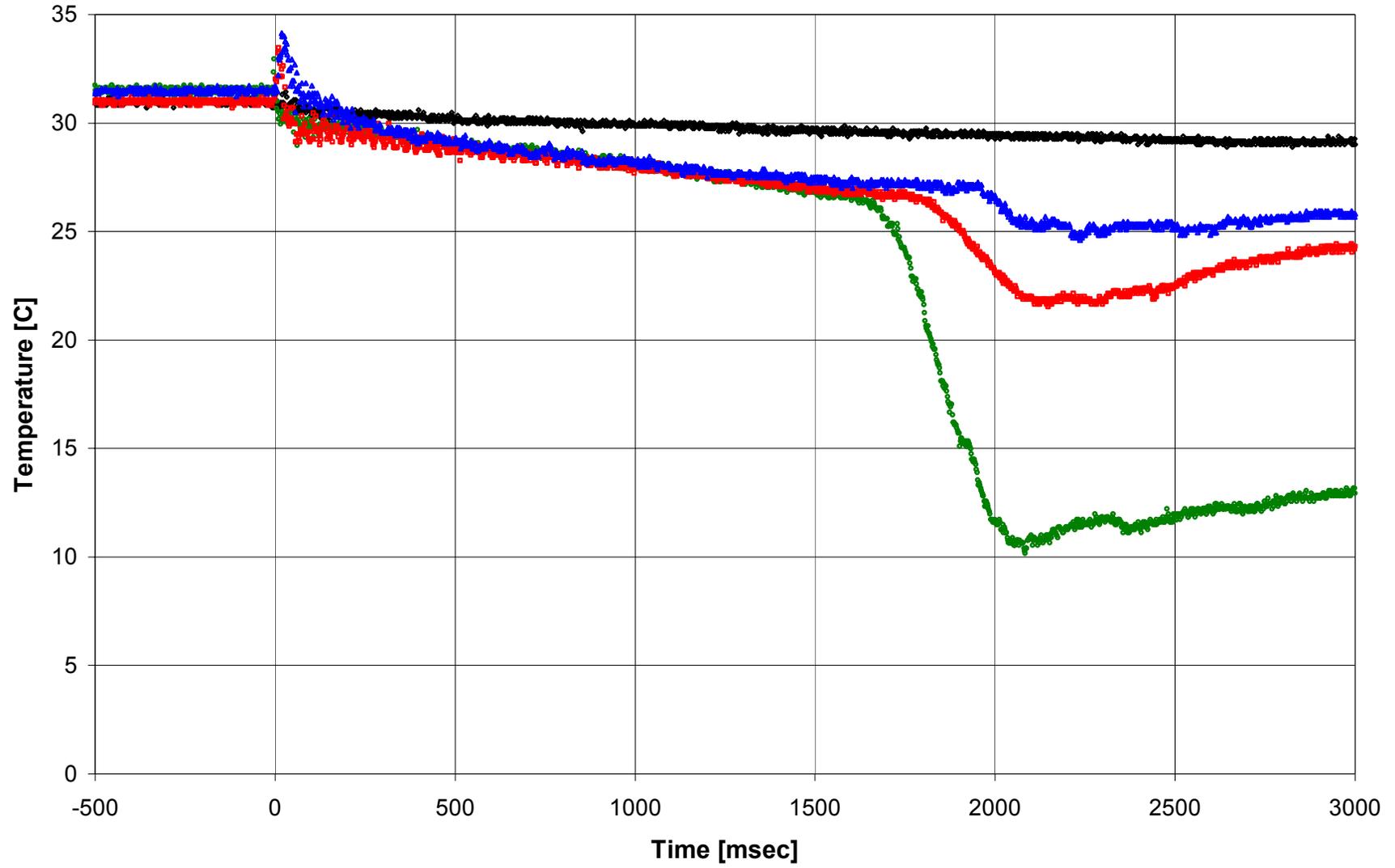
Initial System Temperature: 31° Celsius

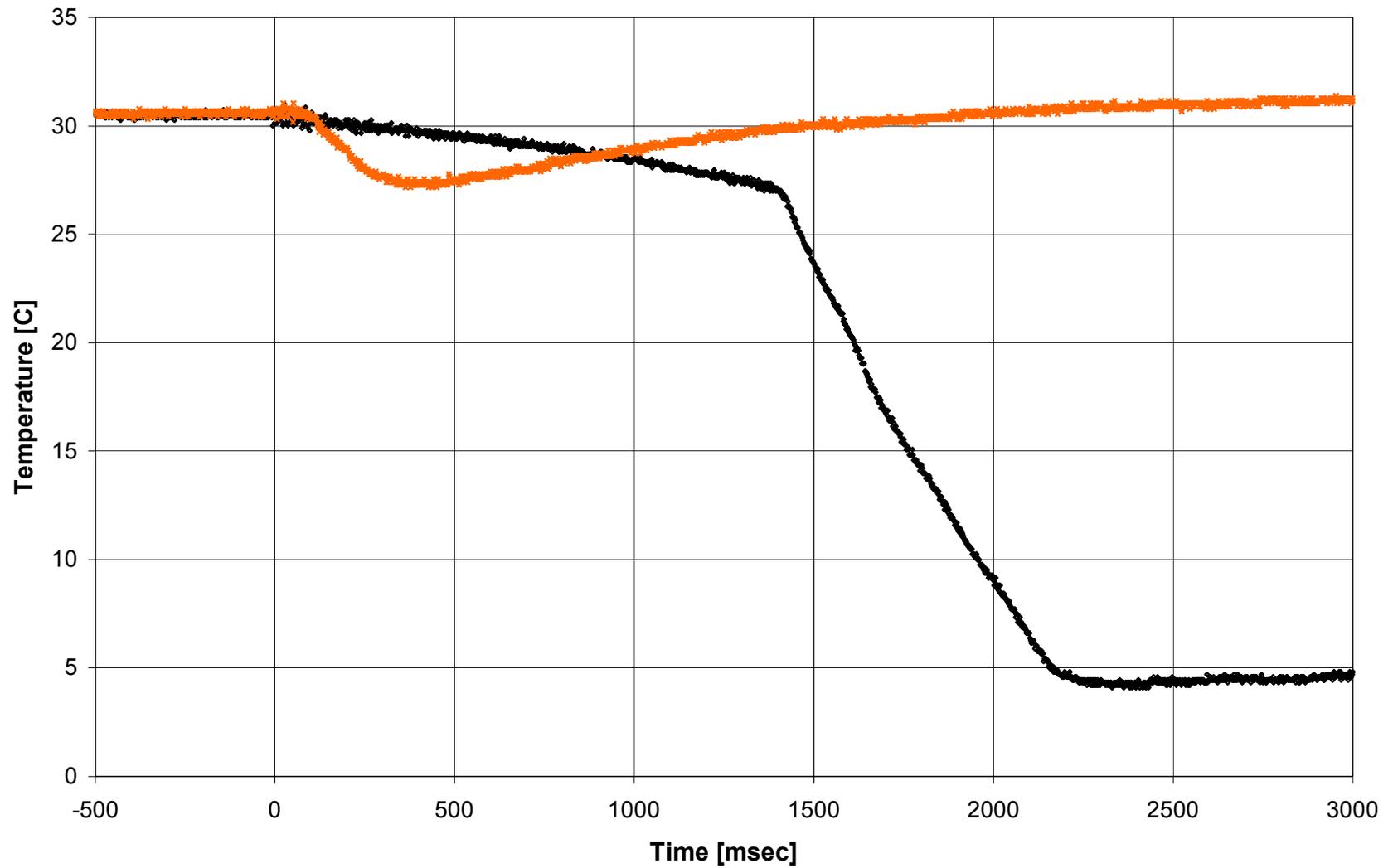
Completion Date: 7/23/99

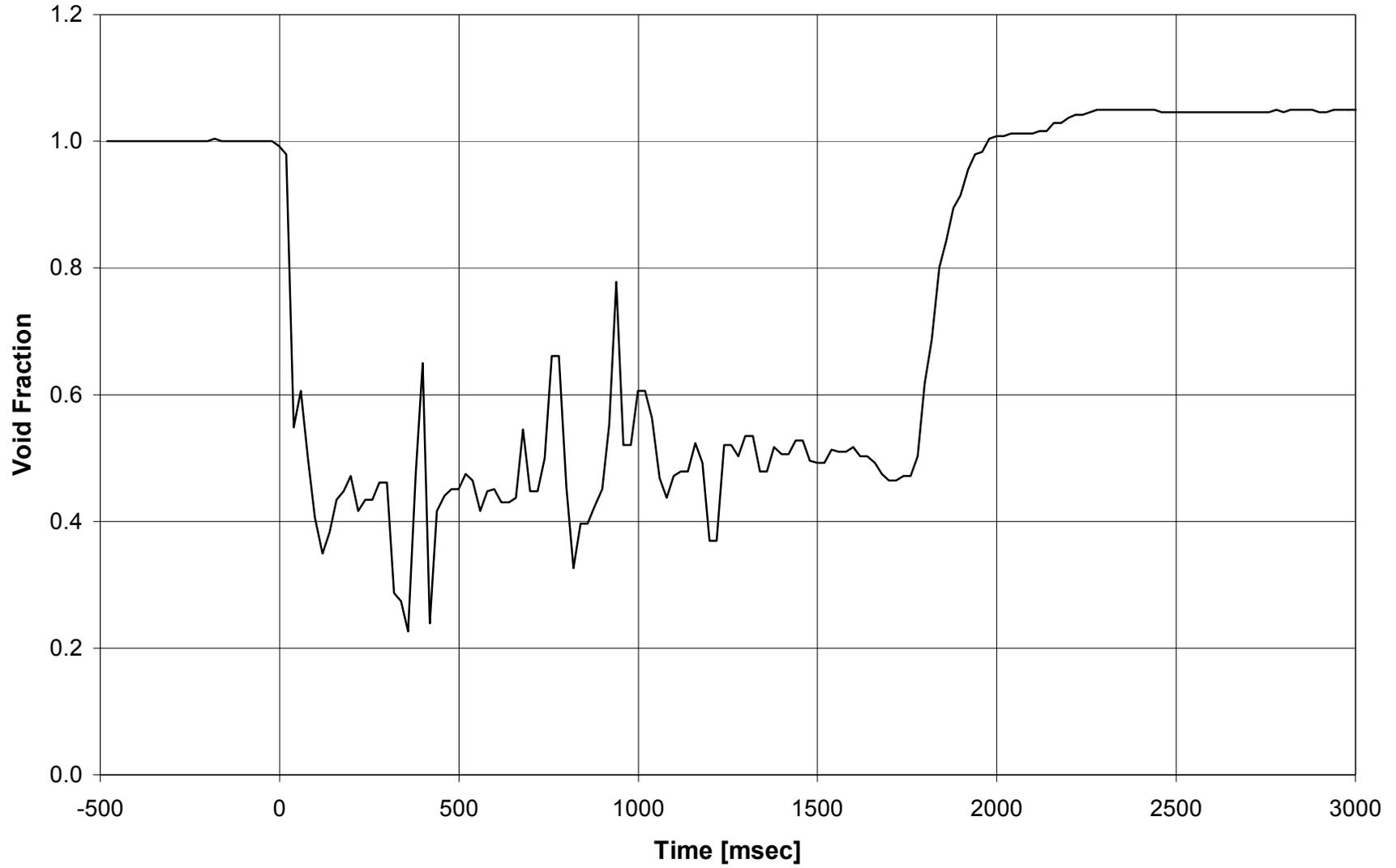
Legend

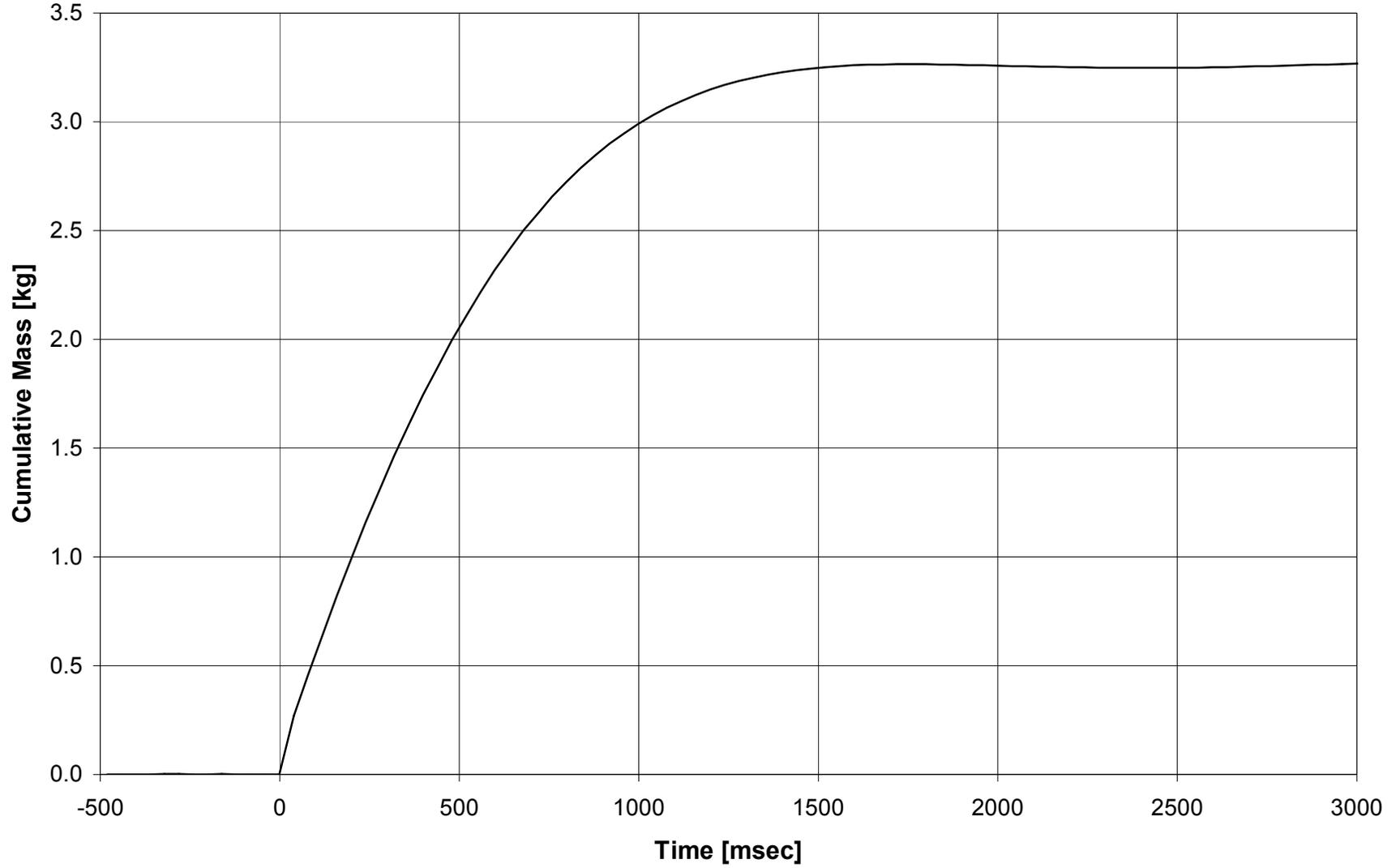












Run #6

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Straight Pipe

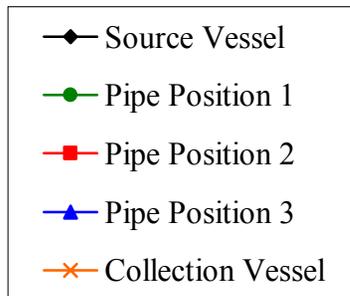
Source Vessel Initial Conditions: Fill Volume: 2150 milliliters
 Fluid Mass: 3.038 kg
 Pressure (Psvo): 4910 kPa
 Nitrogen Mass: 0.162 kg

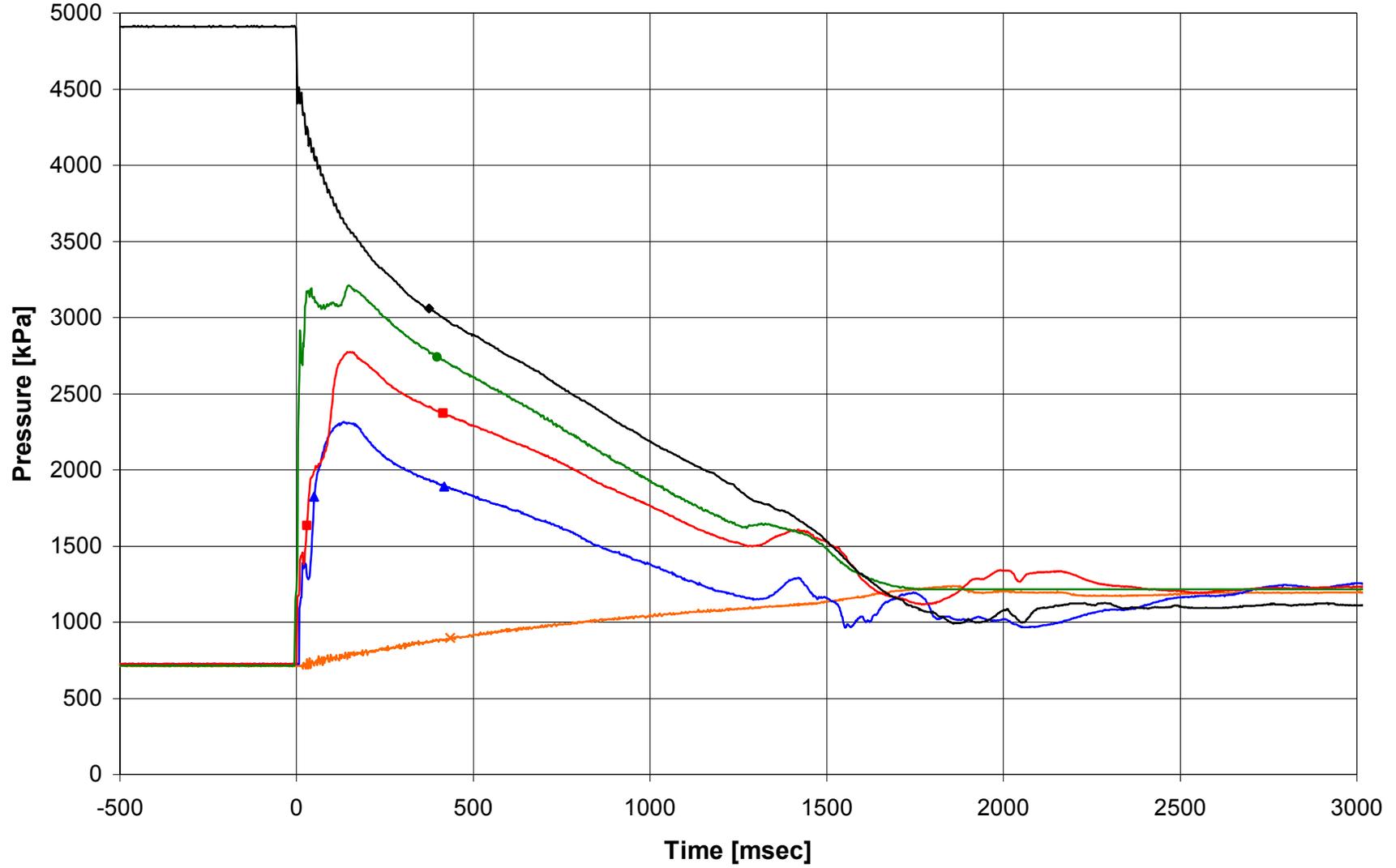
Initial Collection Vessel & Piping Pressure (Pcvo): 715 kPa

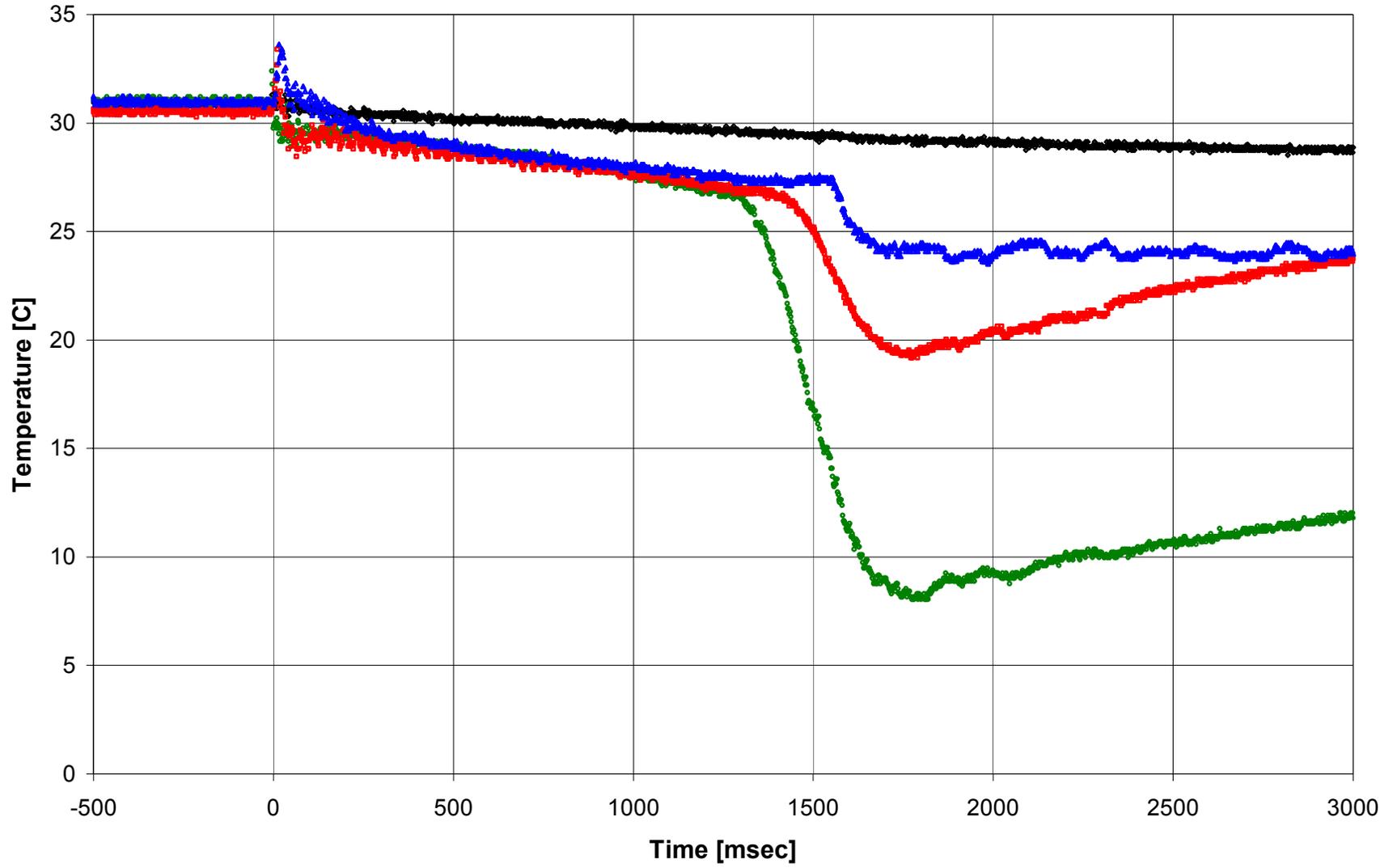
Initial System Temperature: 31° Celsius

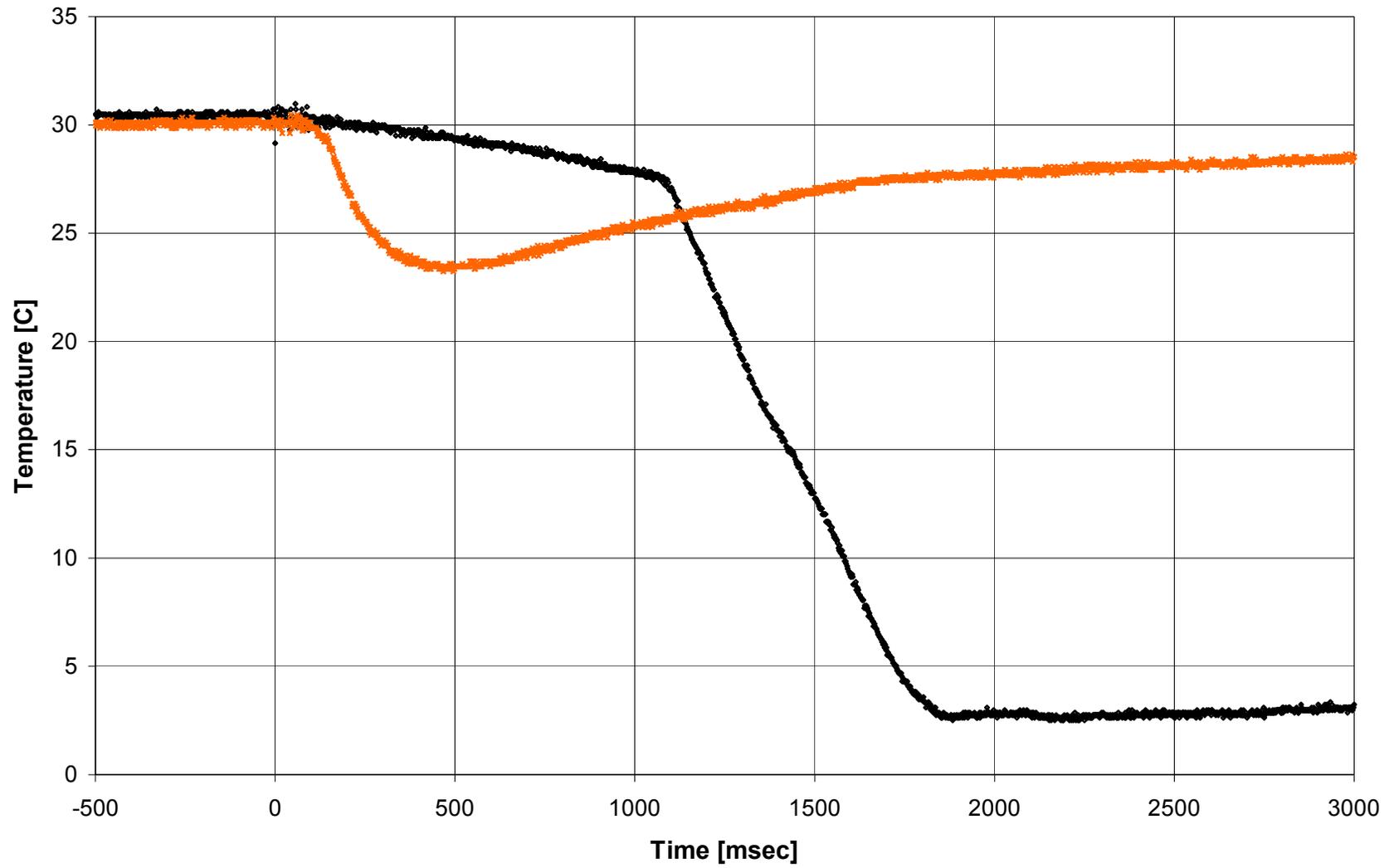
Completion Date: 8/13/99

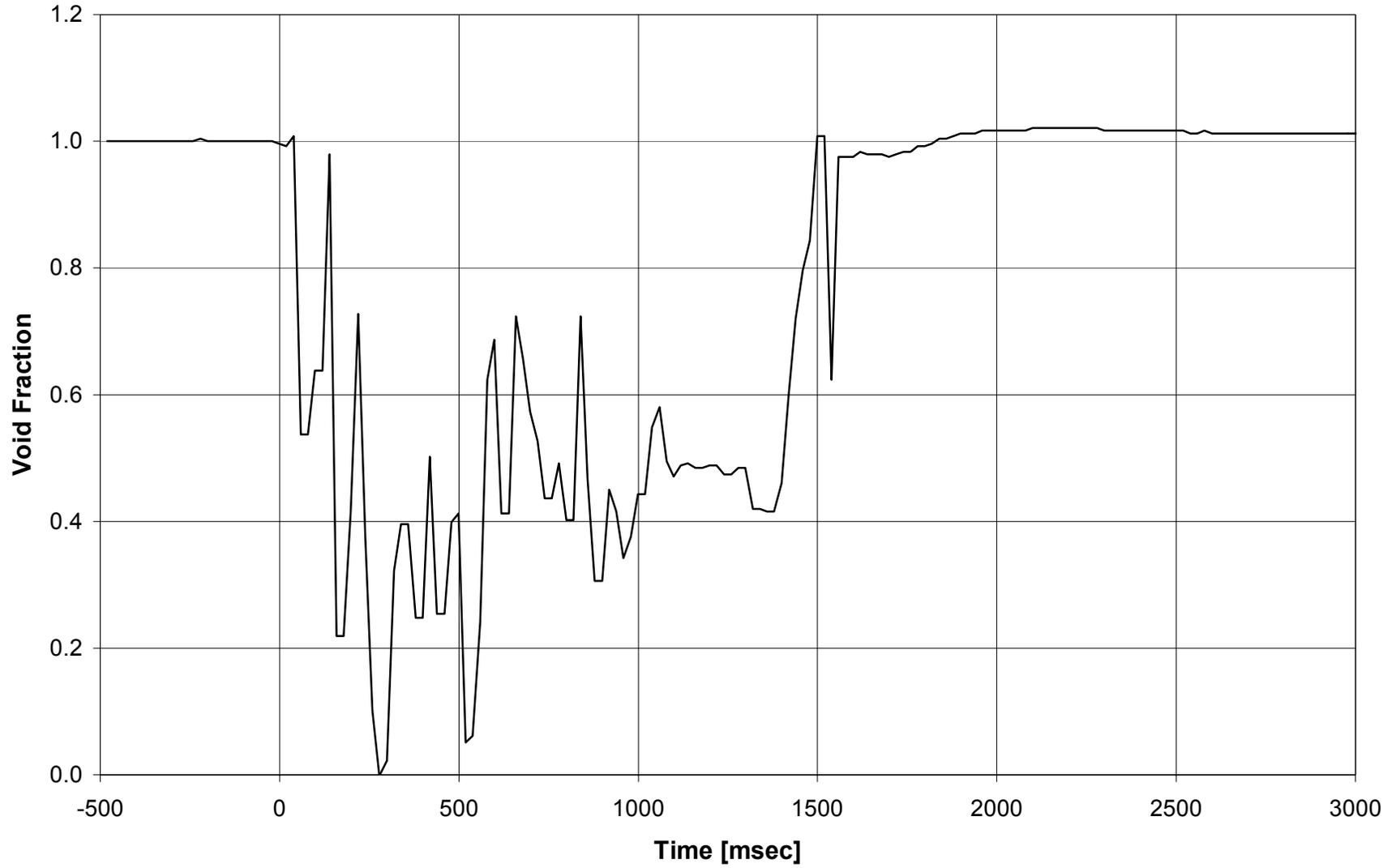
Legend

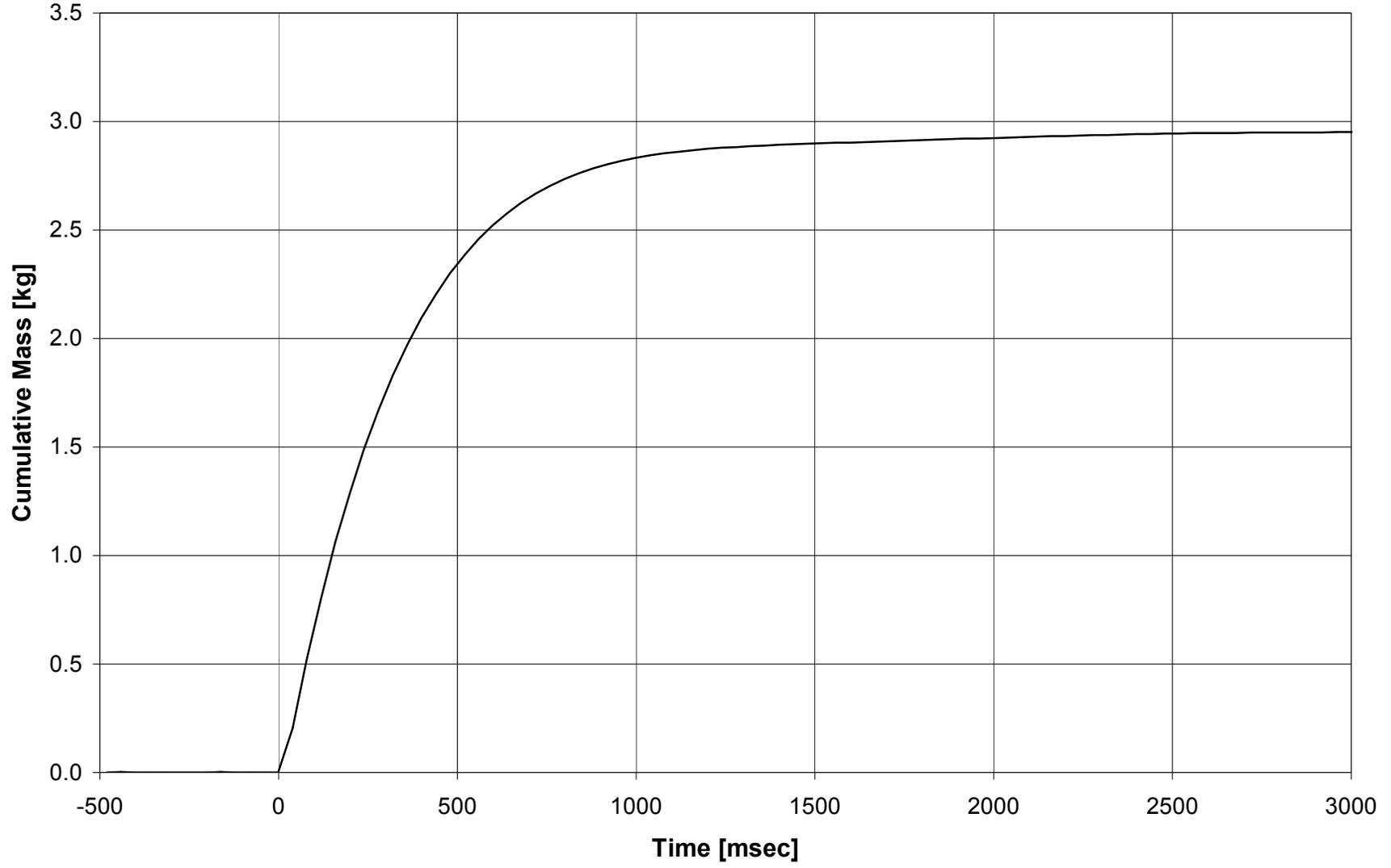












Run #7

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Straight Pipe w/ Hotspot @ 55° C

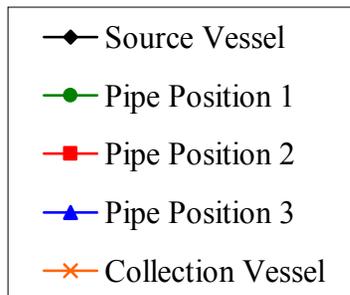
Source Vessel Initial Conditions: Fill Volume: 2200 milliliters
 Fluid Mass: 3.117 kg
 Pressure (Psvo): 4230 kPa
 Nitrogen Mass: 0.140 kg

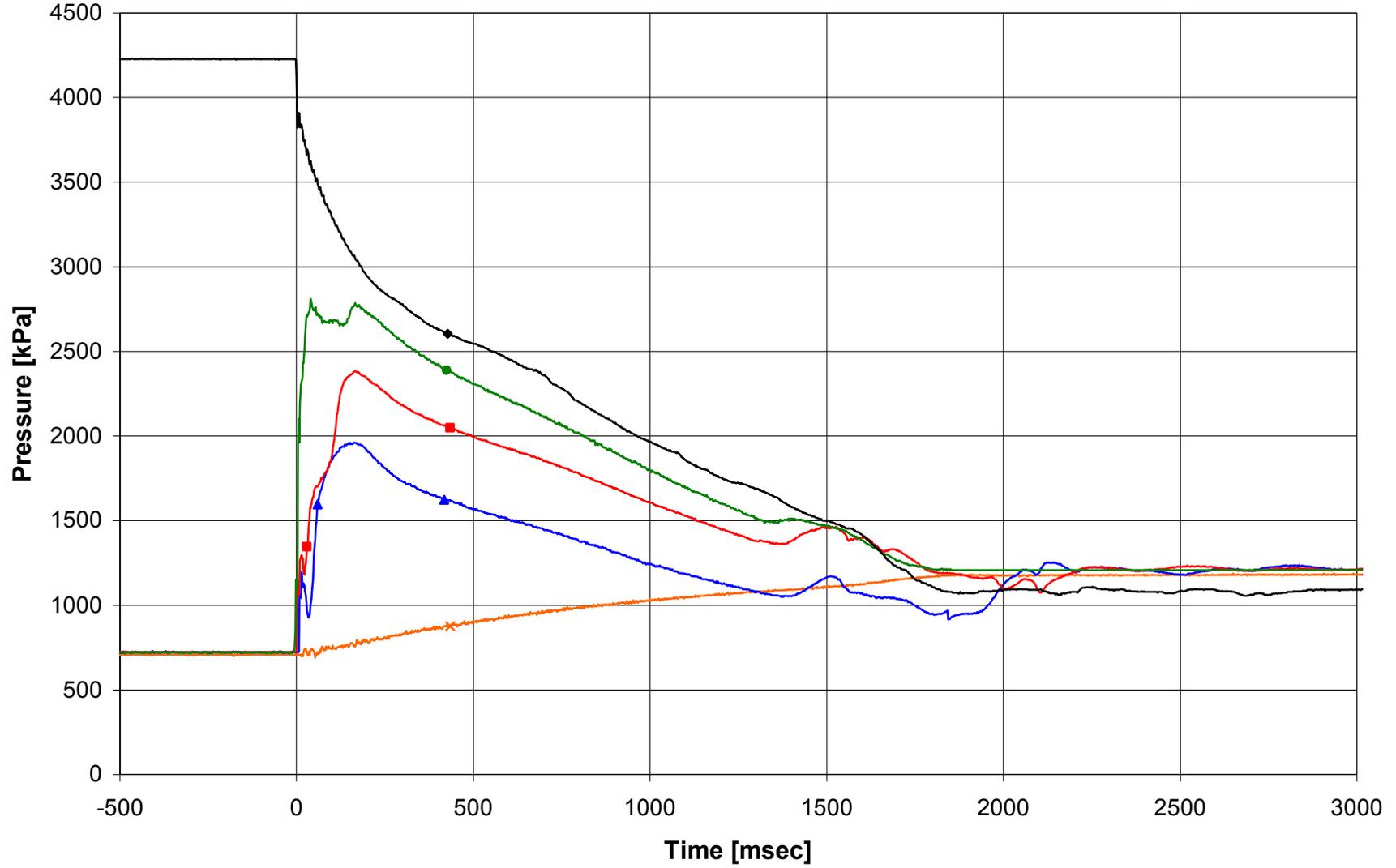
Initial Collection Vessel & Piping Pressure (Pcvo): 710 kPa

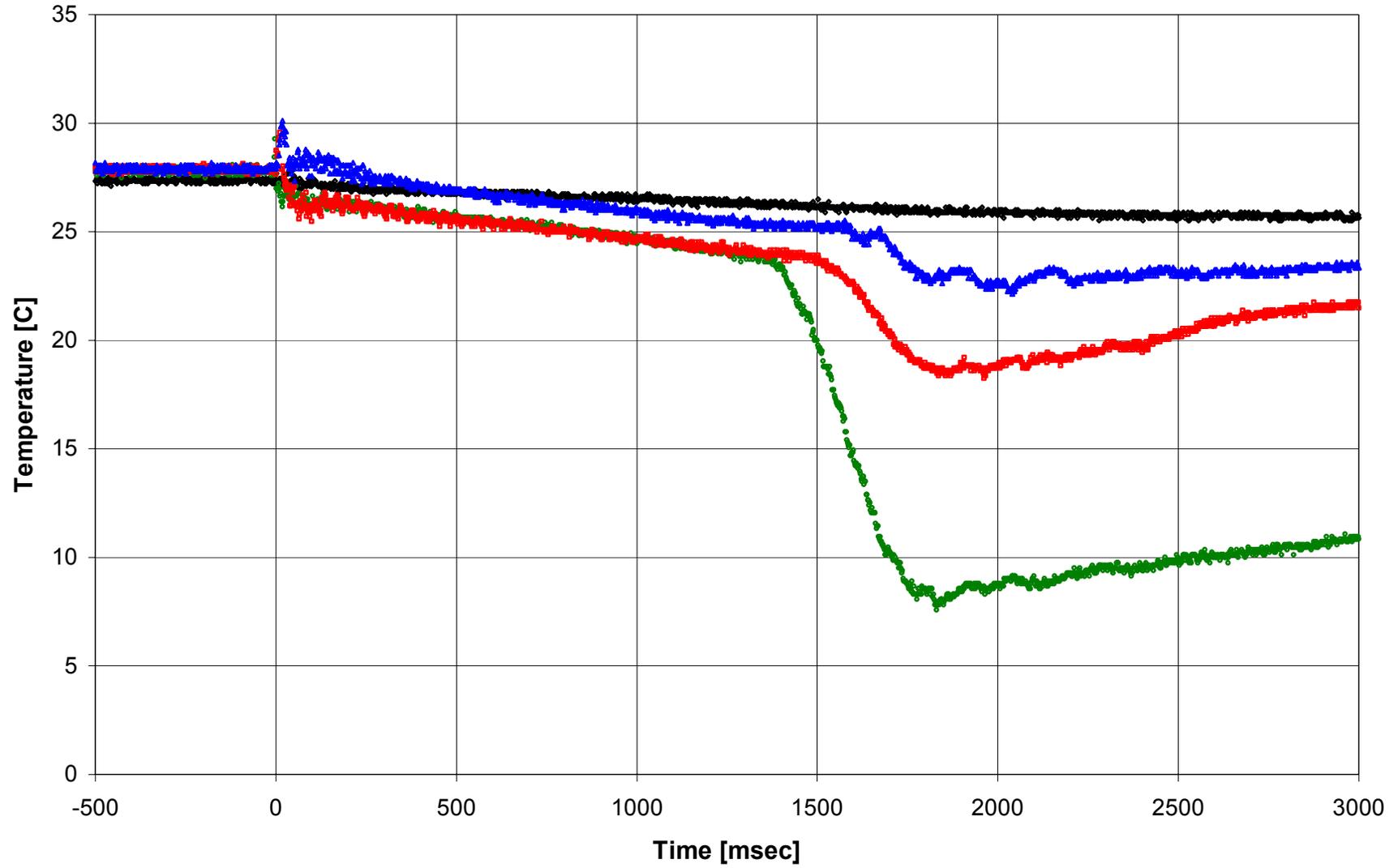
Initial System Temperature: 27° Celsius

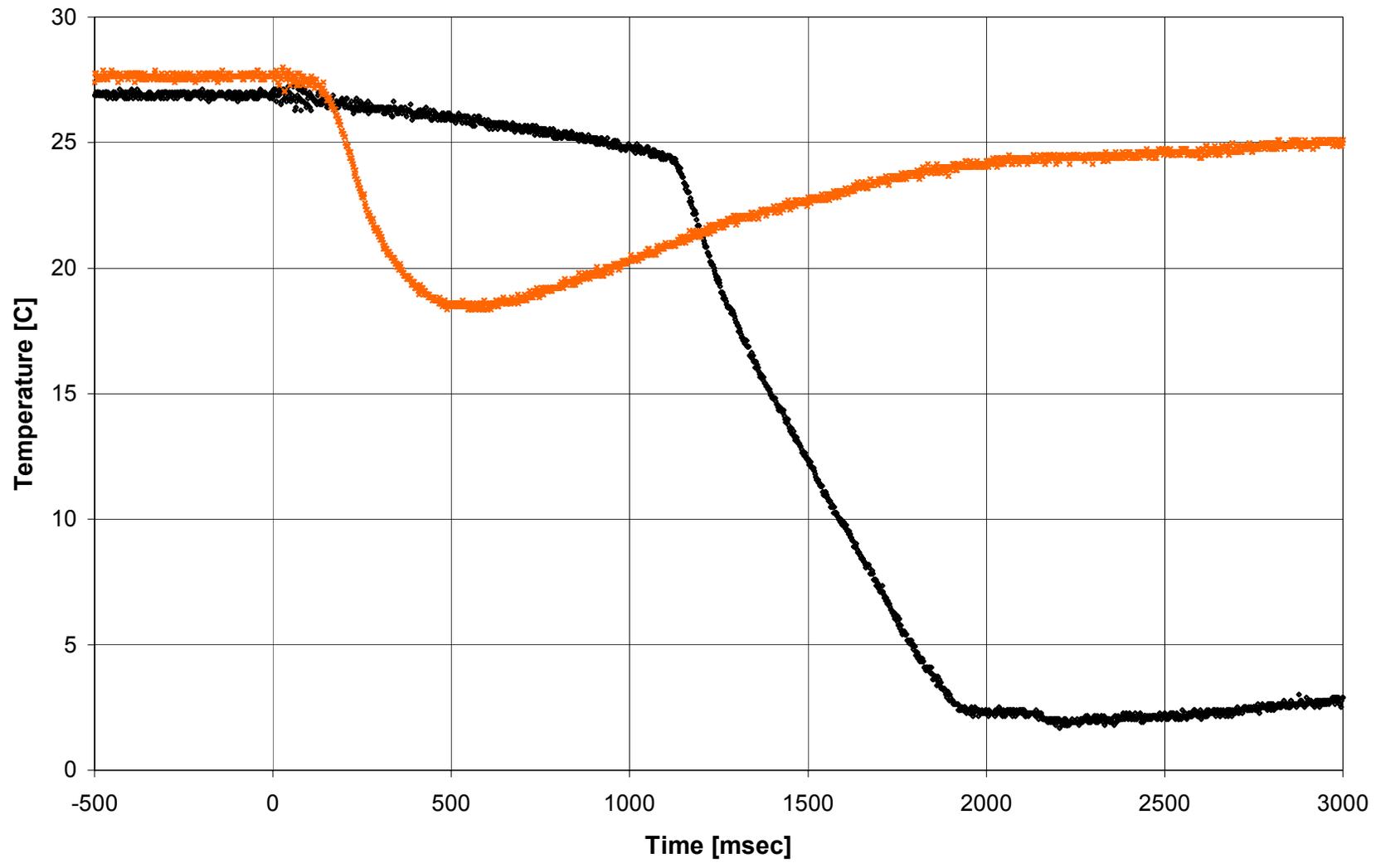
Completion Date: 8/10/99

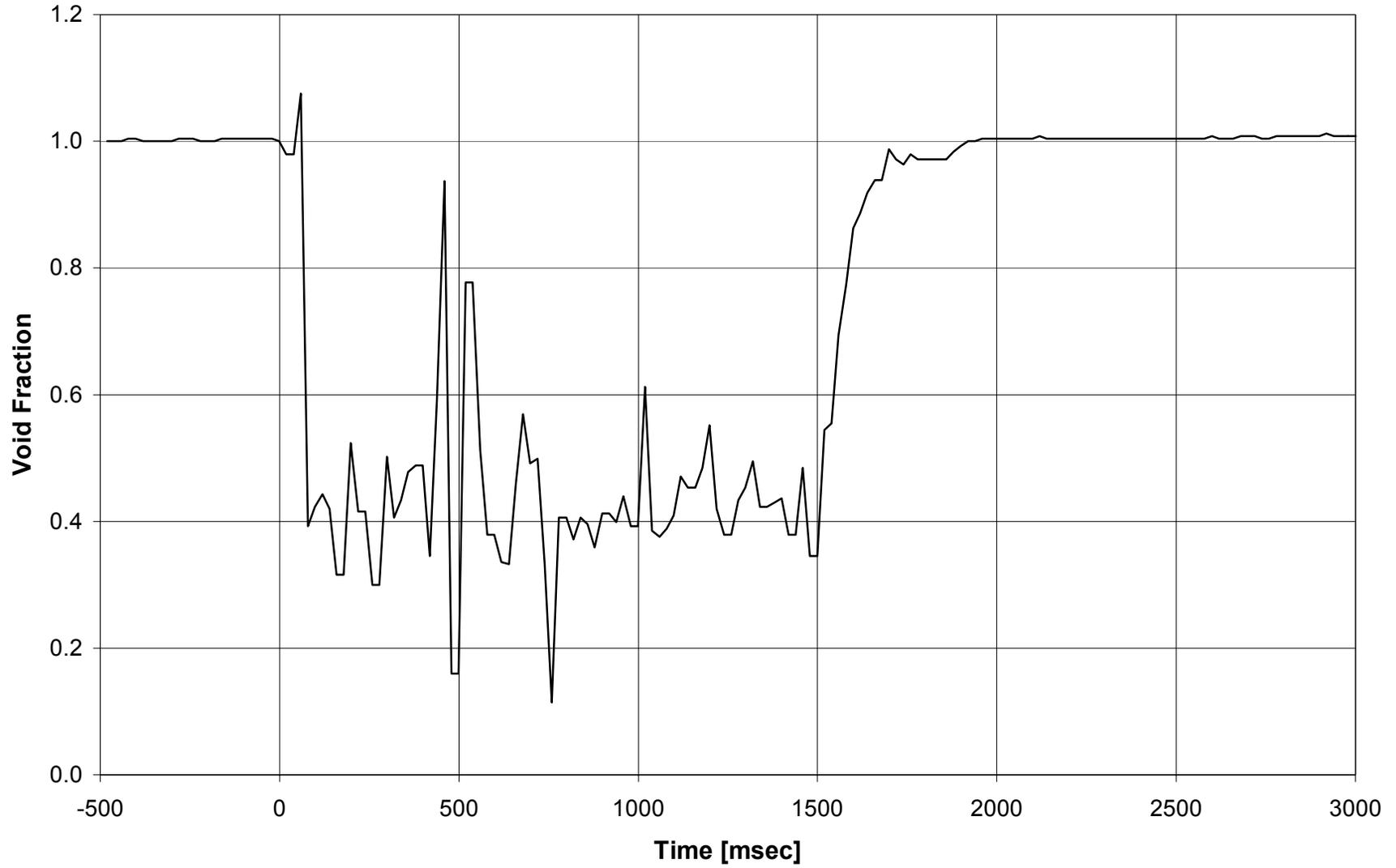
Legend

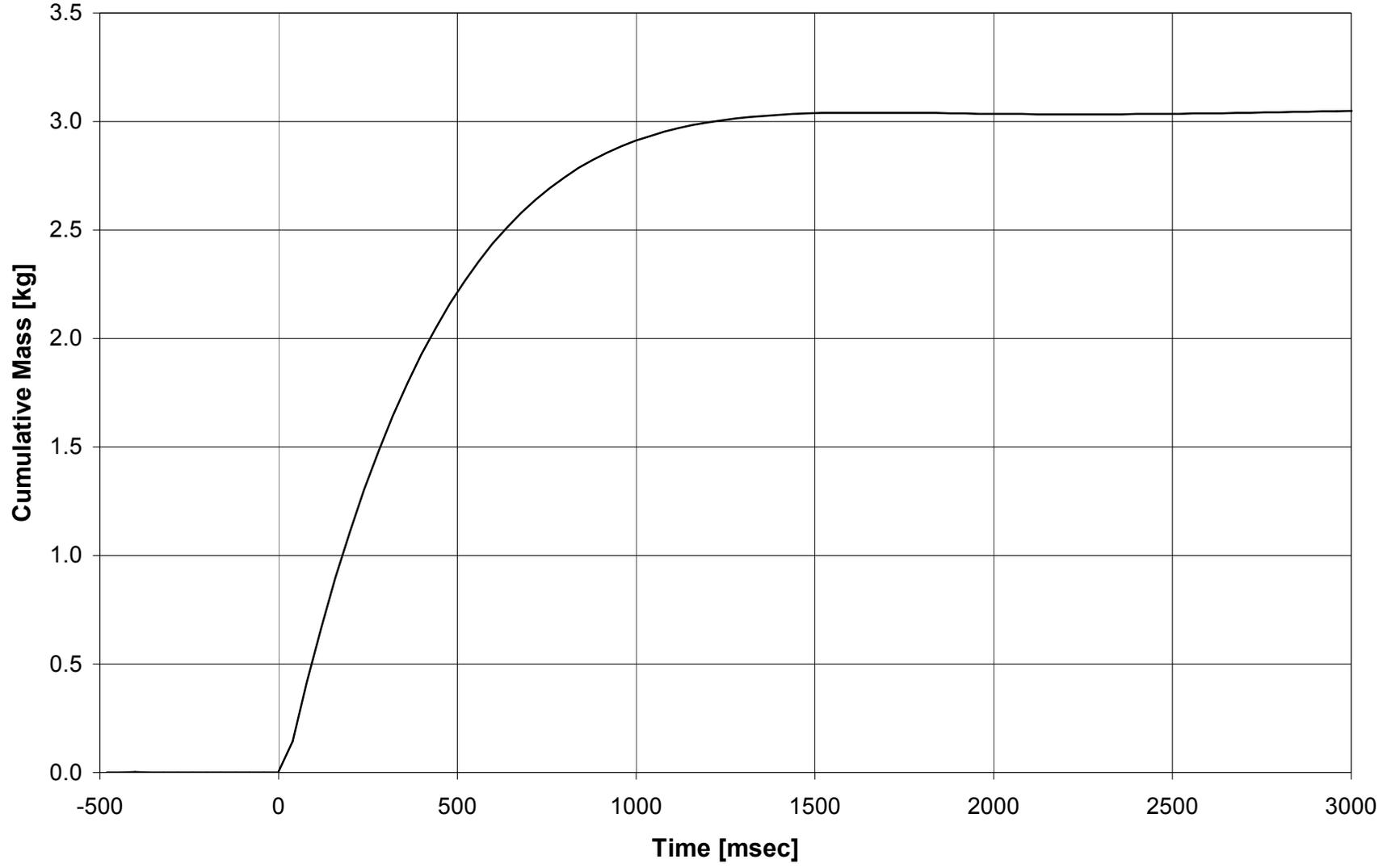












Run #8

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Capped Tee, 90° Elbow, Union, Two 45° Elbows, Capped Tee (Configuration #1)

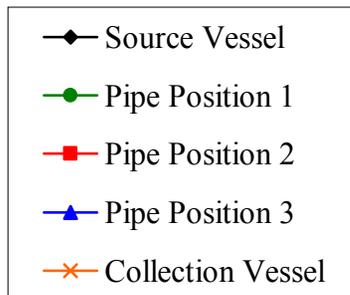
Source Vessel Initial Conditions: Fill Volume: 3420 milliliters
 Fluid Mass: 4.851 kg
 Pressure (Psvo): 2120 kPa
 Nitrogen Mass: 0.058 kg

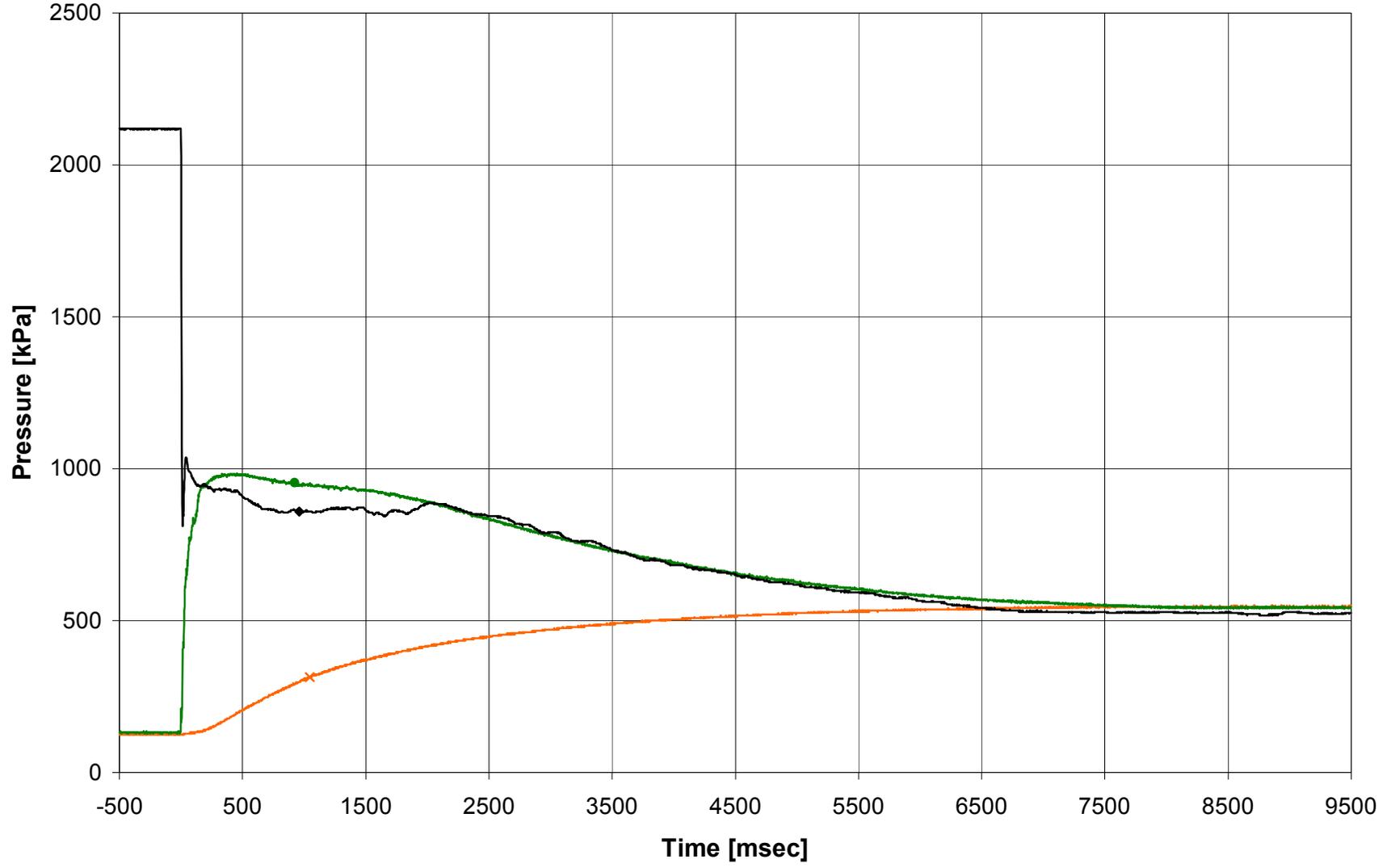
Initial Collection Vessel & Piping Pressure (Pcvo): 125 kPa

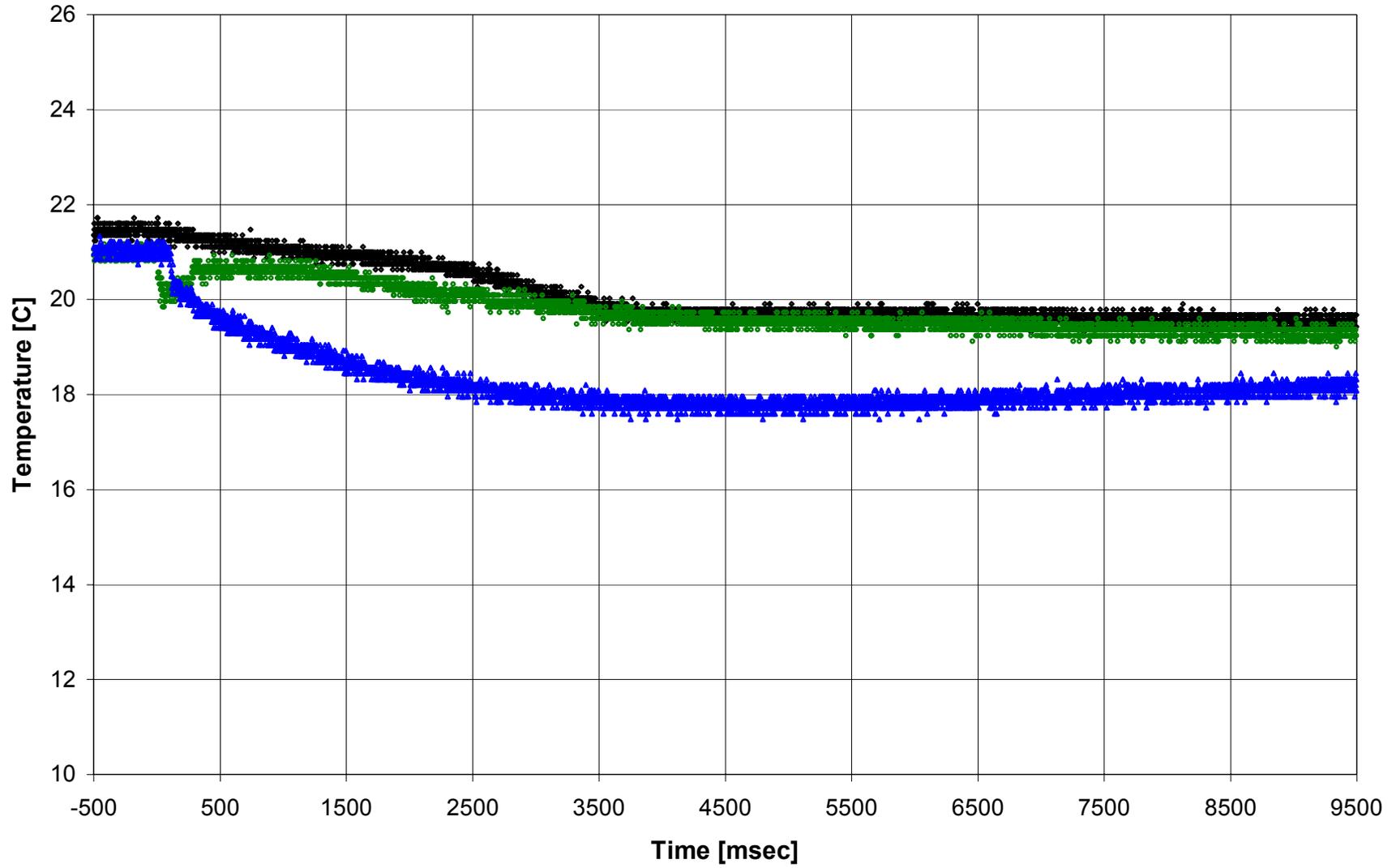
Initial System Temperature: 21° Celsius

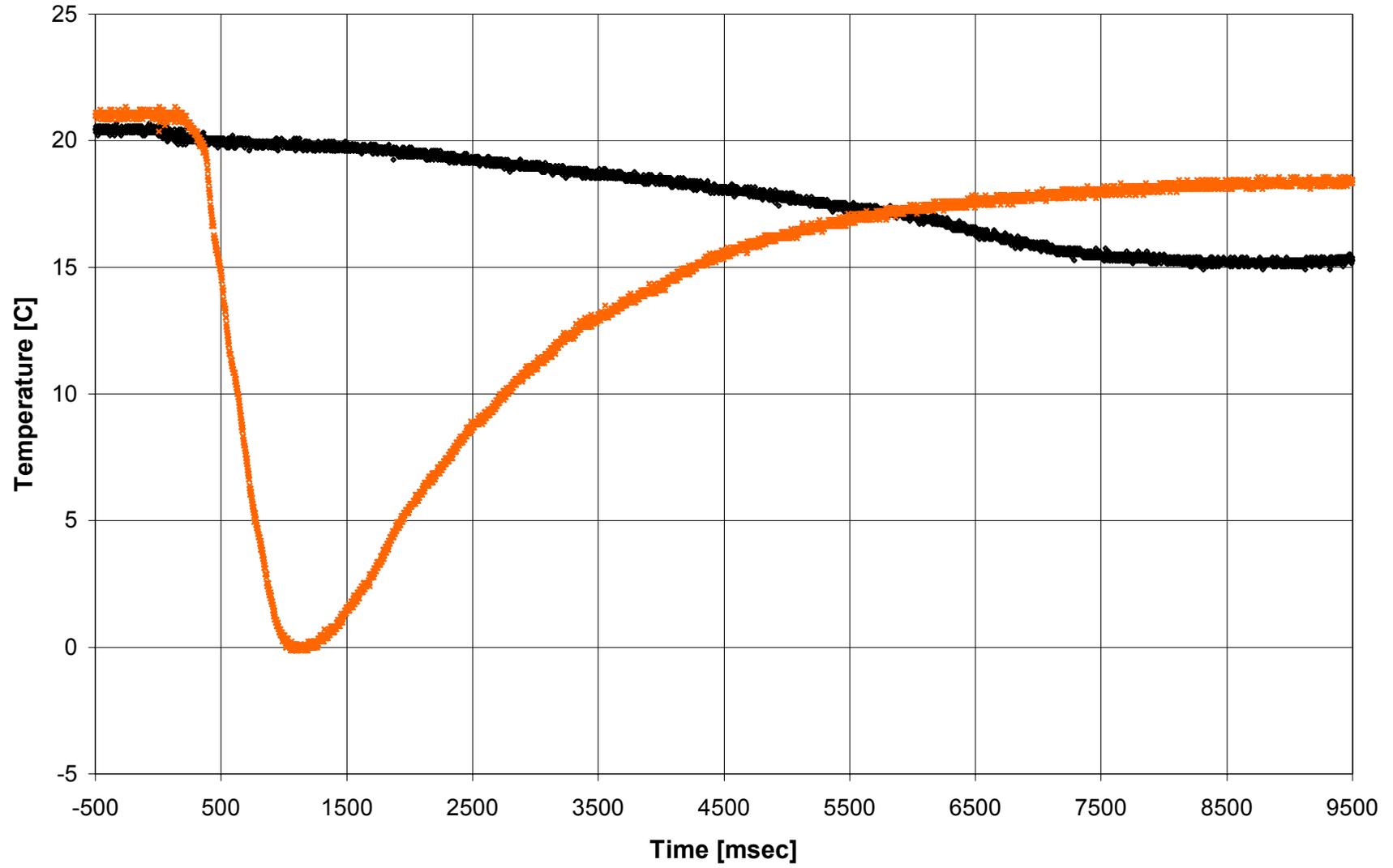
Completion Date: 1/19/00

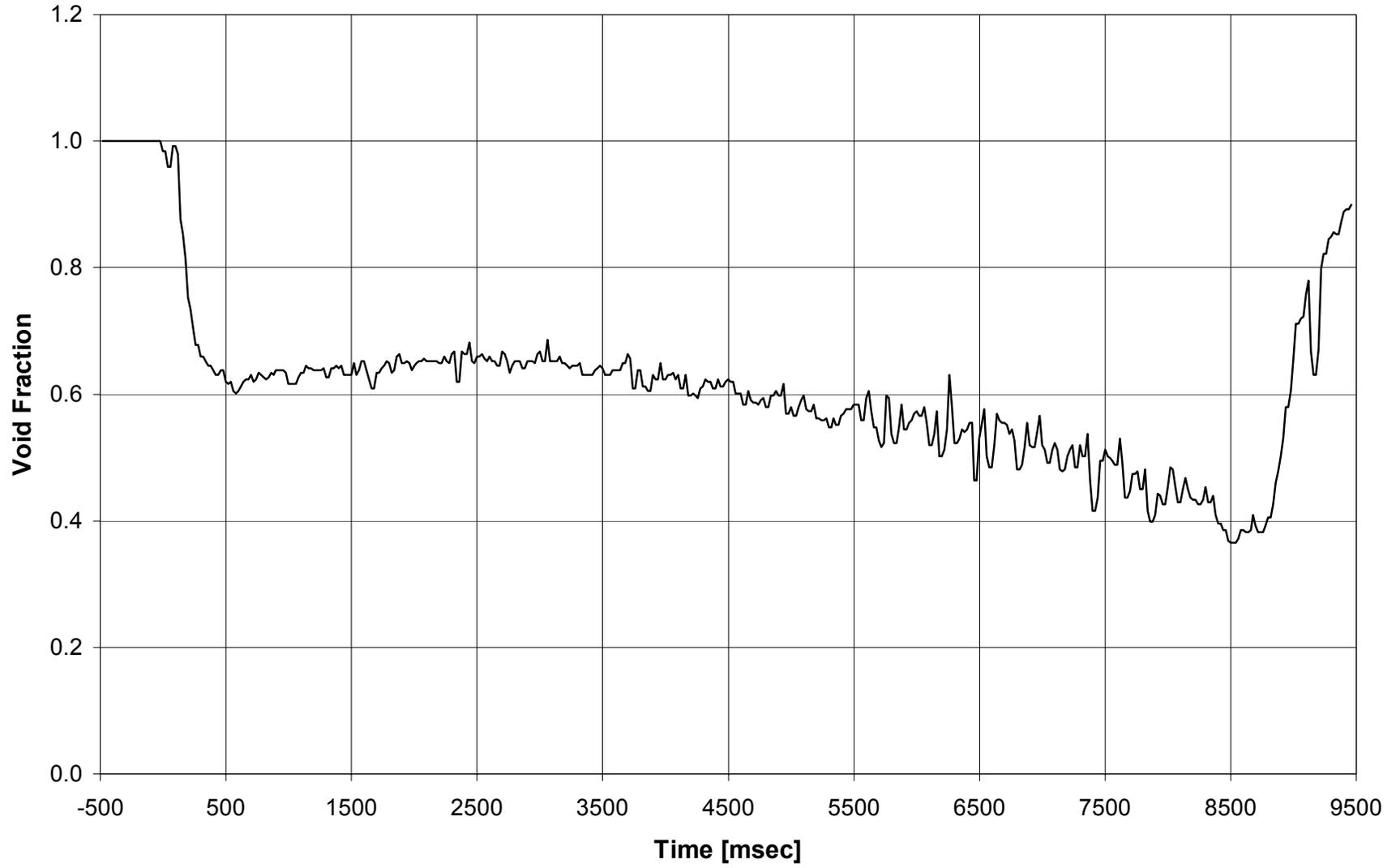
Legend

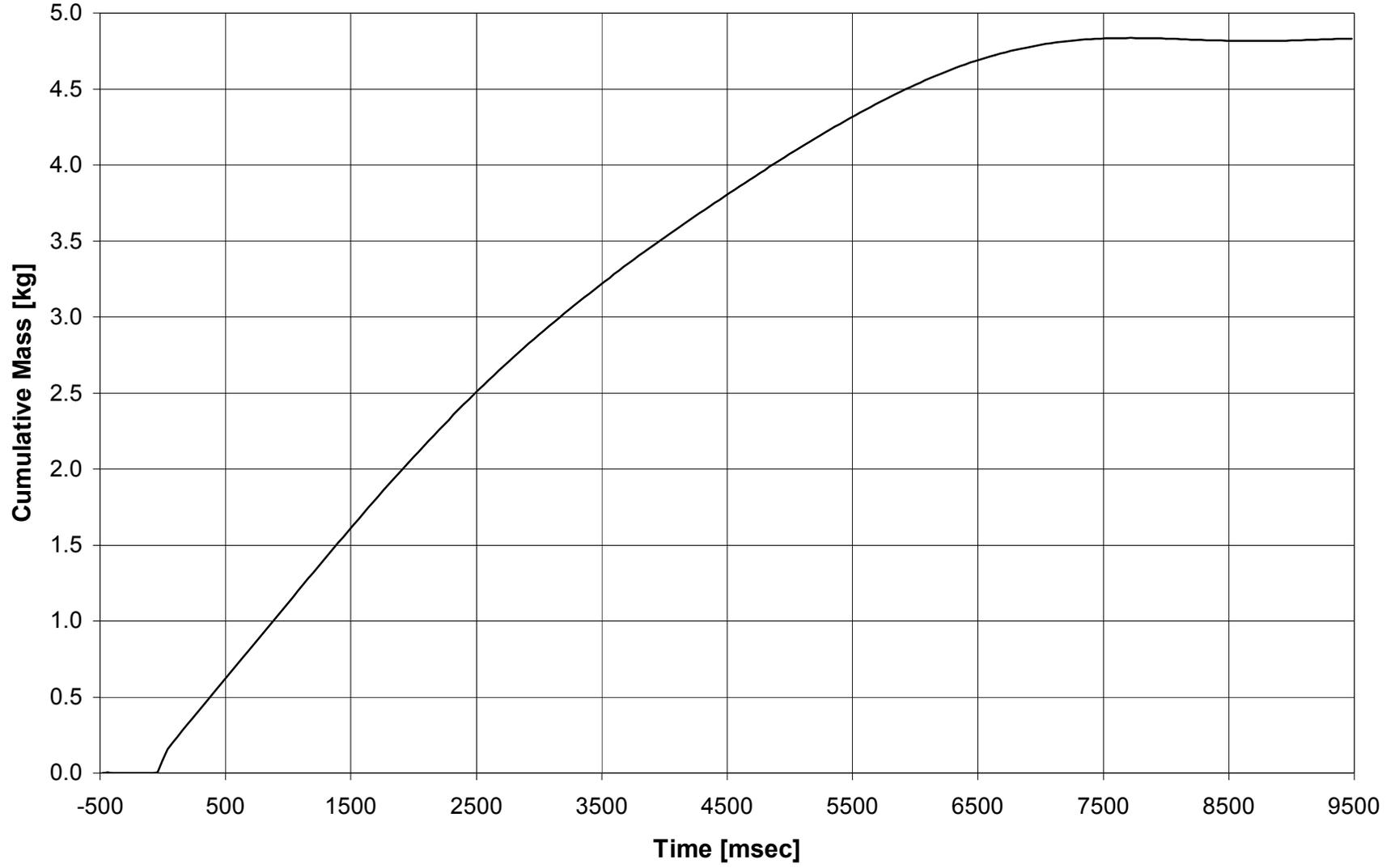


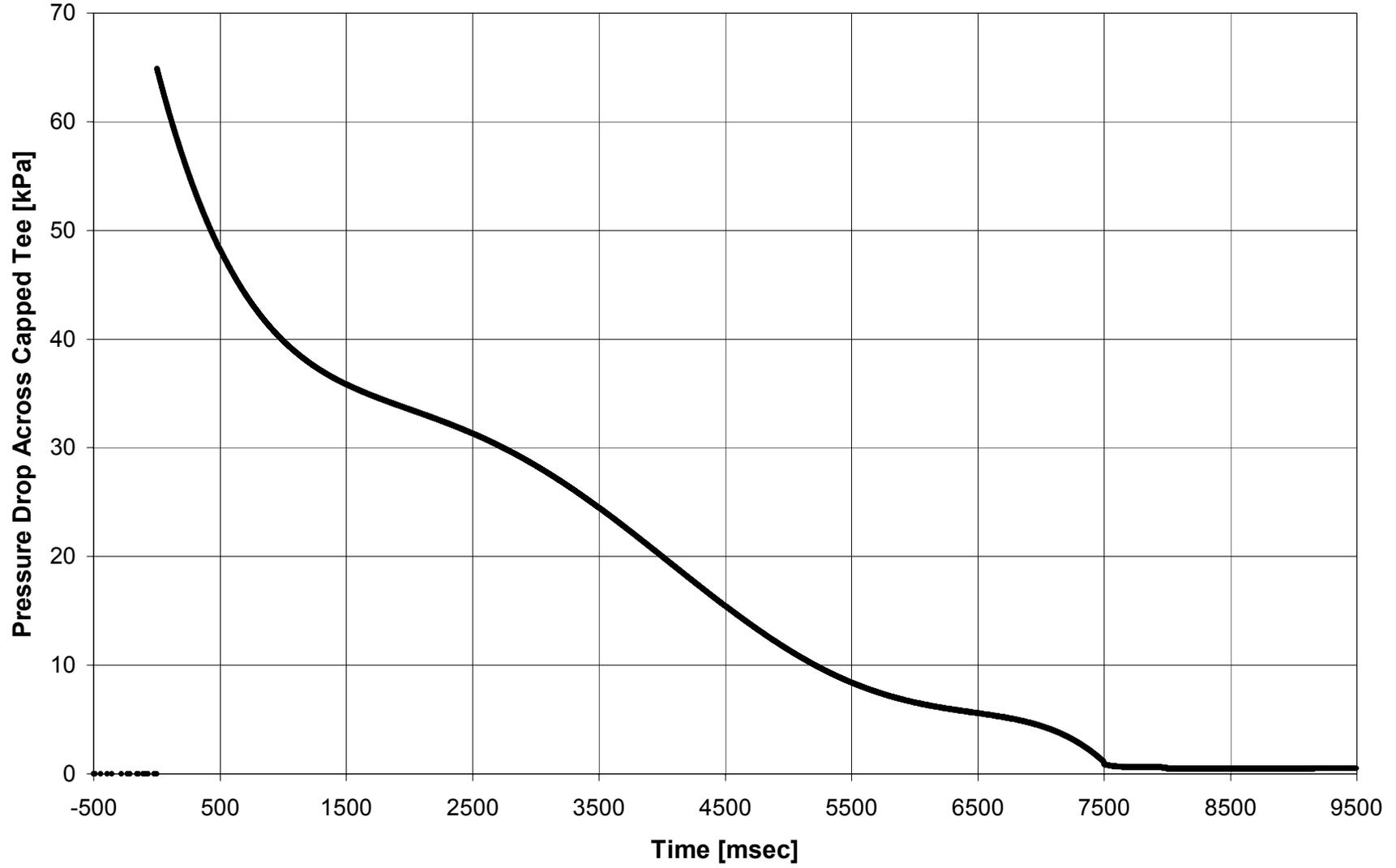


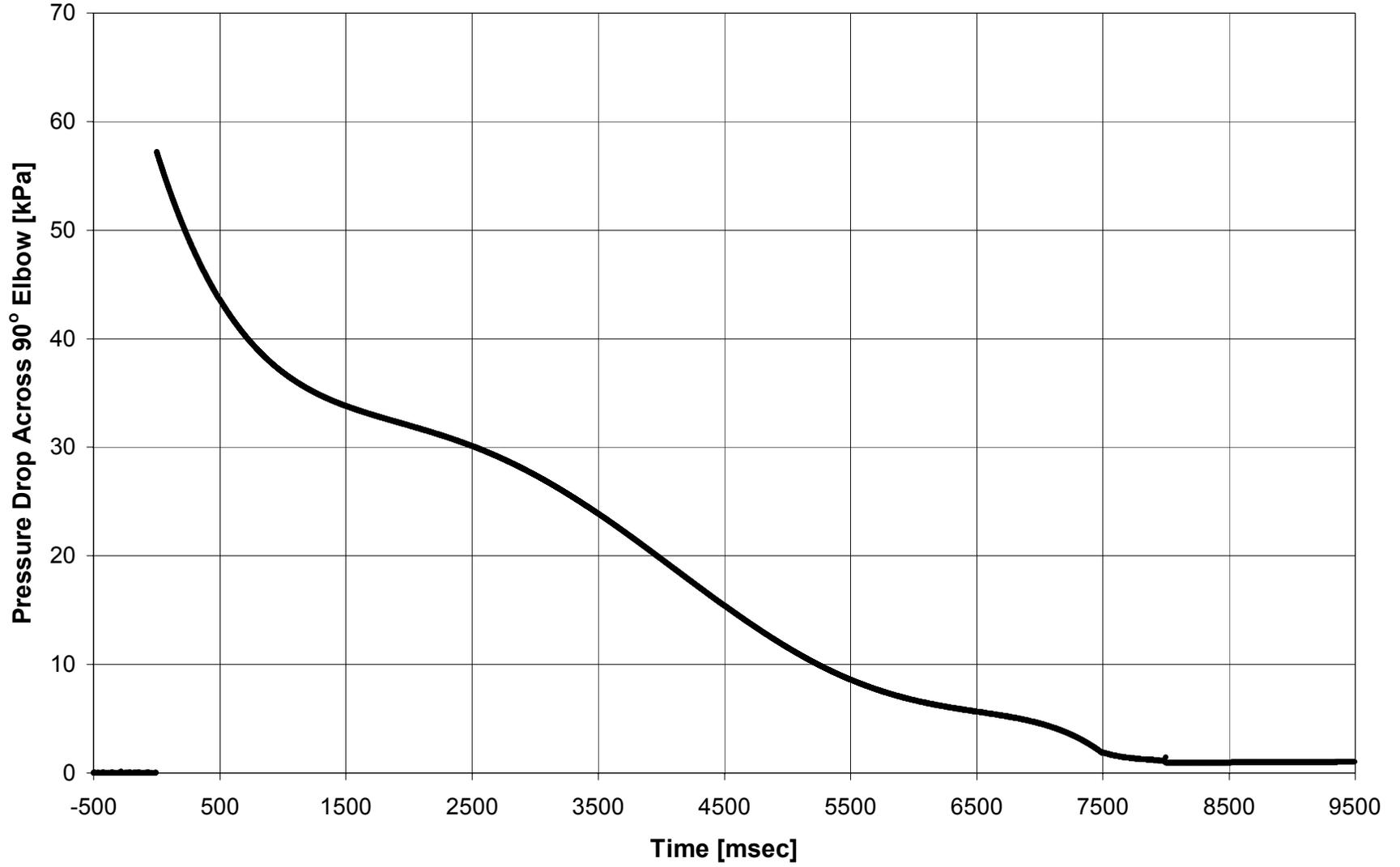


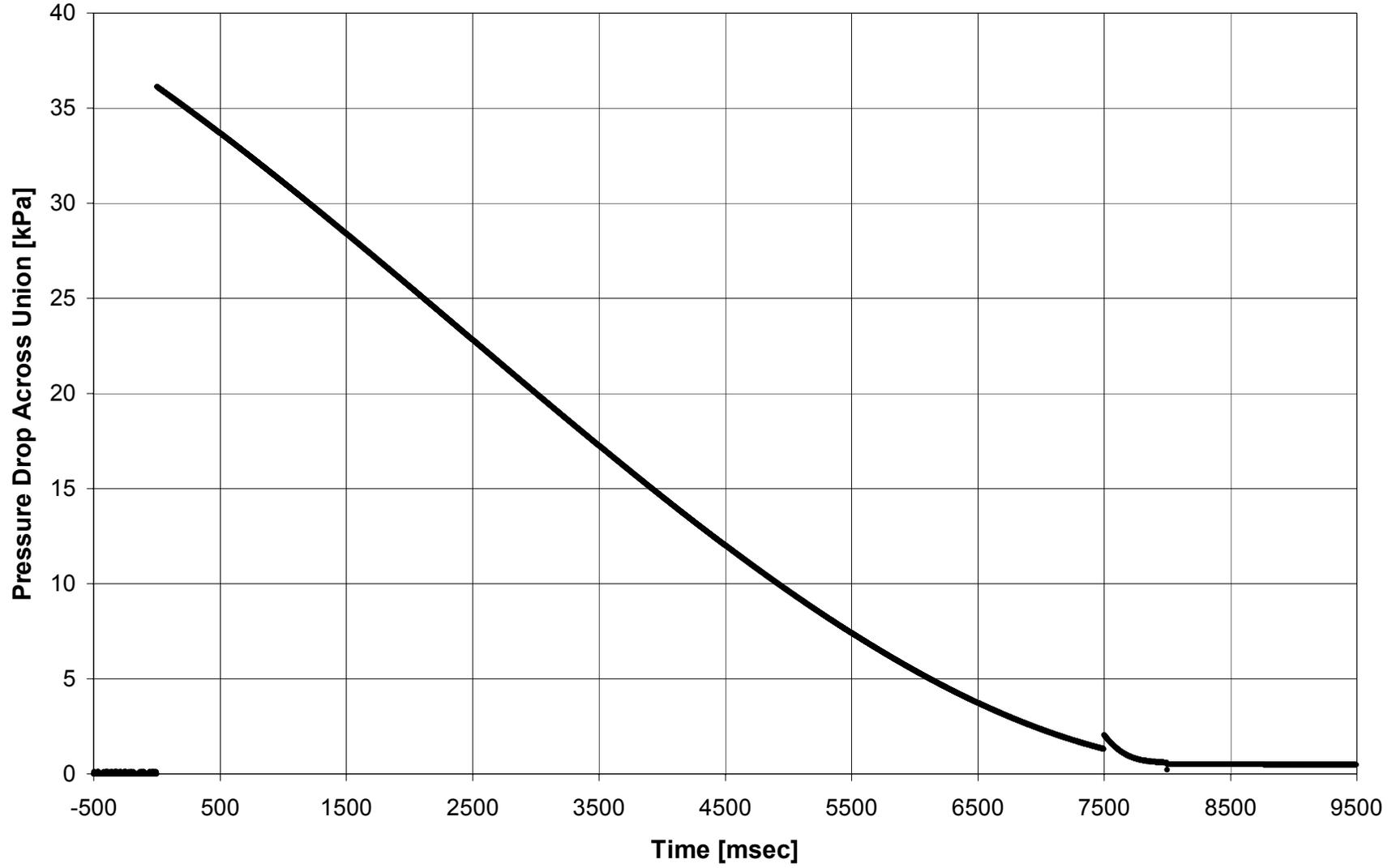












Run #9

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Capped Tee, 90° Elbow, Union, Two 45° Elbows, Capped Tee (Configuration #1)

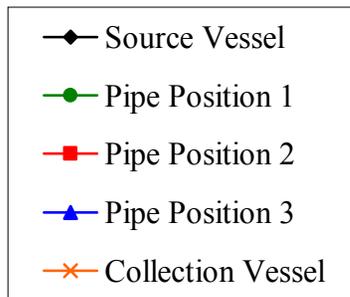
Source Vessel Initial Conditions: Fill Volume: 2500 milliliters
 Fluid Mass: 3.568 kg
 Pressure (Psvo): 3915 kPa
 Nitrogen Mass: 0.127 kg

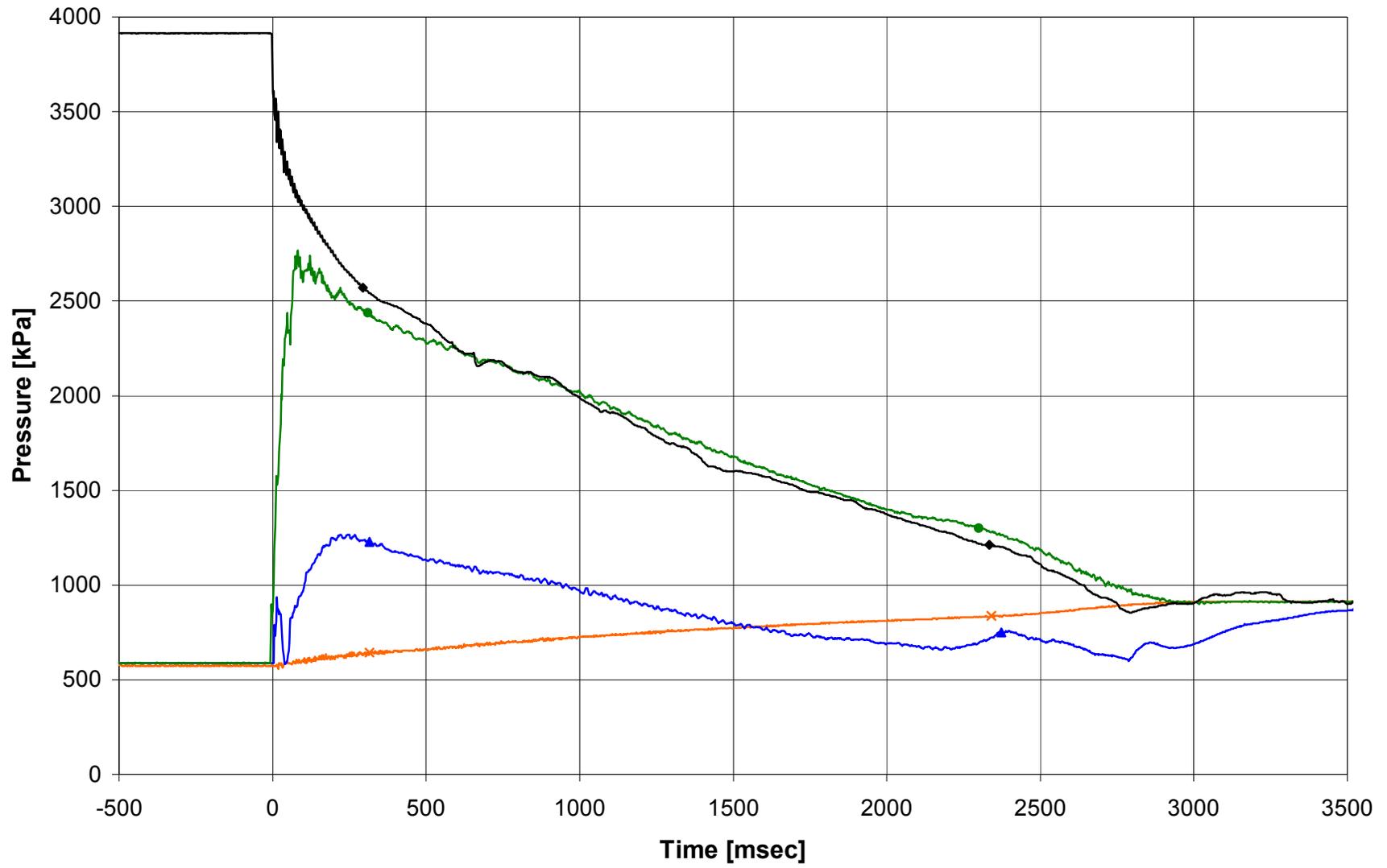
Initial Collection Vessel & Piping Pressure (Pcvo): 575 kPa

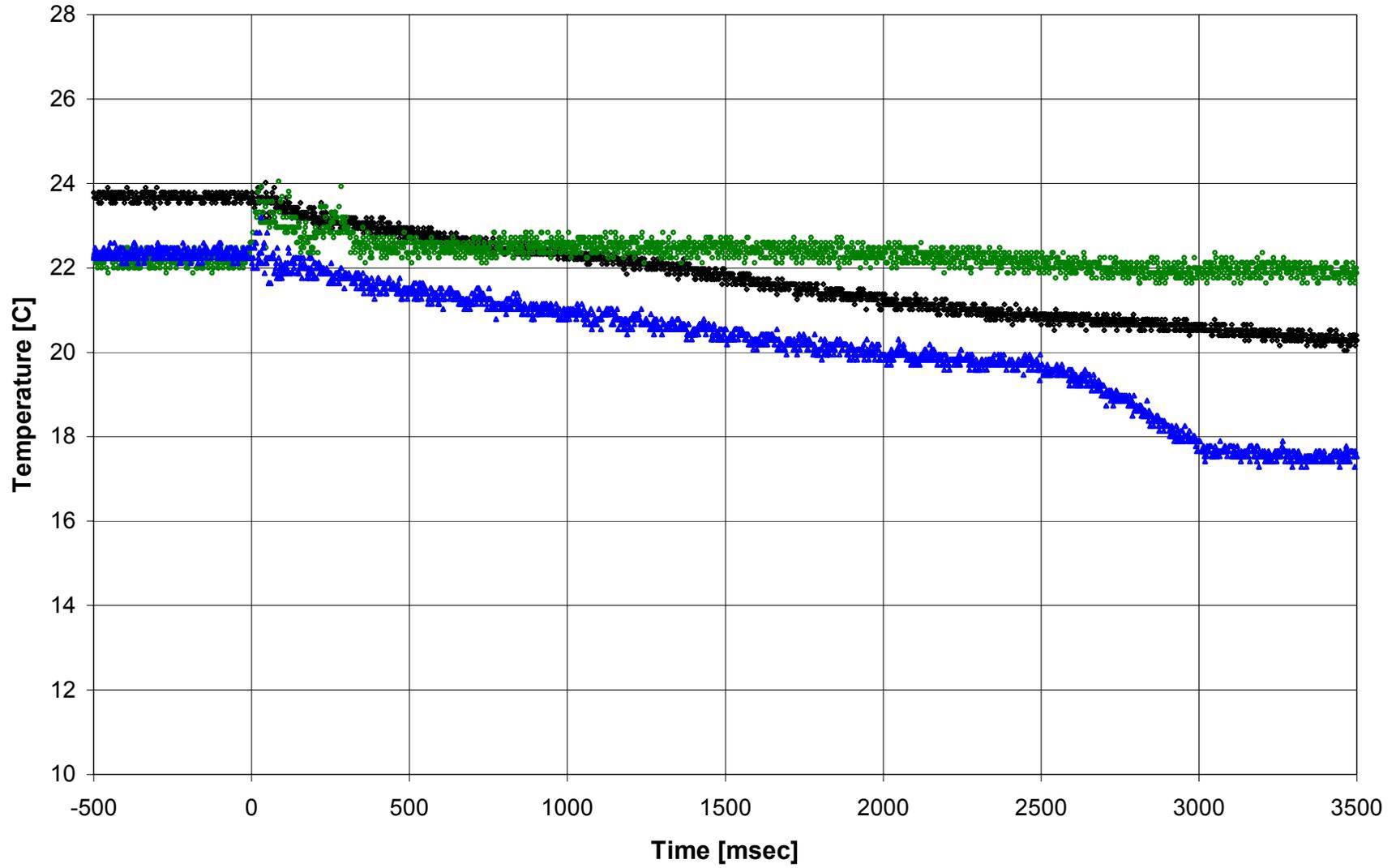
Initial System Temperature: 24° Celsius

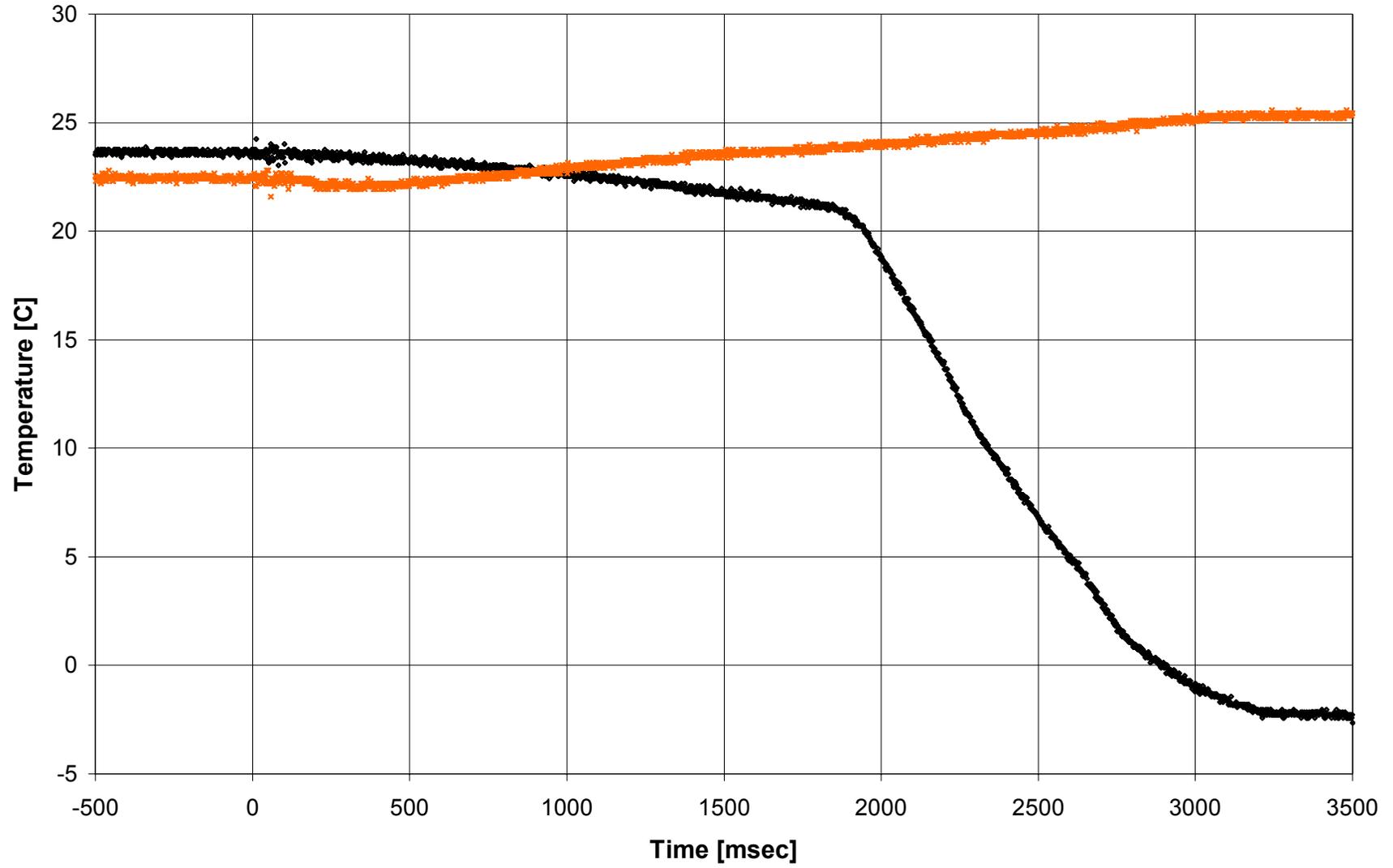
Completion Date: 2/7/00

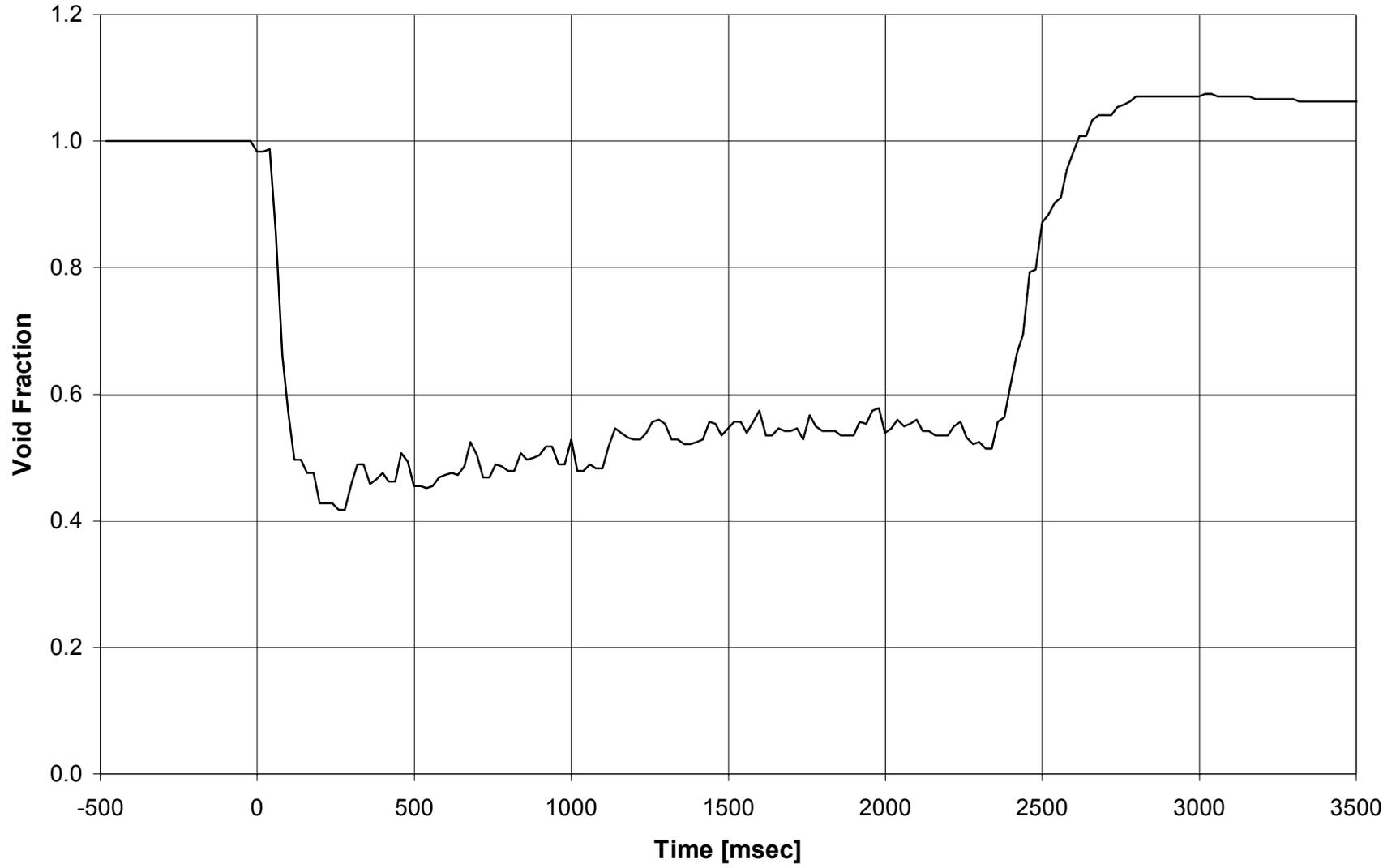
Legend

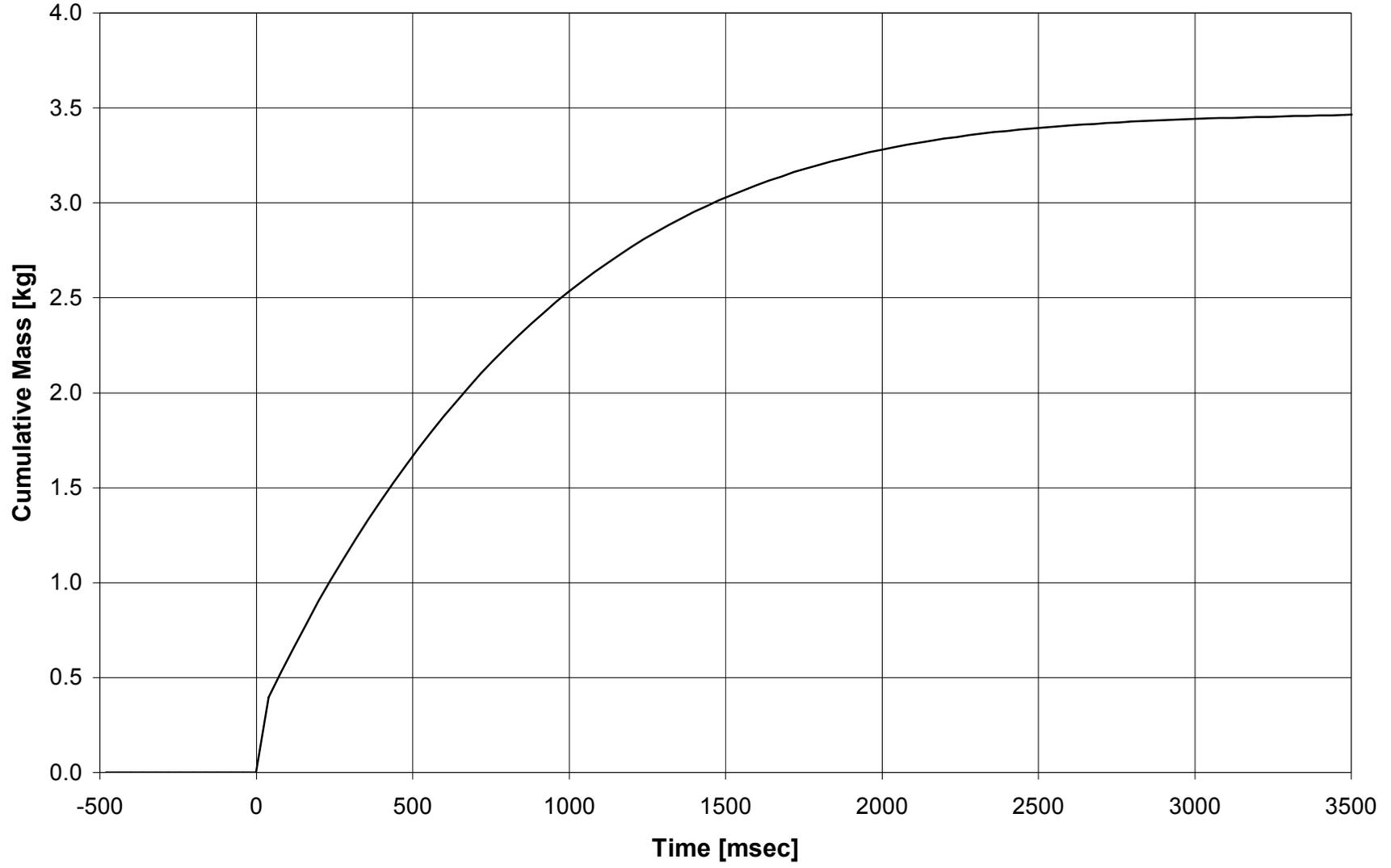


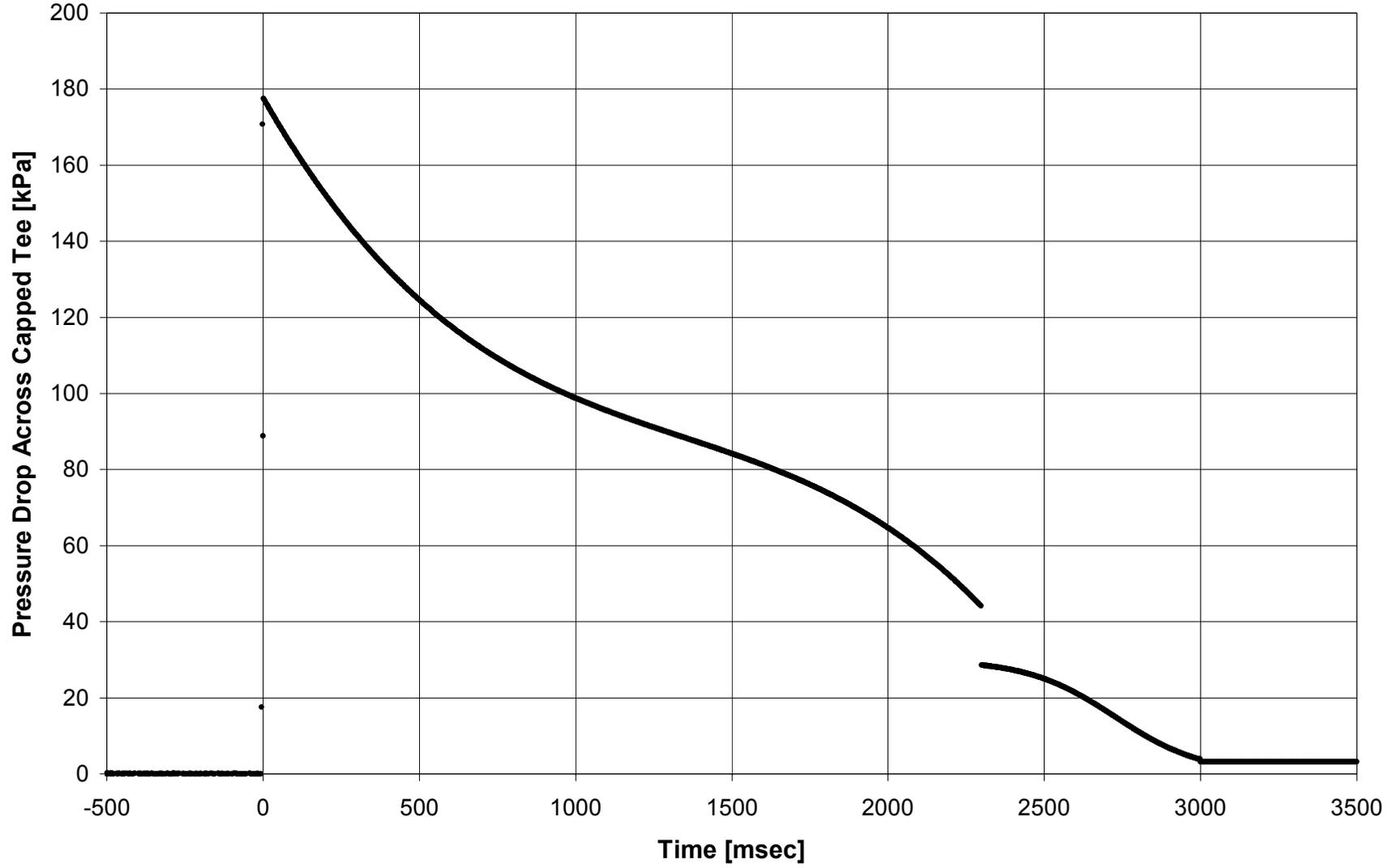


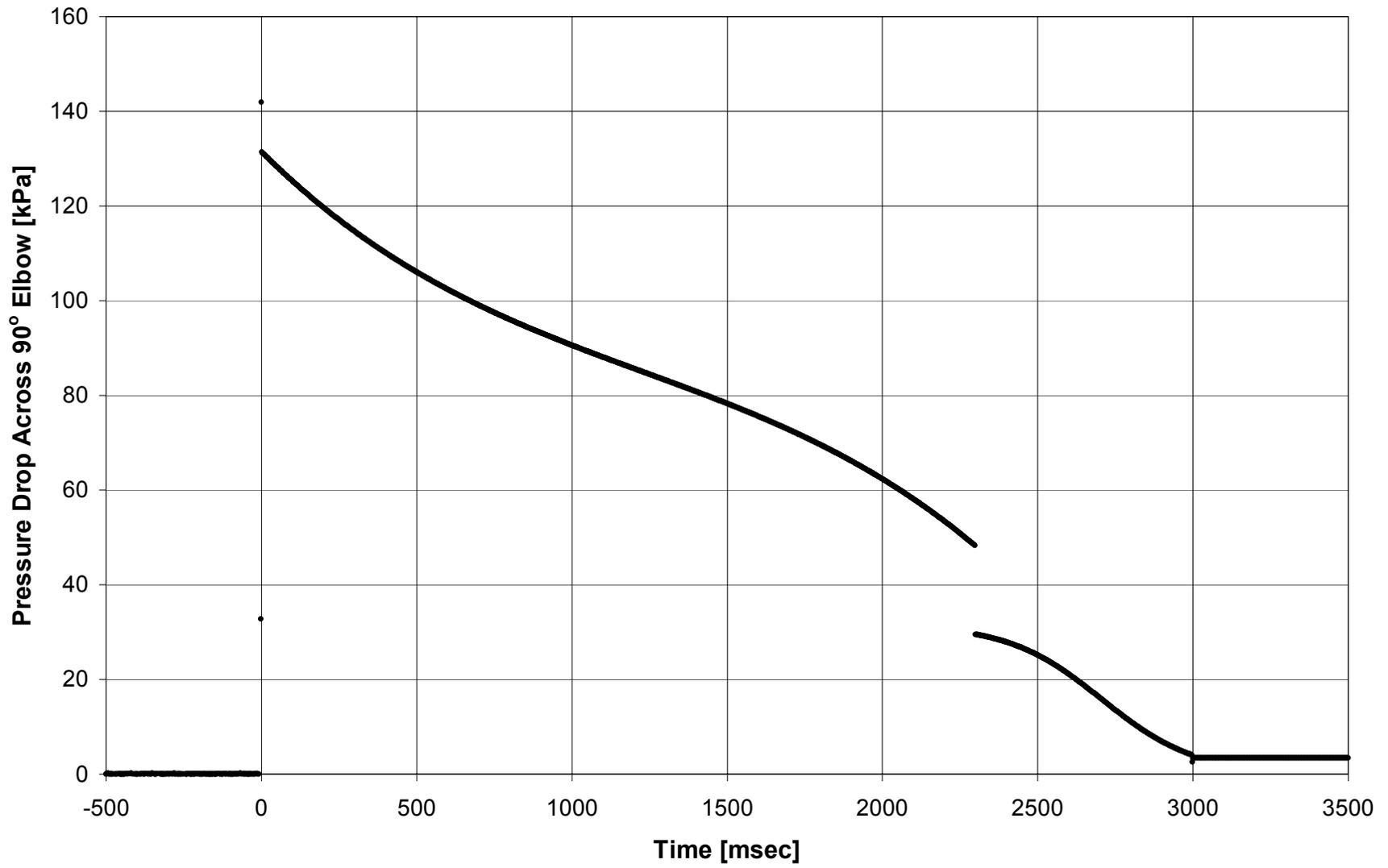


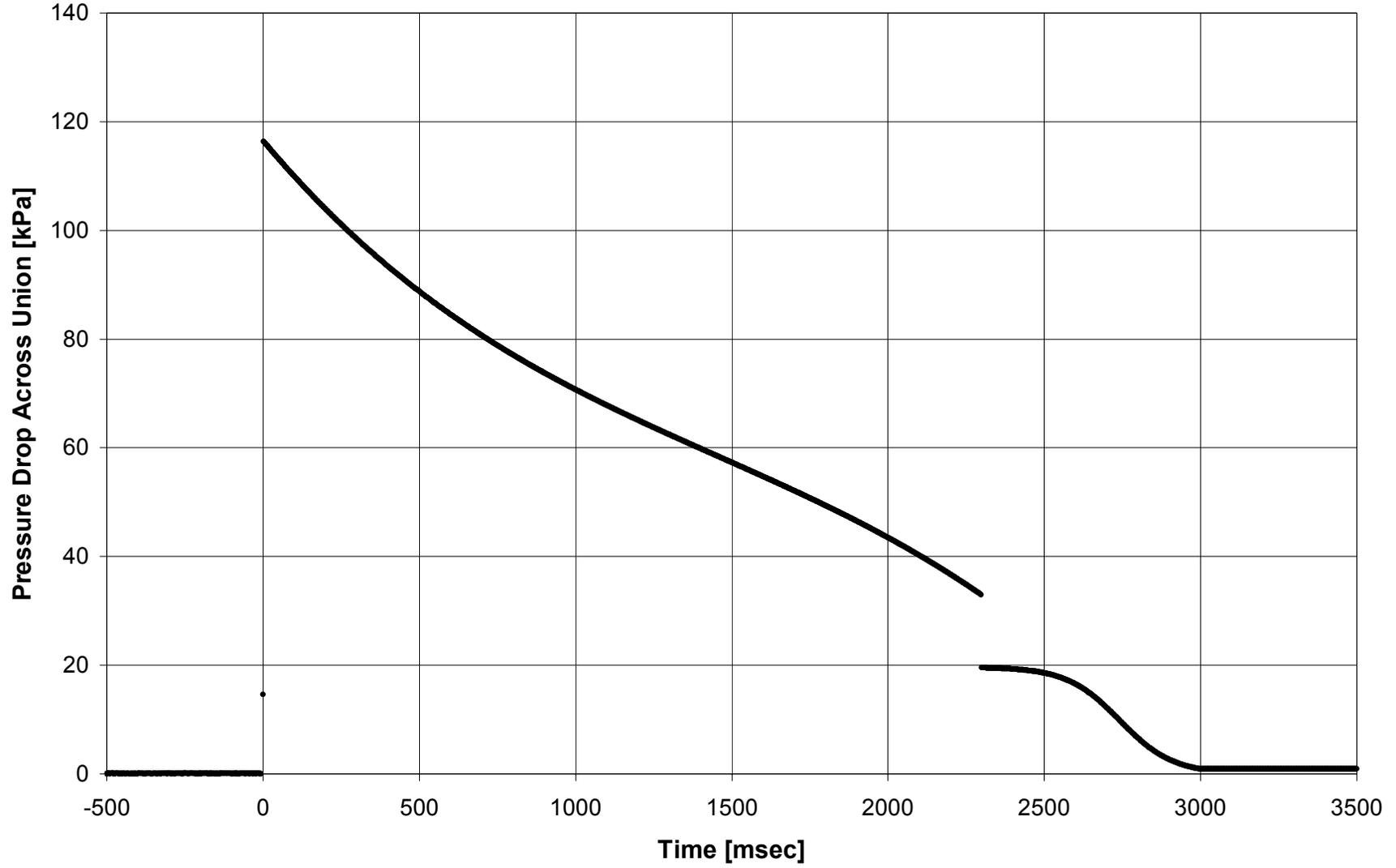












Run #10

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Capped Tee, 90° Elbow, Union, Two 45° Elbows, Capped Tee (Configuration #1)

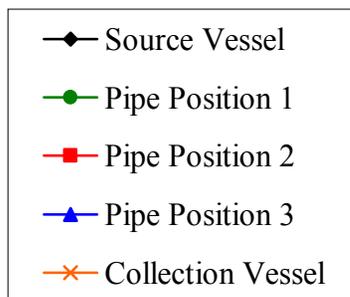
Source Vessel Initial Conditions: Fill Volume: 2450 milliliters
 Fluid Mass: 3.512 kg
 Pressure (Psvo): 4910 kPa
 Nitrogen Mass: 0.163 kg

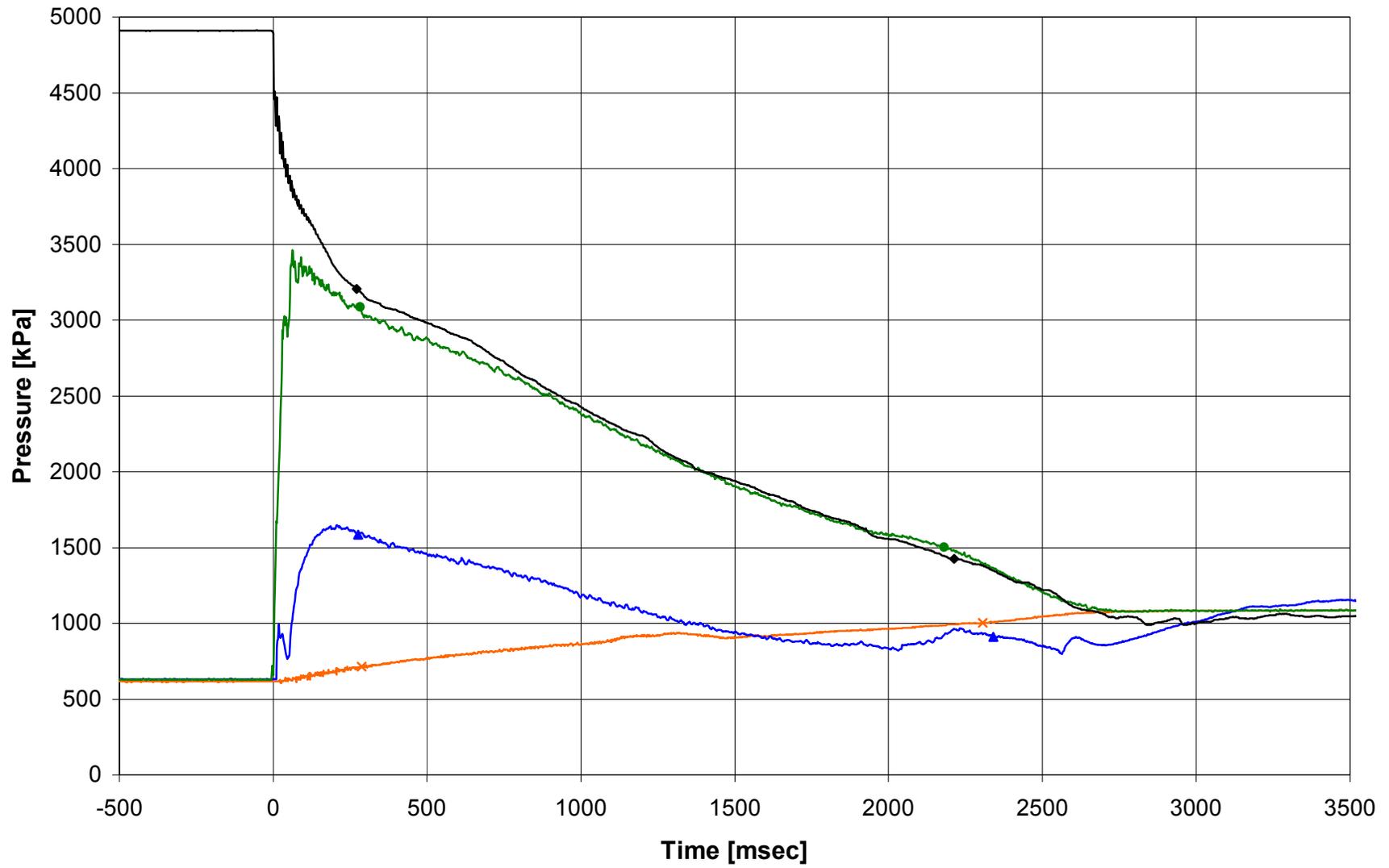
Initial Collection Vessel & Piping Pressure (Pcvo): 615 kPa

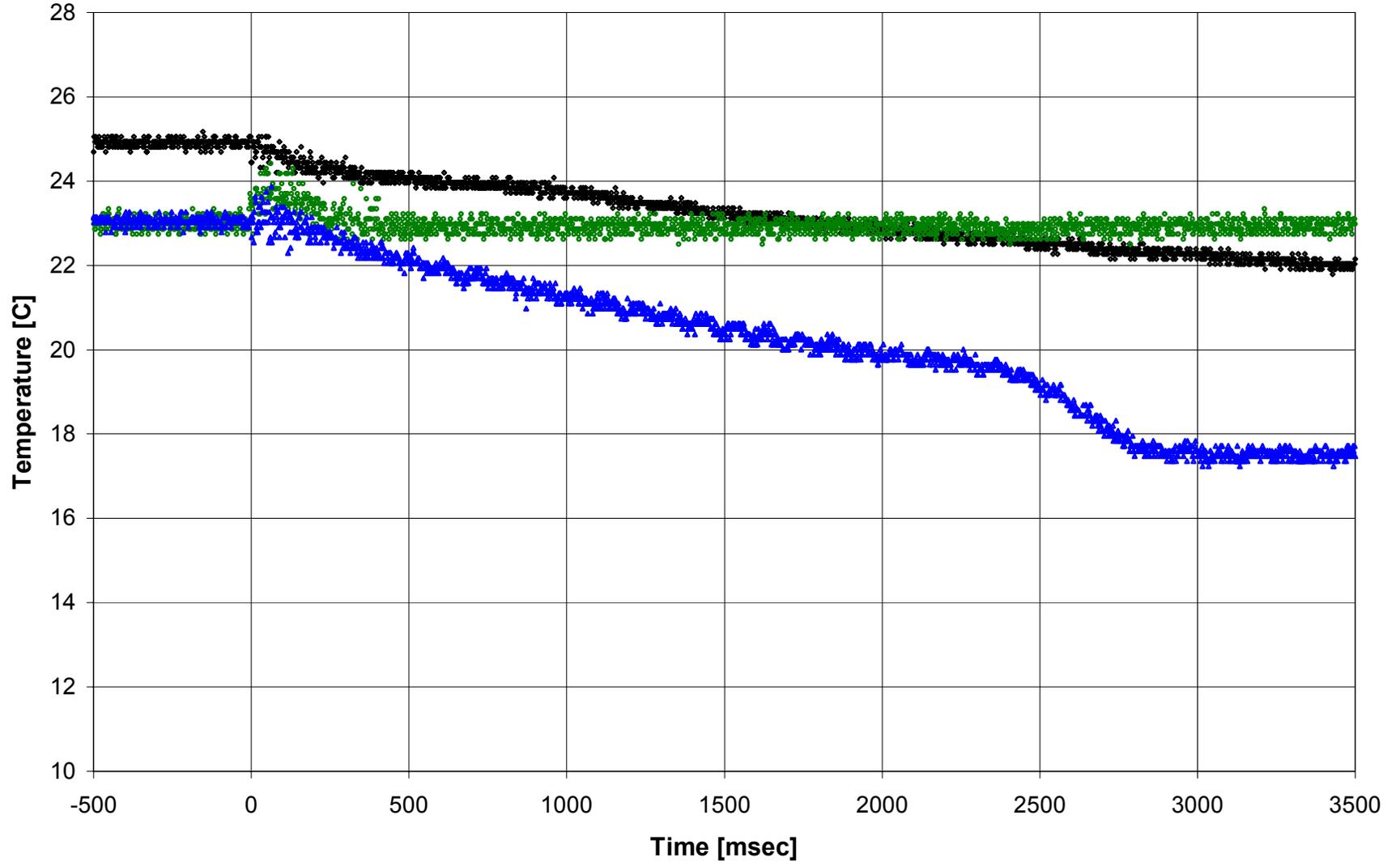
Initial System Temperature: 25° Celsius

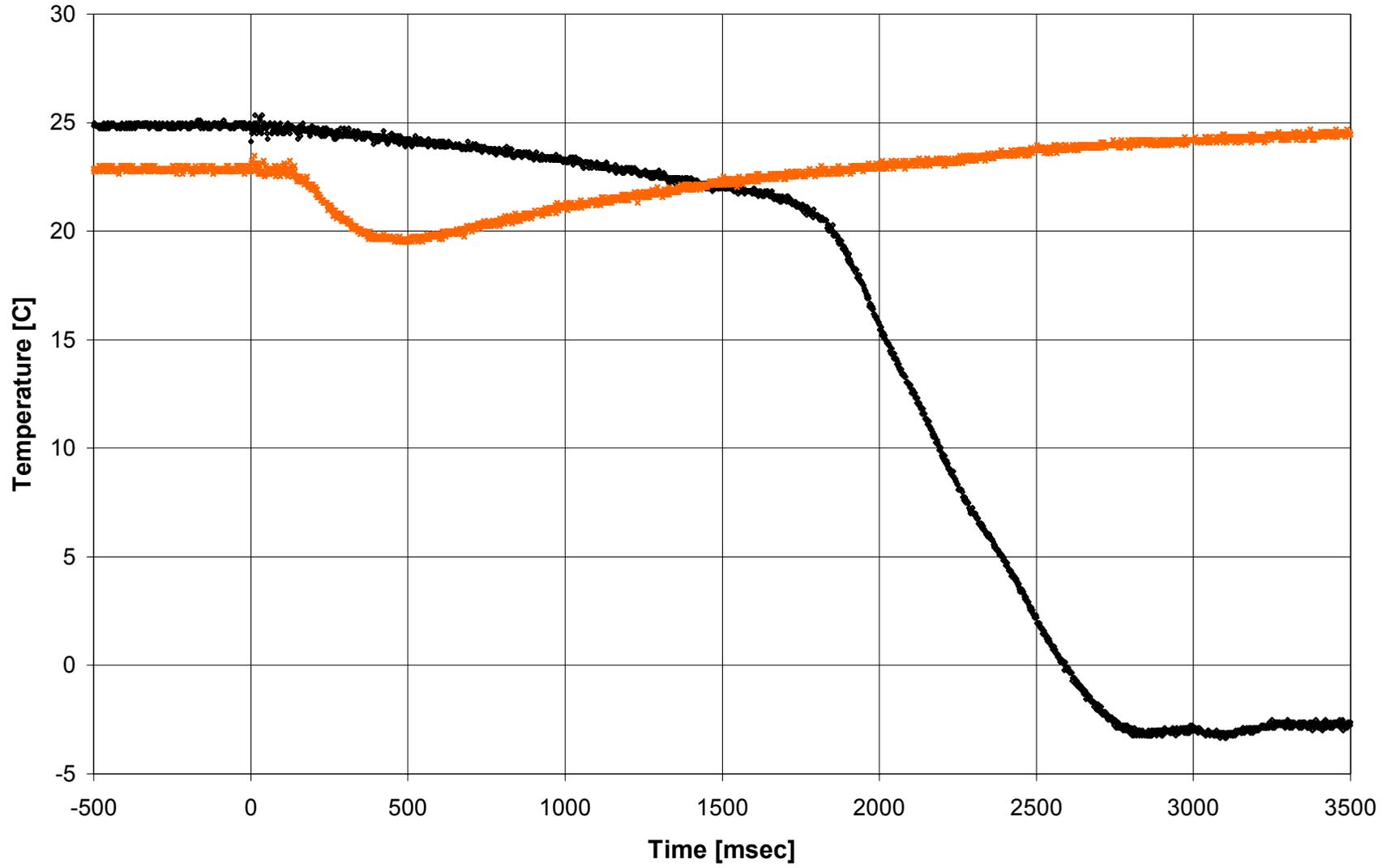
Completion Date: 2/11/00

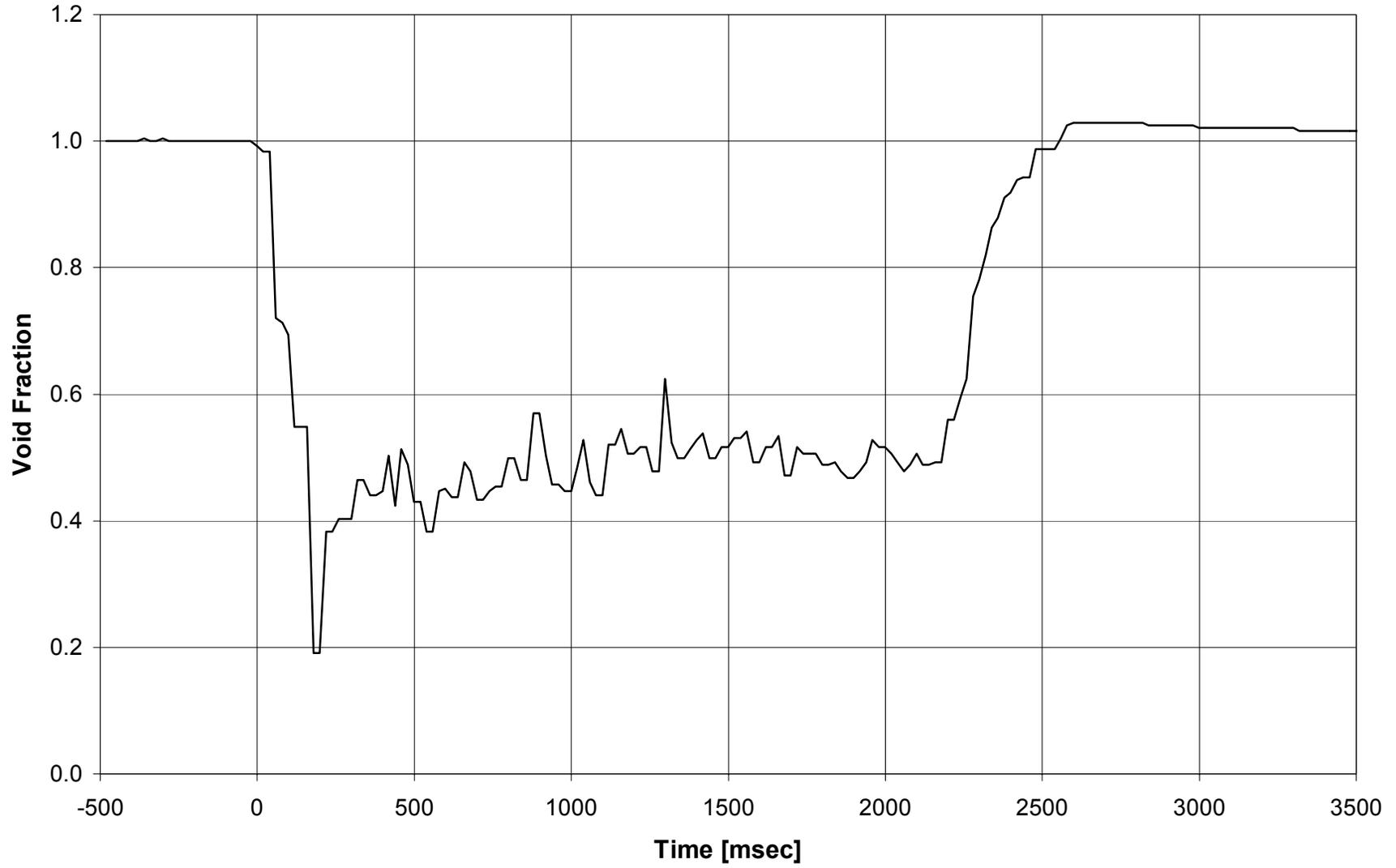
Legend

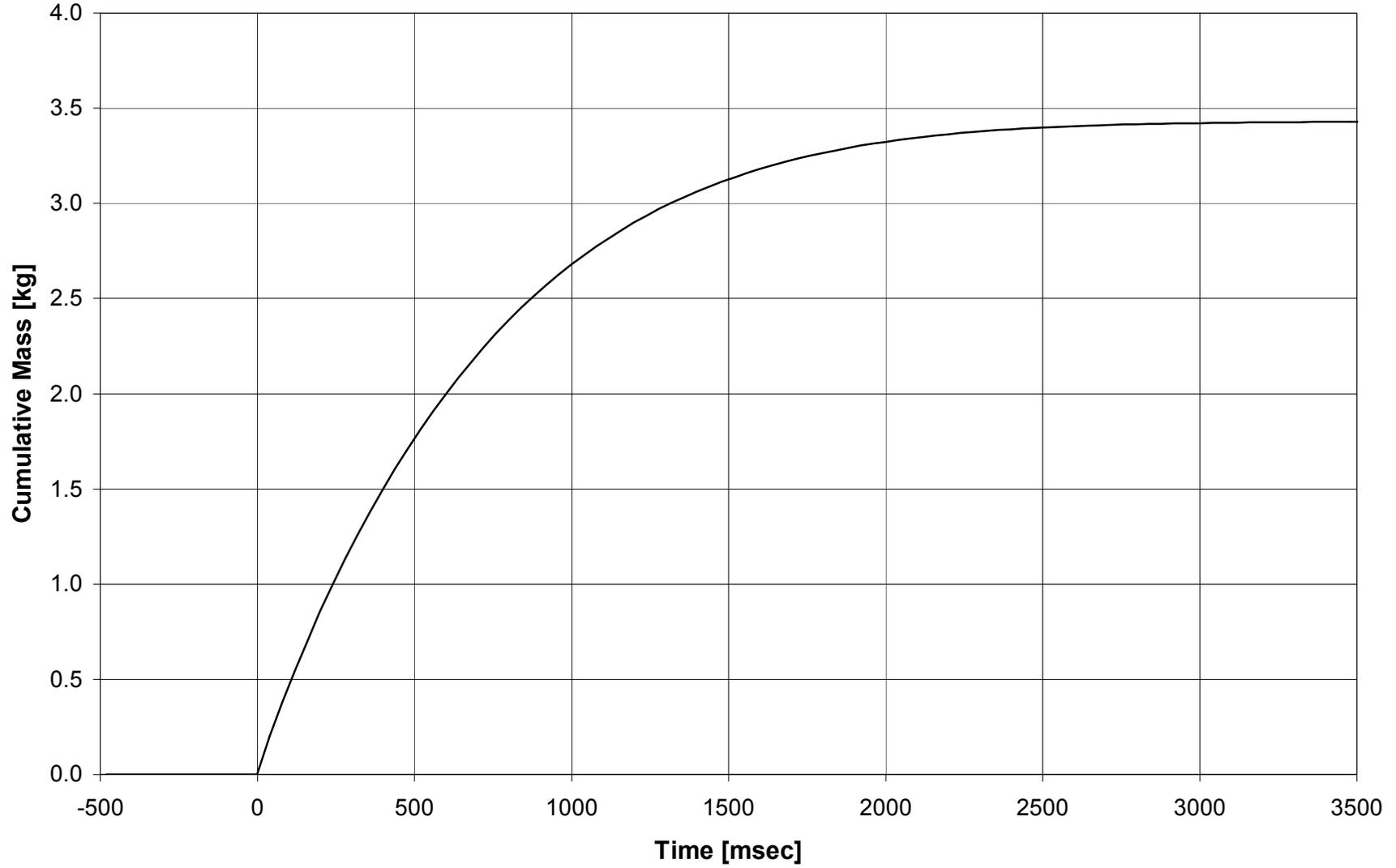


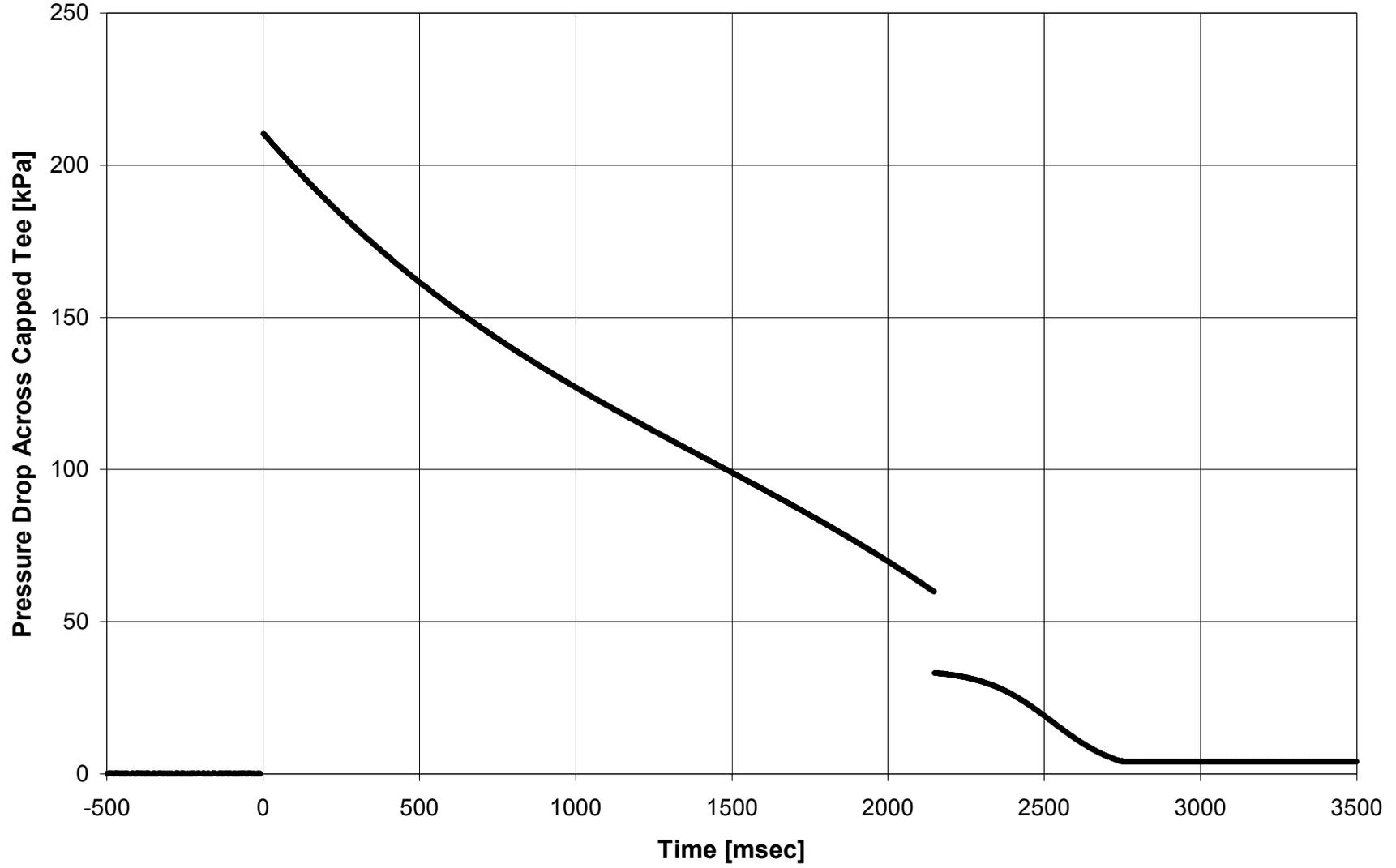


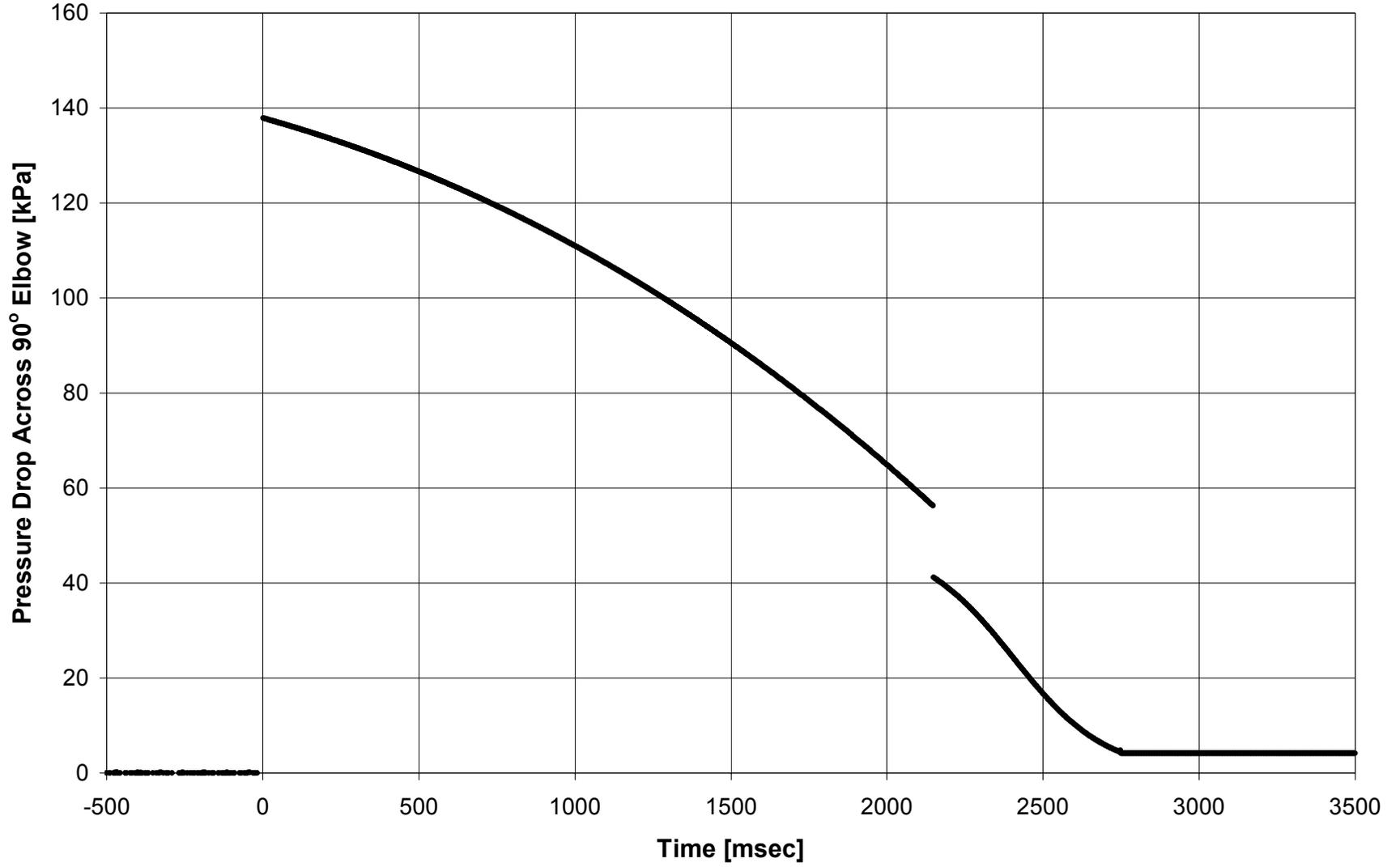


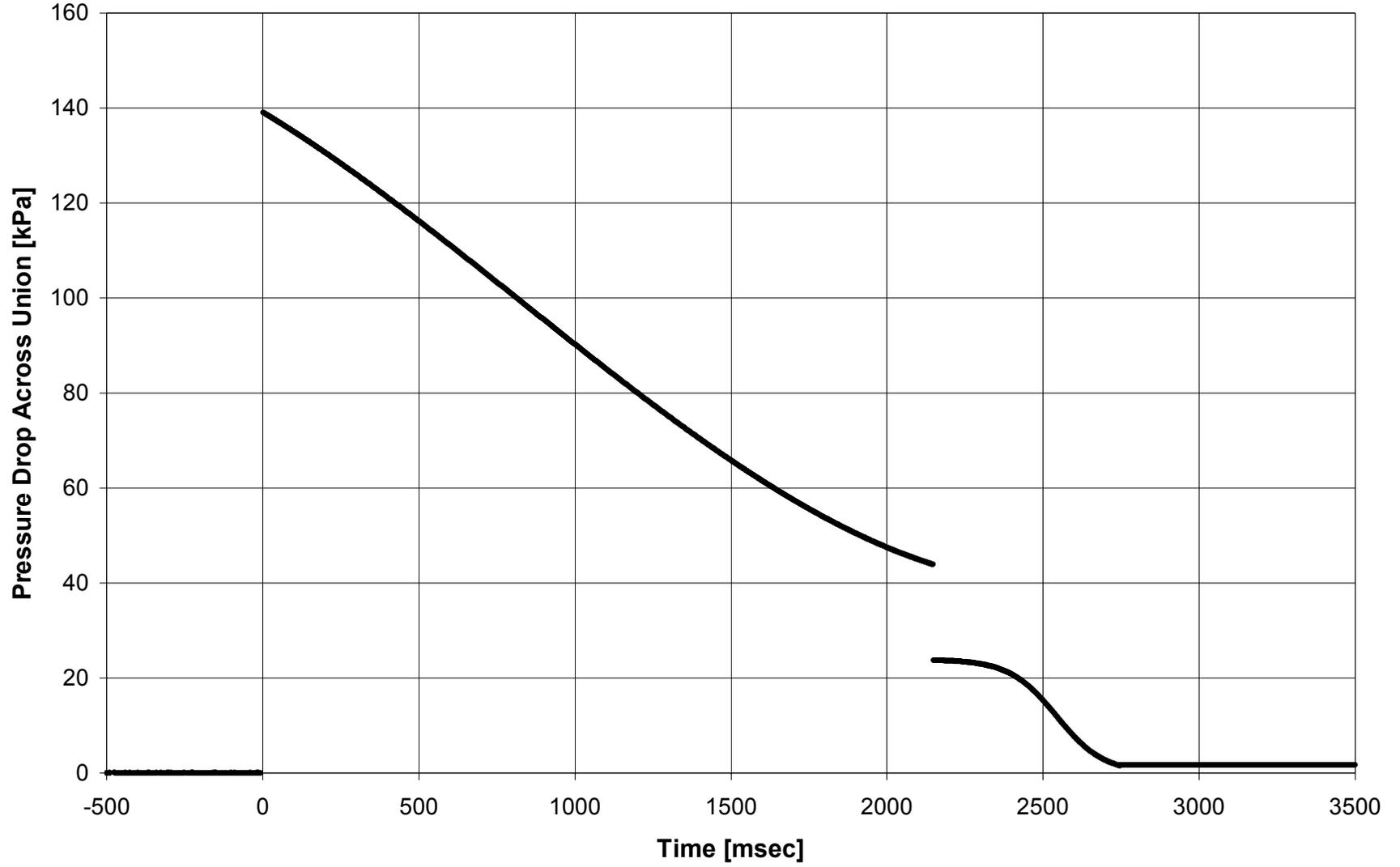












Run #11

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Vertical Tee branching into a 90° Elbow, Union, and Two 45° Elbows (Configuration #2)

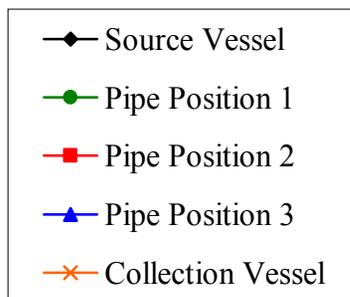
Source Vessel Initial Conditions: Fill Volume: 3507 milliliters
 Fluid Mass: 4.938 kg
 Pressure (Psvo): 2140 kPa
 Nitrogen Mass: 0.055 kg

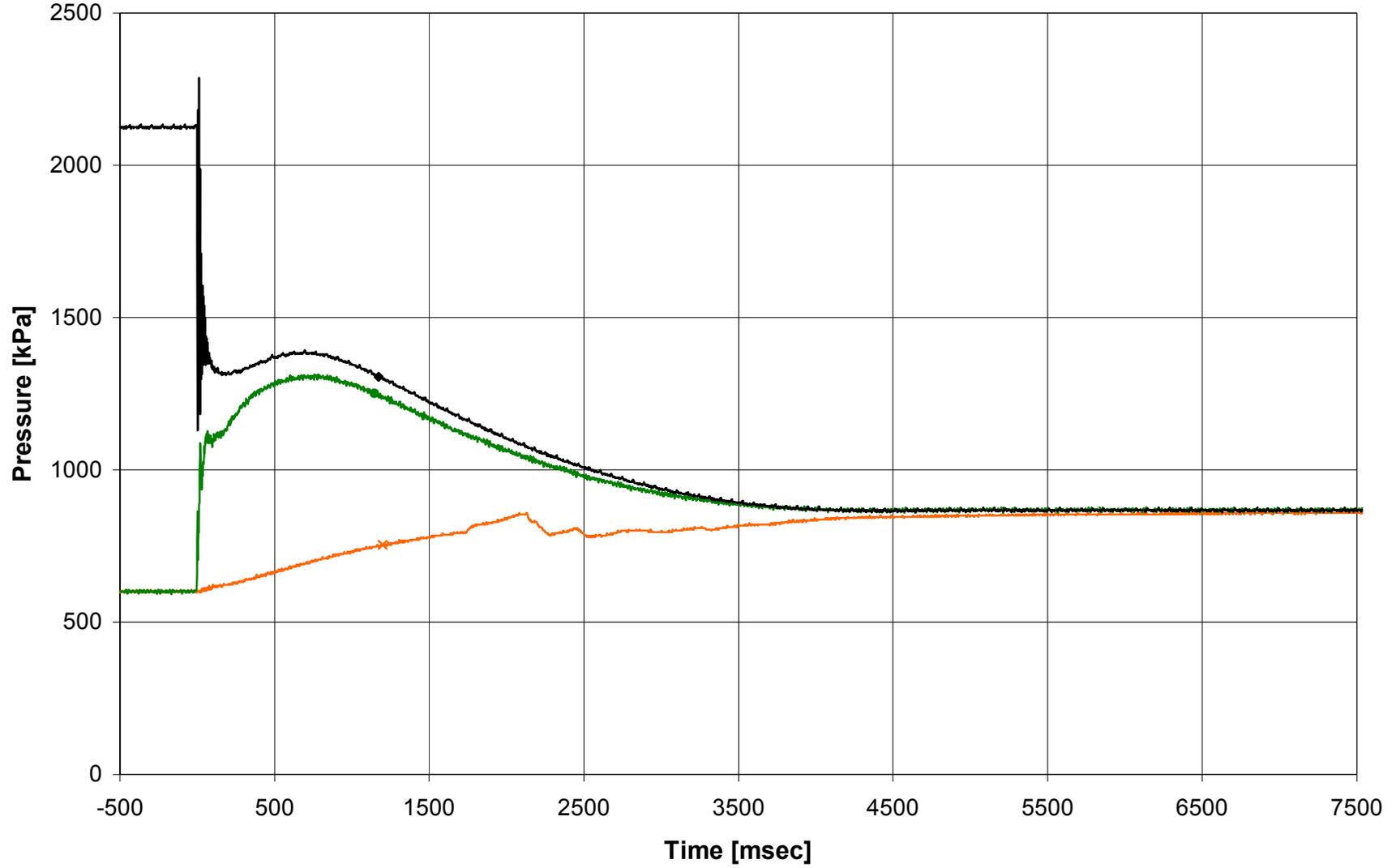
Initial Collection Vessel & Piping Pressure (Pcvo): 600 kPa

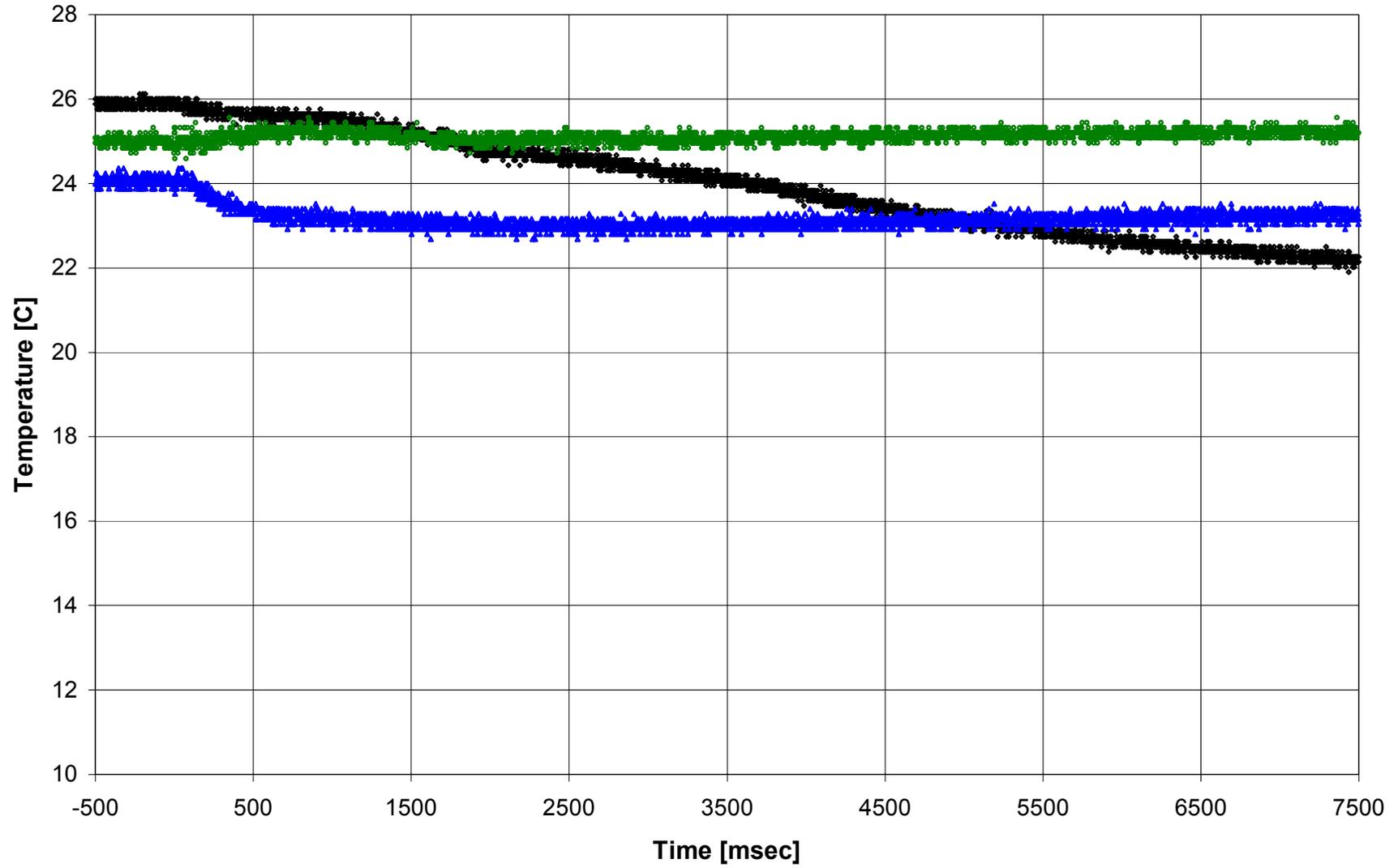
Initial System Temperature: 26° Celsius

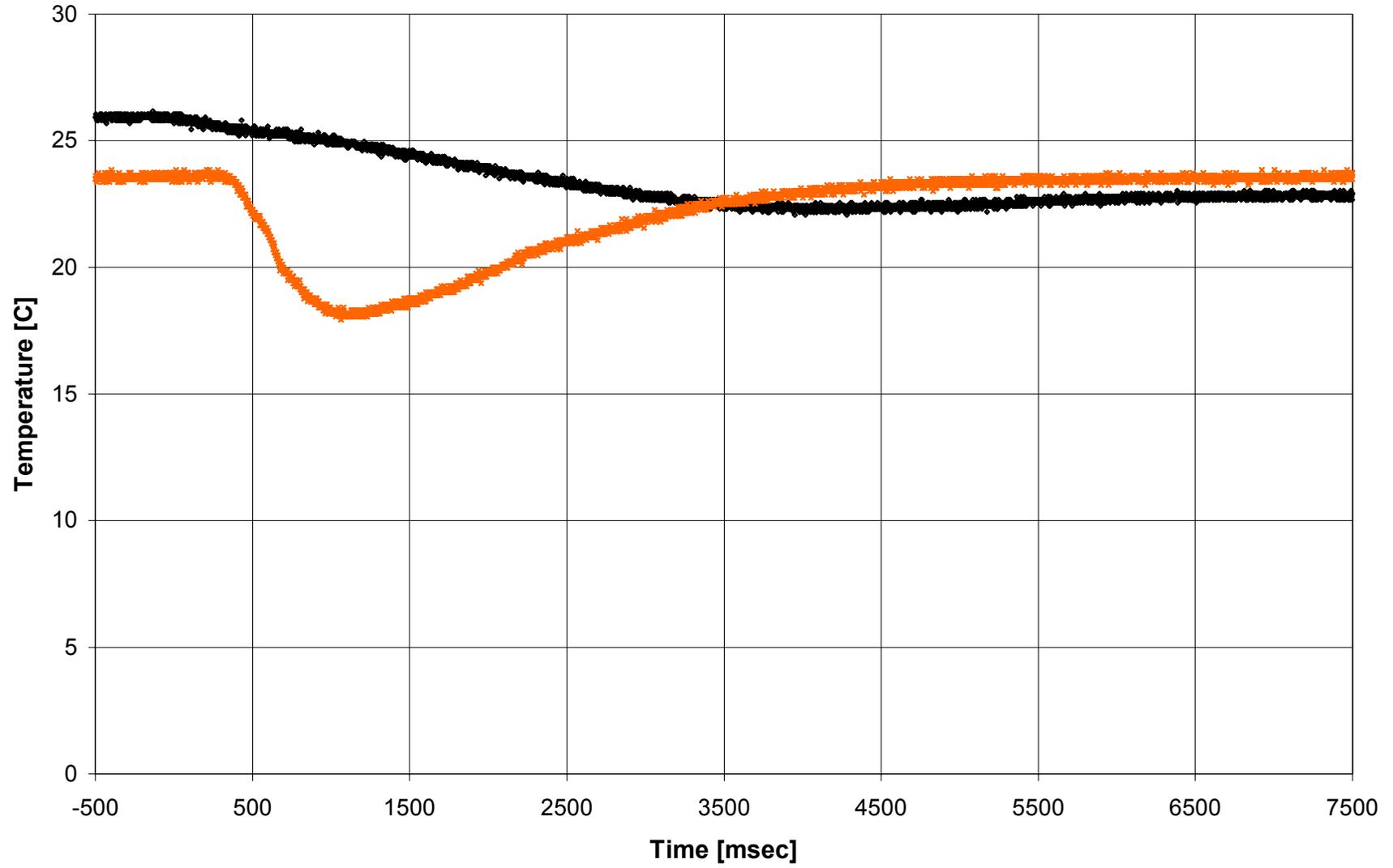
Completion Date: 2/22/00

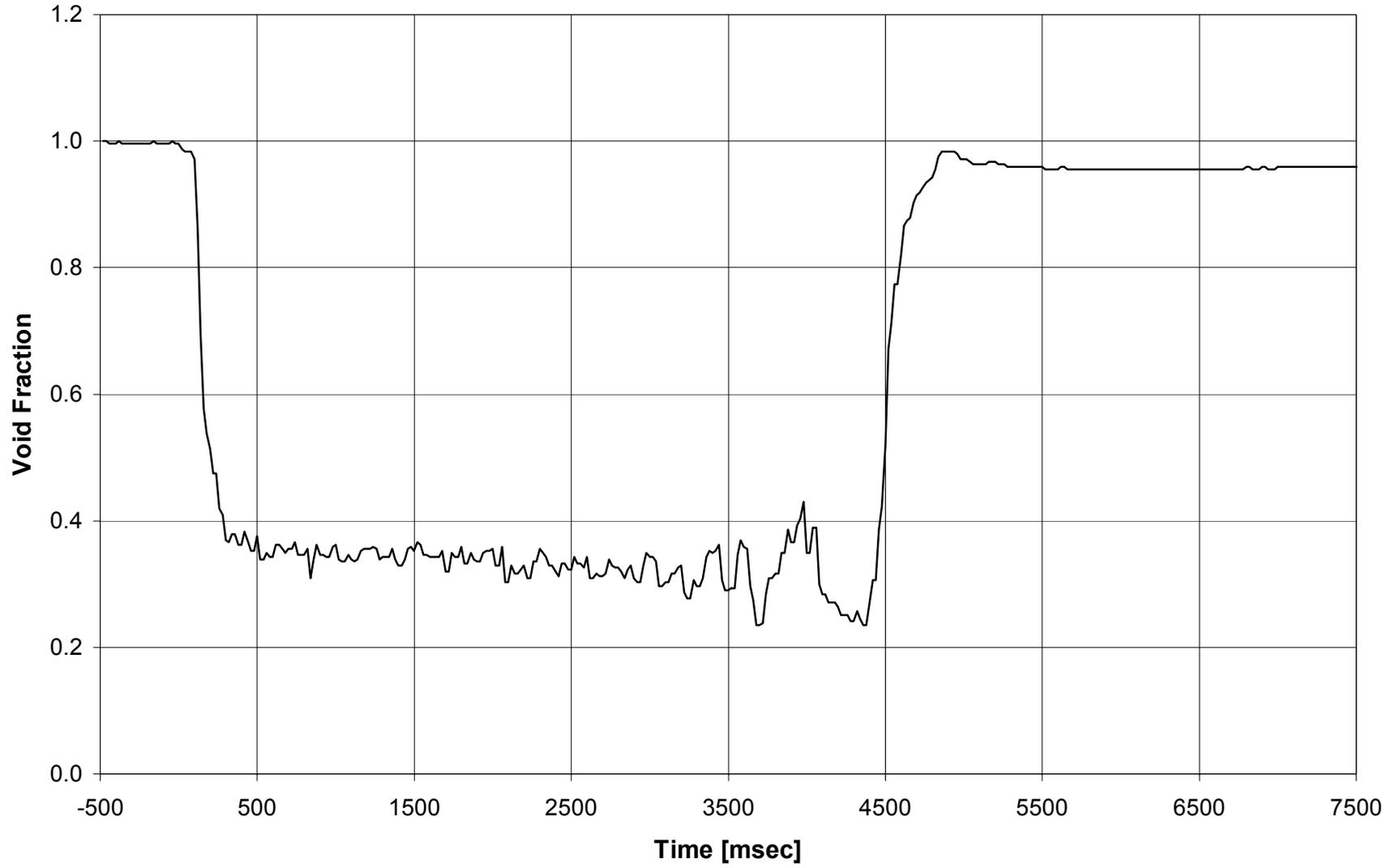
Legend

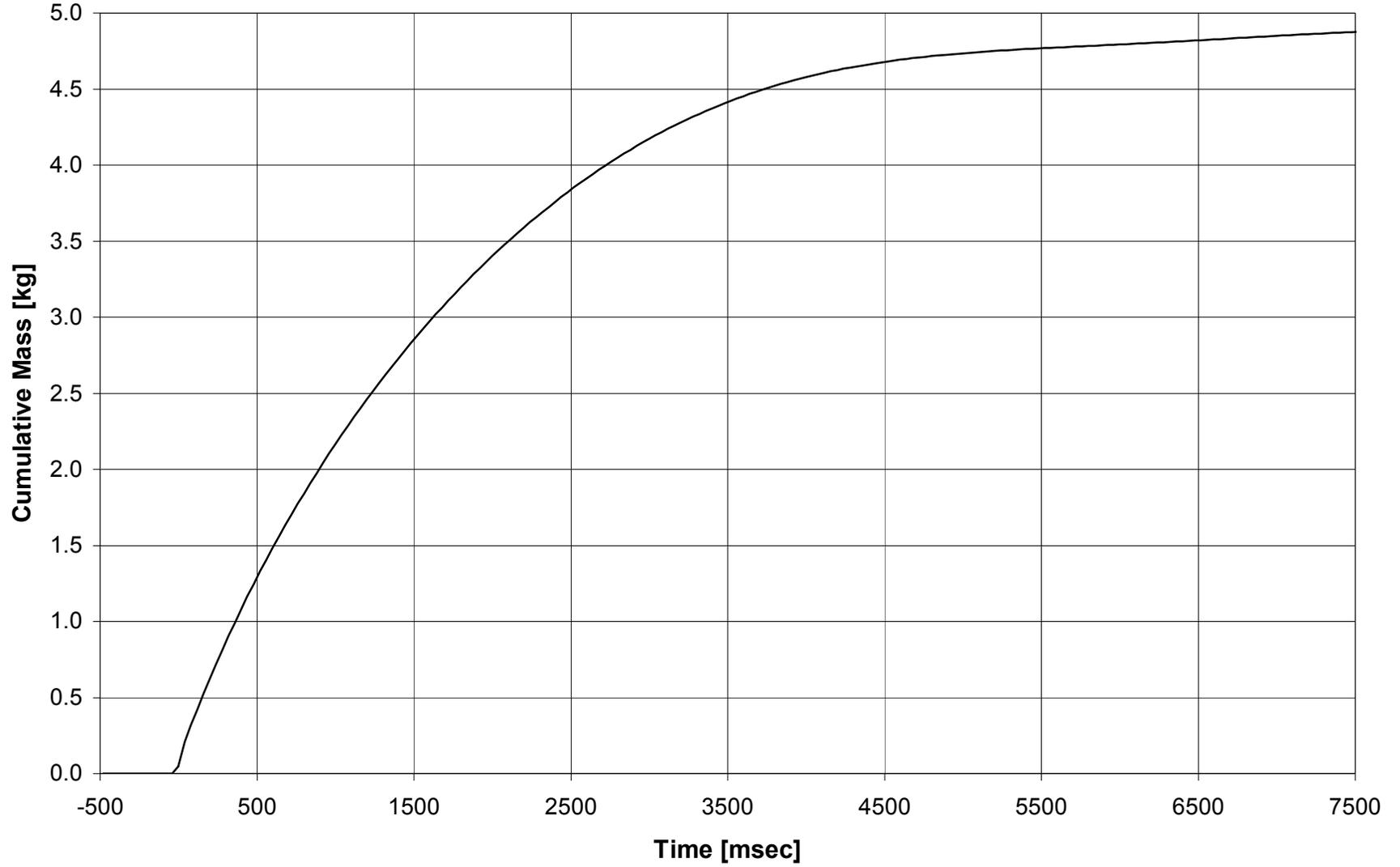


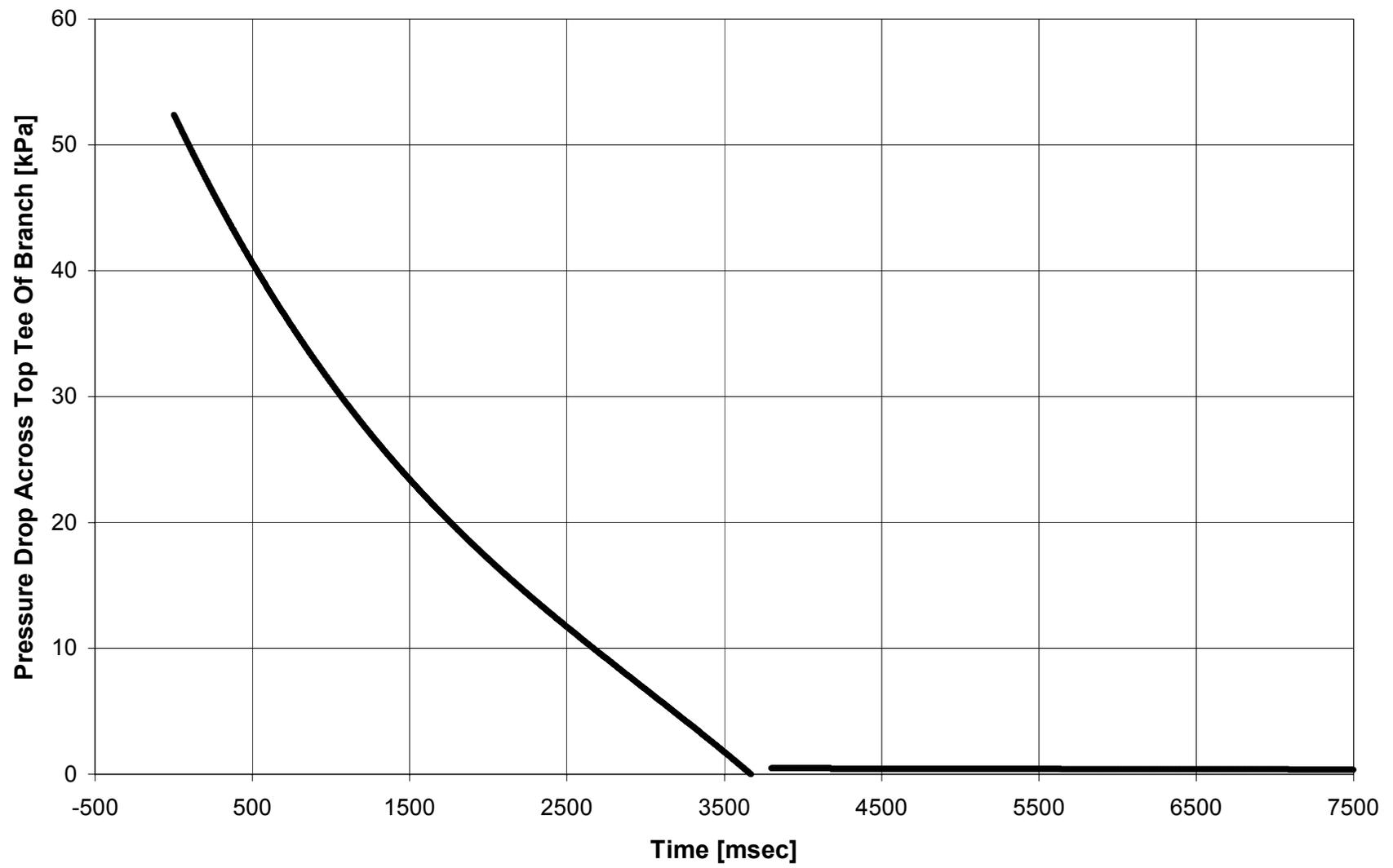


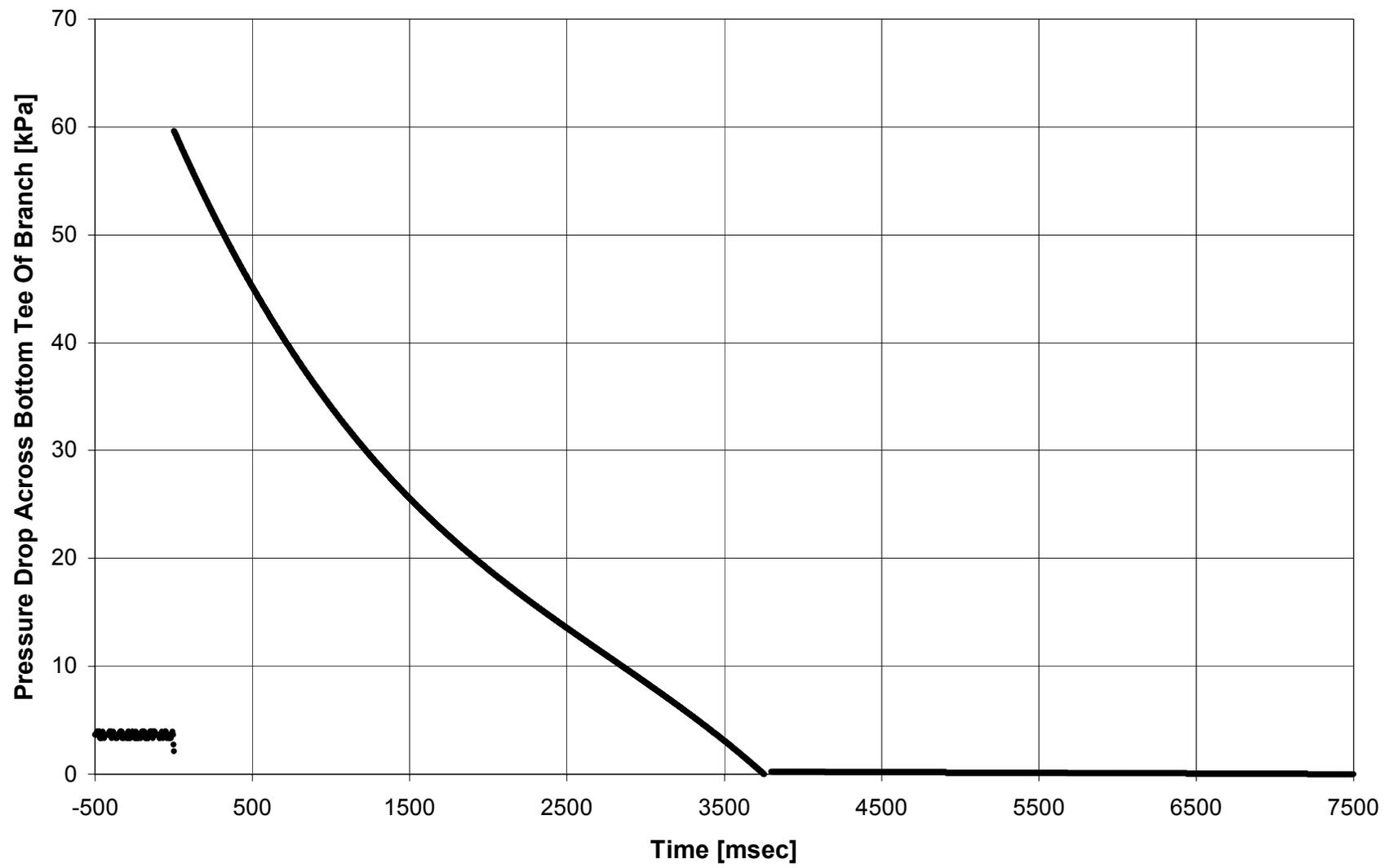












Run #12

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Vertical Tee branching into a 90° Elbow, Union, and Two 45° Elbows (Configuration #2)

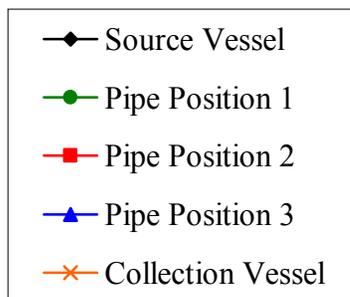
Source Vessel Initial Conditions: Fill Volume: 2400 milliliters
 Fluid Mass: 3.421 kg
 Pressure (Psvo): 3935 kPa
 Nitrogen Mass: 0.129 kg

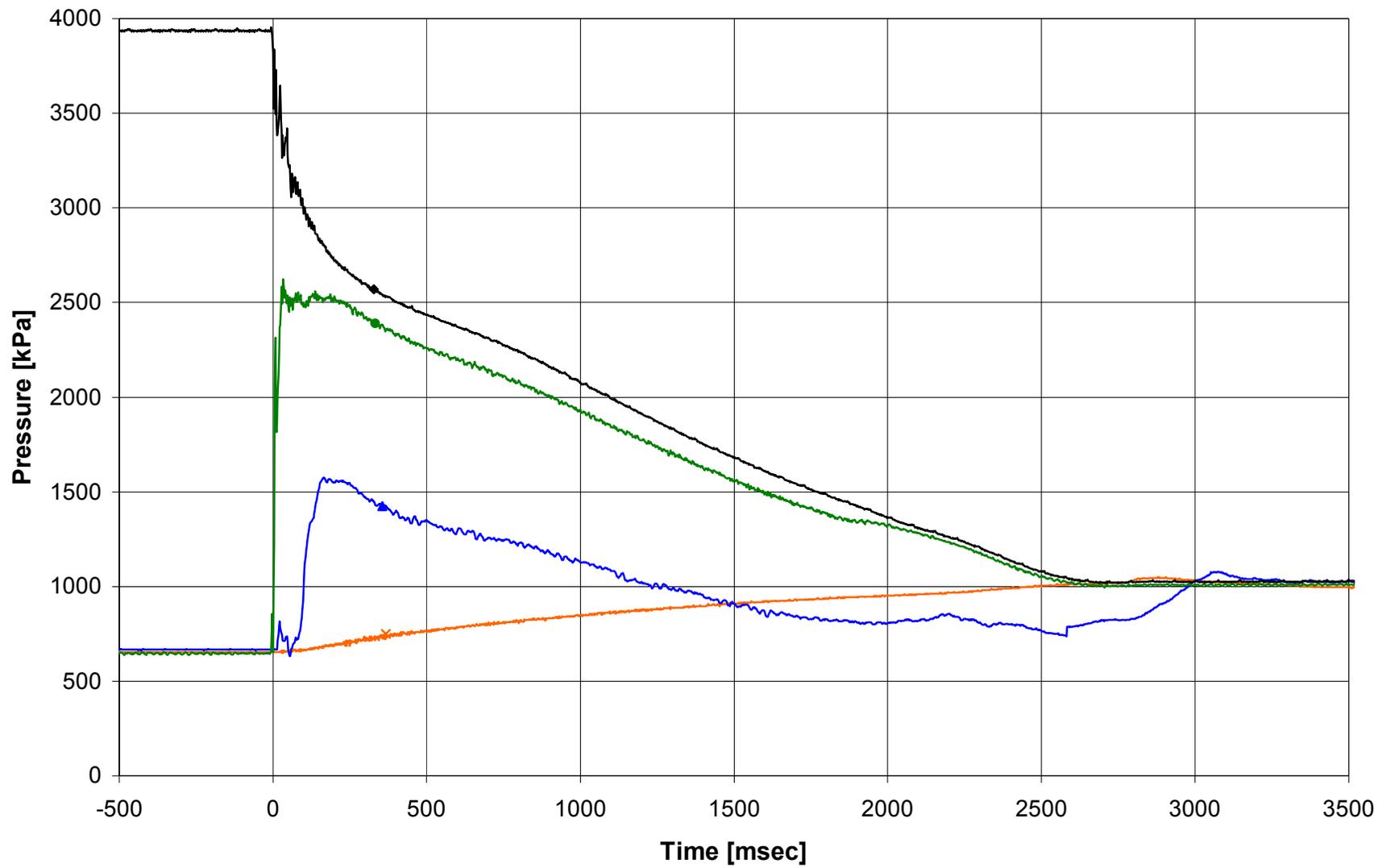
Initial Collection Vessel & Piping Pressure (Pcvo): 655 kPa

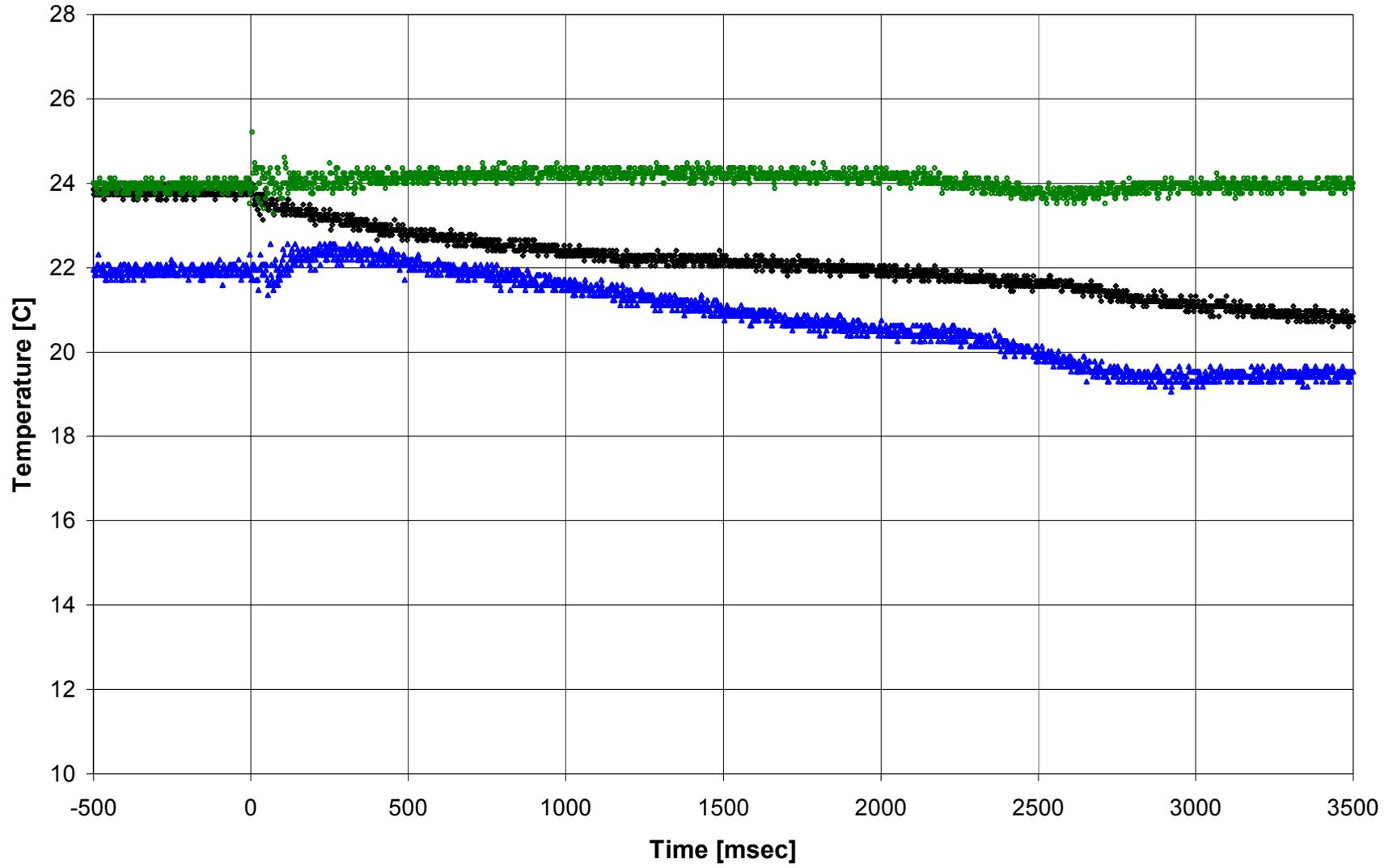
Initial System Temperature: 24° Celsius

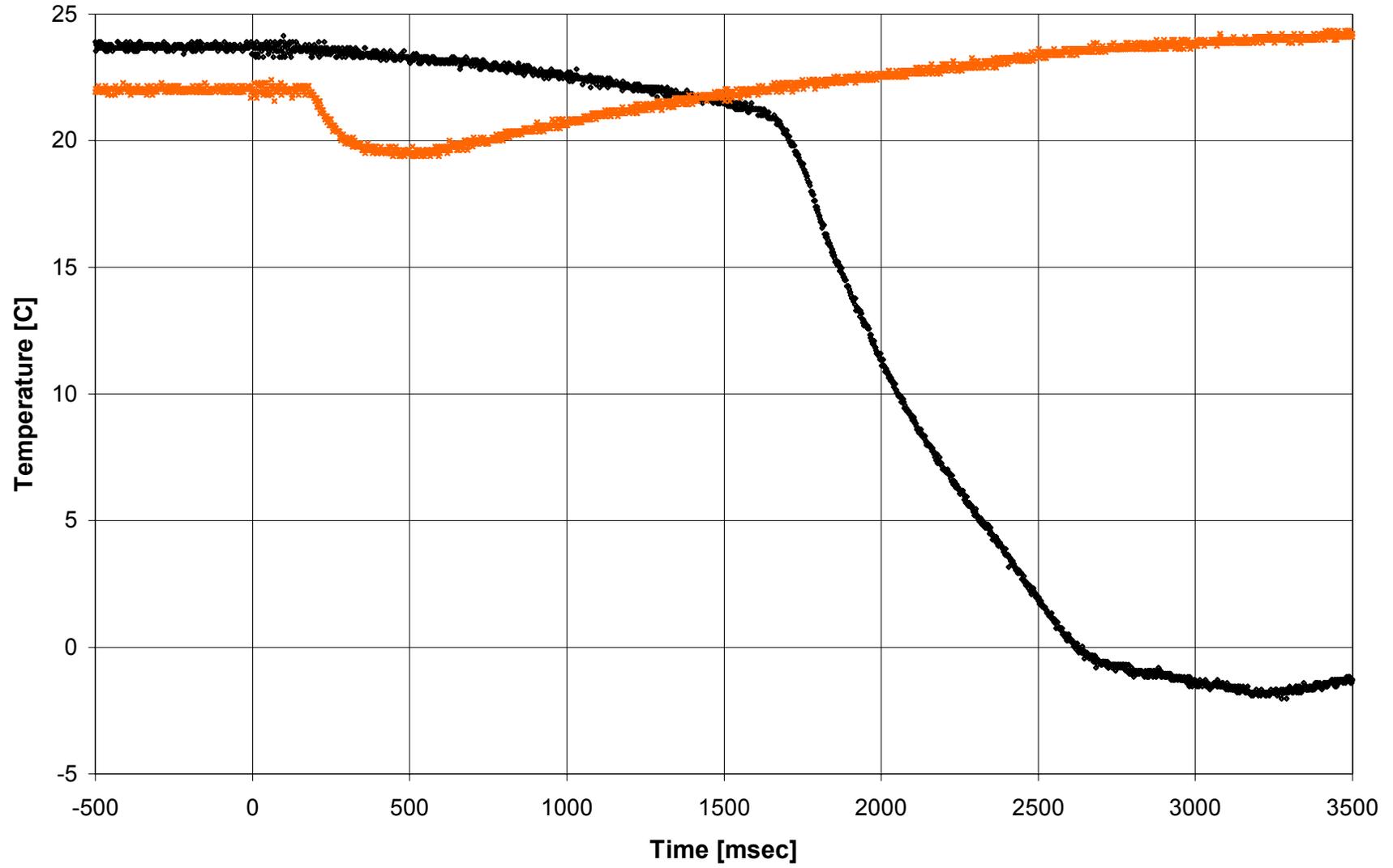
Completion Date: 2/28/00

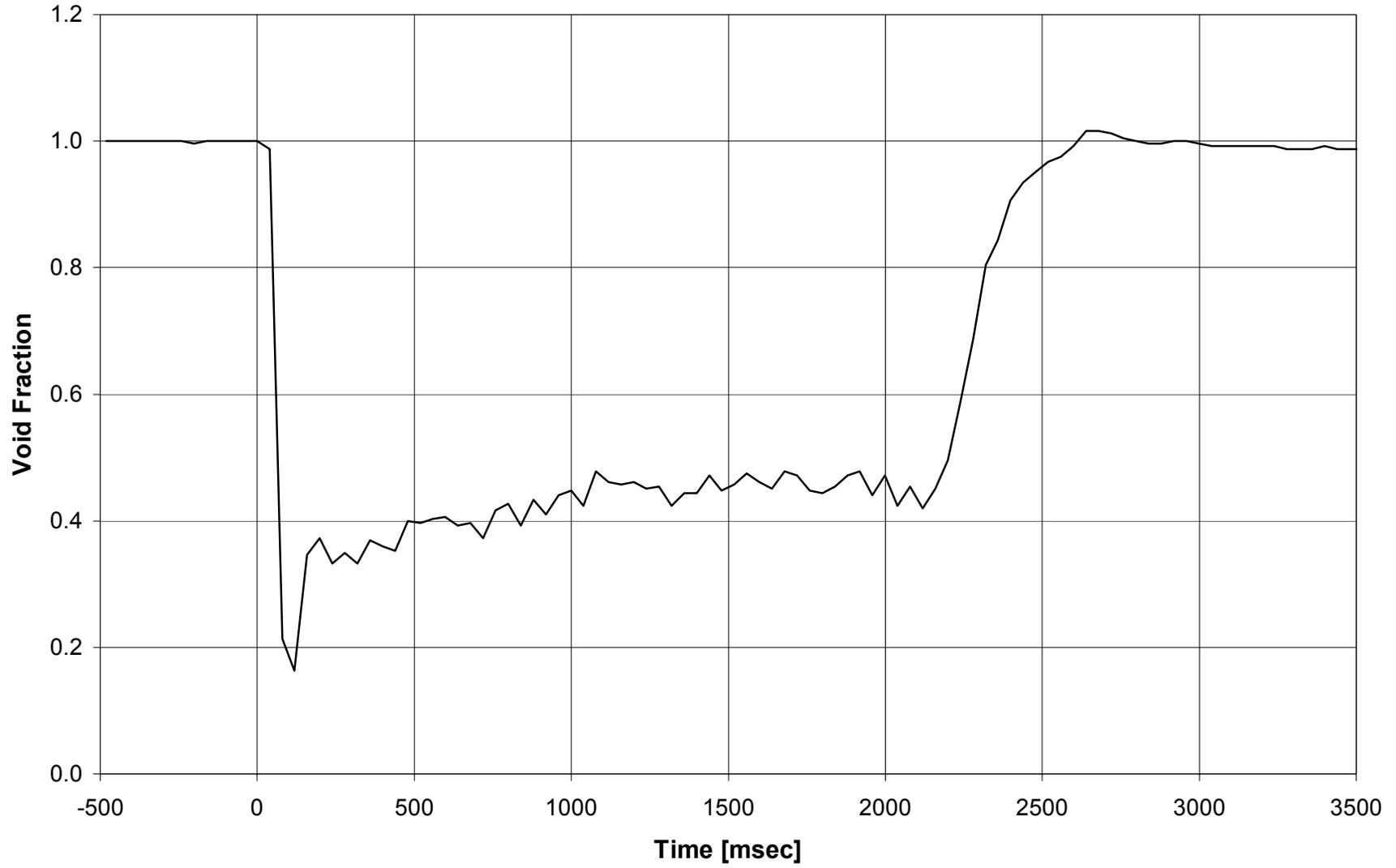
Legend

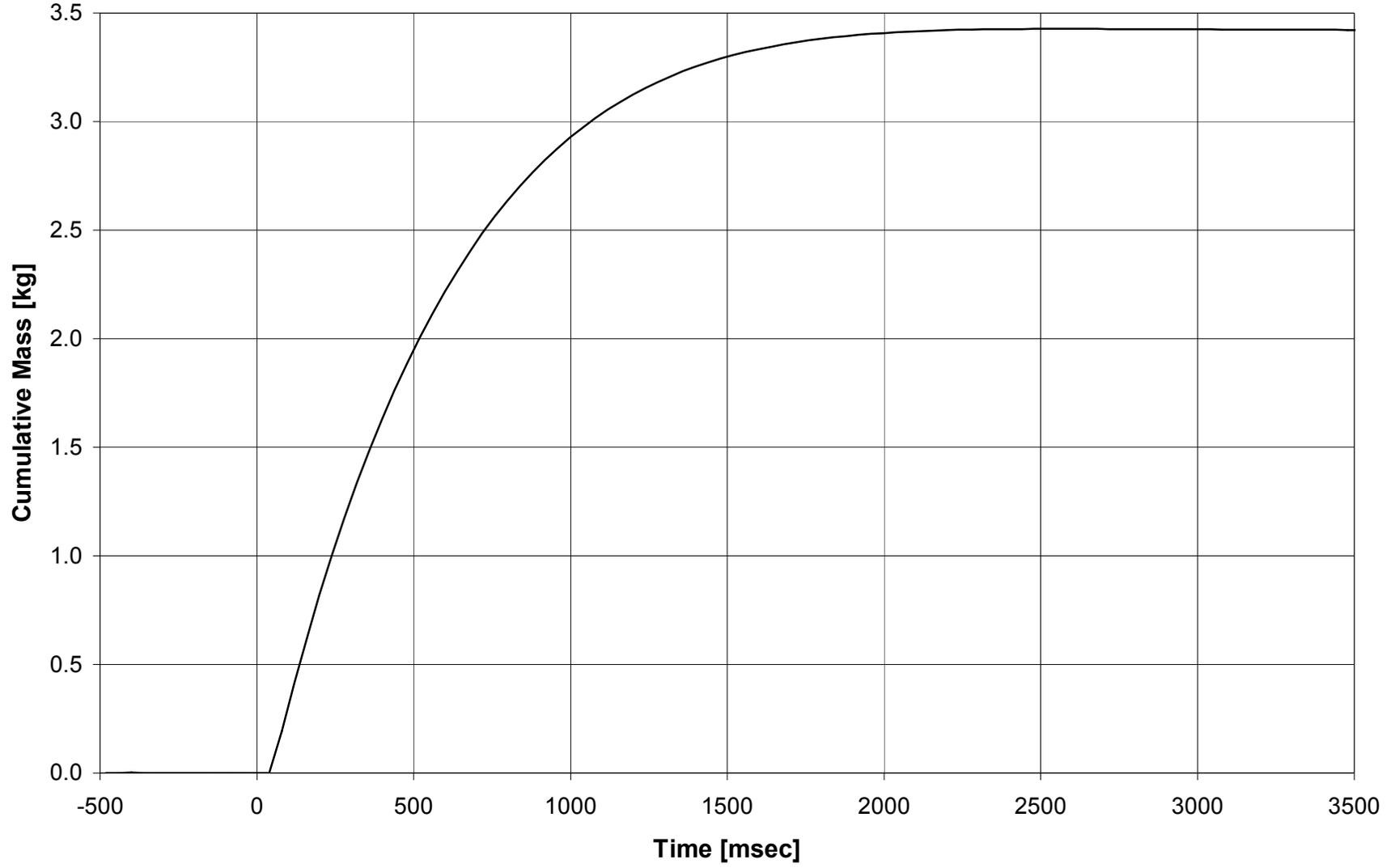


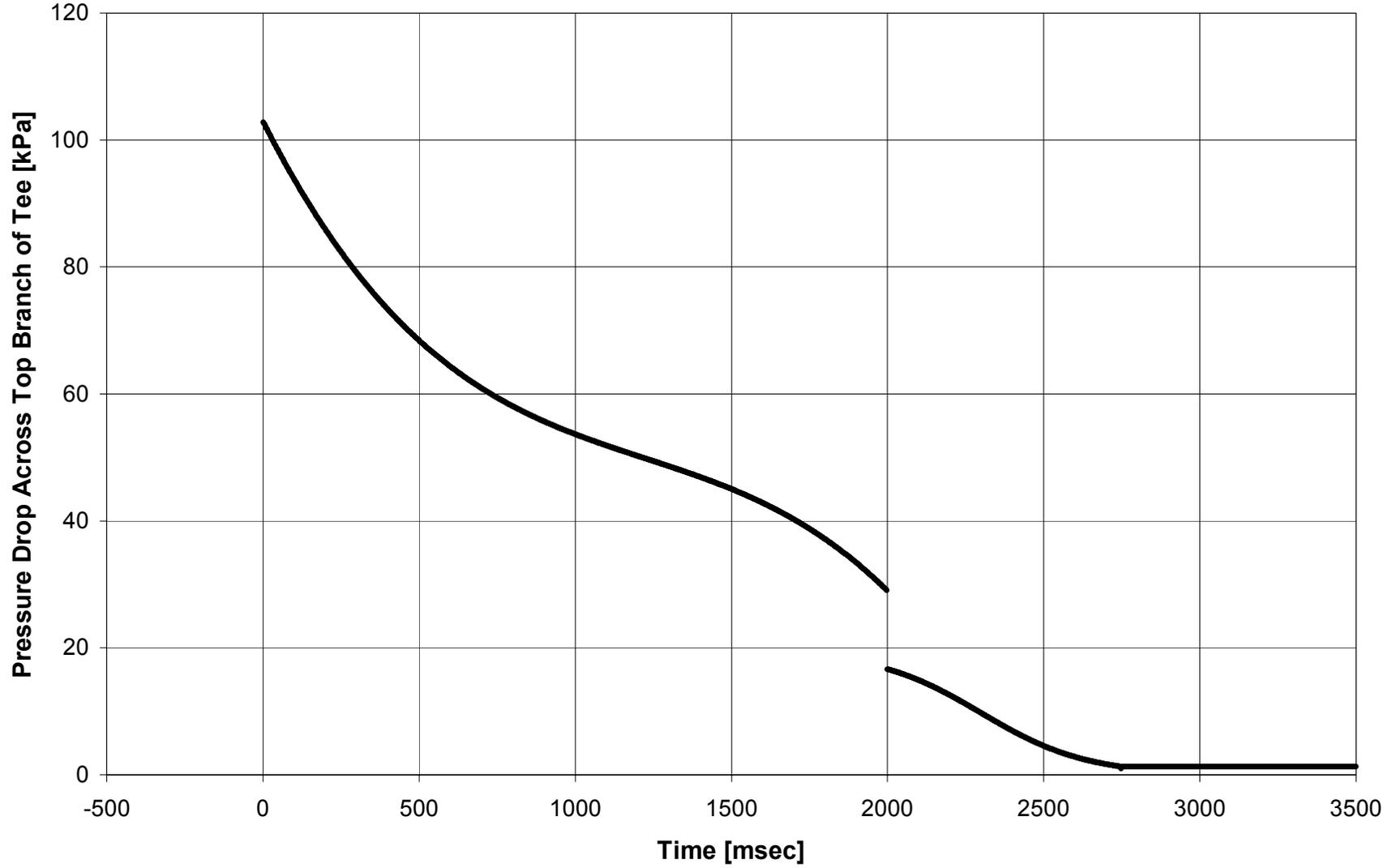


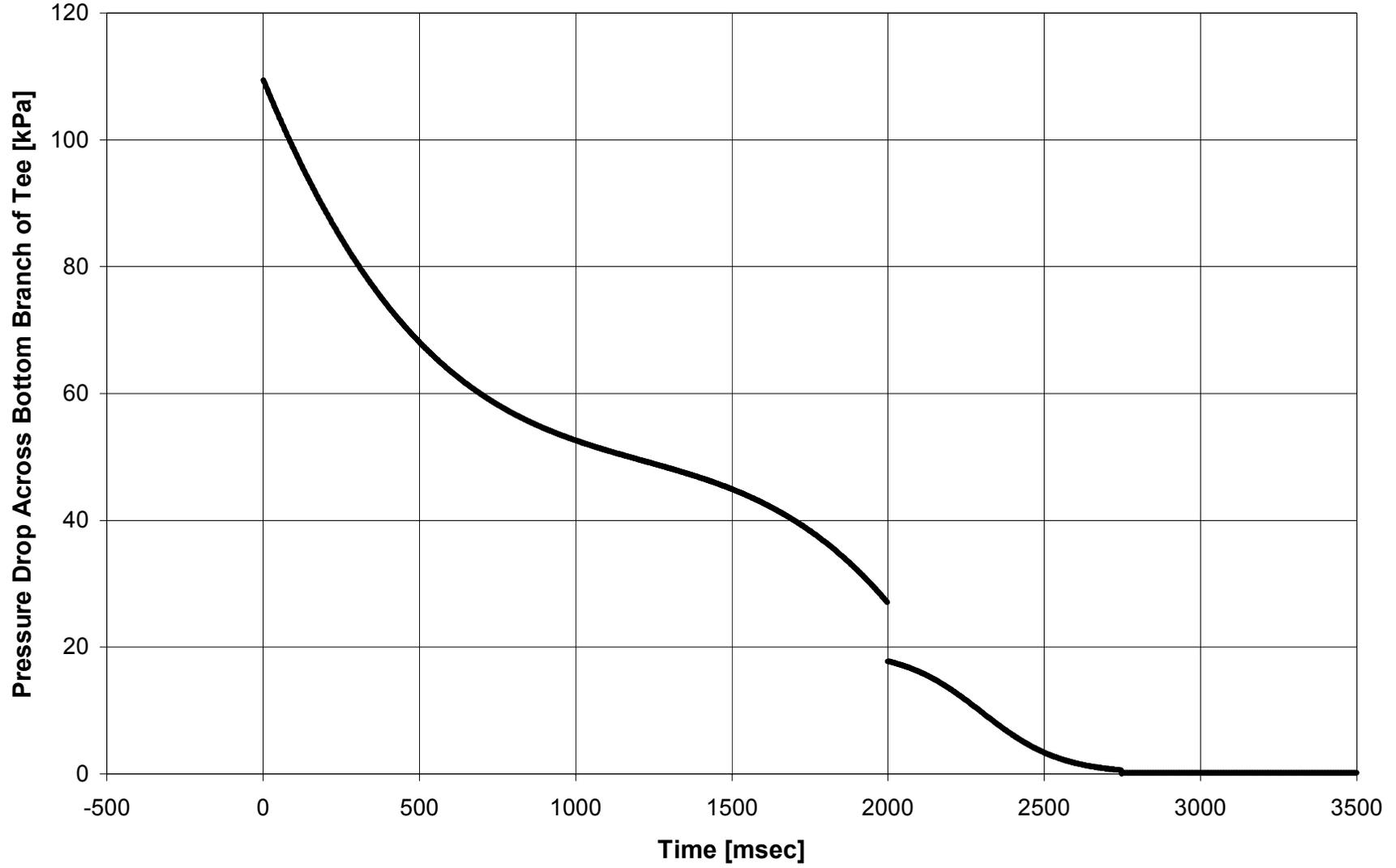












Run #13

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Vertical Tee branching into a 90° Elbow, Union, and Two 45° Elbows (Configuration #2)

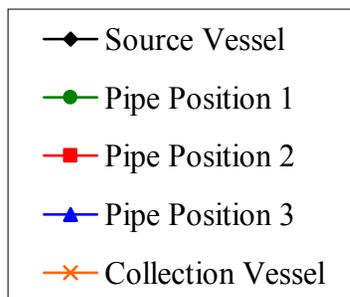
Source Vessel Initial Conditions: Fill Volume: 2460 milliliters
 Fluid Mass: 3.520 kg
 Pressure (Psvo): 4910 kPa
 Nitrogen Mass: 0.163 kg

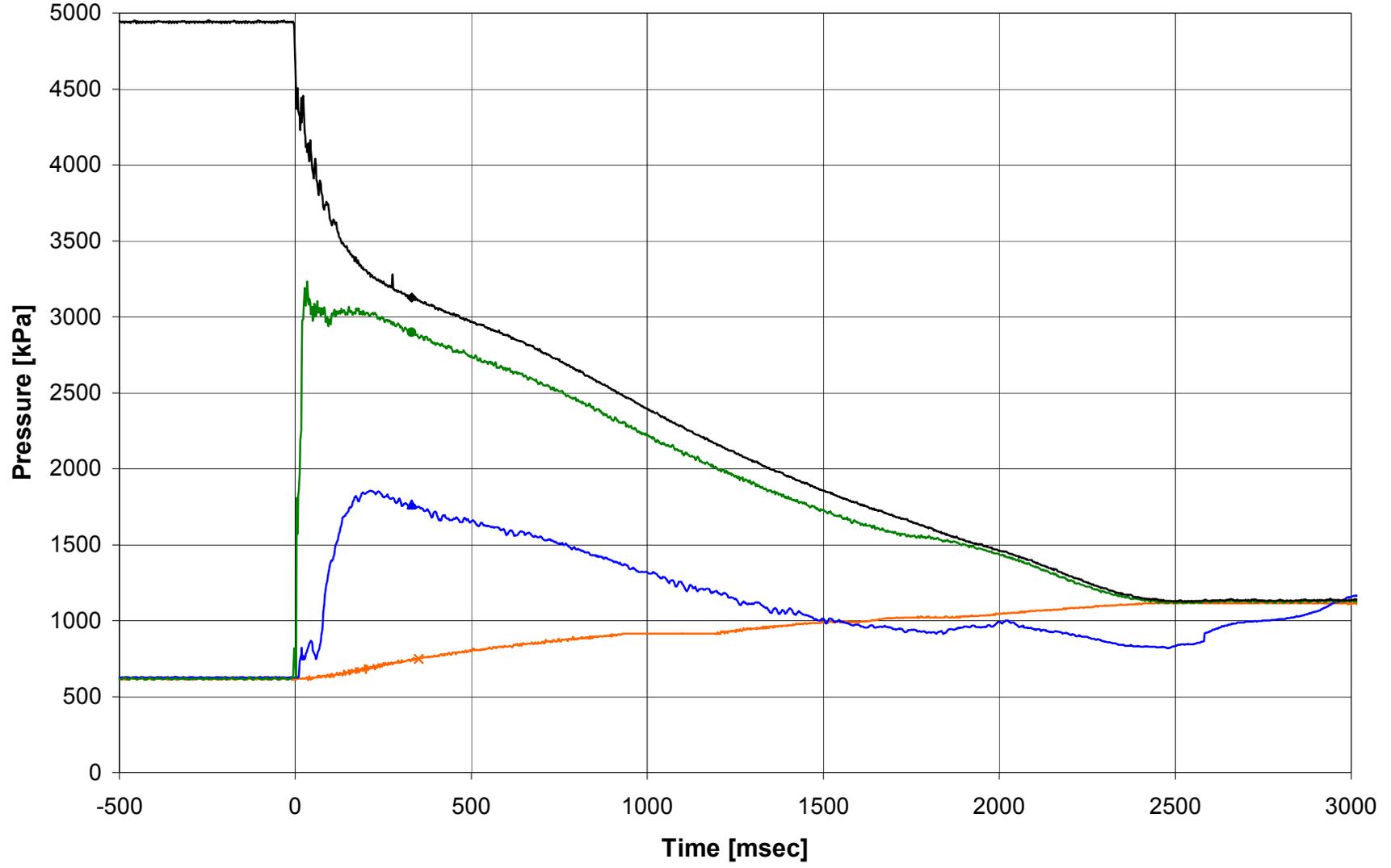
Initial Collection Vessel & Piping Pressure (Pcvo): 615 kPa

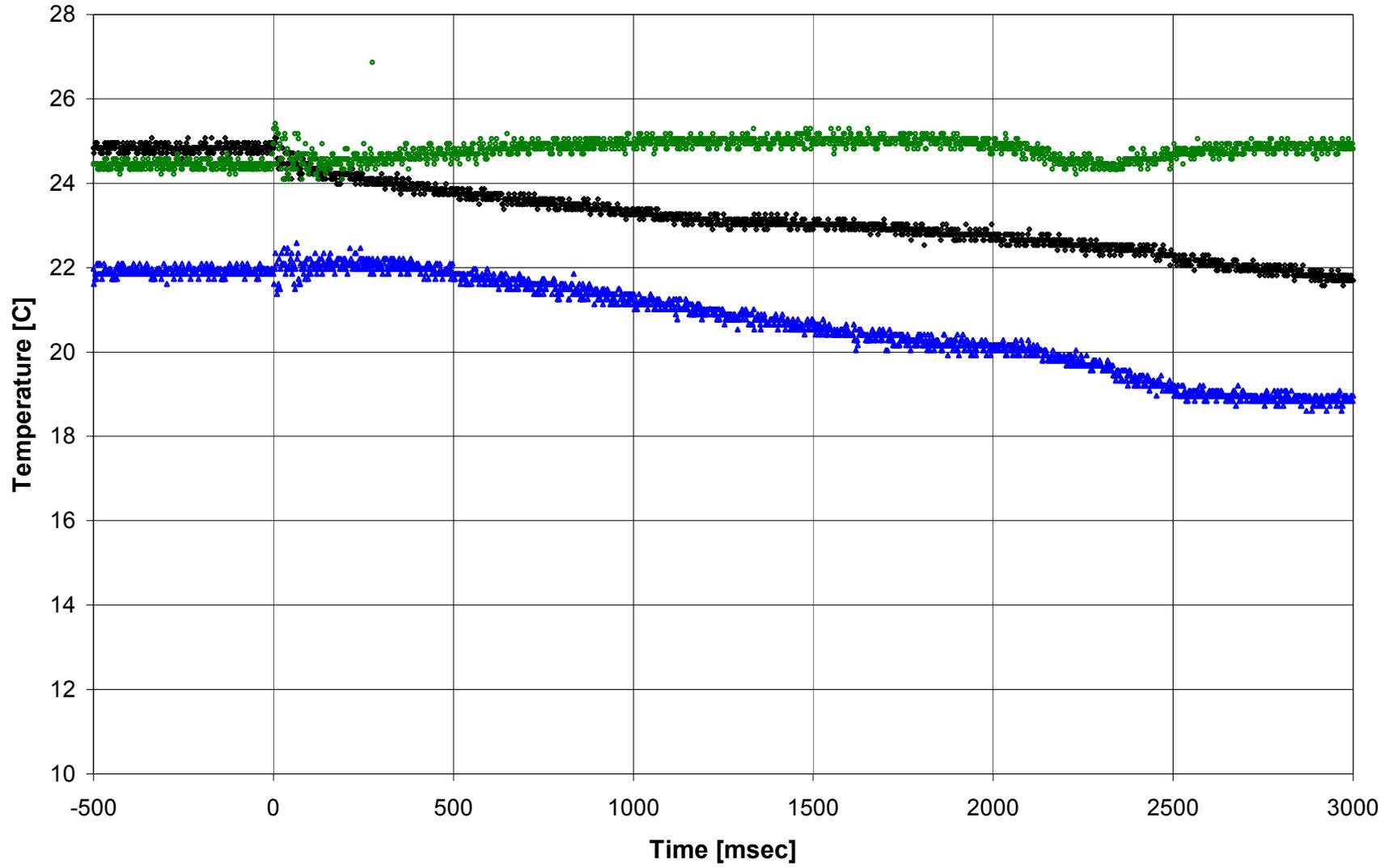
Initial System Temperature: 25° Celsius

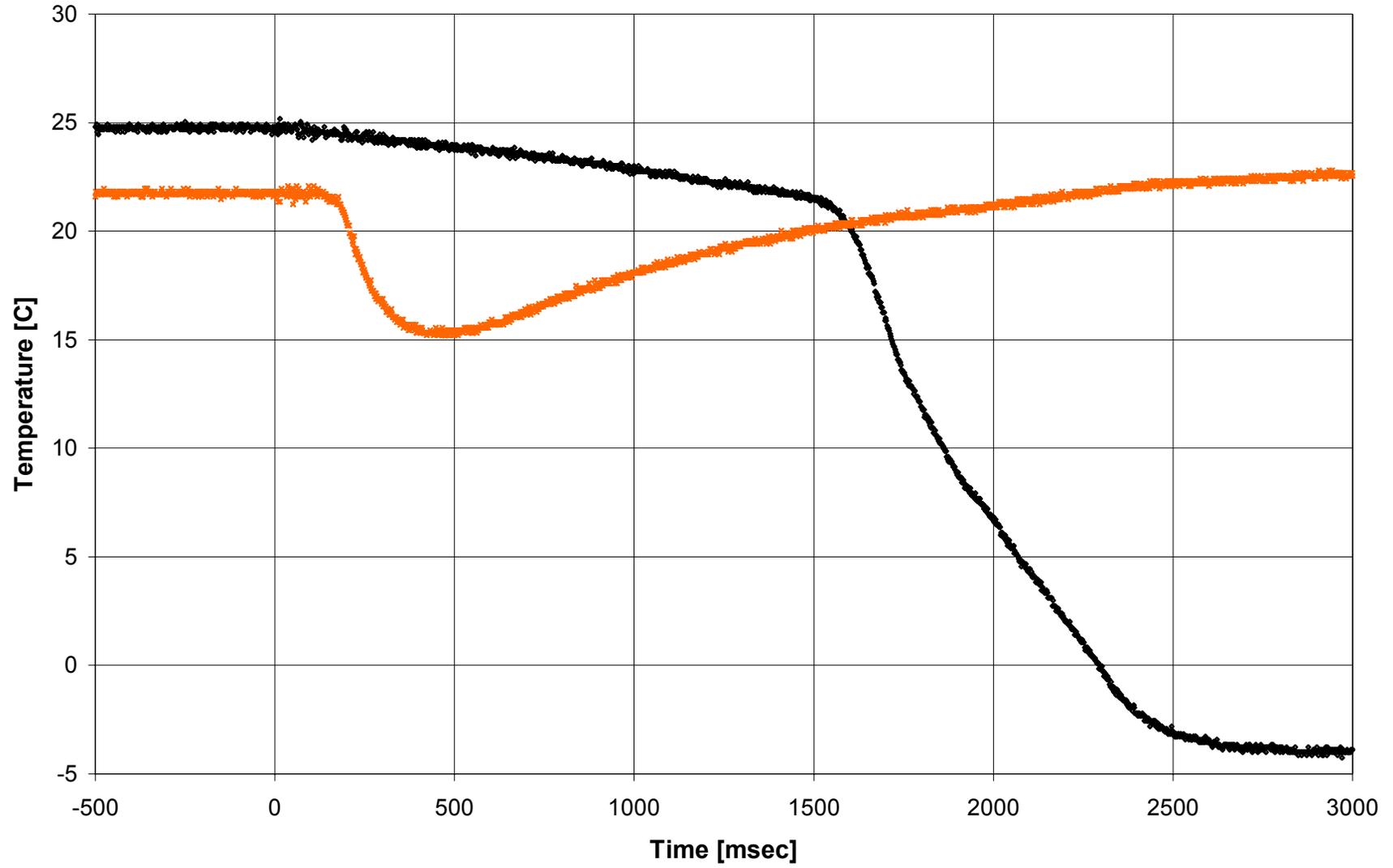
Completion Date: 3/3/00

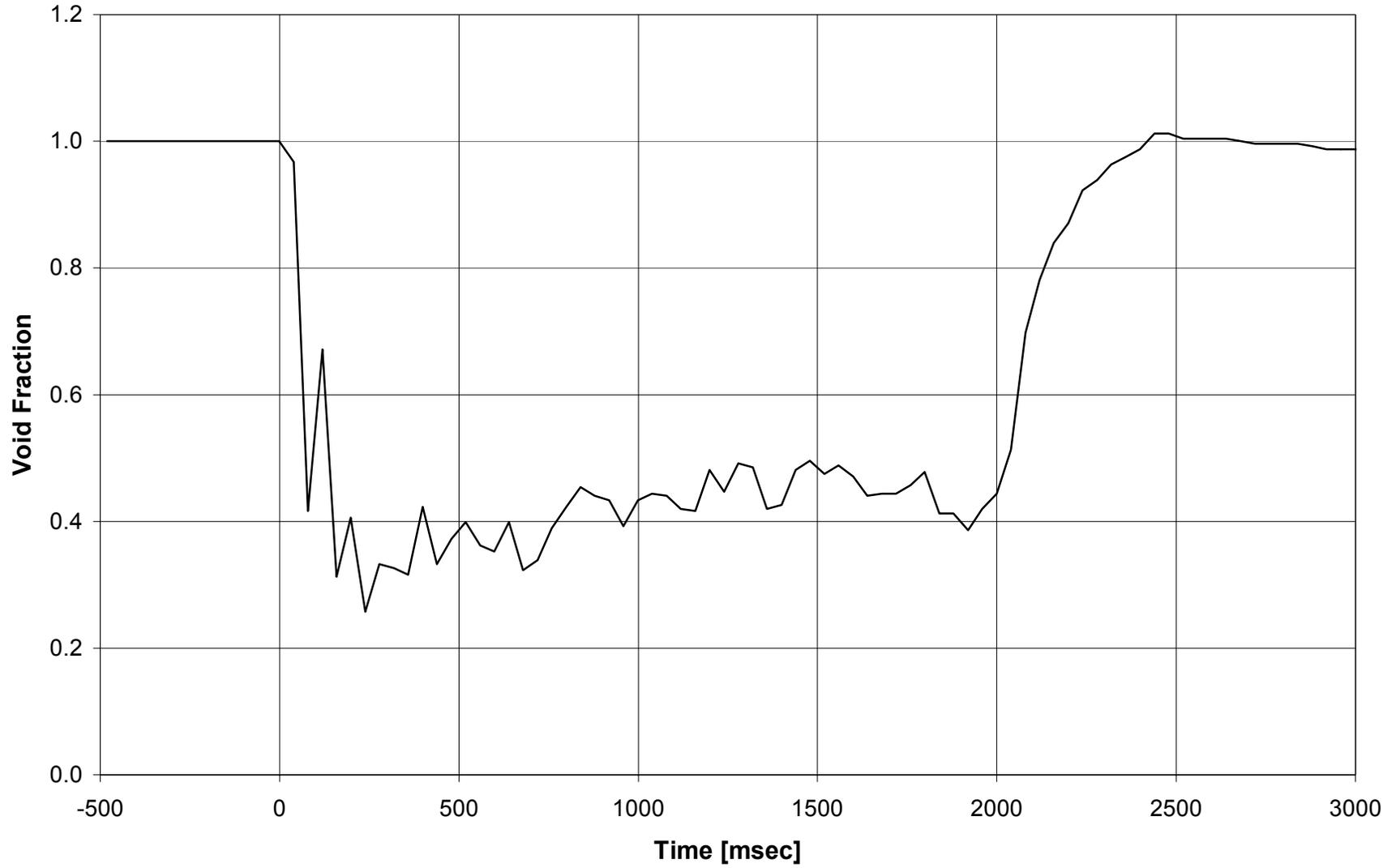
Legend

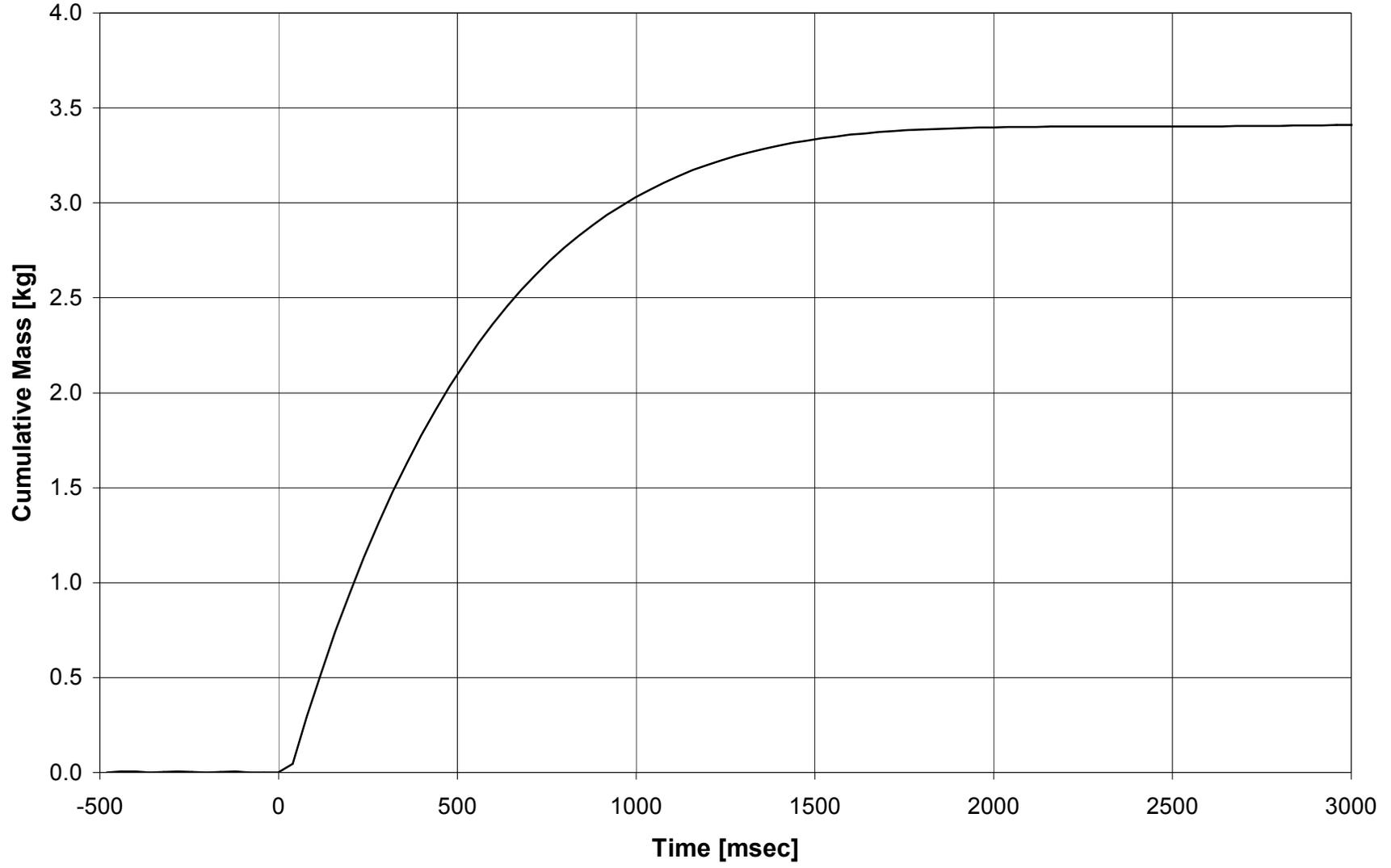


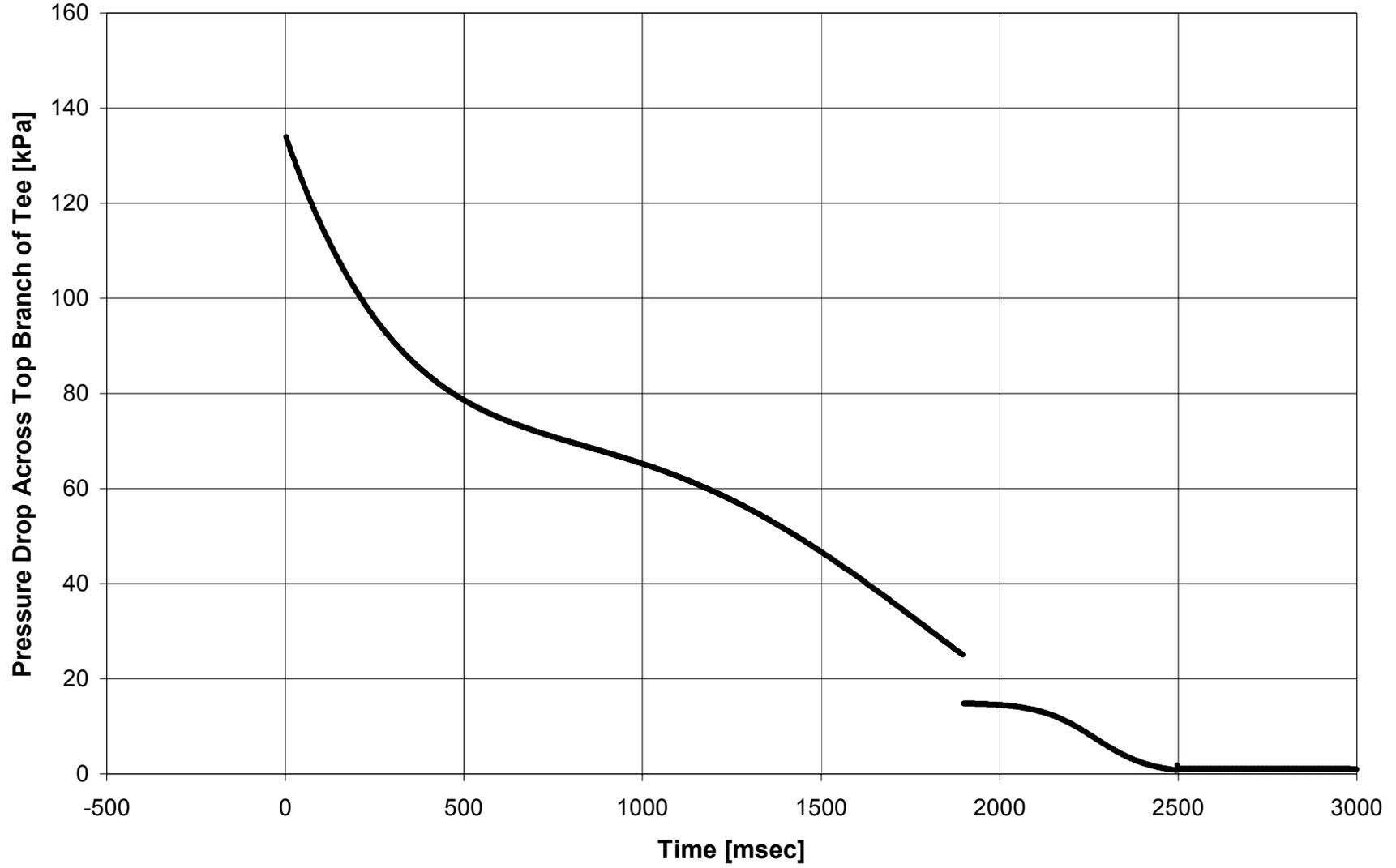


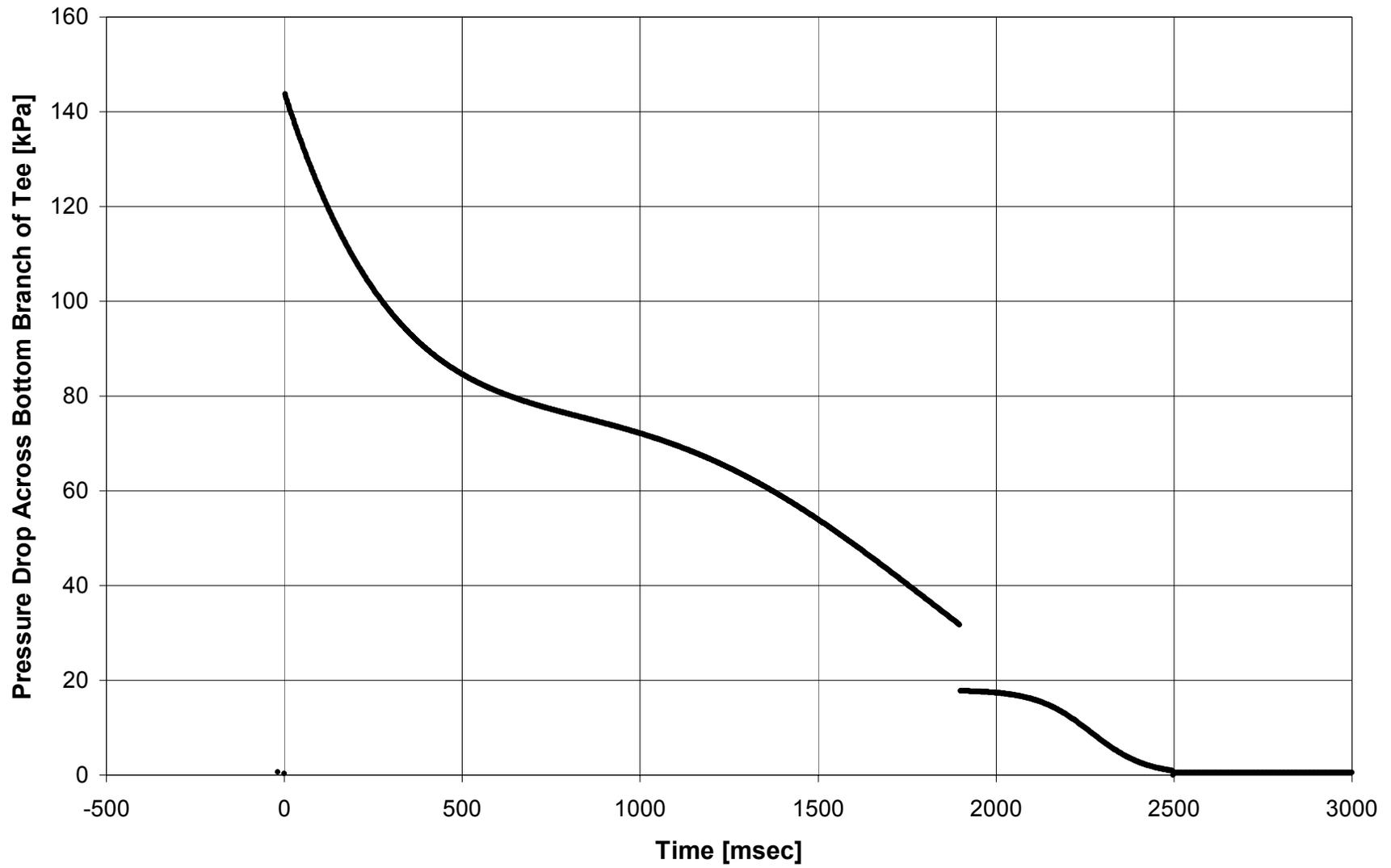












Run #14

Test Fluid: C2HF5 Pentafluoroethane (HFC-125)
CAS #: 354-33-6
Molecular Weight: 120.3

System Piping Configuration: Straight Pipe

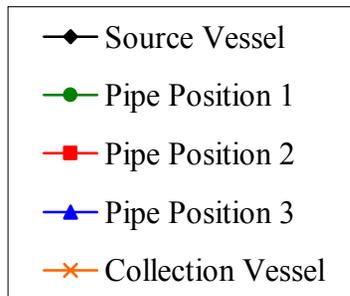
Source Vessel Initial Conditions: Fill Volume: 2900 milliliters
 Fluid Mass: 3.459 kg
 Pressure (Psvo): 2050 kPa
 Nitrogen Mass: 0.026 kg

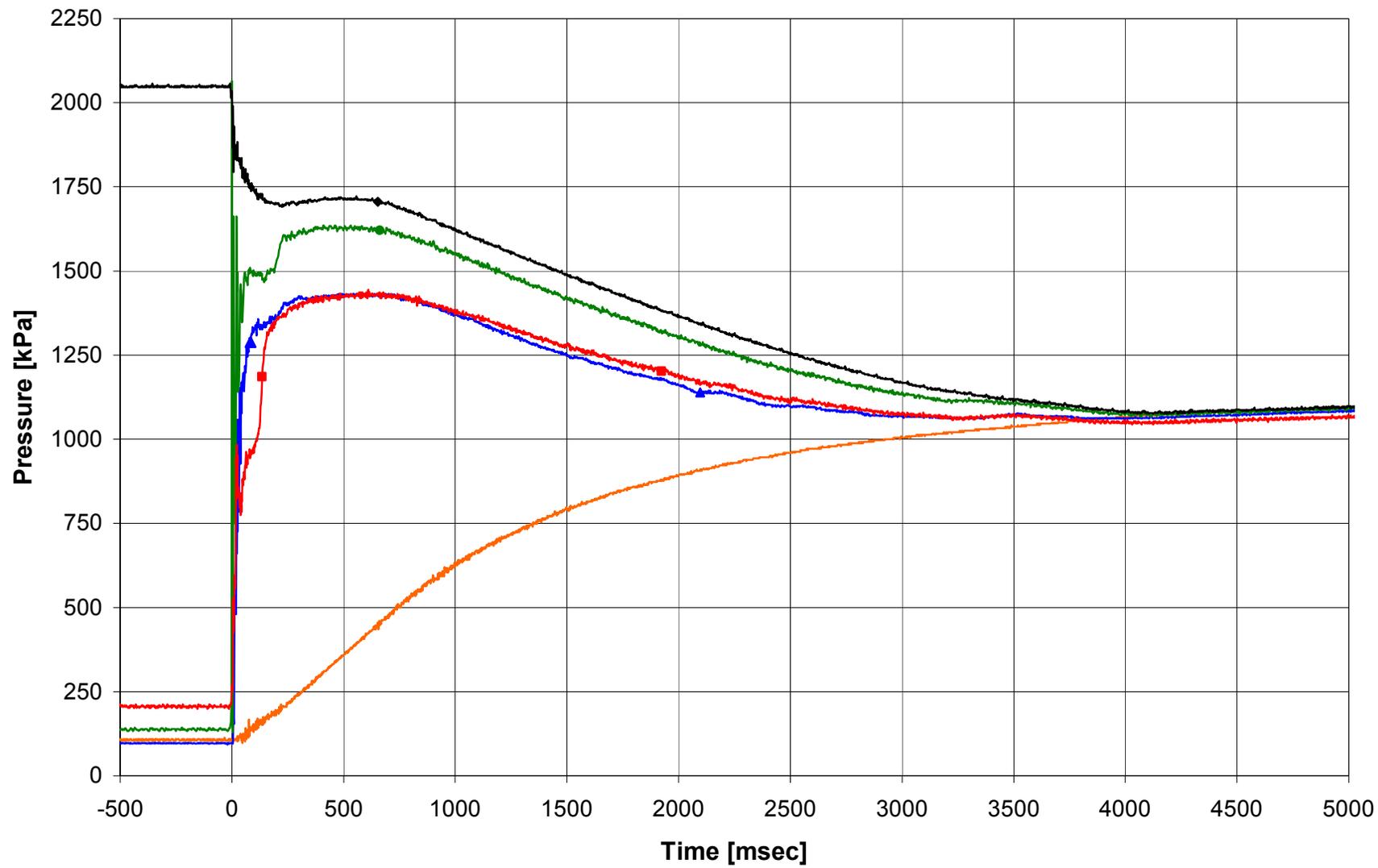
Initial Collection Vessel & Piping Pressure (Pcvo): 110 kPa

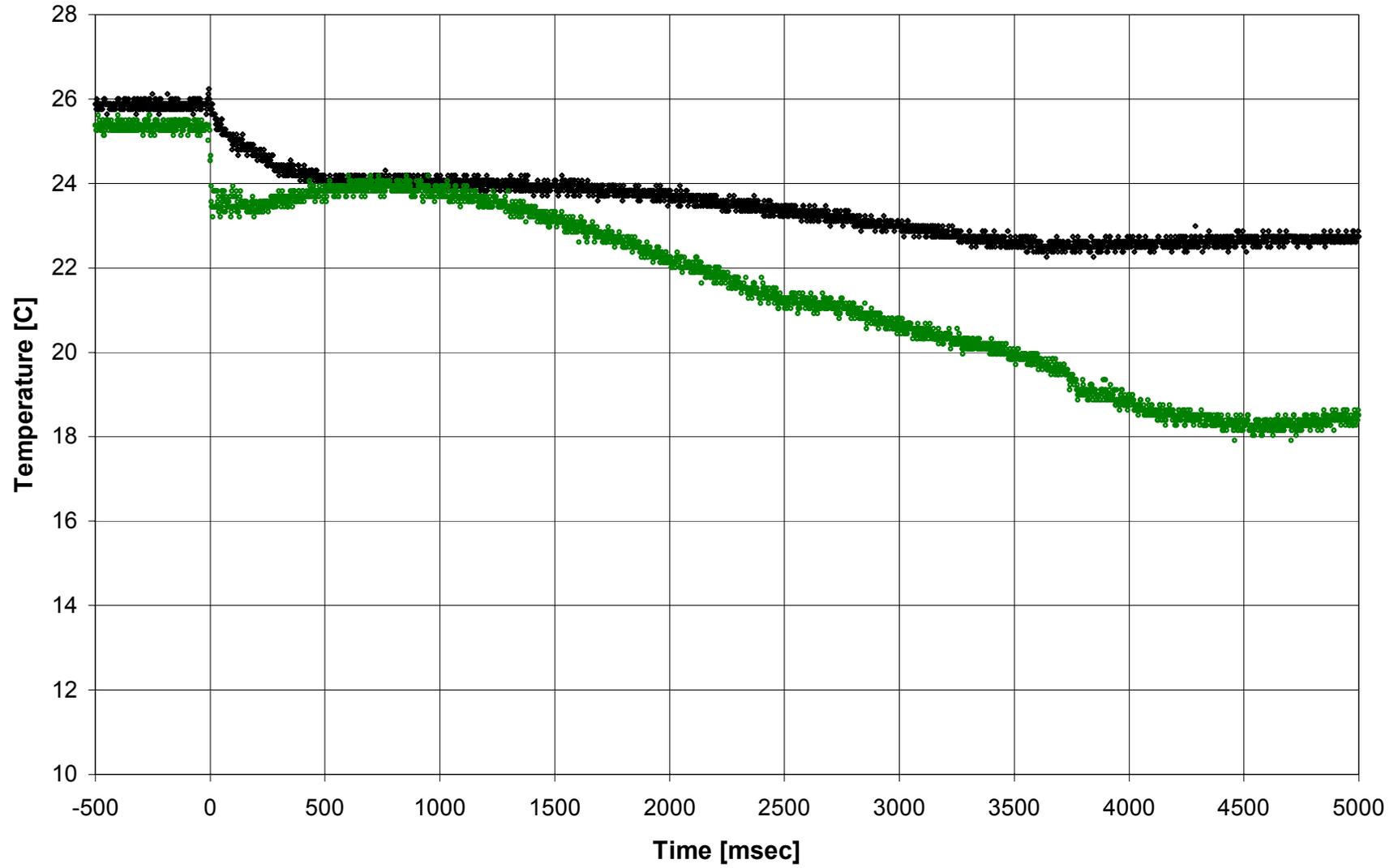
Initial System Temperature: 26° Celsius

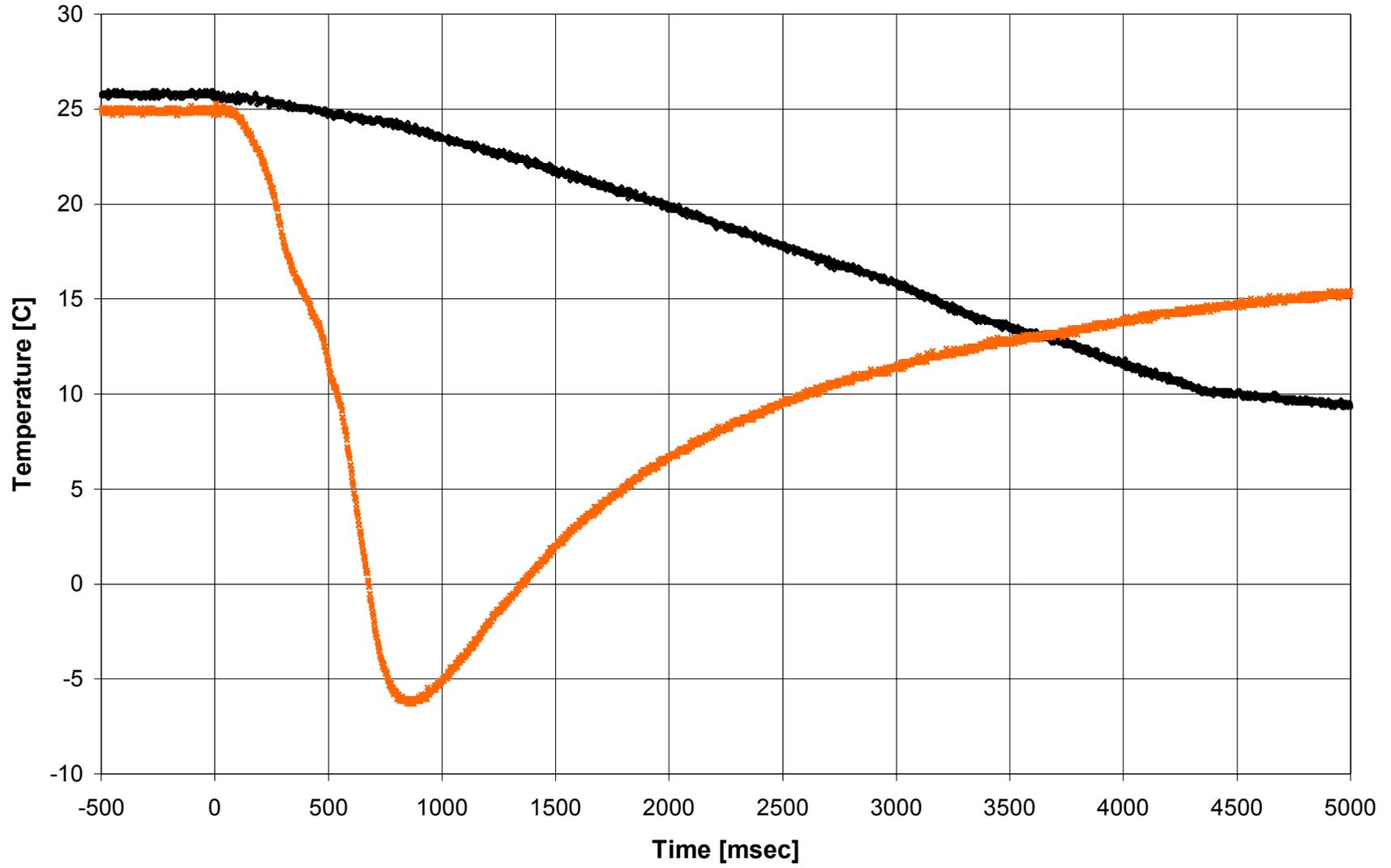
Completion Date: 4/3/00

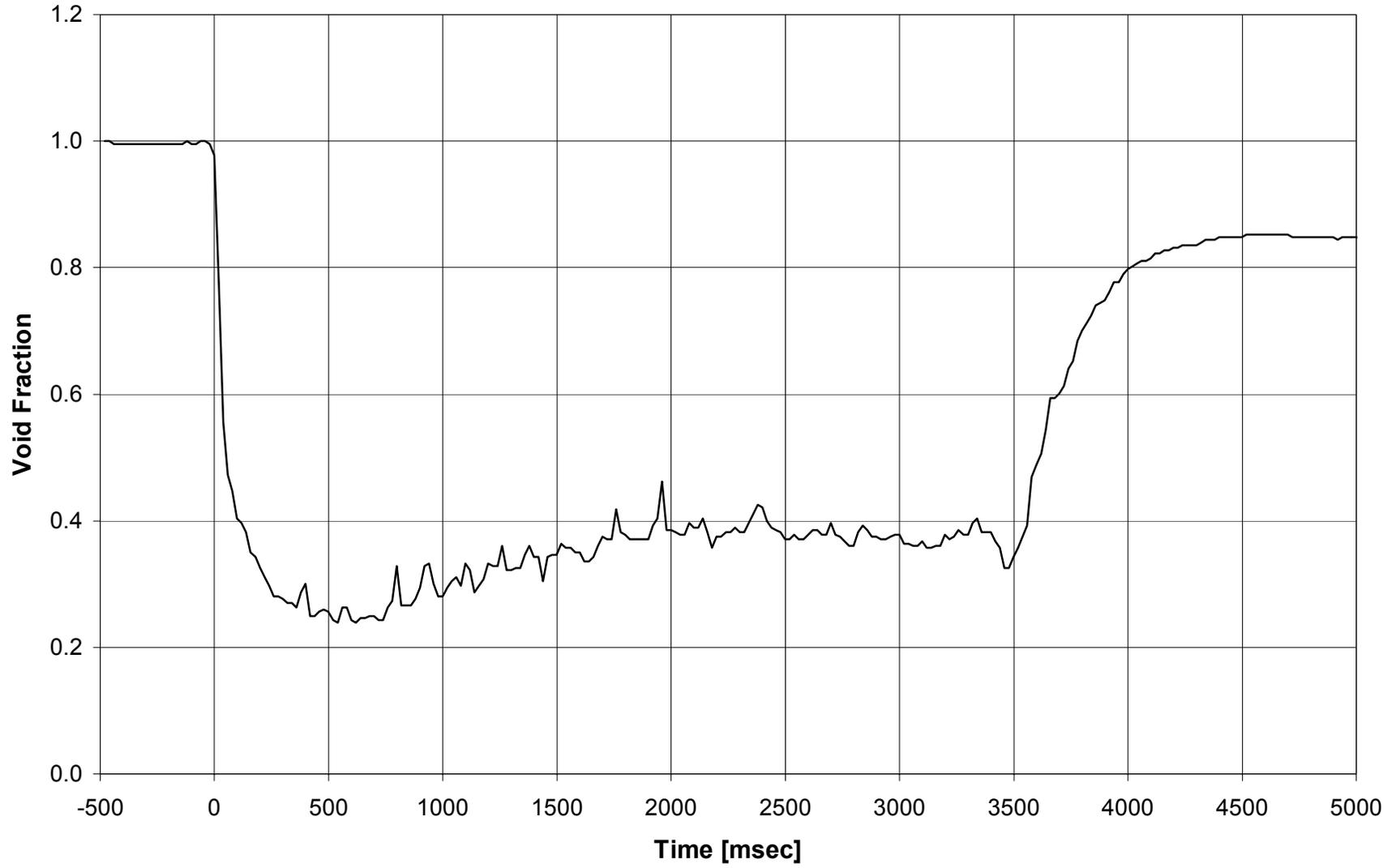
Legend

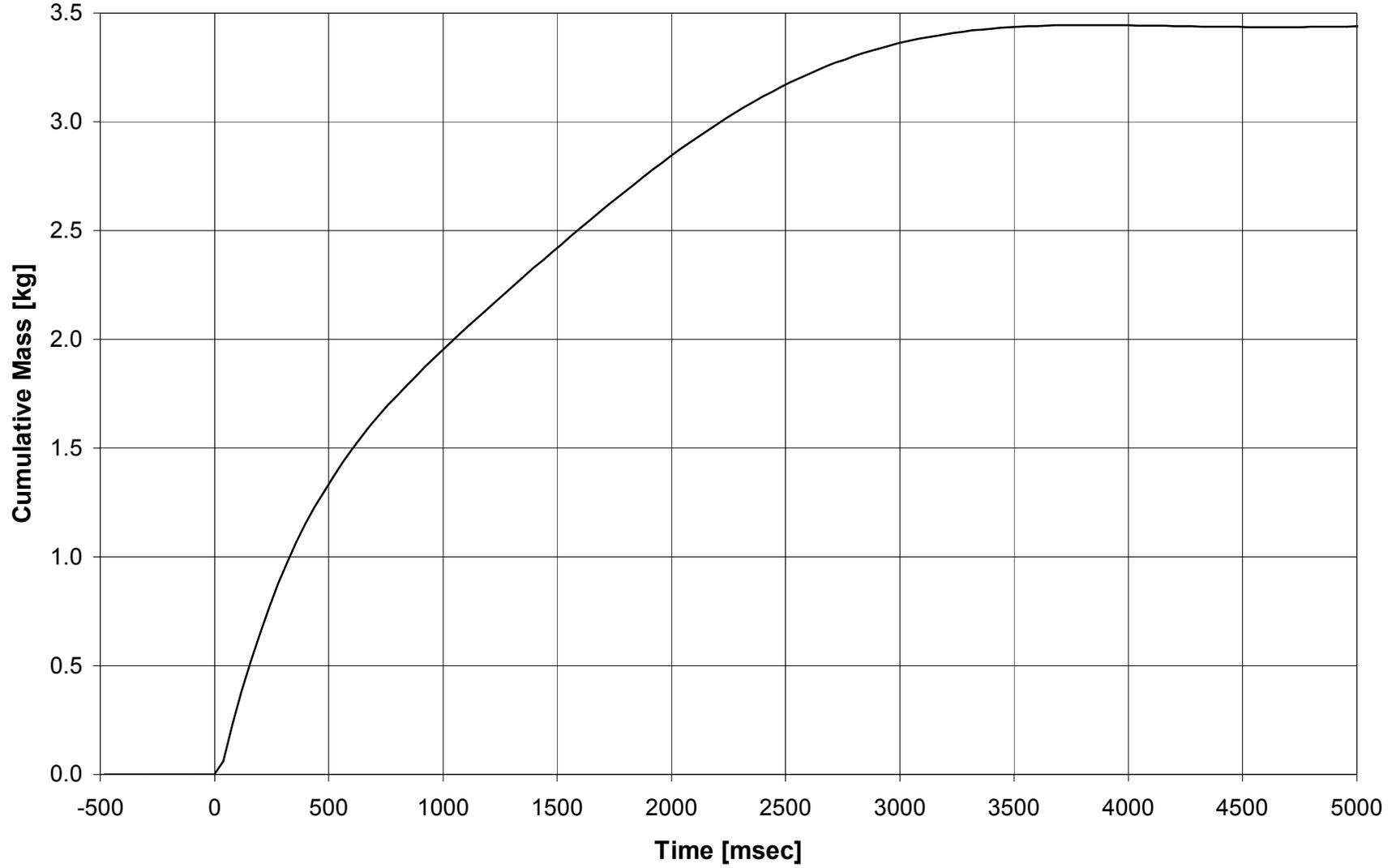












Run #15

Test Fluid: C2HF5 Pentafluoroethane (HFC-125)
CAS #: 354-33-6
Molecular Weight: 120.3

System Piping Configuration: Straight Pipe

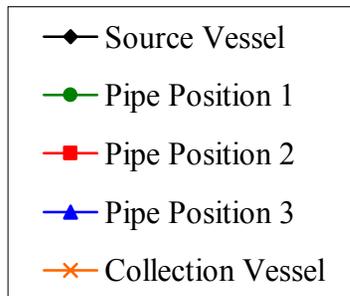
Source Vessel Initial Conditions: Fill Volume: 2363 milliliters
 Fluid Mass: 2.868 kg
 Pressure (Psvo): 3635 kPa
 Nitrogen Mass: 0.092 kg

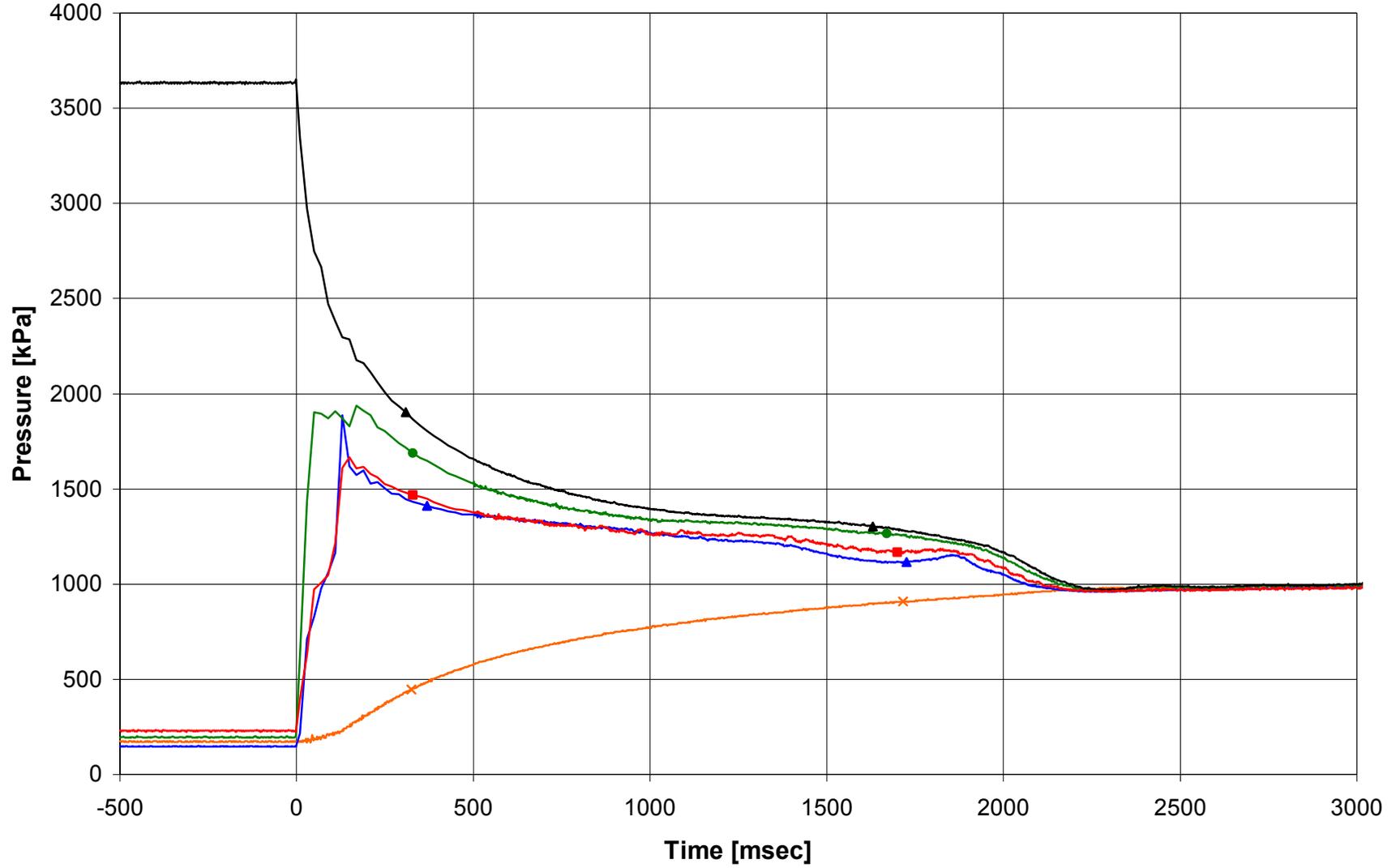
Initial Collection Vessel & Piping Pressure (Pcvo): 175 kPa

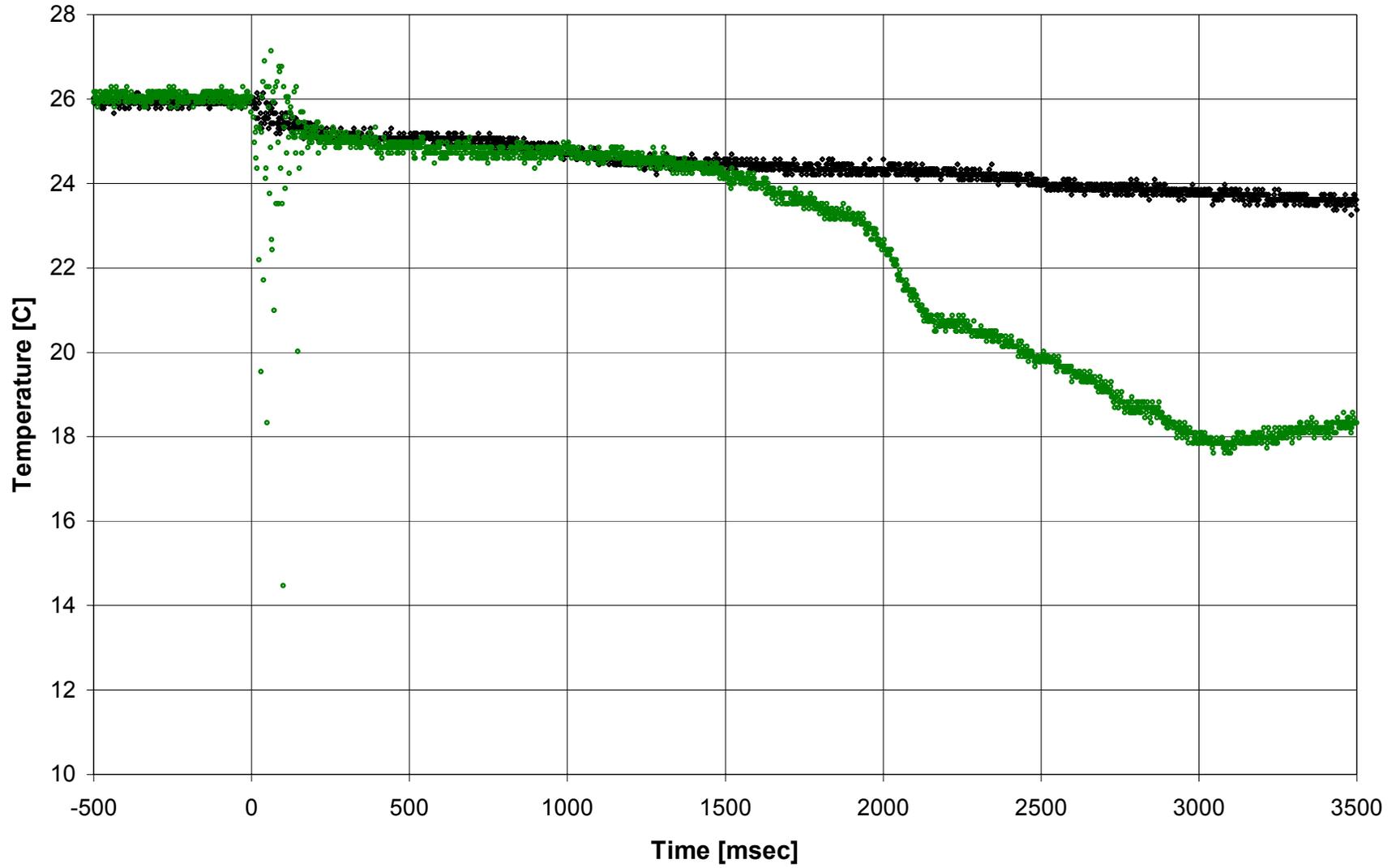
Initial System Temperature: 26° Celsius

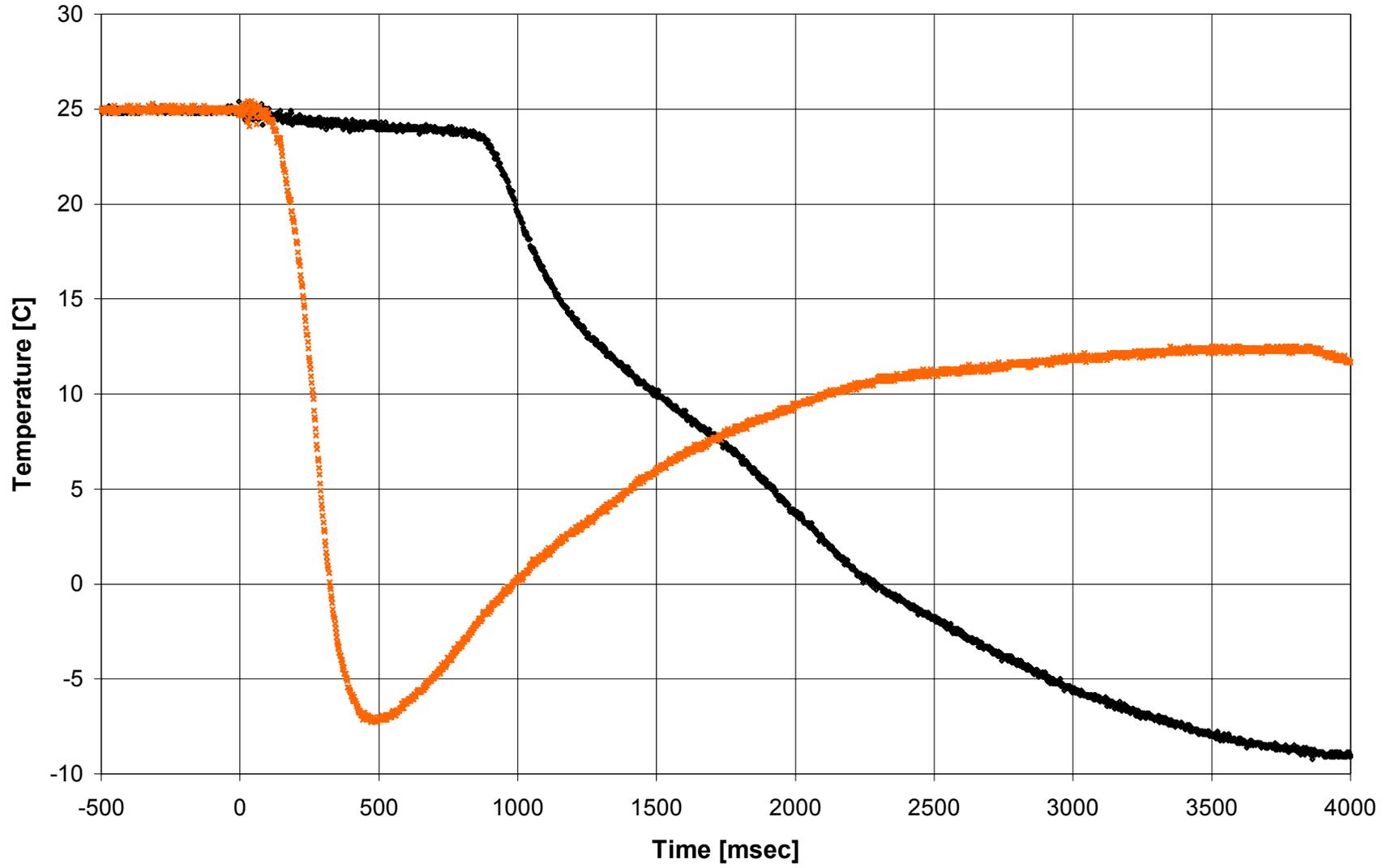
Completion Date: 4/6/00

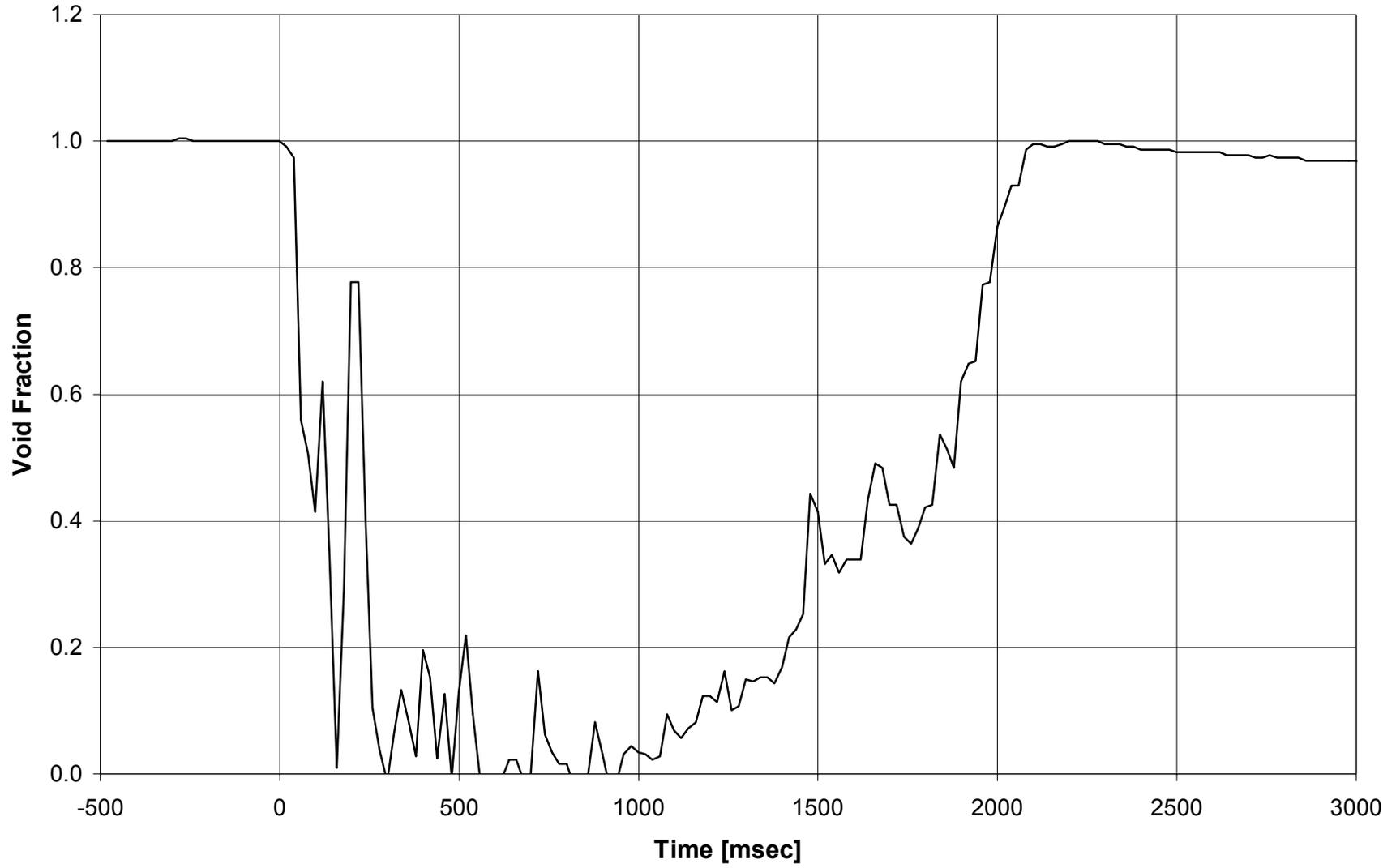
Legend

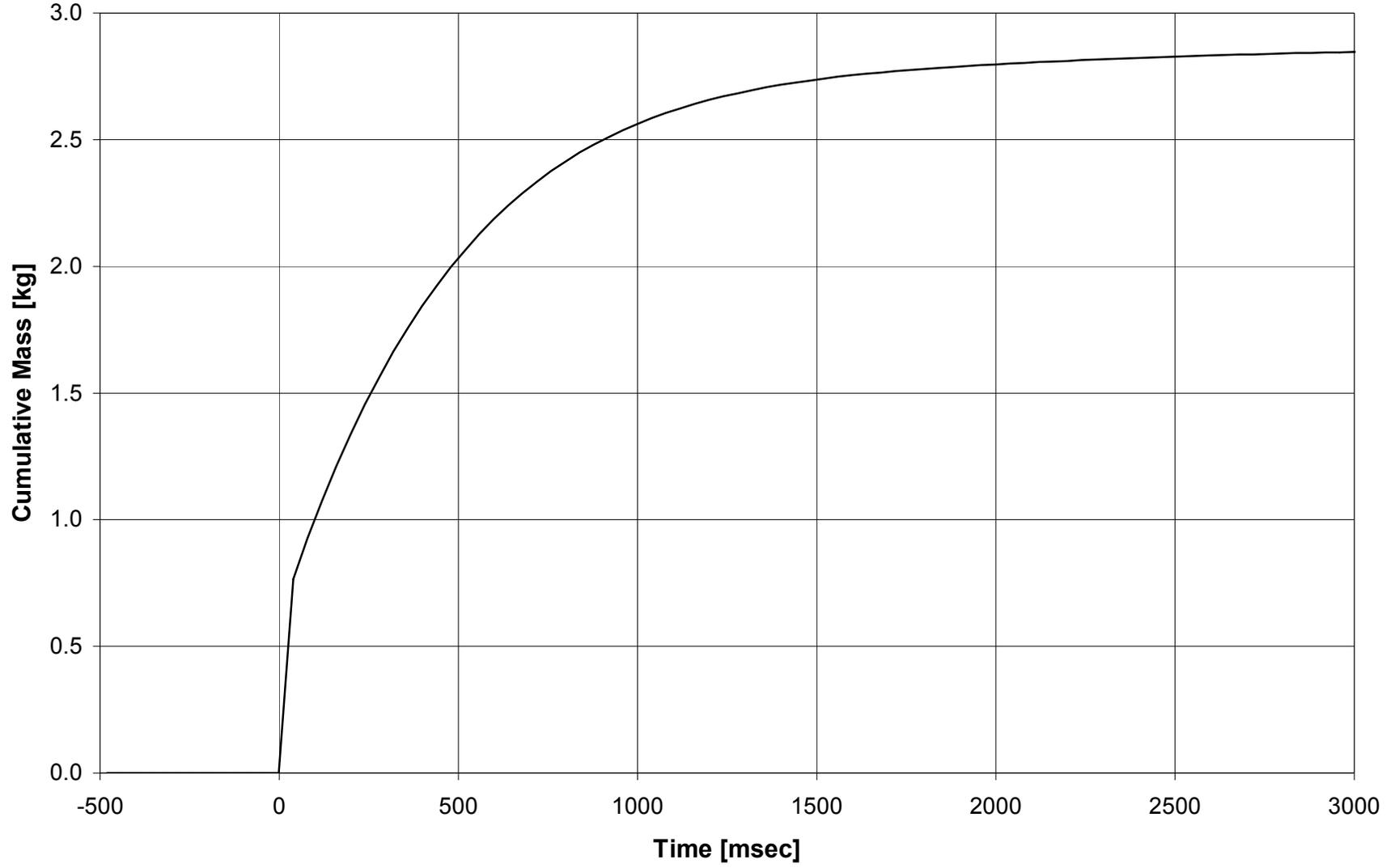












Run #16

Test Fluid: C2HF5 Pentafluoroethane (HFC-125)
CAS #: 354-33-6
Molecular Weight: 120.3

System Piping Configuration: Straight Pipe

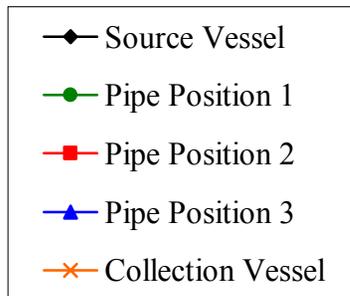
Source Vessel Initial Conditions: Fill Volume: 2400 milliliters
 Fluid Mass: 2.936 kg
 Pressure (Psvo): 4245 kPa
 Nitrogen Mass: 0.118 kg

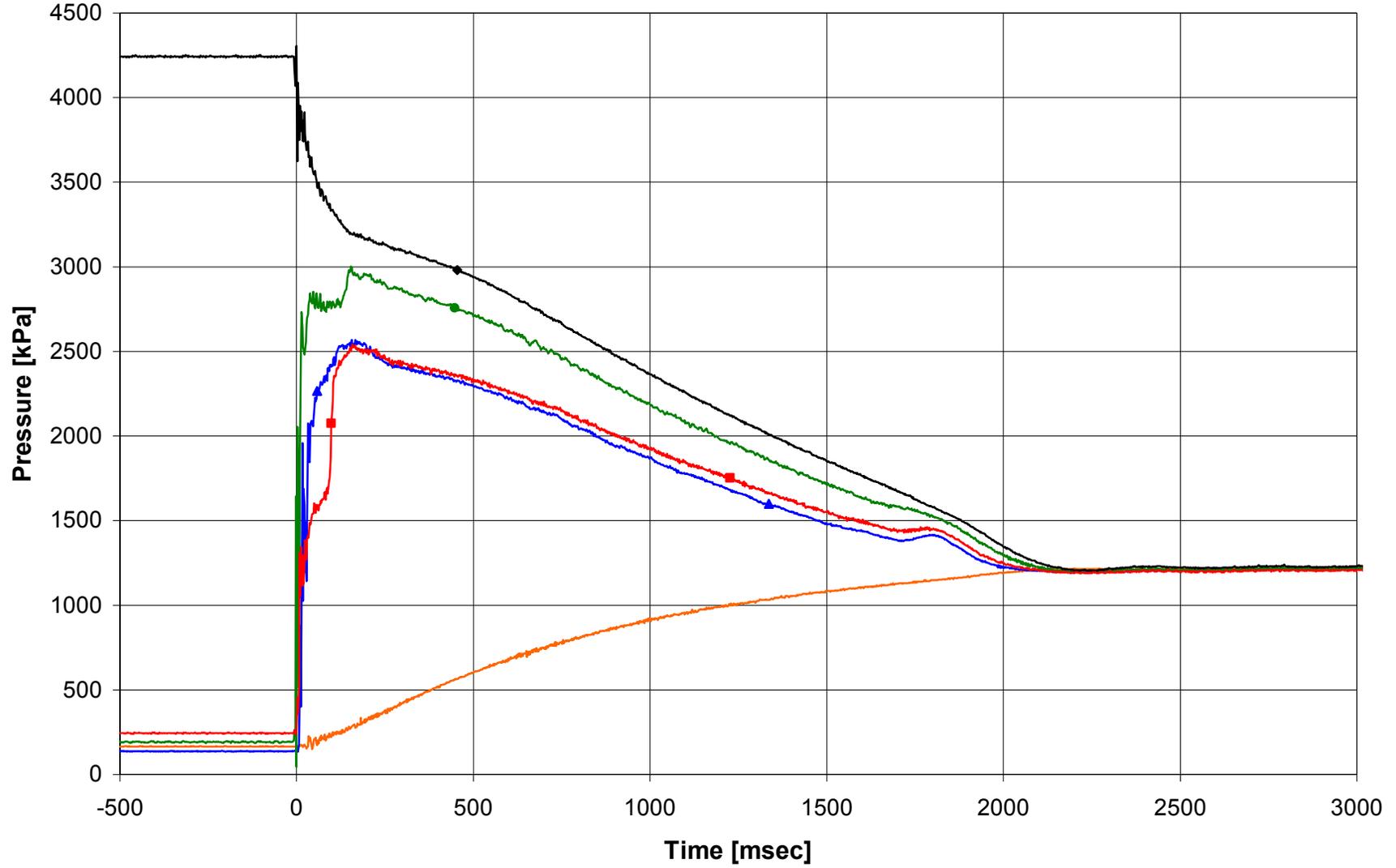
Initial Collection Vessel & Piping Pressure (Pcvo): 165 kPa

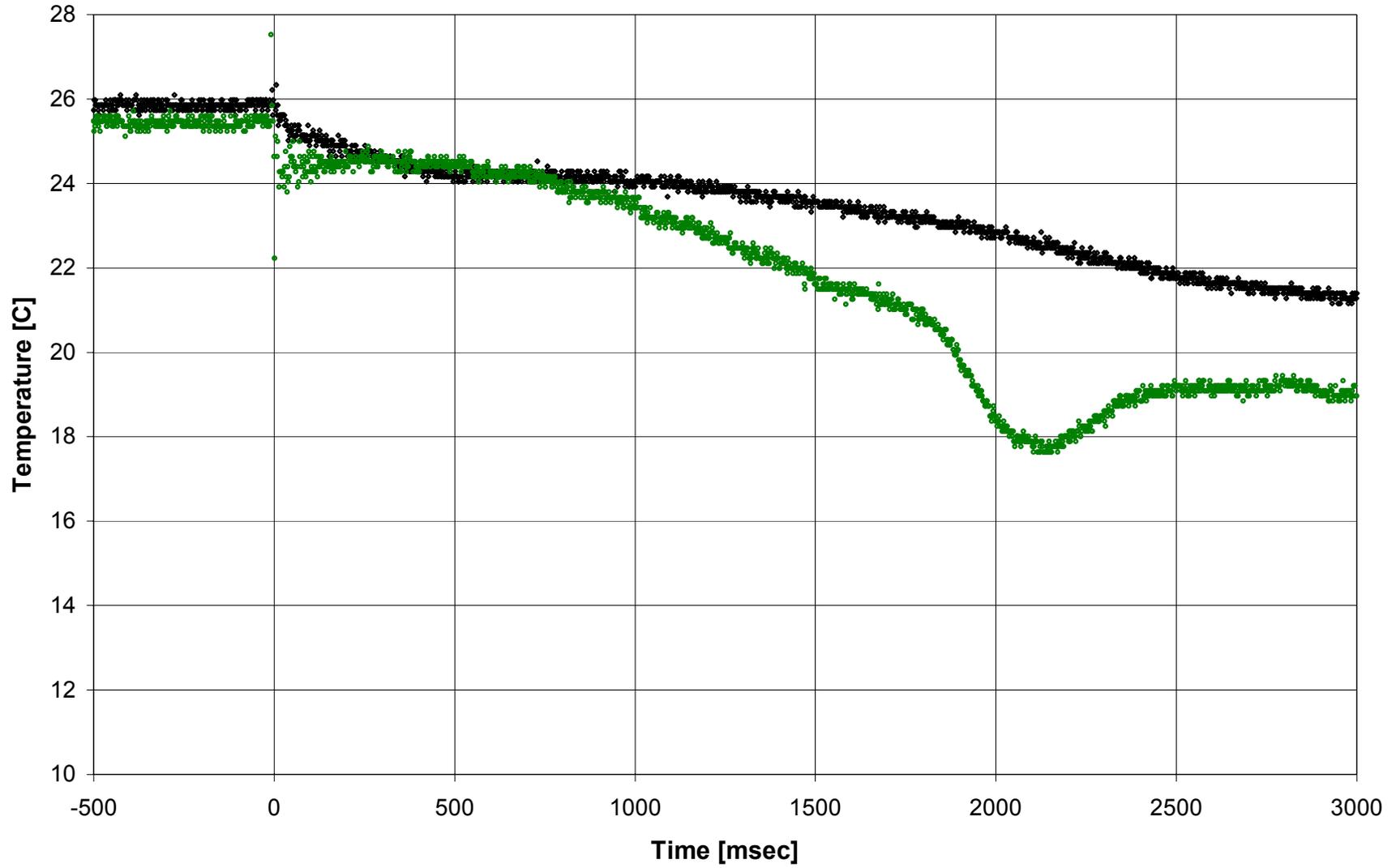
Initial System Temperature: 26° Celsius

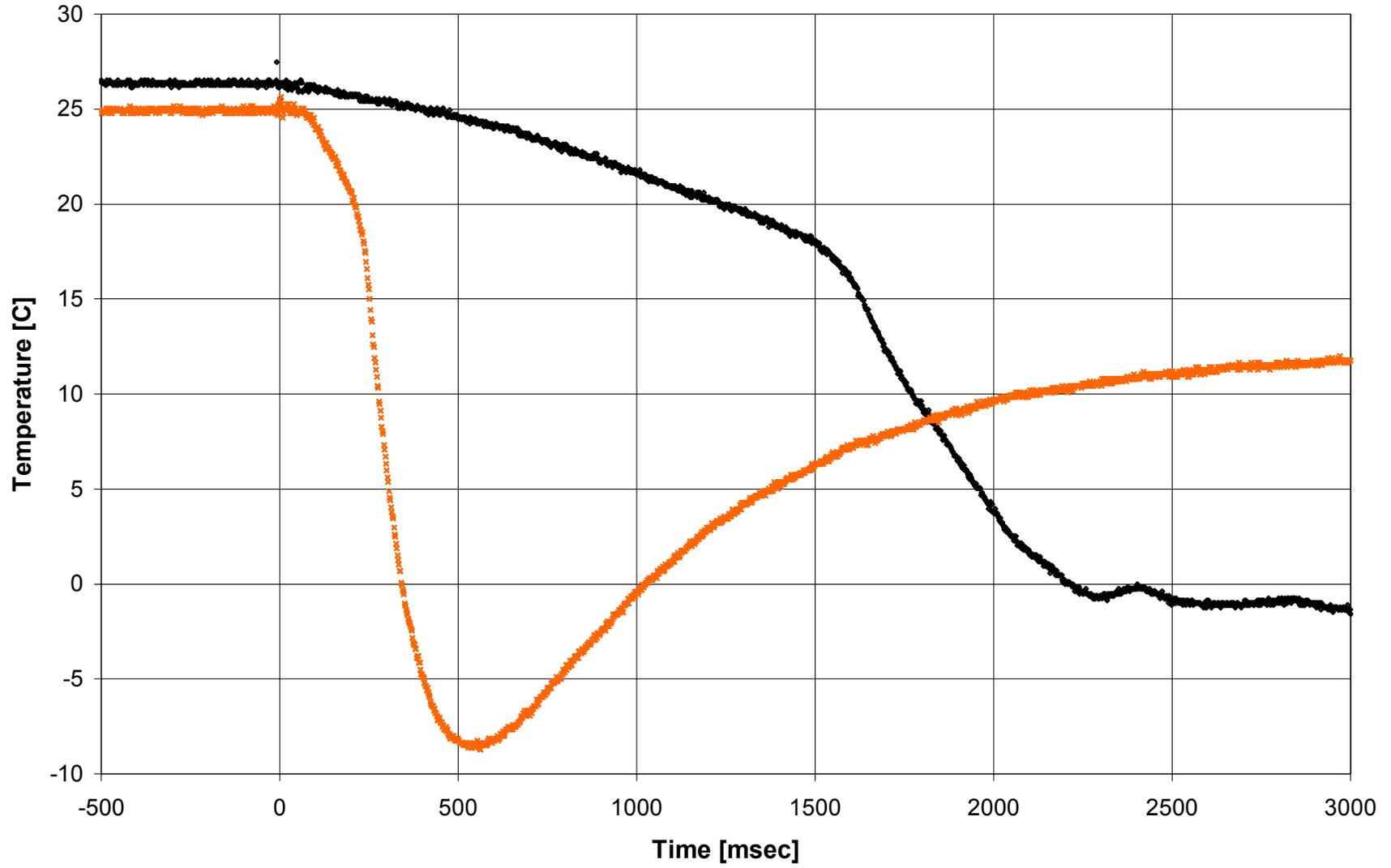
Completion Date: 4/4/00

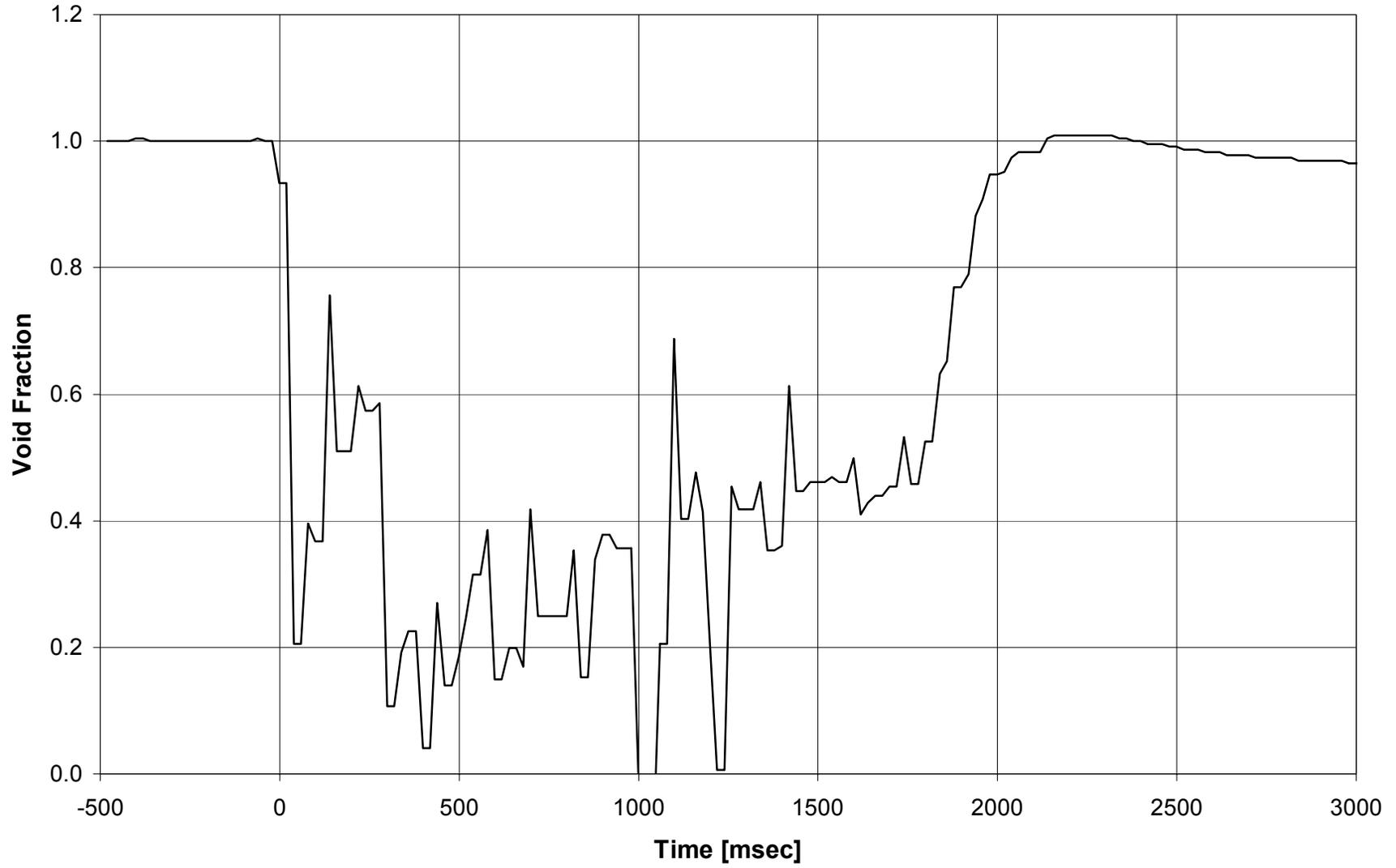
Legend

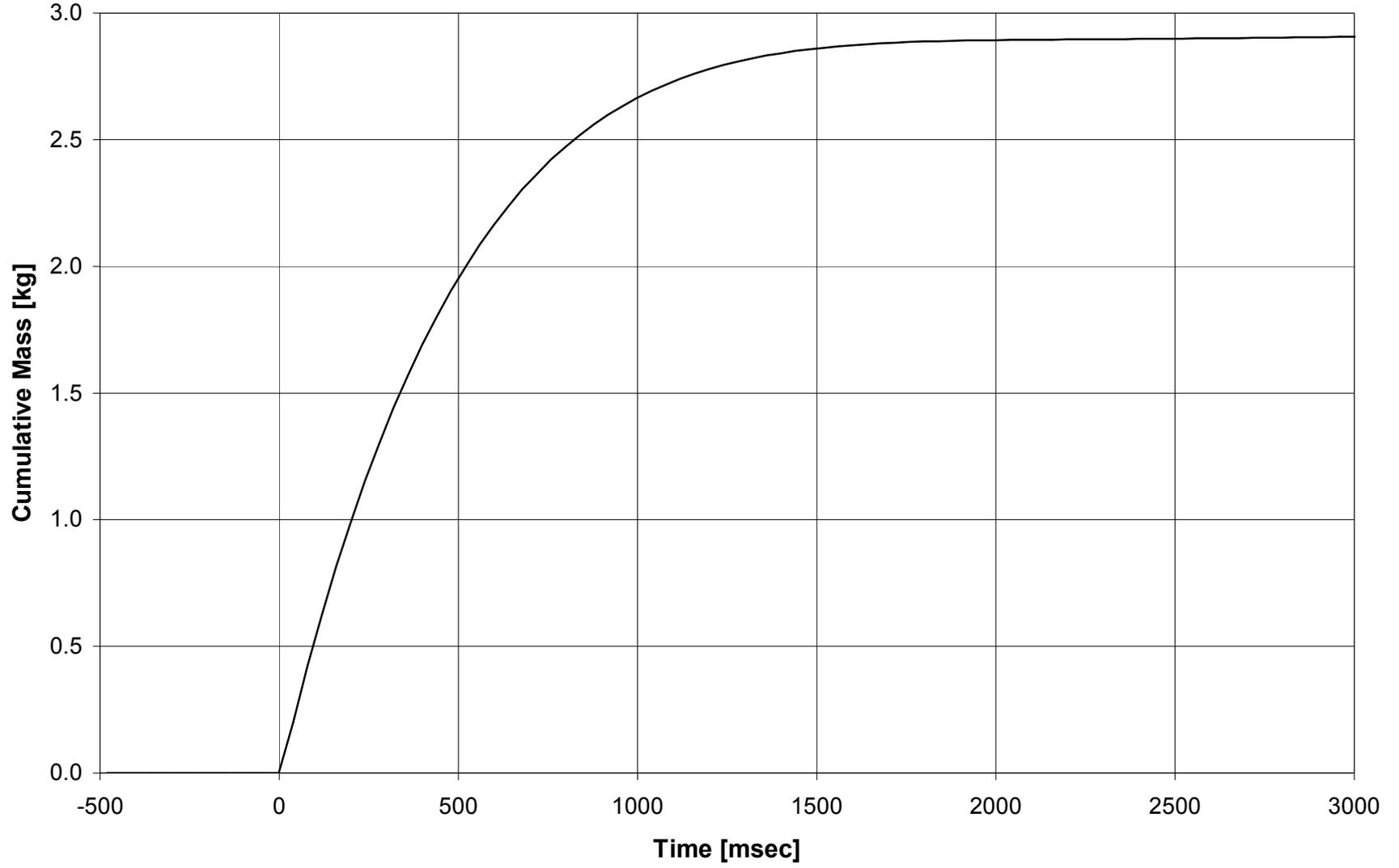












Run #17

Test Fluid: C2HF5 Pentafluoroethane (HFC-125)
CAS #: 354-33-6
Molecular Weight: 120.3

System Piping Configuration: Straight Pipe

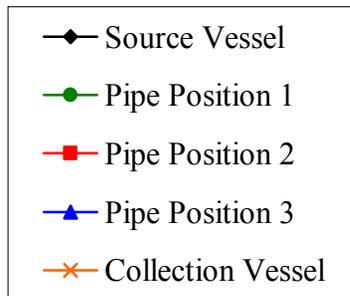
Source Vessel Initial Conditions: Fill Volume: 2467 milliliters
 Fluid Mass: 3.066 kg
 Pressure (Psvo): 5000 kPa
 Nitrogen Mass: 0.152 kg

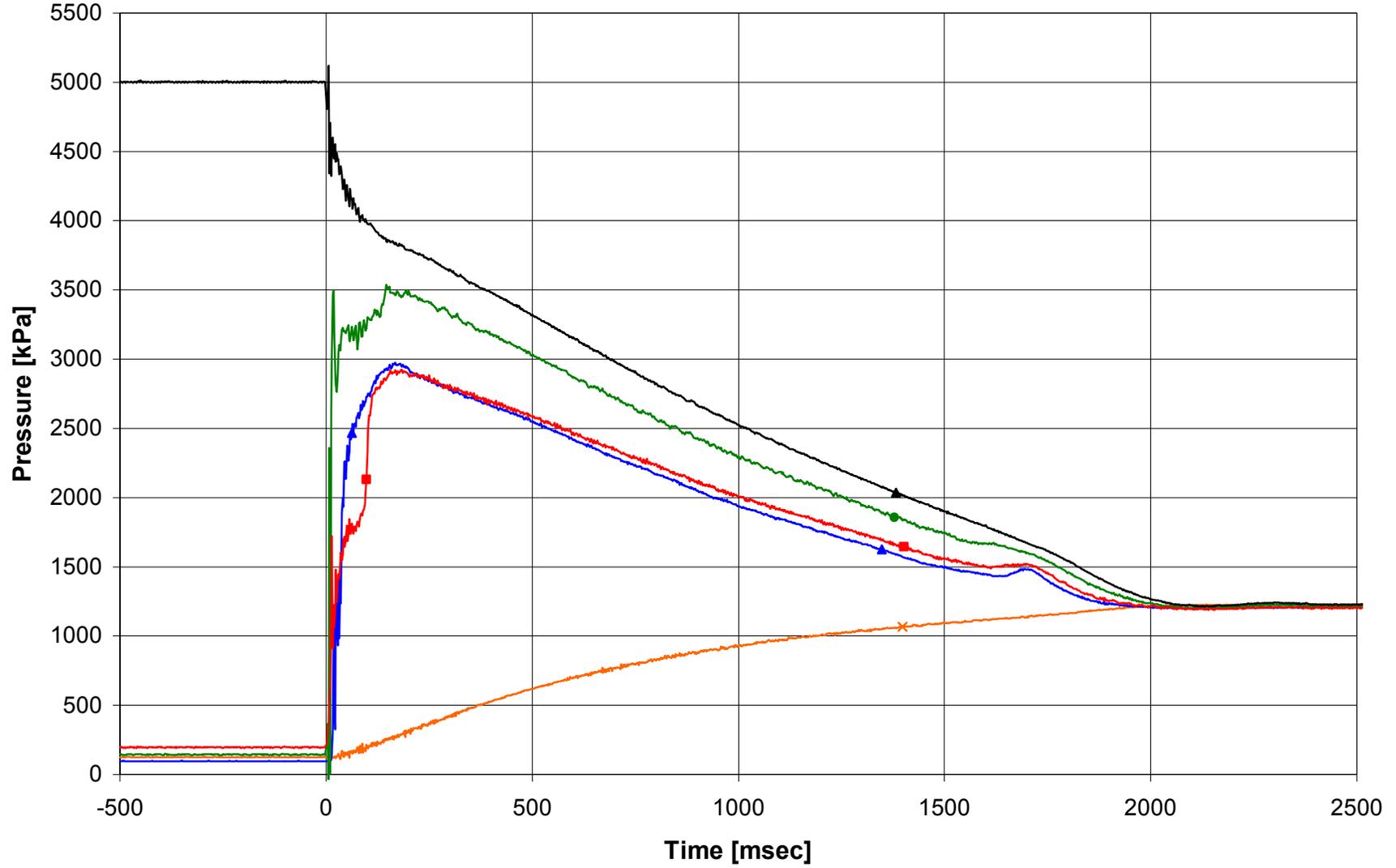
Initial Collection Vessel & Piping Pressure (Pcvo): 125 kPa

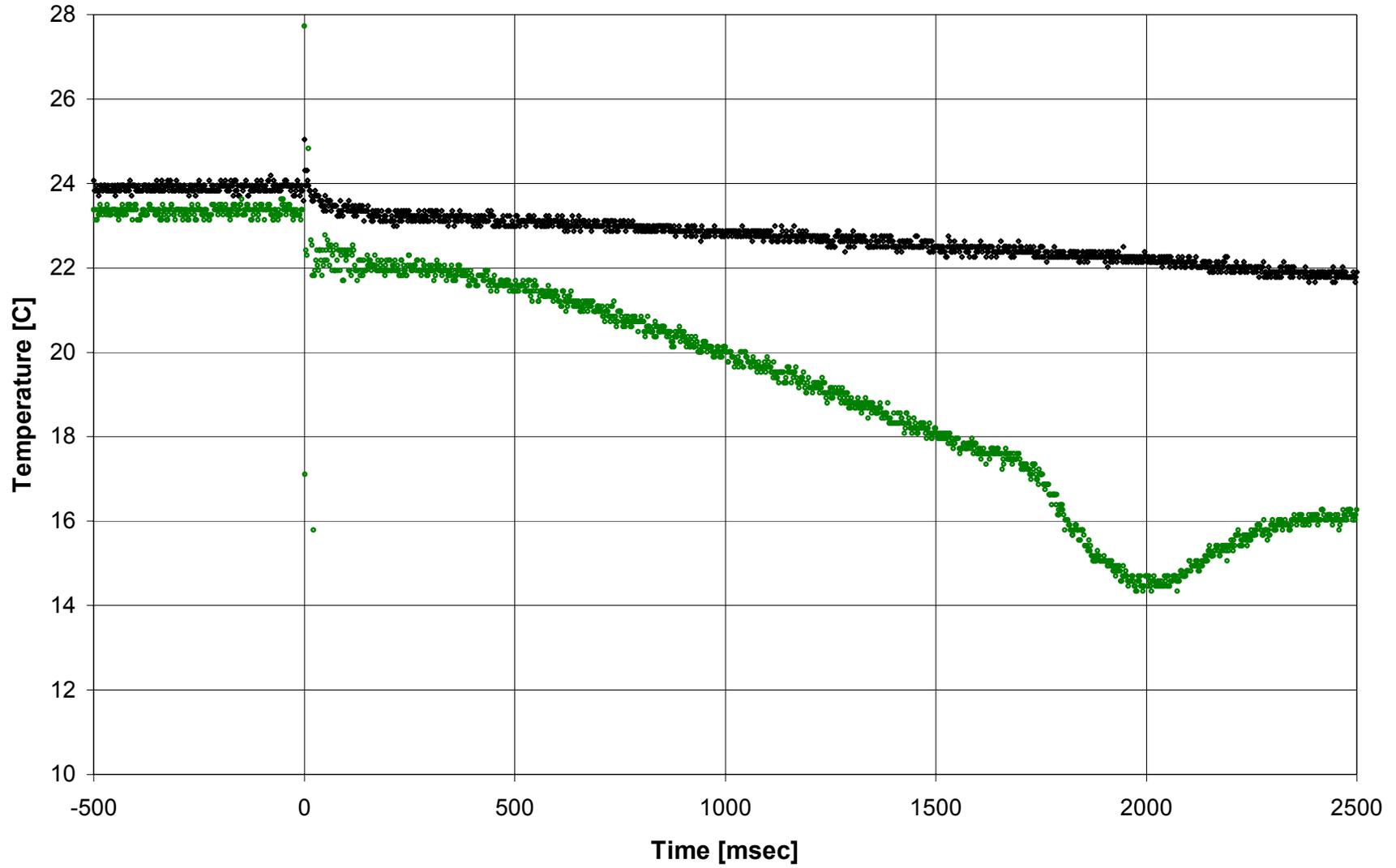
Initial System Temperature: 24° Celsius

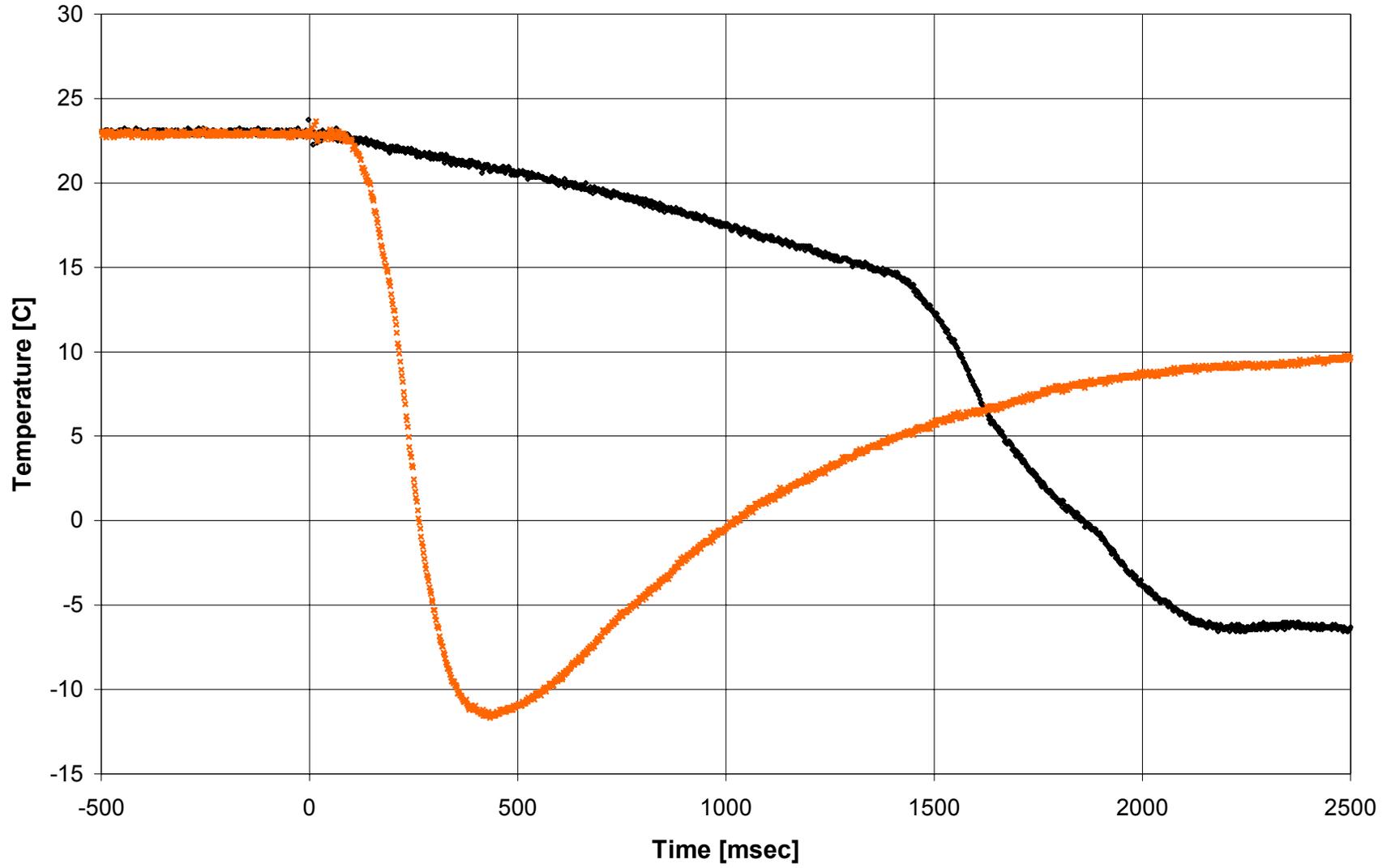
Completion Date: 4/10/00

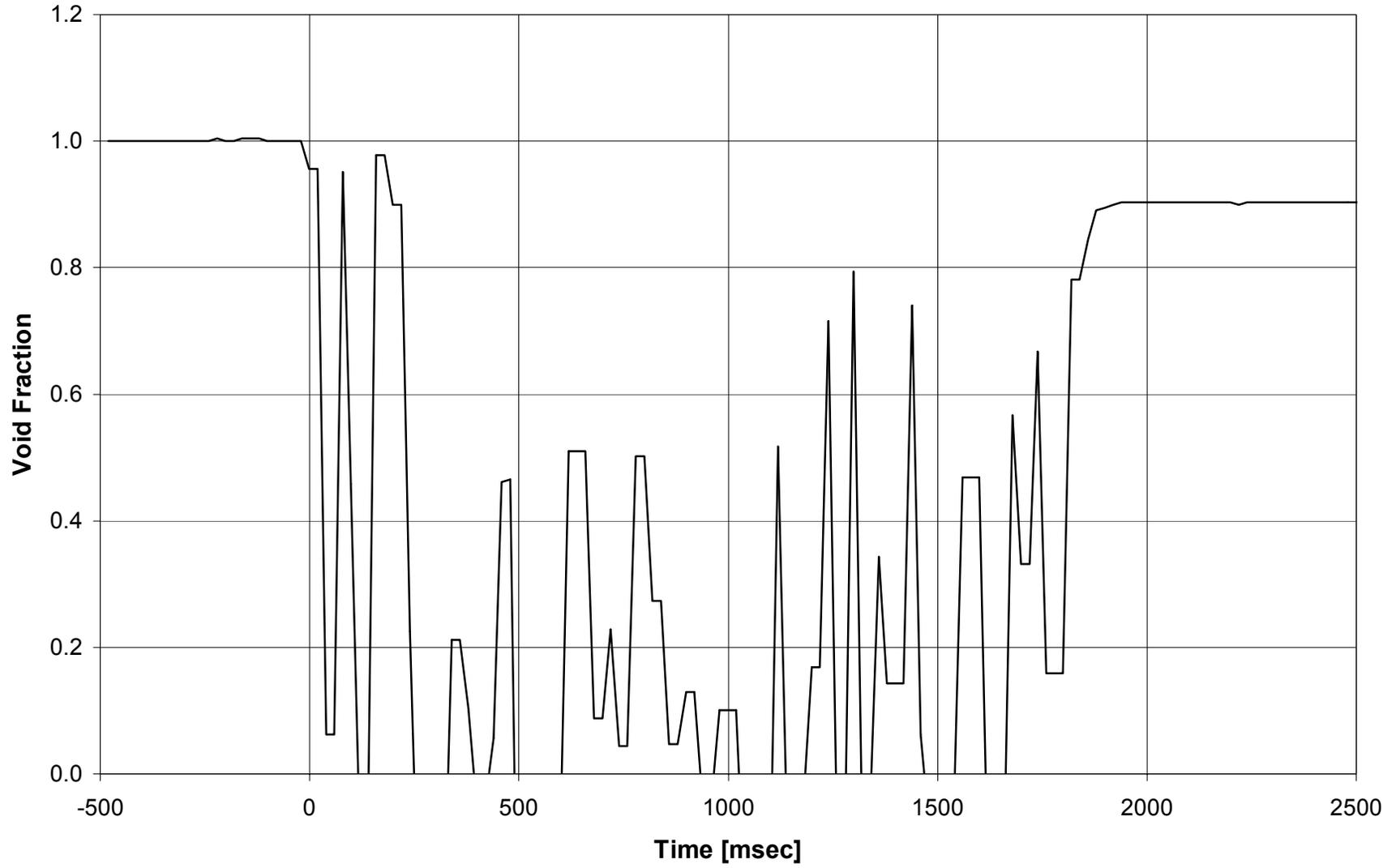
Legend

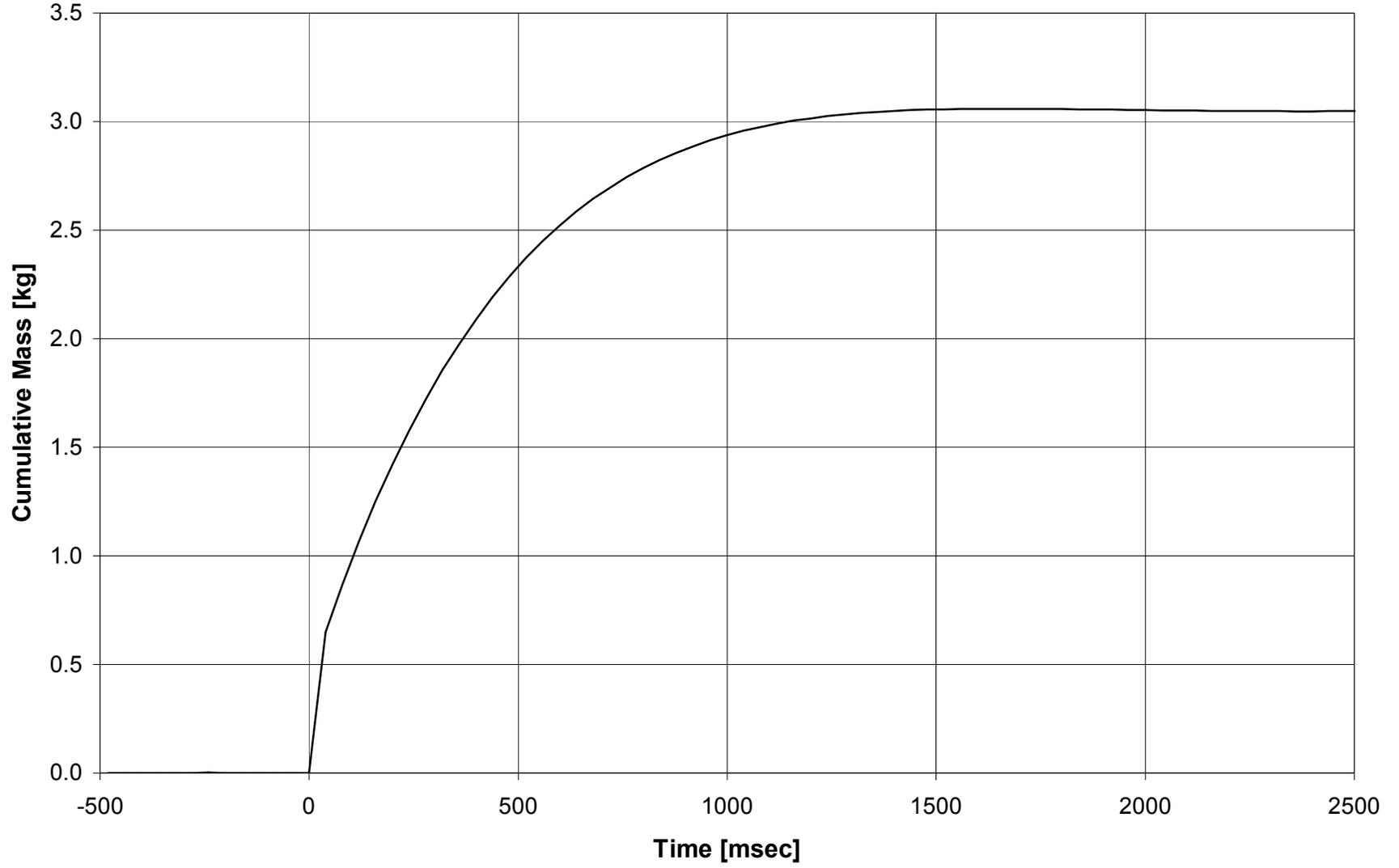












Run #18

Test Fluid: Water

System Piping Configuration: Straight Pipe

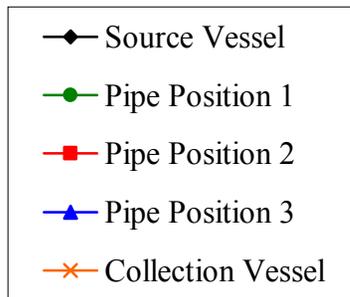
Source Vessel Initial Conditions: Fill Volume: 3585 milliliters
 Fluid Mass: 3.585 kg
 Pressure (Psvo): 2875 kPa

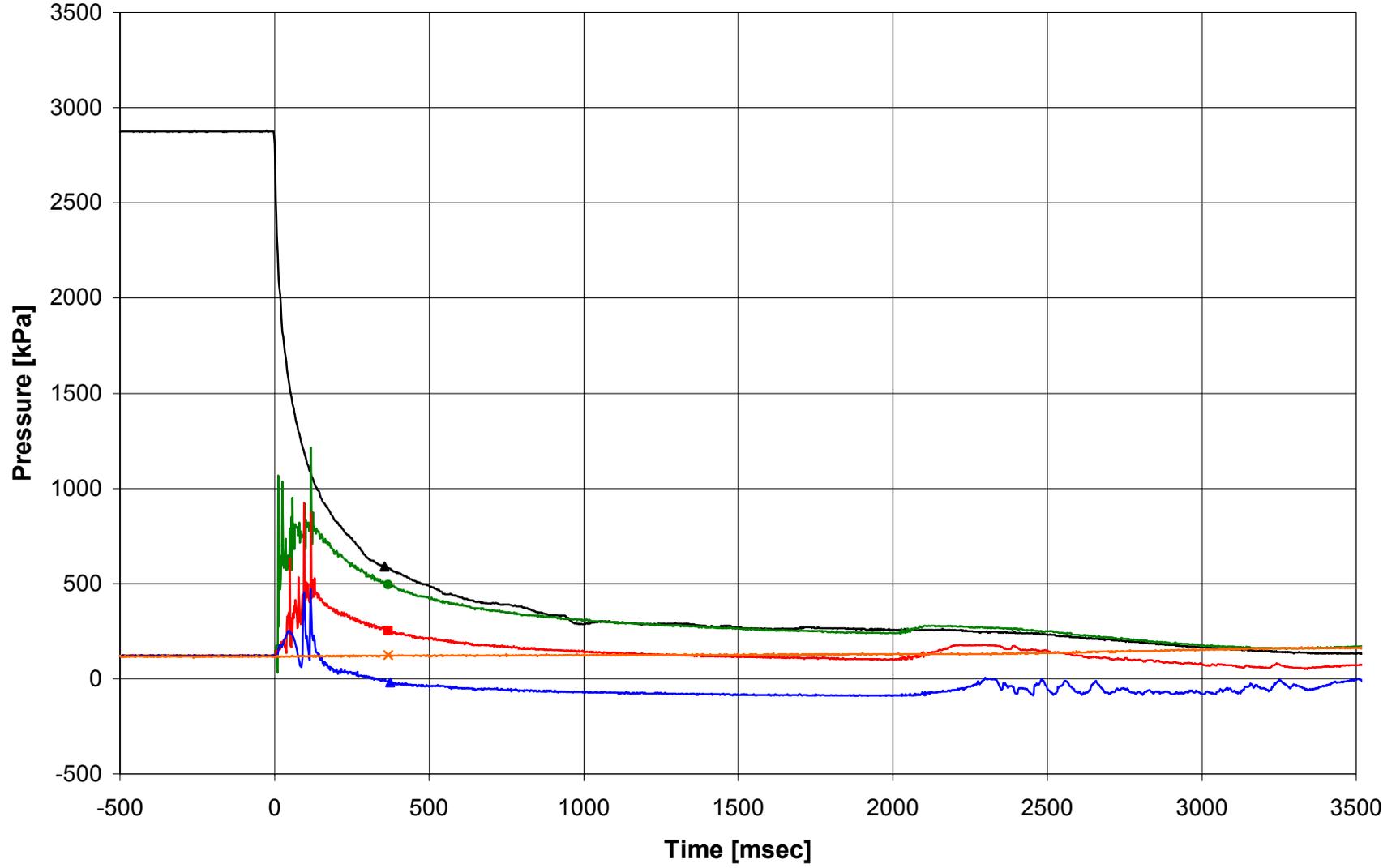
Initial Collection Vessel & Piping Pressure (Pcvo): 120 kPa

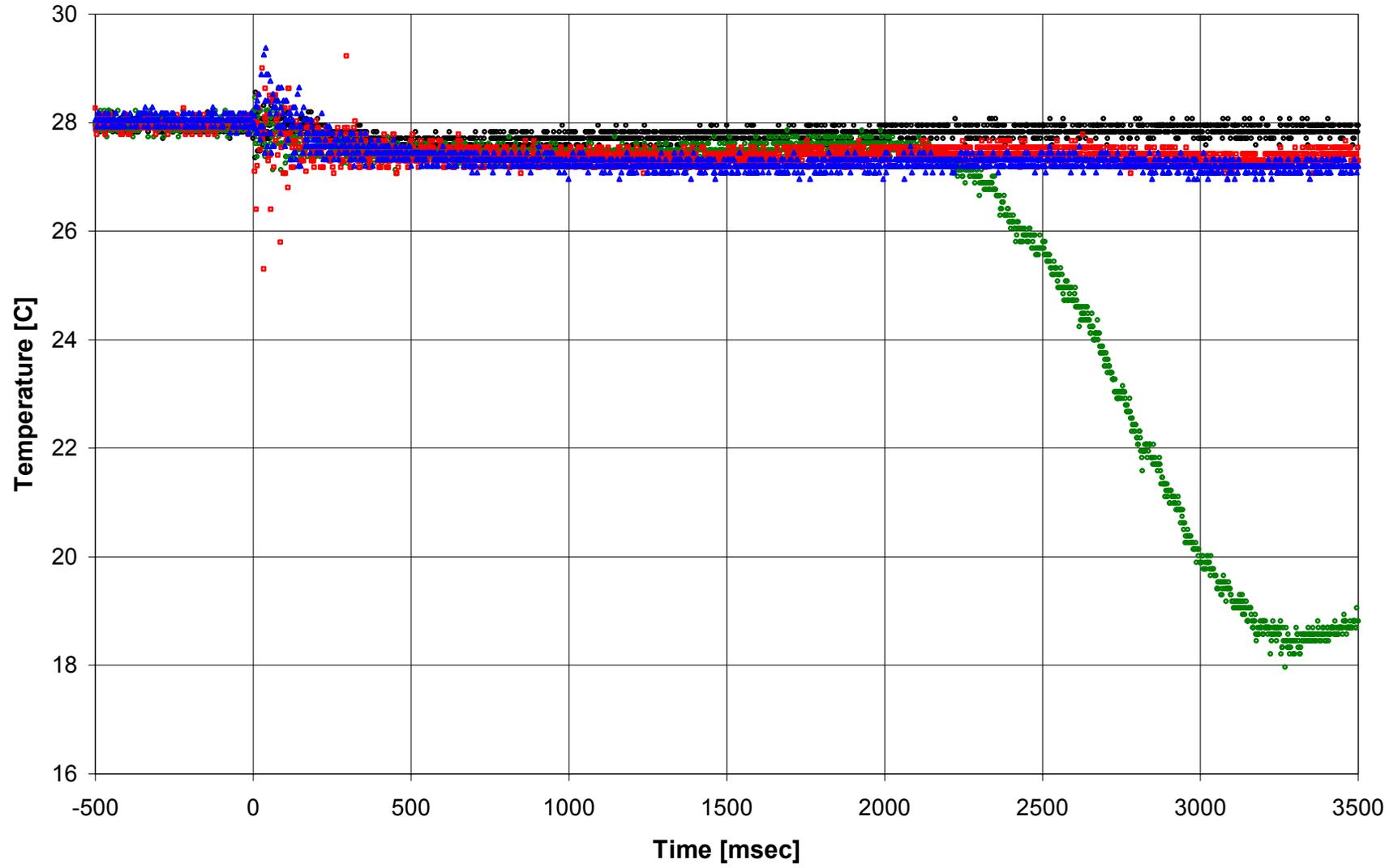
Initial System Temperature: 28° Celsius

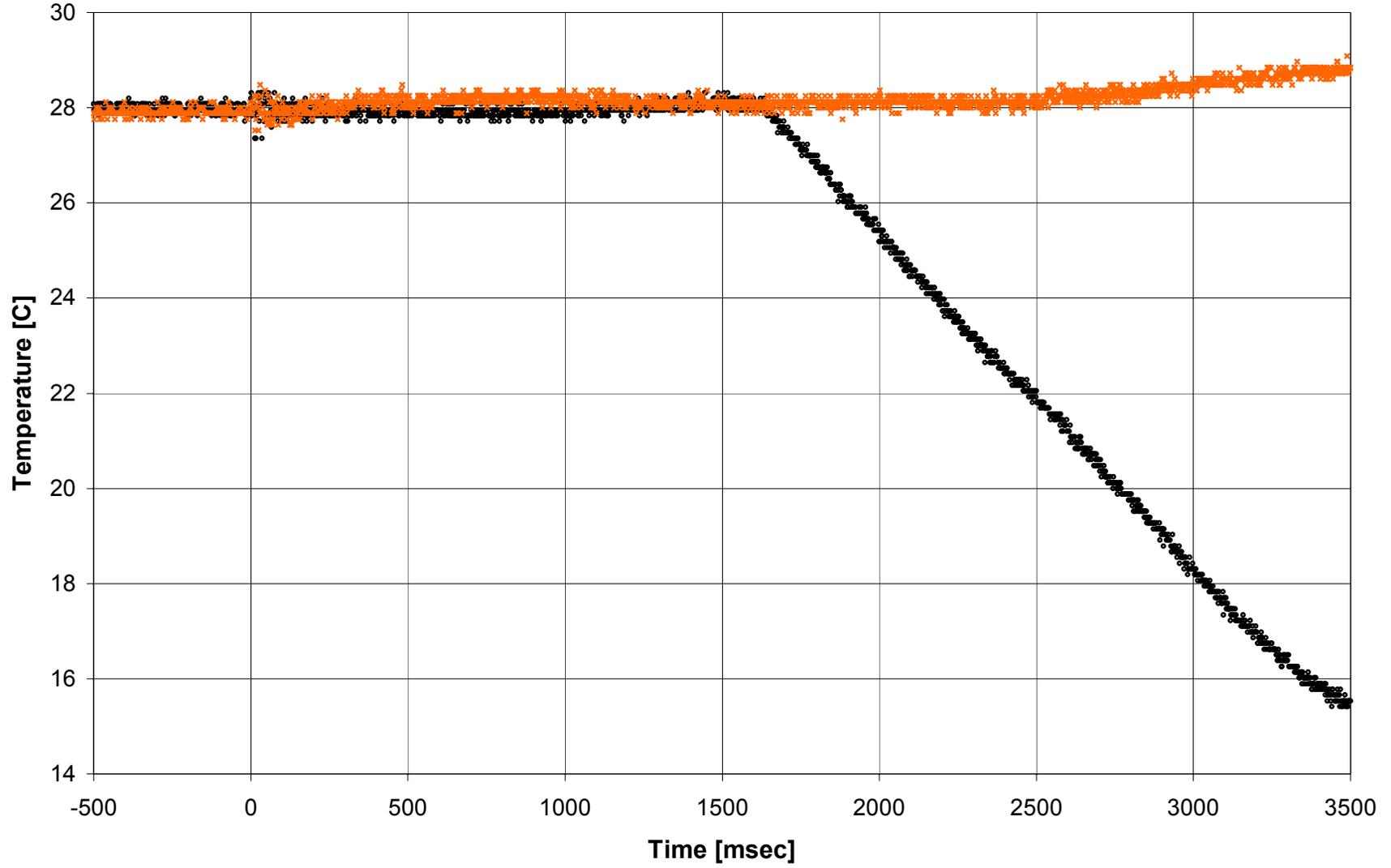
Completion Date: 7/1/99

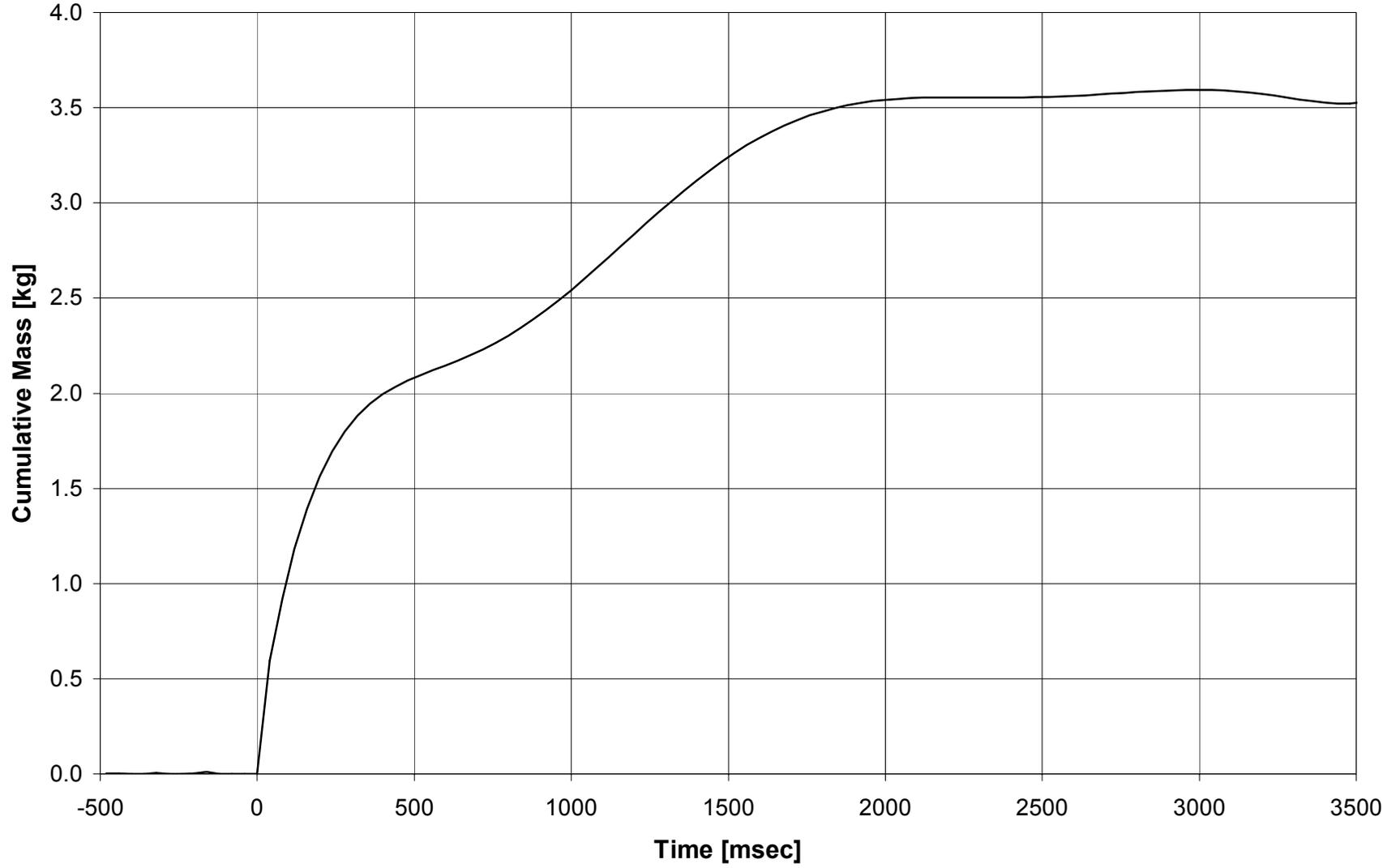
Legend











Run #19

Test Fluid: Water

System Piping Configuration: Straight Pipe

Source Vessel Initial Conditions: Fill Volume: 3100 milliliters
 Fluid Mass: 3.100 kg
 Pressure (Psv0): 4150 kPa

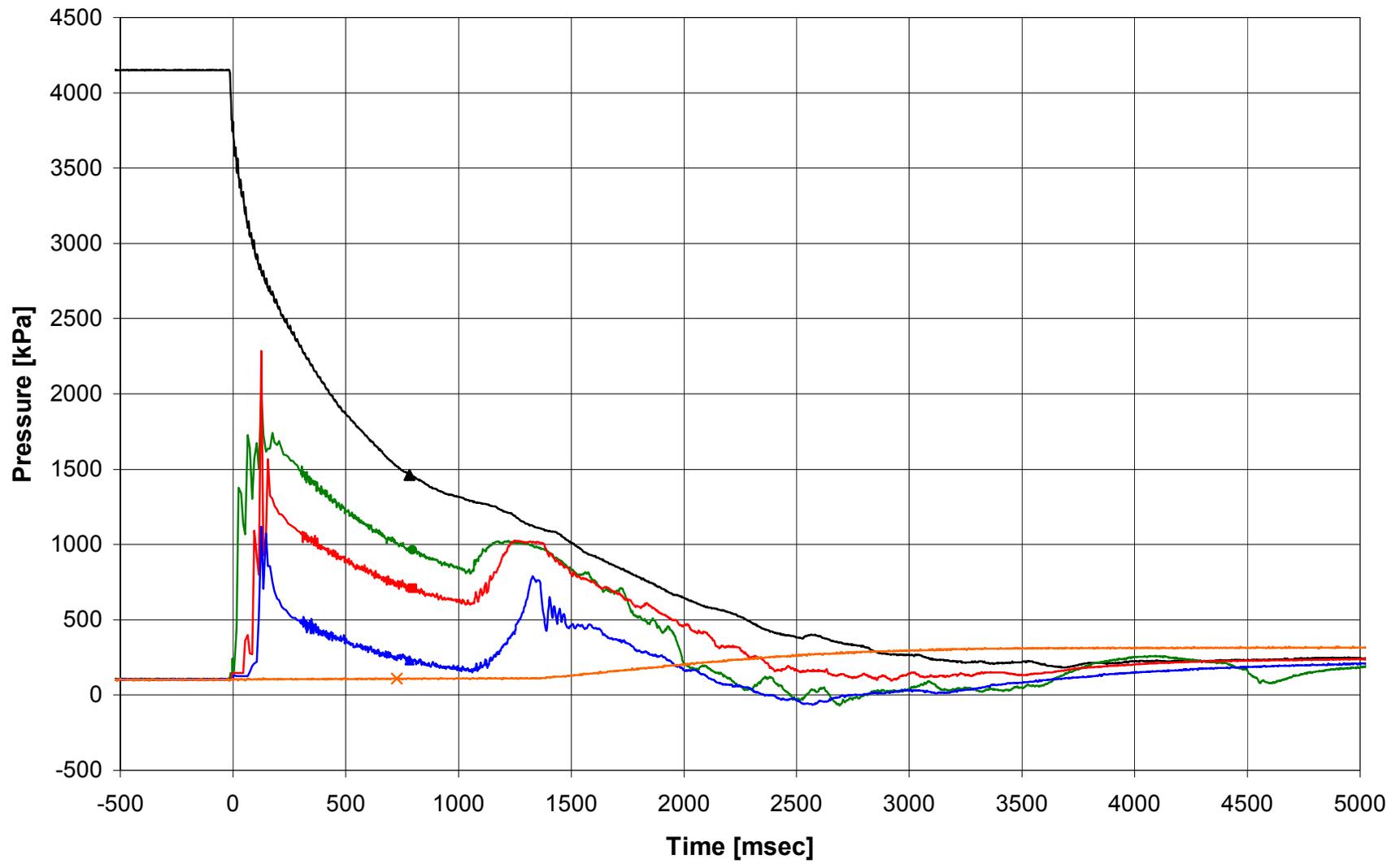
Initial Collection Vessel & Piping Pressure (Pcvo): 100 kPa

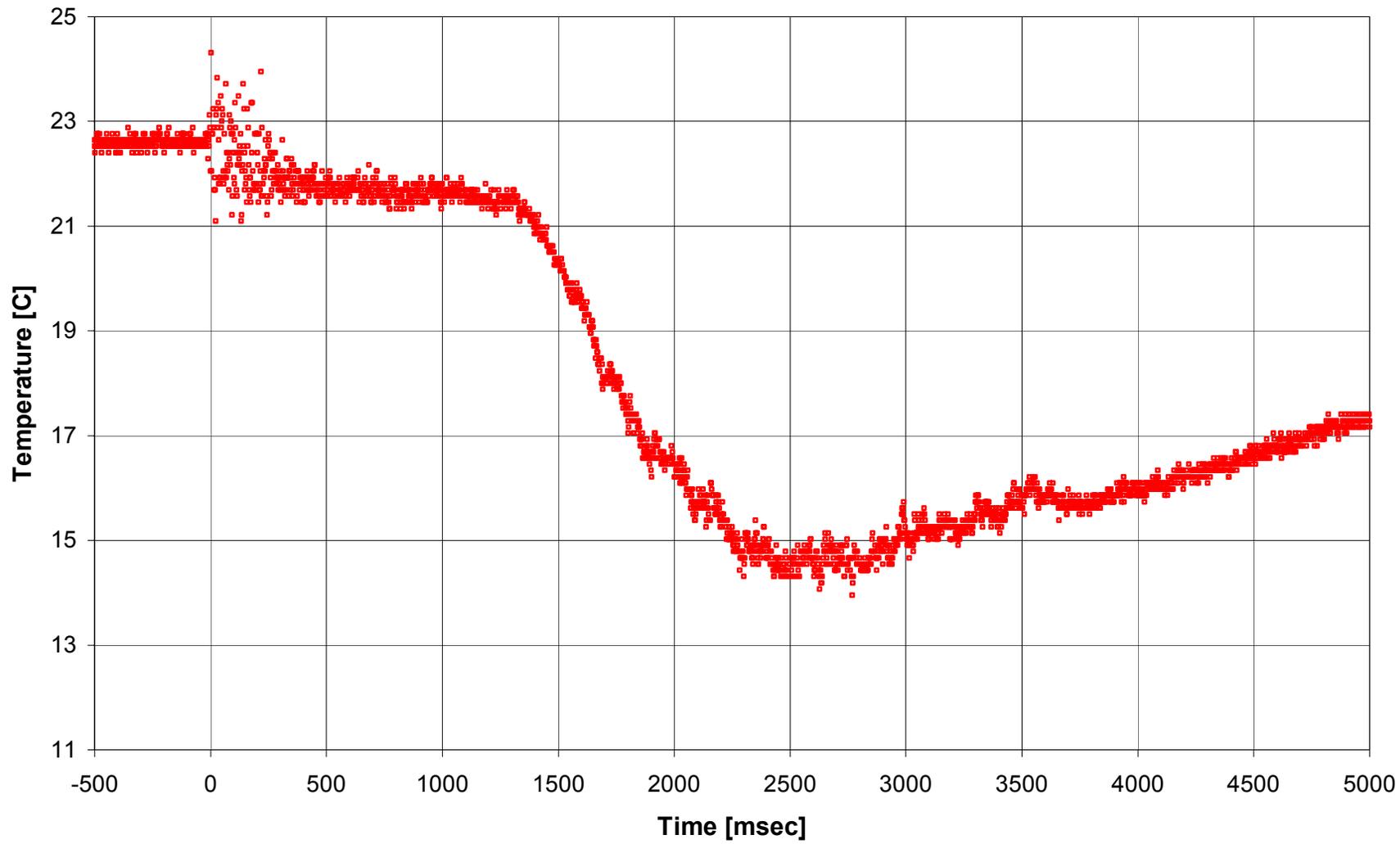
Initial System Temperature: 23° Celsius

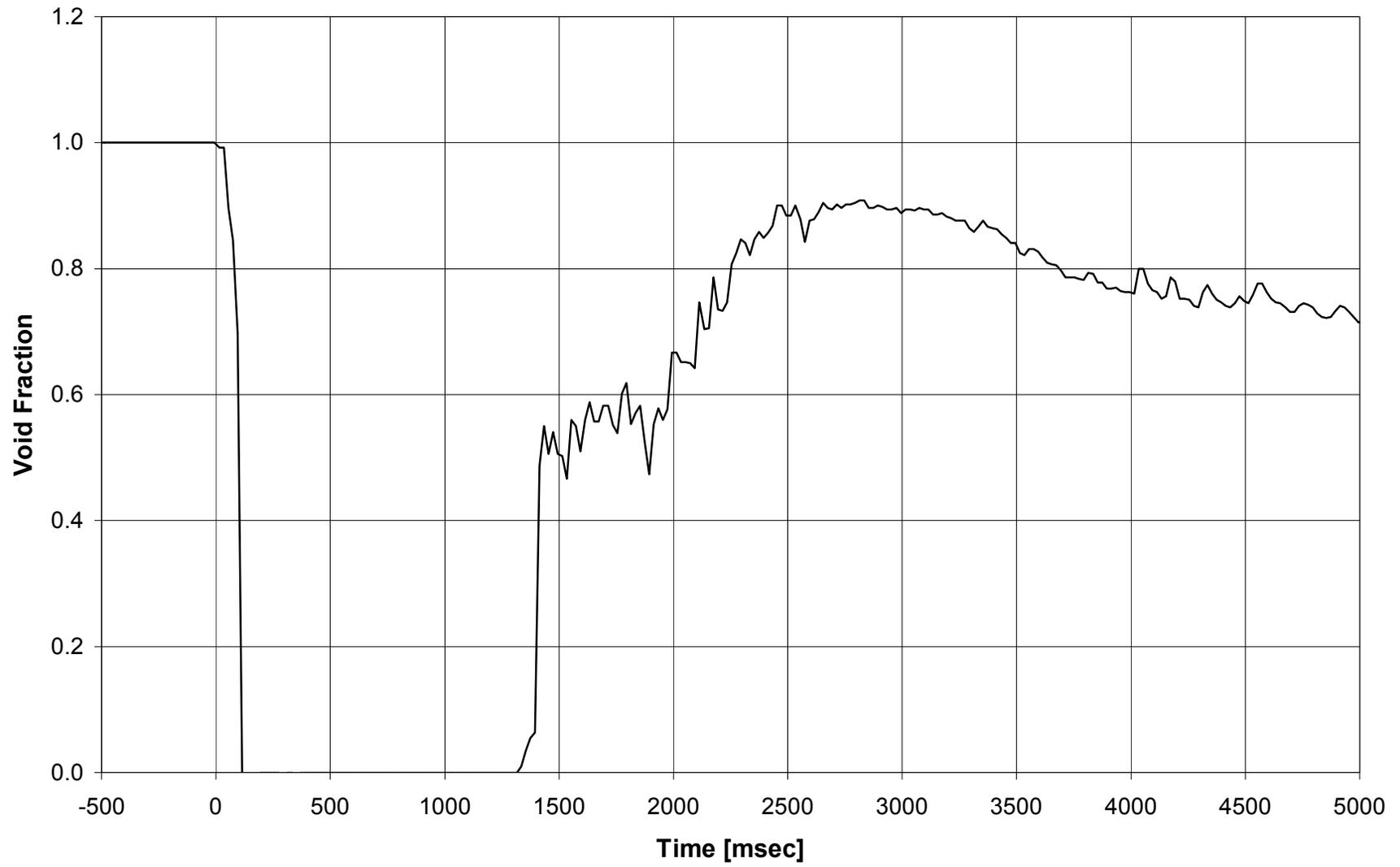
Completion Date: 3/2/99

Legend

◆	Source Vessel
●	Pipe Position 1
■	Pipe Position 2
▲	Pipe Position 3
×	Collection Vessel







Run #20

Test Fluid: Carbon Dioxide (CO₂)
CAS #: 124-38-9
Molecular Weight: 44.01

System Piping Configuration: Straight Pipe

Source Vessel Initial Conditions: Fill Volume: ~1800 milliliters
Pressure (Psvo): 5215 kPa

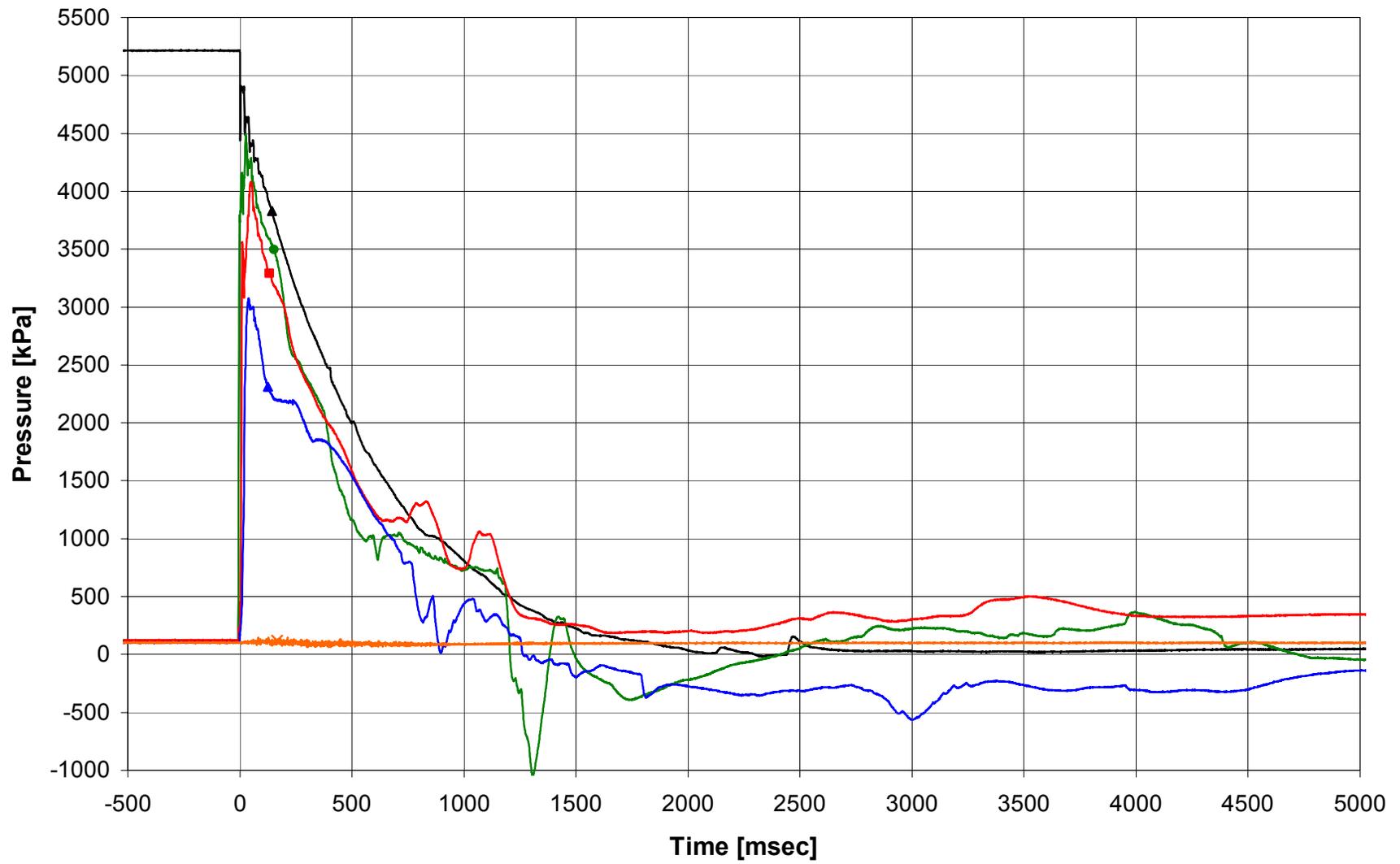
Initial Collection Vessel & Piping Pressure (Pcvo): 100 kPa

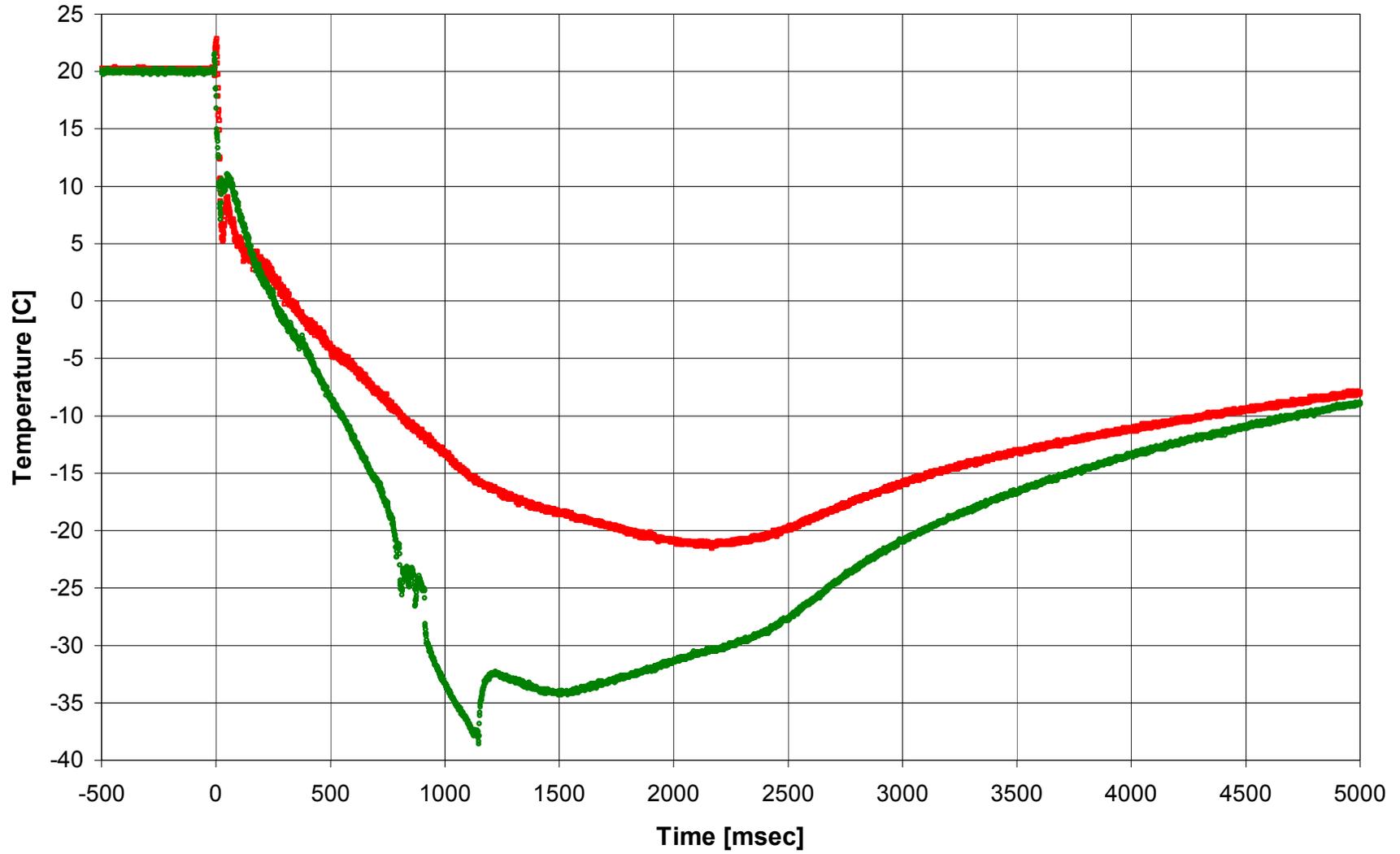
Initial System Temperature: 20° Celsius

Completion Date: 3/11/99

Legend

—◆—	Source Vessel
—●—	Pipe Position 1
—■—	Pipe Position 2
—▲—	Pipe Position 3
—×—	Collection Vessel





Run #21

Test Fluid: Carbon Dioxide (CO₂)
CAS #: 124-38-9
Molecular Weight: 44.01

System Piping Configuration: Straight Pipe

Source Vessel Initial Conditions: Fill Volume: ~1000 milliliters
Pressure (P_{svo}): 5360 kPa

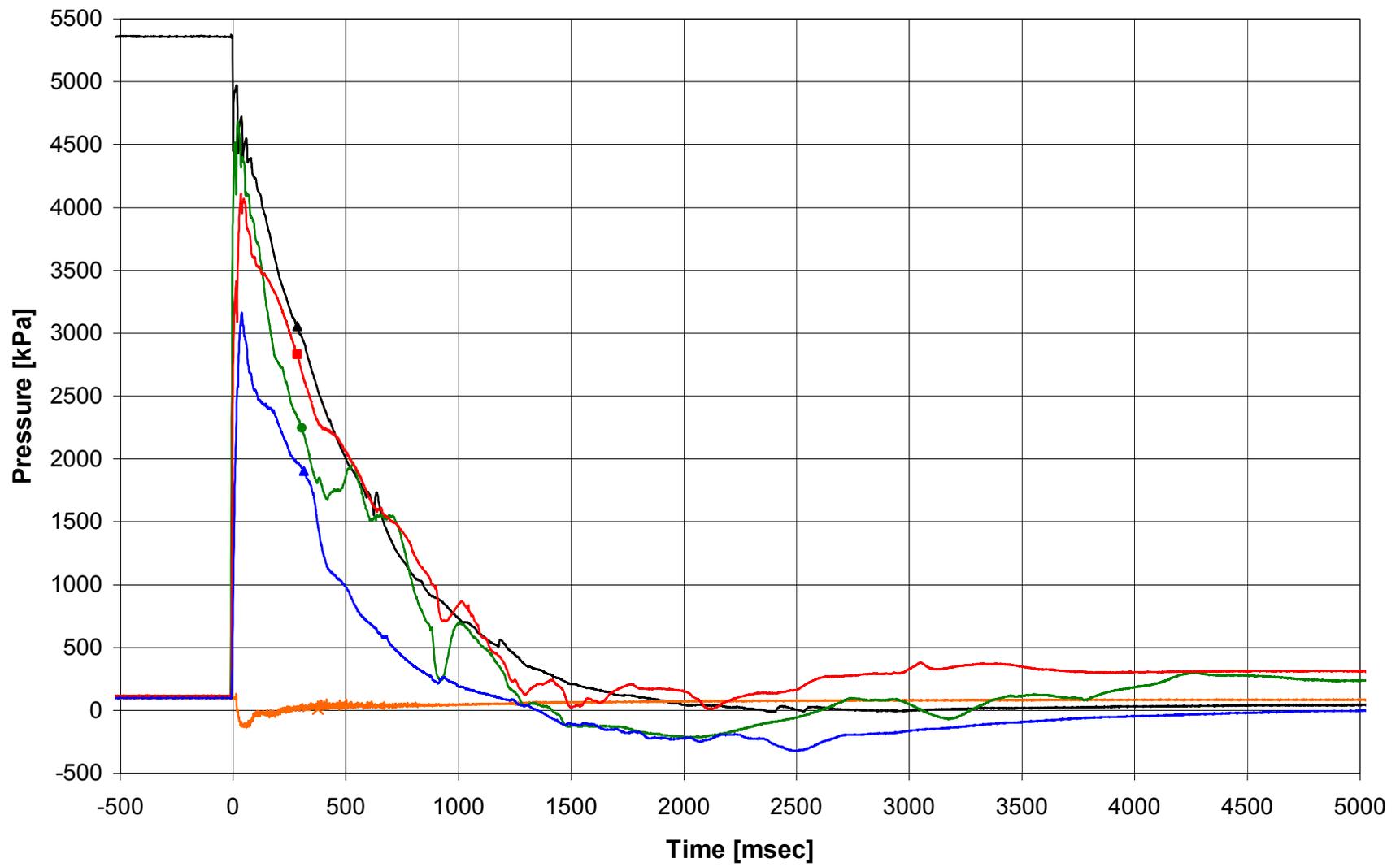
Initial Collection Vessel & Piping Pressure (P_{cvo}): 100 kPa

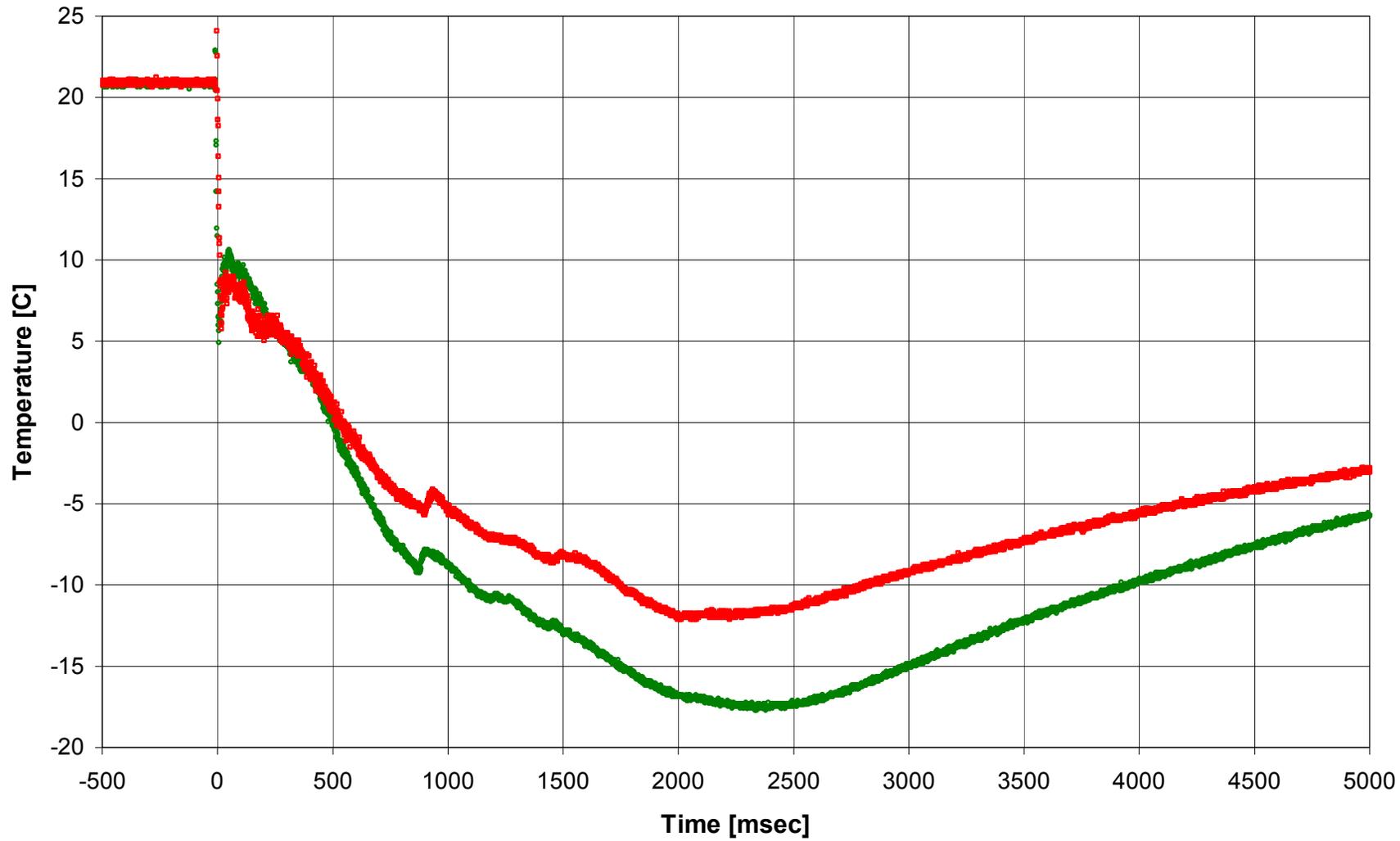
Initial System Temperature: 20° Celsius

Completion Date: 3/10/99

Legend

—◆—	Source Vessel
—●—	Pipe Position 1
—■—	Pipe Position 2
—▲—	Pipe Position 3
—×—	Collection Vessel





APPENDIX C

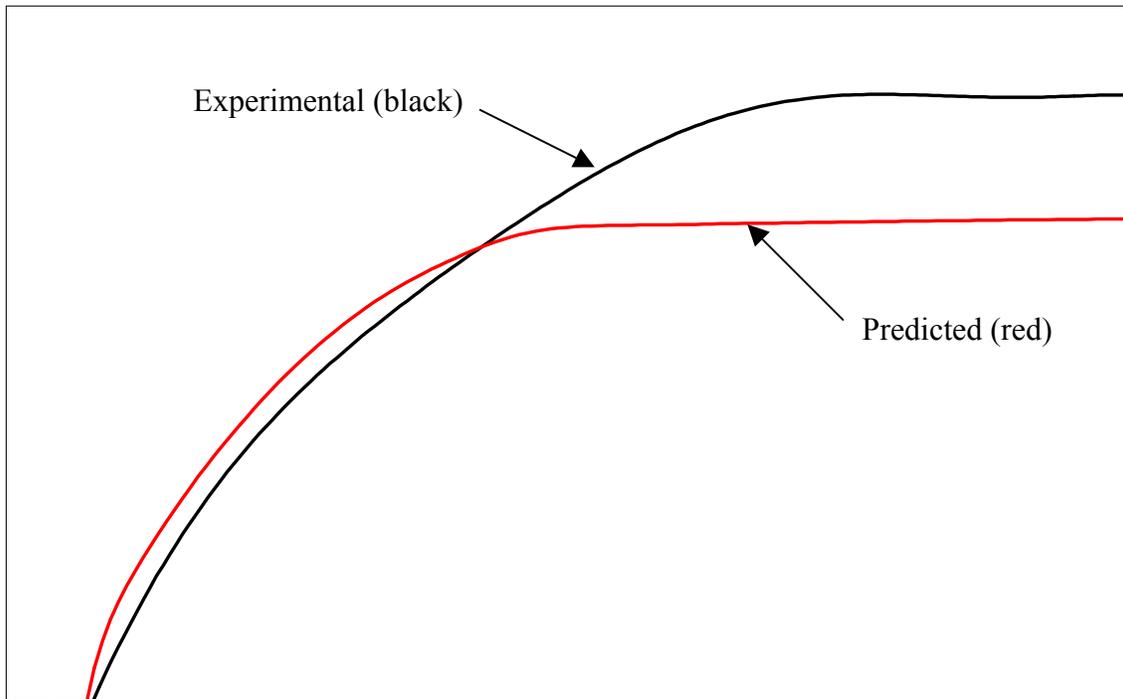
COMPARISON OF PREDICTION

VERSUS

EXPERIMENTAL RESULTS

This appendix contains the complete results of the comparisons made between the predictive output of the computer program and the experimental tests conducted at the Lehigh University facility. The next page is a chart of all of the experimental runs included in this appendix.

Each run will include a cover page describing the initial operating conditions and any necessary identification information of the experimental run along with a list of the comparison graphs included in the set. Each plot follows the same format, the black line shows the experimental values and the red line depicts the prediction results. An example is shown below.



Run #	Γ_O	R_C [m]	V_E [mL]	V_P [mL]	P_{SE} [kPa]	P_{SP} [kPa]	P_{CE} [kPa]	P_{CP} [kPa]	T_E [°C]	T_{SP} [°C]	T_{CP} [°C]
1	2000	1.0e-8	3571	3571	2125	2125	10	600	32	32	32
2	2000	1.0e-8	2340	2340	3235	3235	635	635	33	33	33
3	2000	1.0e-8	2358	2358	4180	4180	720	720	32	32	32
4	2000	1.0e-8	2370	2370	4195	4195	525	525	29	29	29
5	2000	1.0e-8	2388	2388	4220	4220	720	720	31	30	30
6	2000	1.0e-8	2150	2150	4910	4860	715	715	31	2	30
7	2000	1.0e-8	2200	2388	4230	4230	710	720	27	30	30
8	2000	1.0e-8	3420	3420	2120	2120	125	405	21	21	21
9	2000	1.0e-8	2500	2500	3915	3915	575	575	24	24	24
10	2000	1.0e-8	2450	2450	4910	4860	615	615	25	1	25
11	2000	1.0e-8	3507	3507	2140	2140	600	600	26	26	26
12	2000	1.0e-8	2400	2400	3935	3935	655	655	24	27	27
13	2000	1.0e-8	2460	2460	4910	4860	615	615	25	1	25
14	2000	1.0e-8	2900	2900	2050	2050	110	110	26	24	24
15	2000	1.0e-8	2363	2363	3635	3635	175	175	26	26	26
16	2000	1.0e-8	2400	2400	4245	4245	165	165	26	26	26
17	2000	1.0e-8	2467	2467	5000	4970	125	125	24	1	24
18	2000	1.0e-8	3585	3585	2875	2875	120	120	28	28	28
19	2000	1.0e-8	3100	na	4150	na	100	na	23	na	na
20	2000	1.0e-8	~1000	na	5215	na	100	na	20	na	na
21	2000	1.0e-8	~1000	na	5360	na	100	na	20	na	na

Run #1 with Code Prediction

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Straight Pipe

Source Vessel Initial Conditions: Fill Volume: 3571 milliliters
 Fluid Mass: 4.925 kg
 Pressure (Psvo): 2125 kPa
 Nitrogen Mass: 0.051 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 10 kPa

Initial System Temperature: 32° Celsius

Completion Date: 7/12/99

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

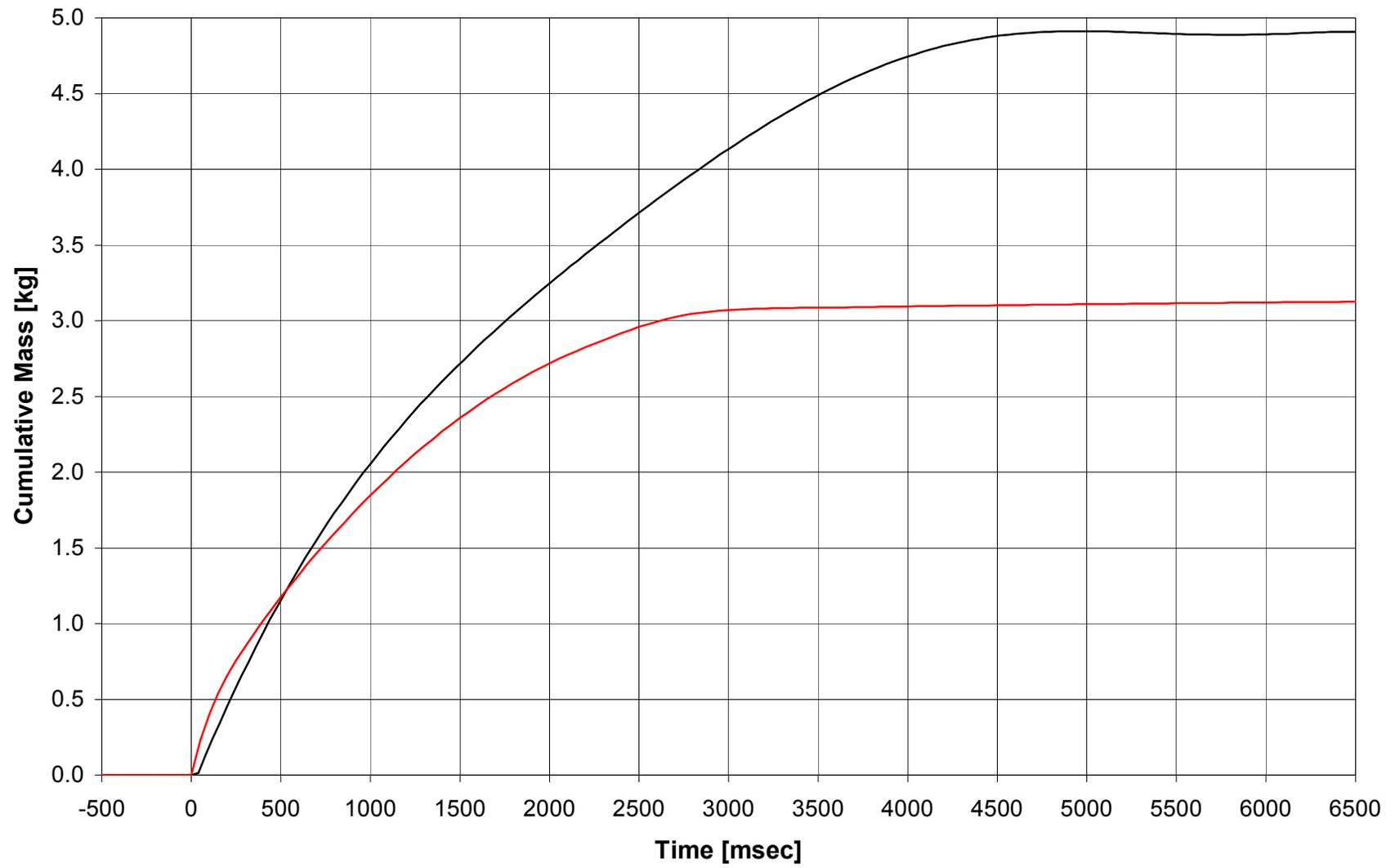
Graph 3: Source Vessel Pressure

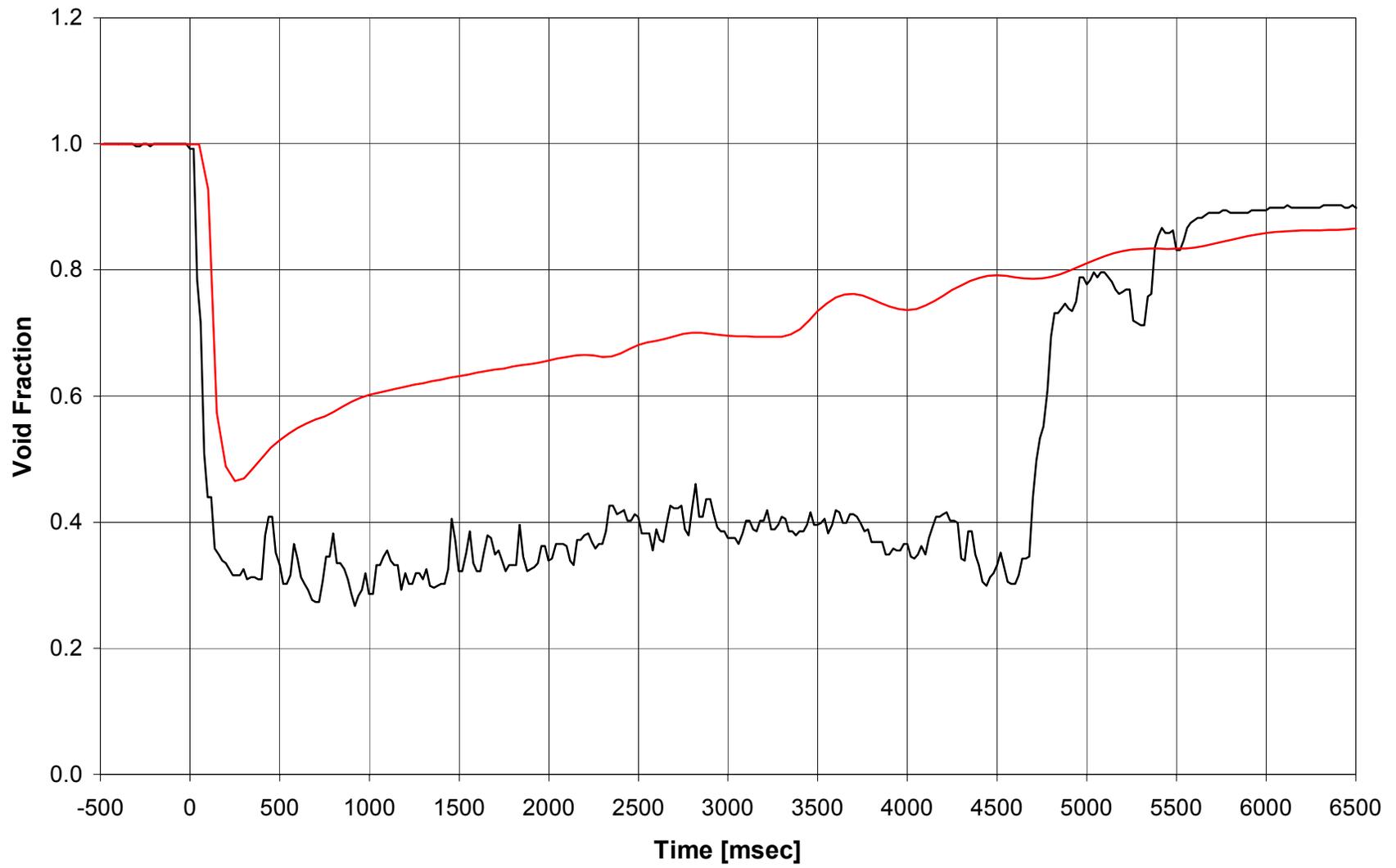
Graph 4: Pipe Position #1 Pressure

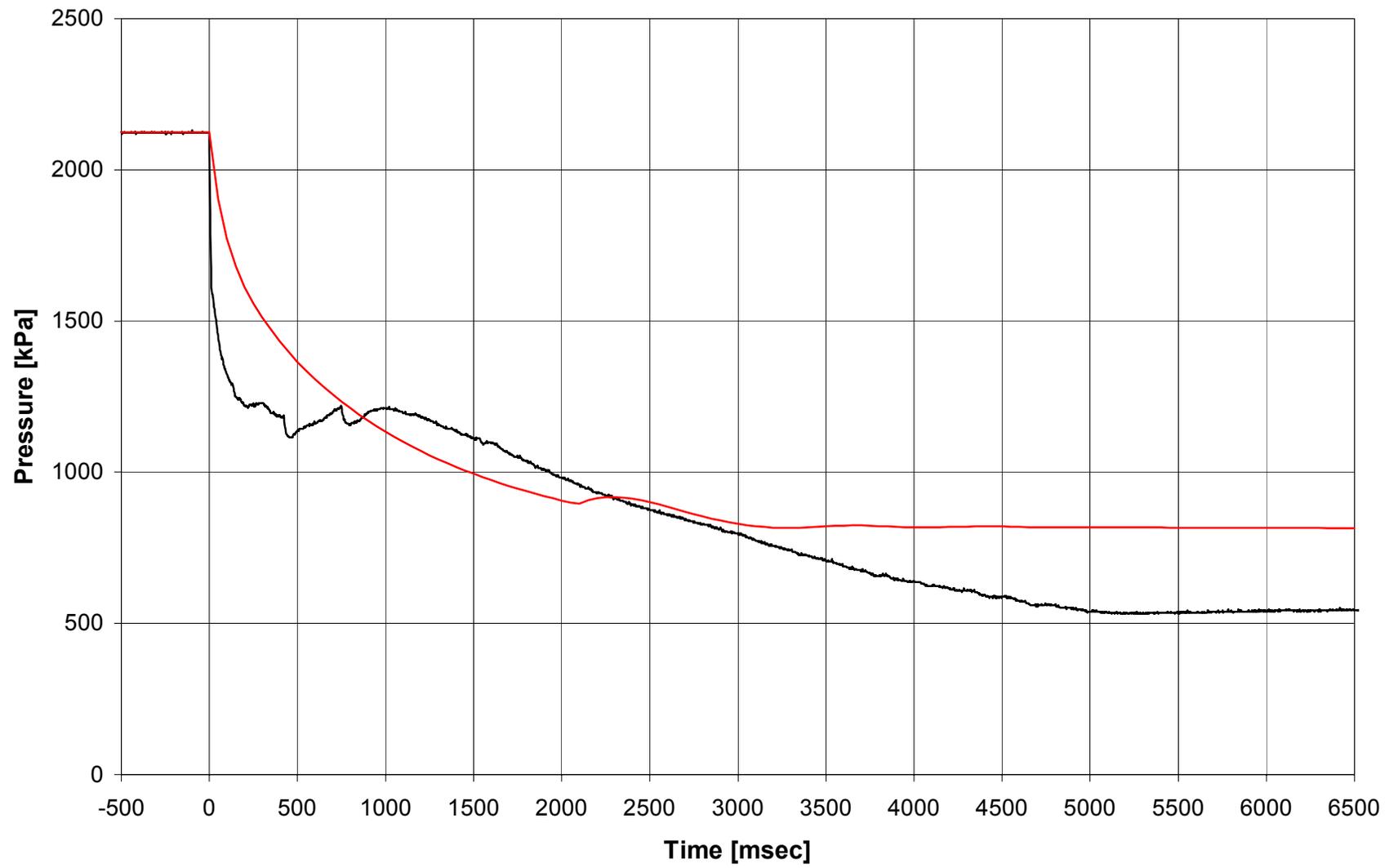
Graph 5: Pipe Position #2 Pressure

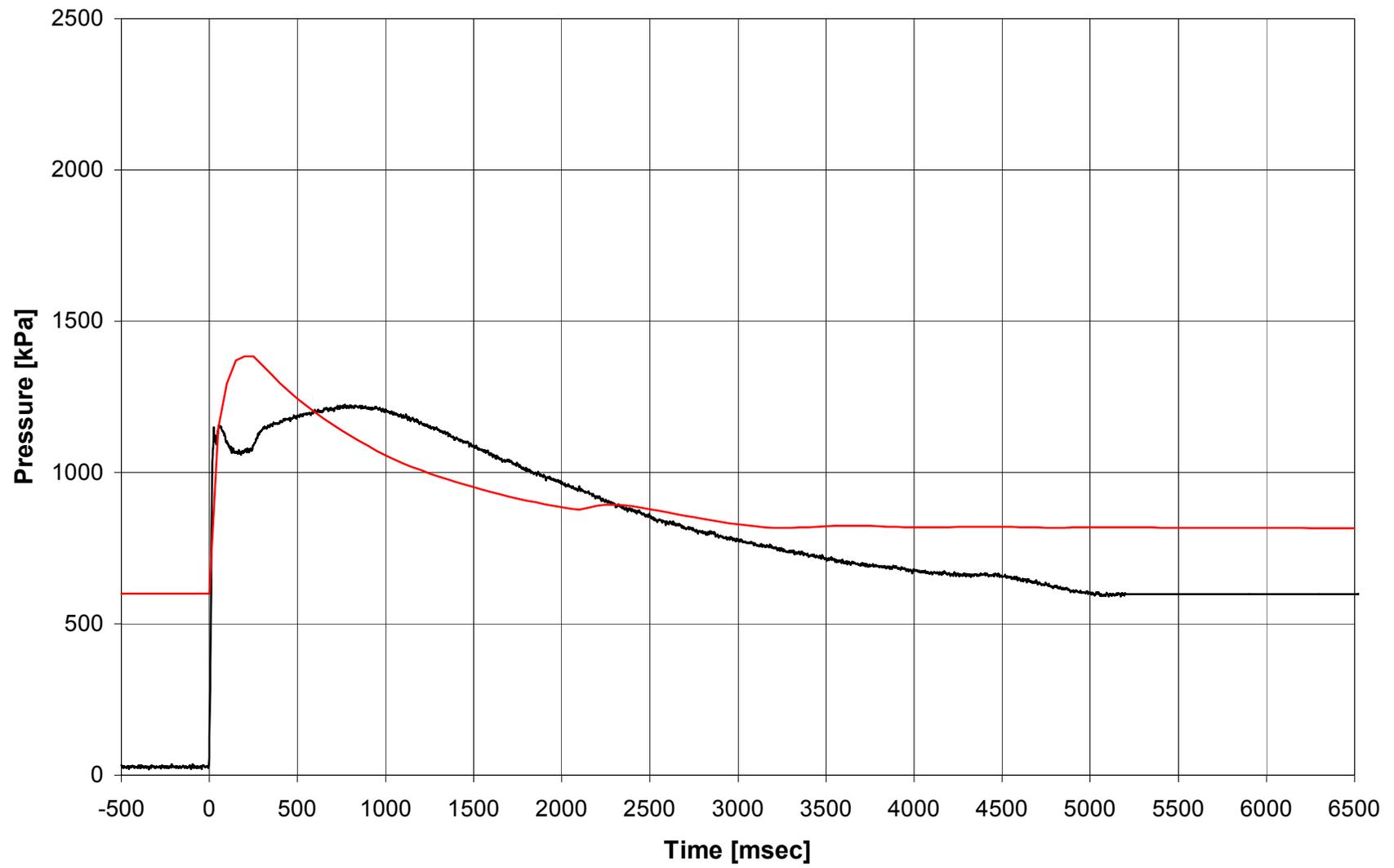
Graph 6: Pipe Position #3 Pressure

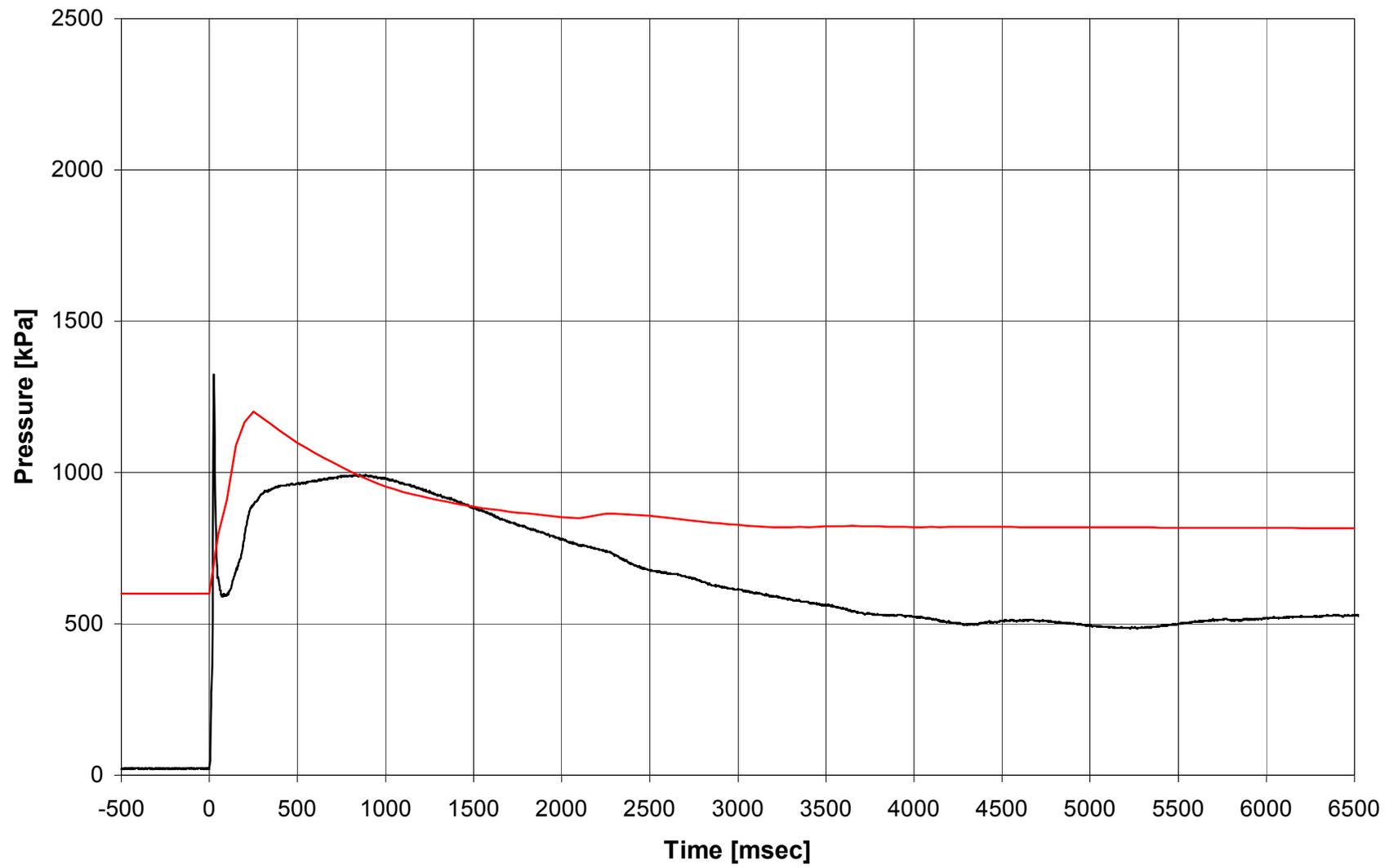
Graph 7: Collection Vessel Pressure

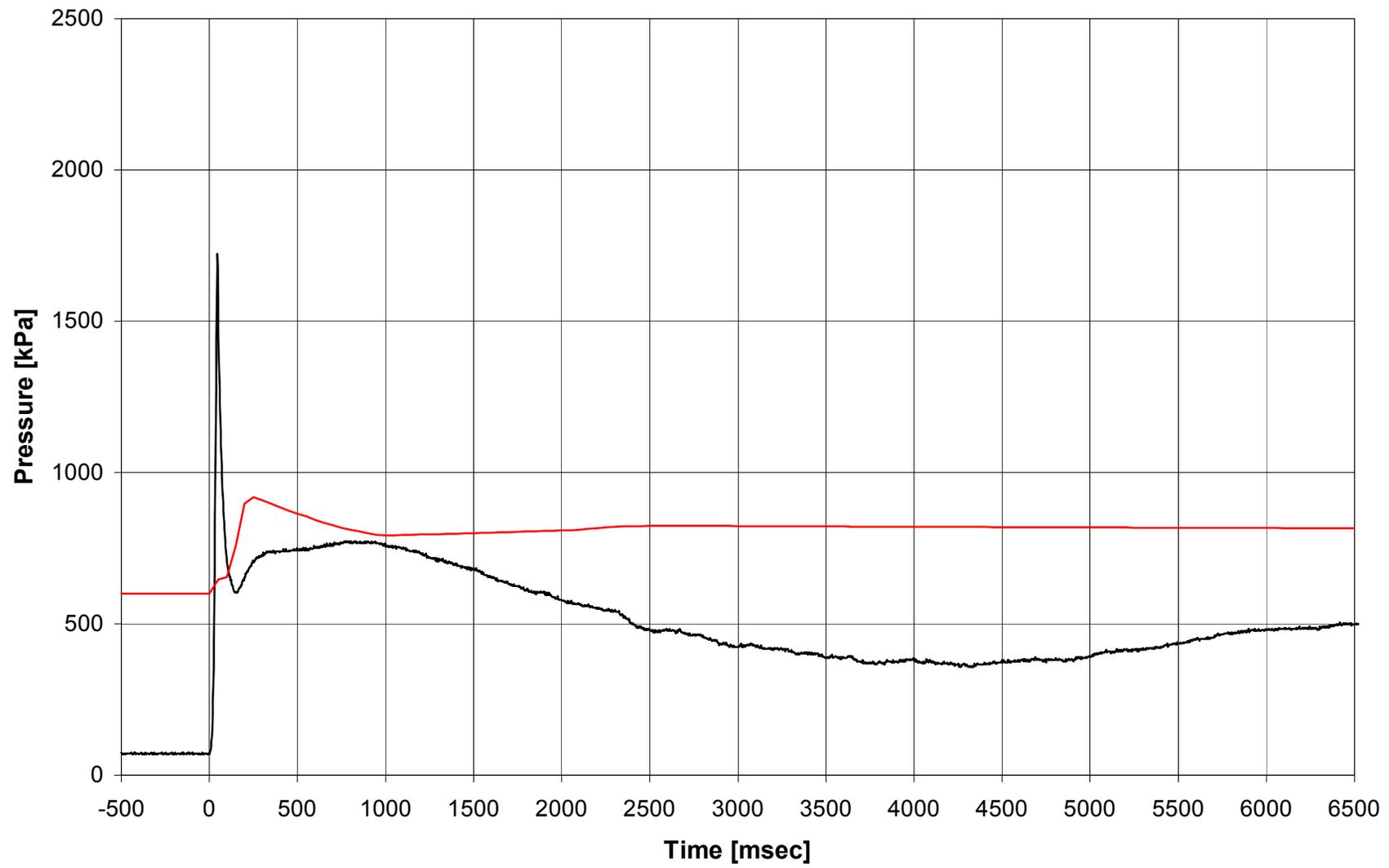


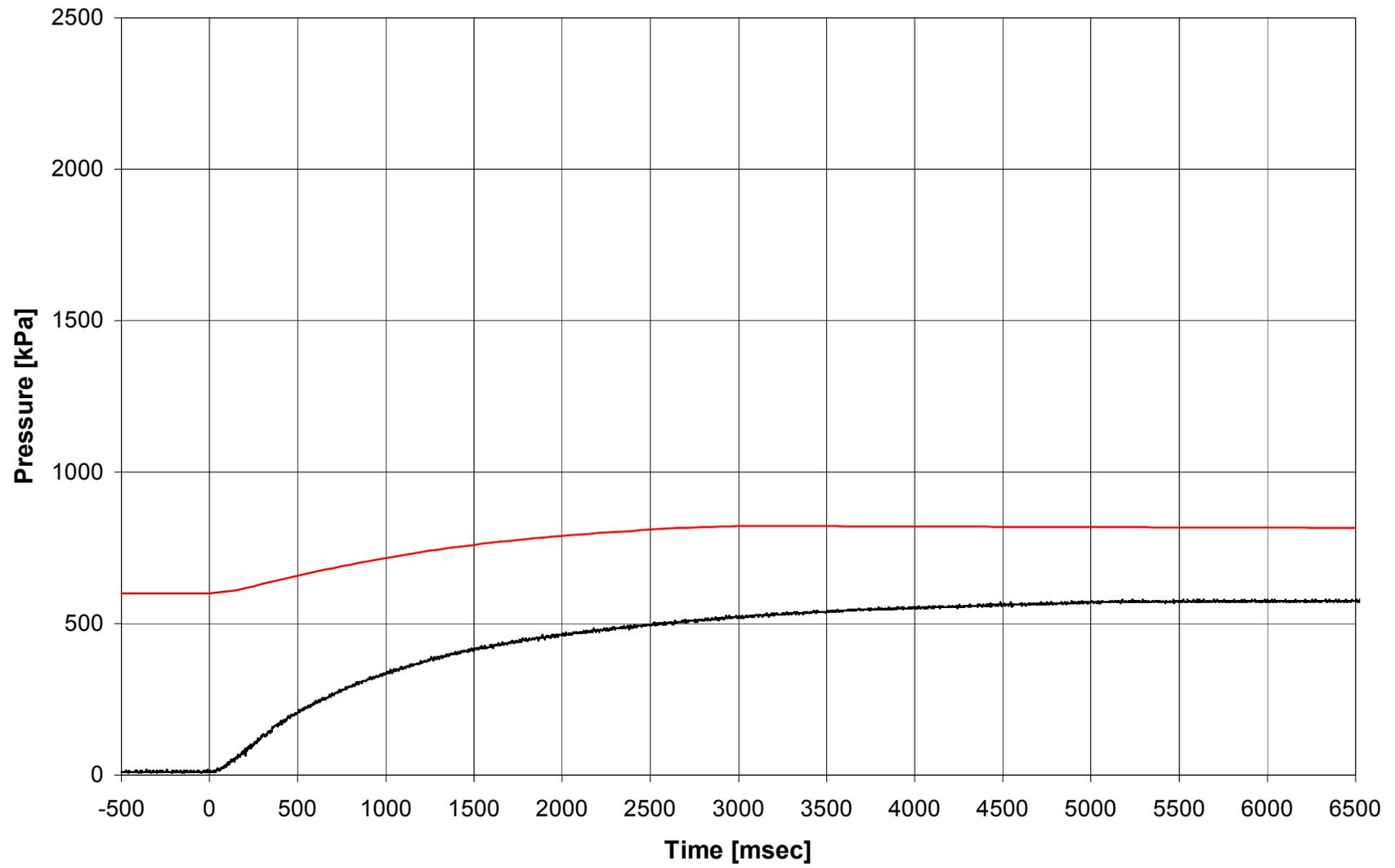












Run #2 with Code Prediction

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea) C₂HF₅ Pentafluoroethane
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Straight Pipe

Source Vessel Initial Conditions: Fill Volume: 2340 milliliters
 Fluid Mass: 3.246 kg
 Pressure (Psvo): 3235 kPa
 Nitrogen Mass: 0.097 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 635 kPa

Initial System Temperature: 33° Celsius

Completion Date: 8/12/99

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

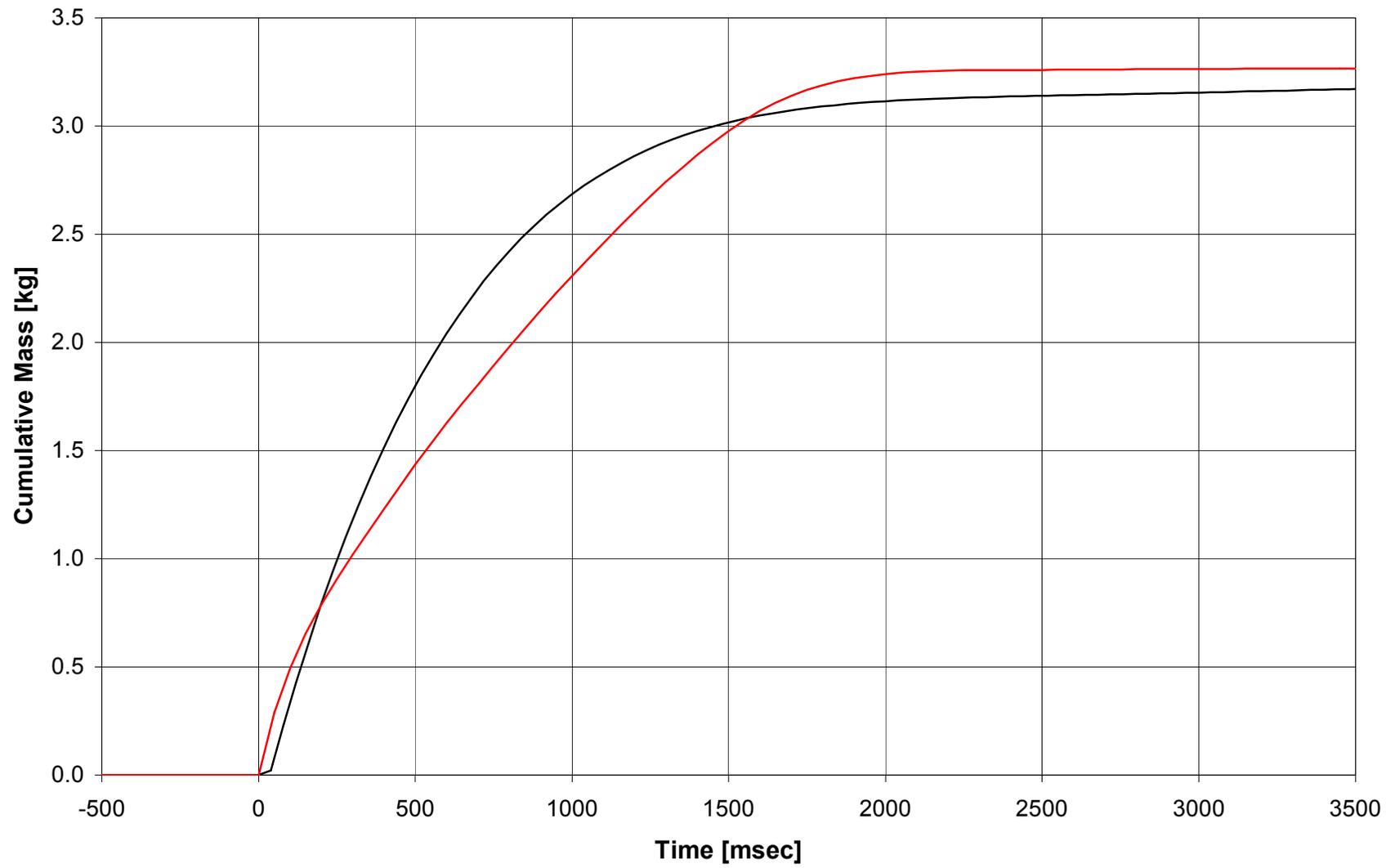
Graph 3: Source Vessel Pressure

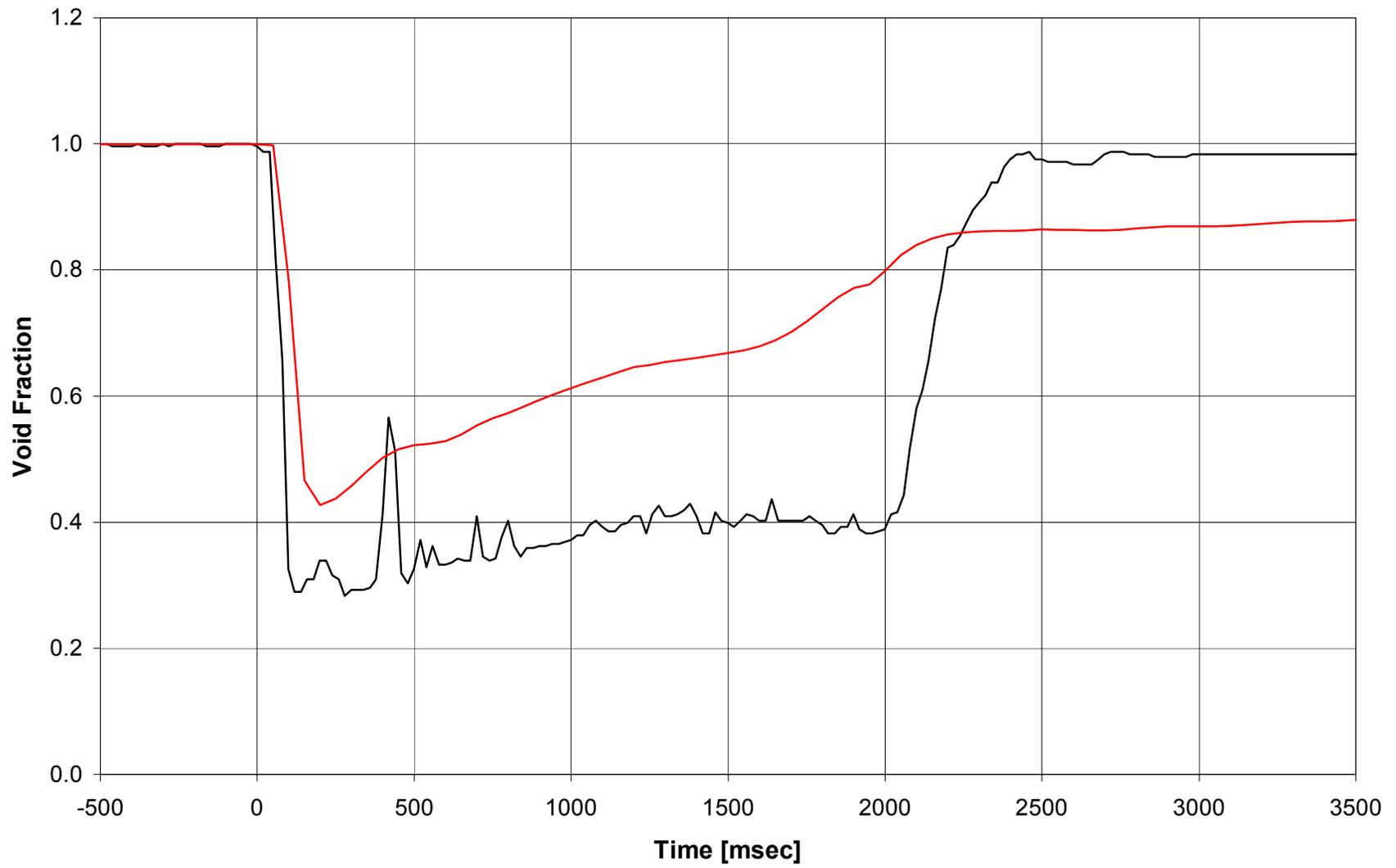
Graph 4: Pipe Position #1 Pressure

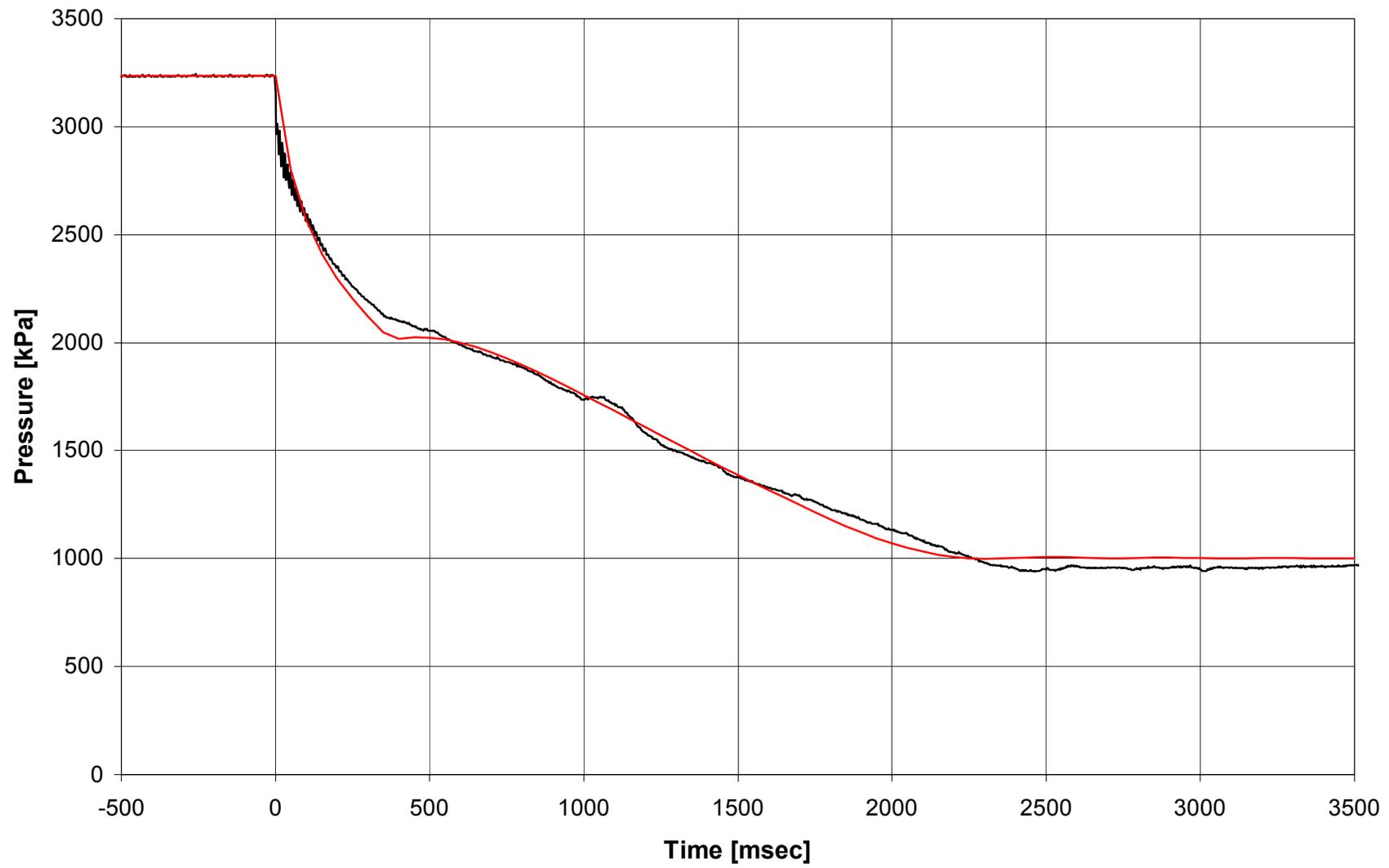
Graph 5: Pipe Position #2 Pressure

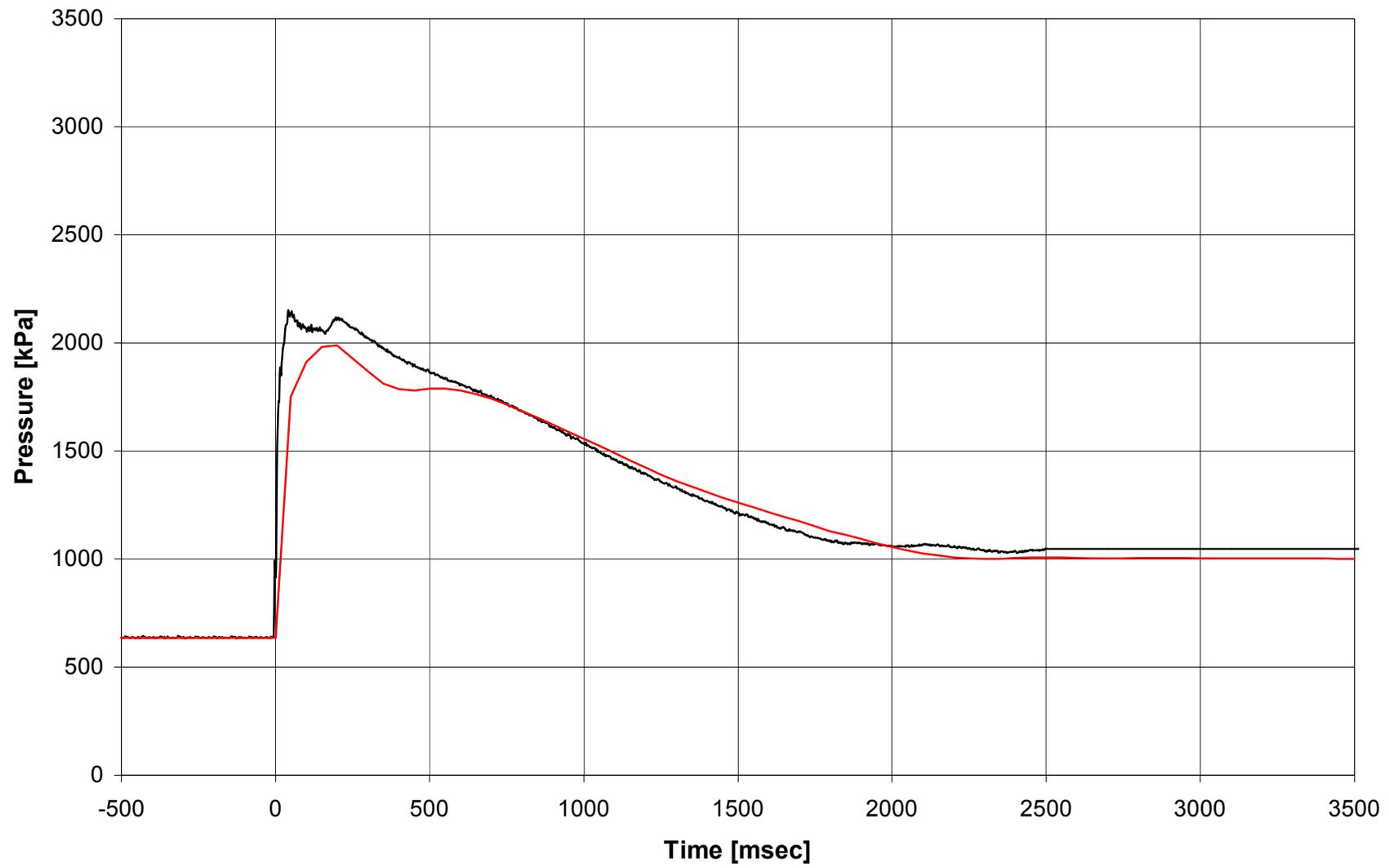
Graph 6: Pipe Position #3 Pressure

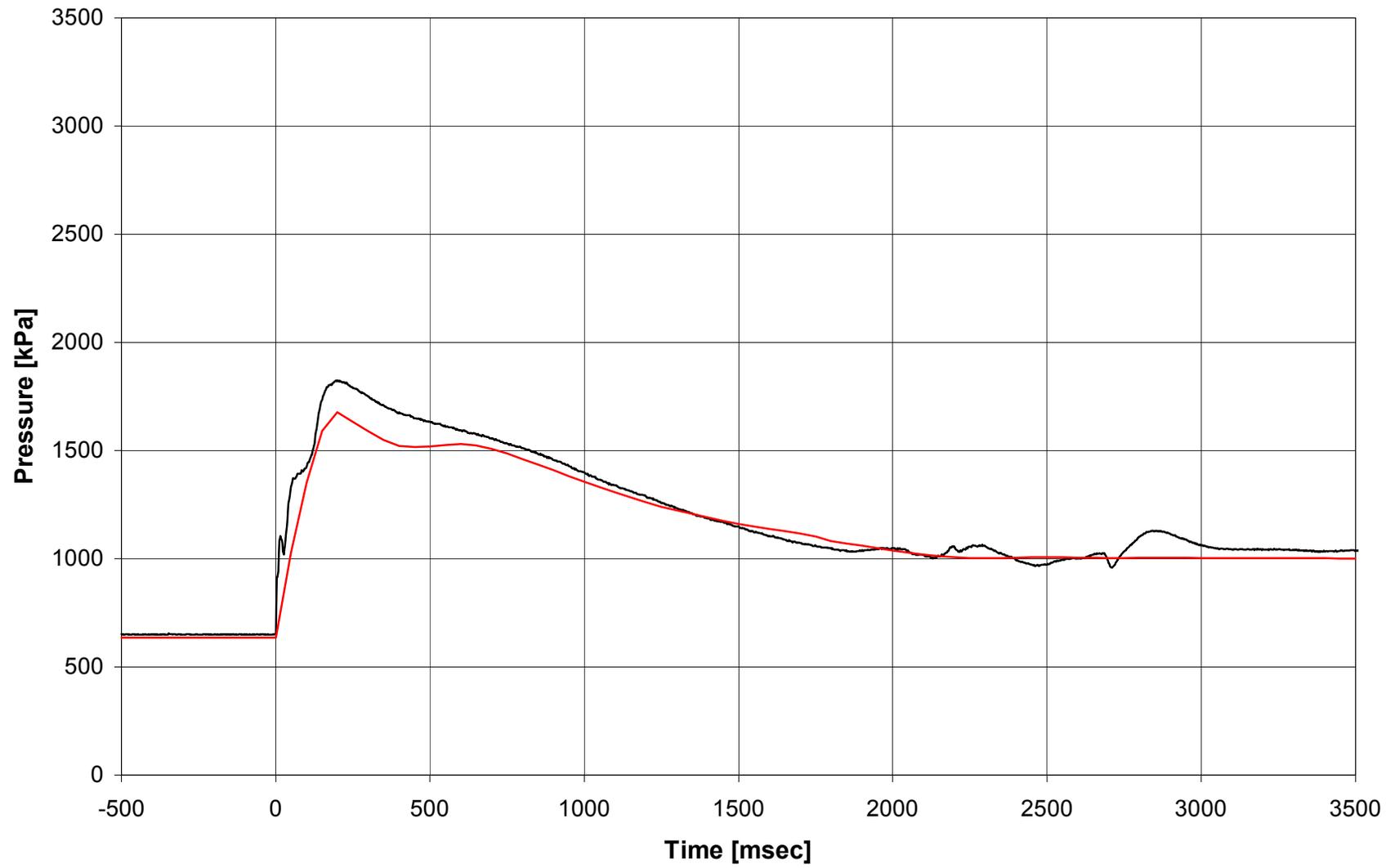
Graph 7: Collection Vessel Pressure

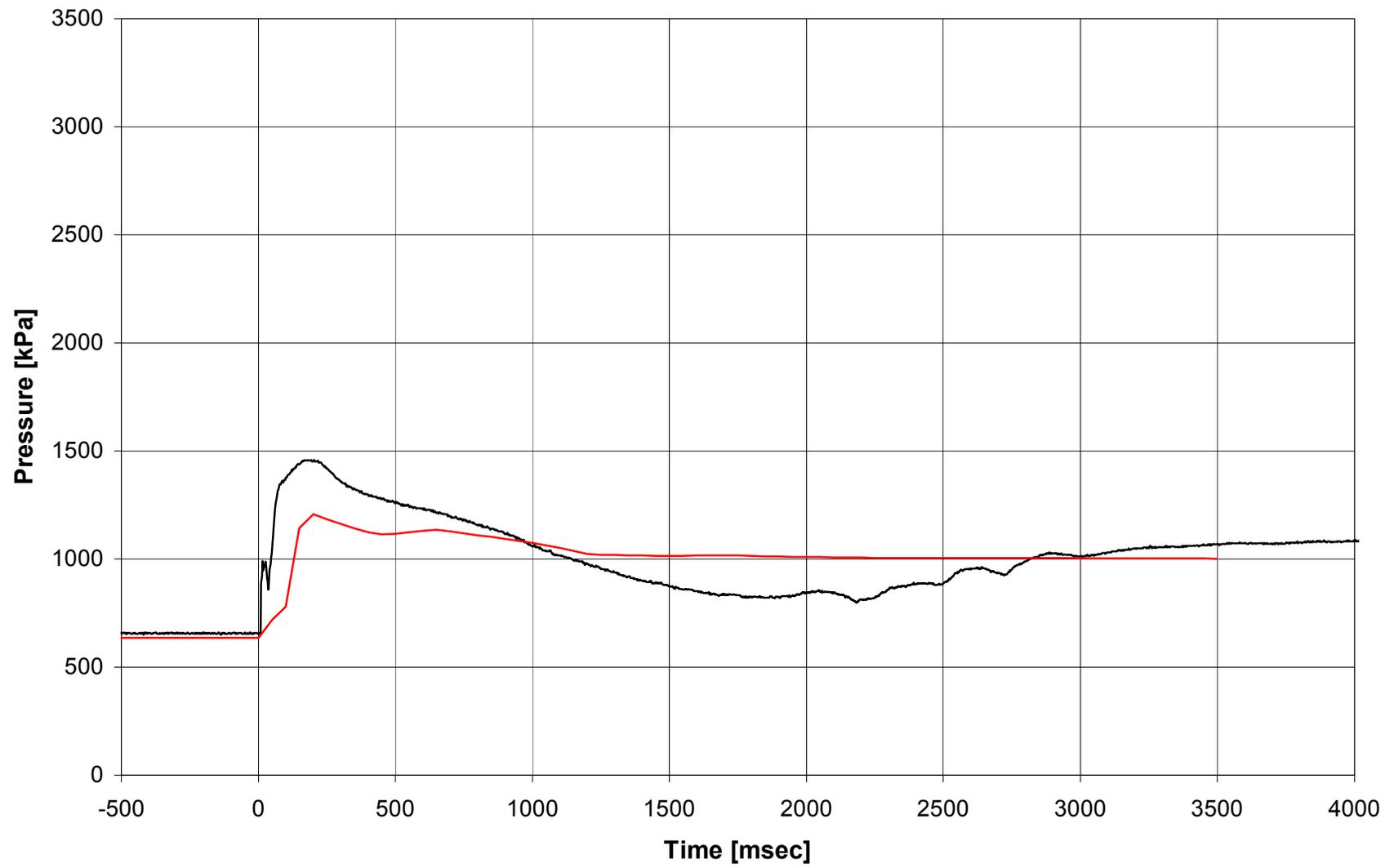


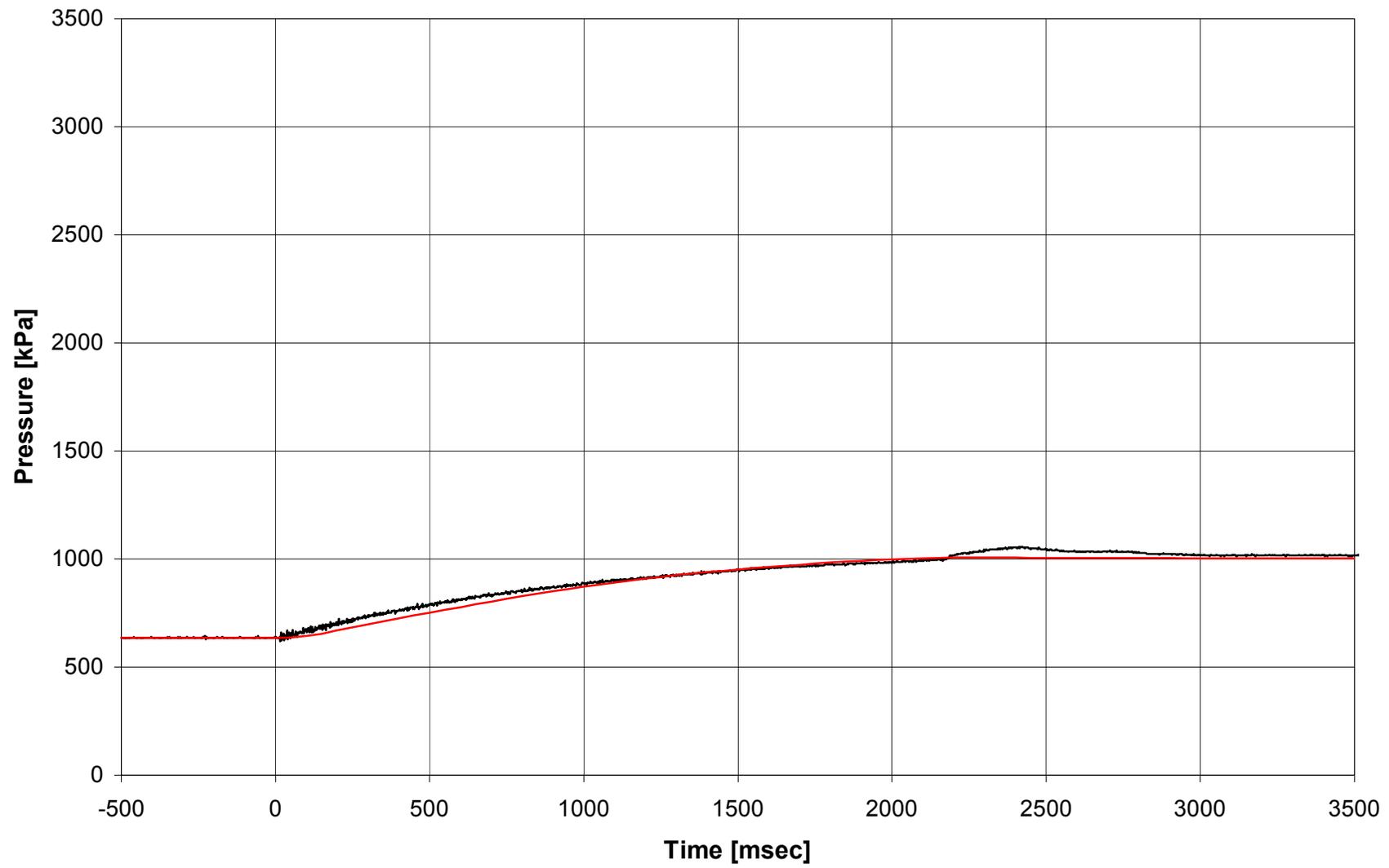












Run #3 with Code Prediction

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Straight Pipe

Source Vessel Initial Conditions: Fill Volume: 2358 milliliters
 Fluid Mass: 3.305 kg
 Pressure (Psvo): 4180 kPa
 Nitrogen Mass: 0.132 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 720 kPa

Initial System Temperature: 32° Celsius

Completion Date: 7/19/99

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

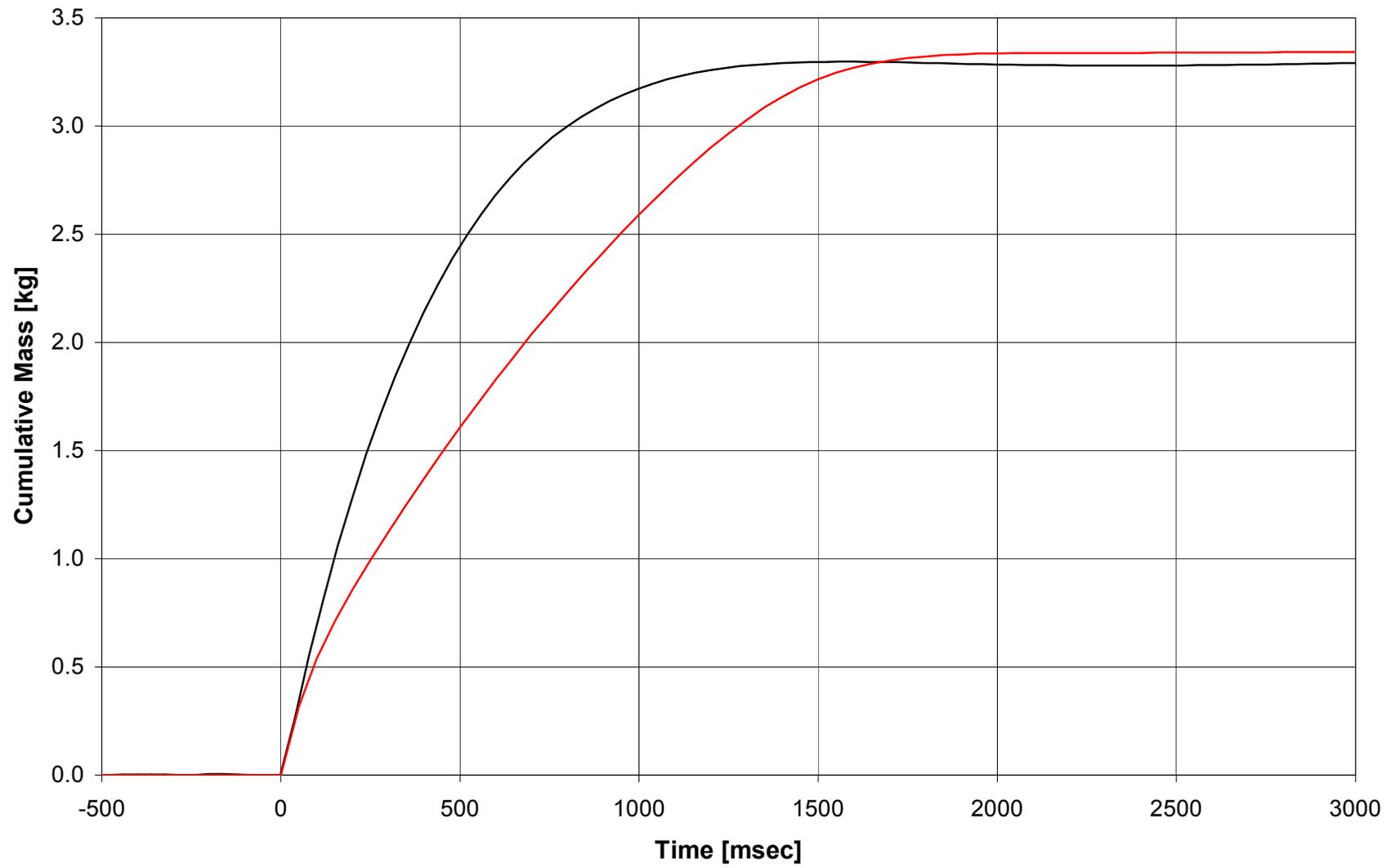
Graph 3: Source Vessel Pressure

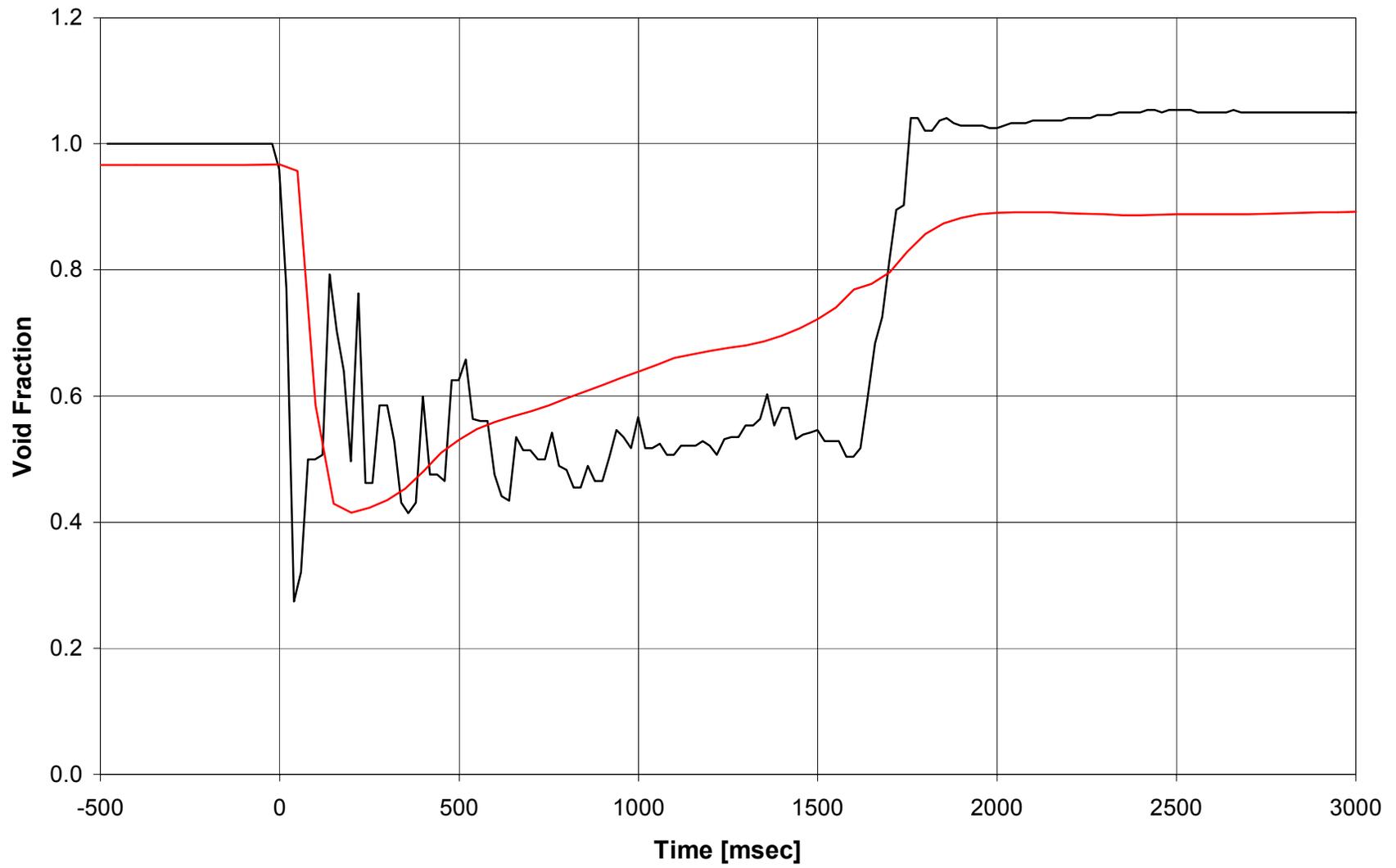
Graph 4: Pipe Position #1 Pressure

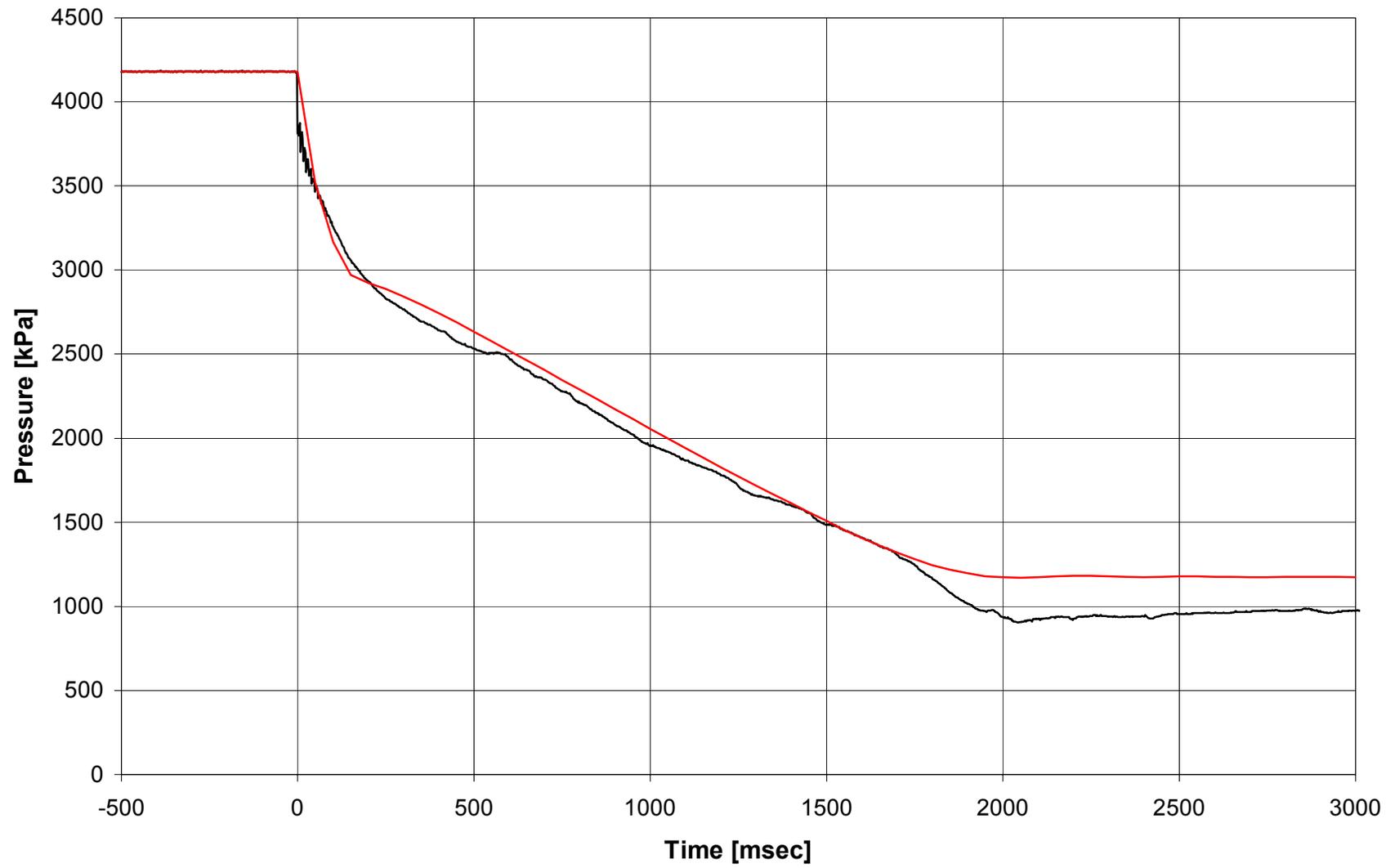
Graph 5: Pipe Position #2 Pressure

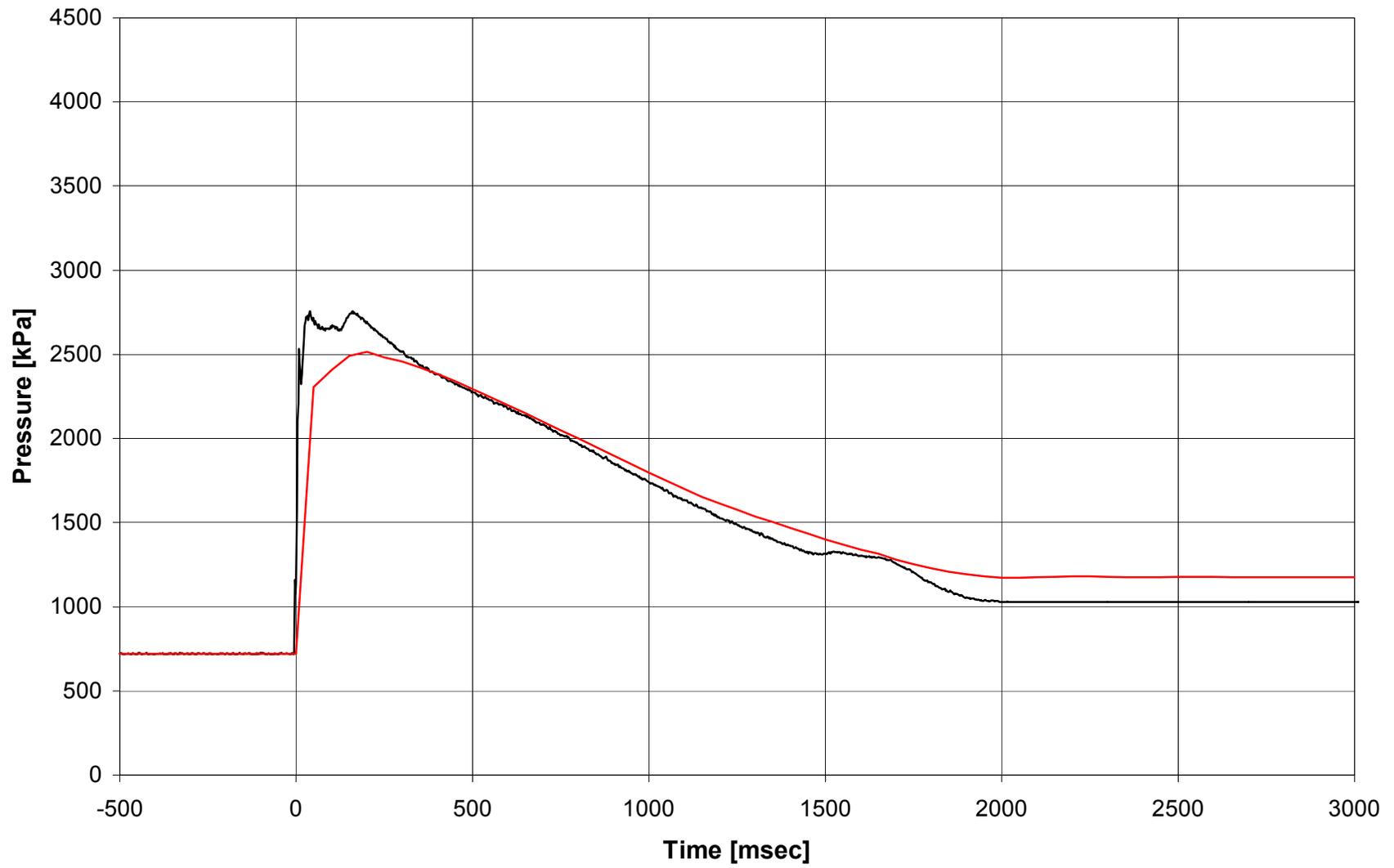
Graph 6: Pipe Position #3 Pressure

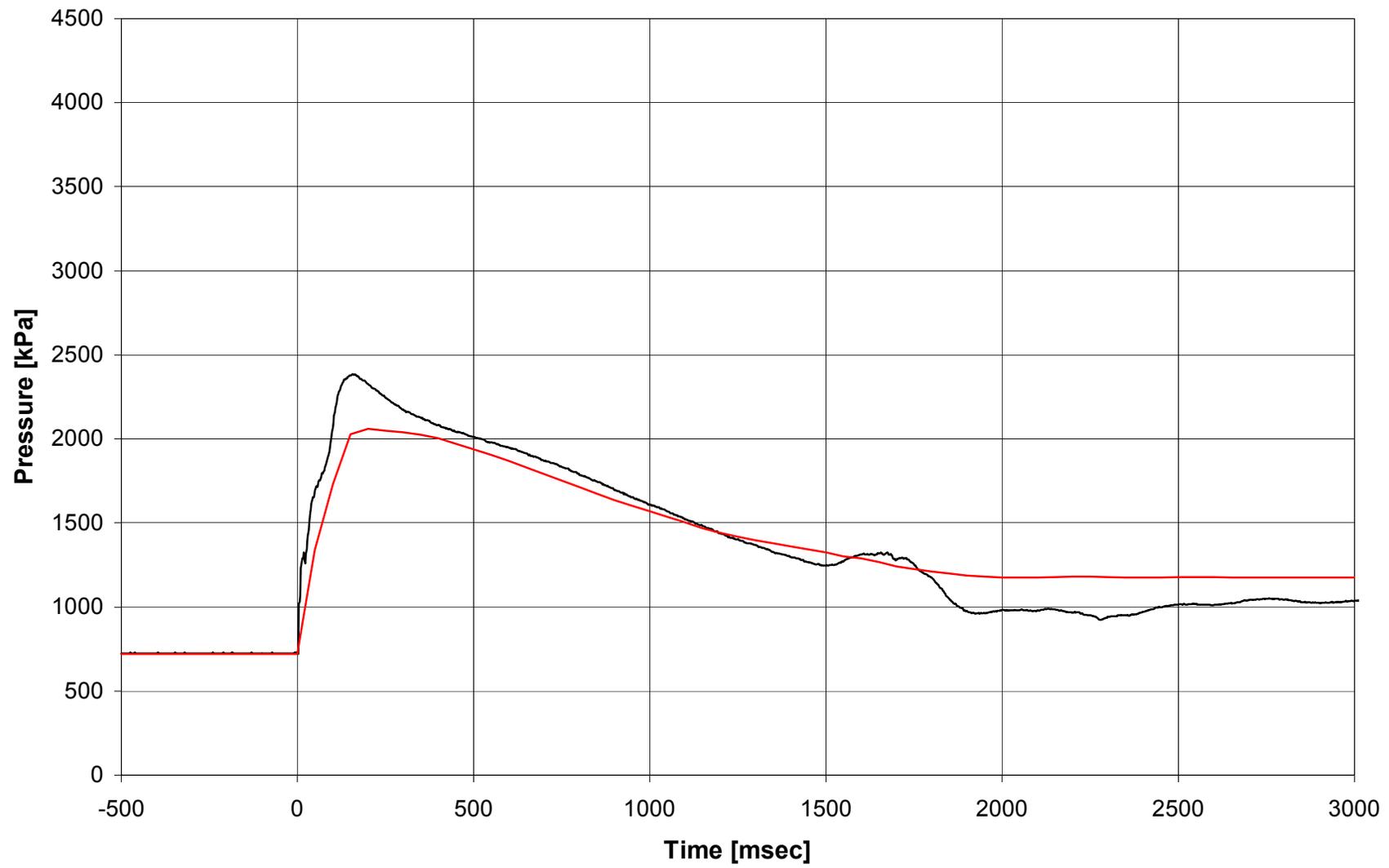
Graph 7: Collection Vessel Pressure

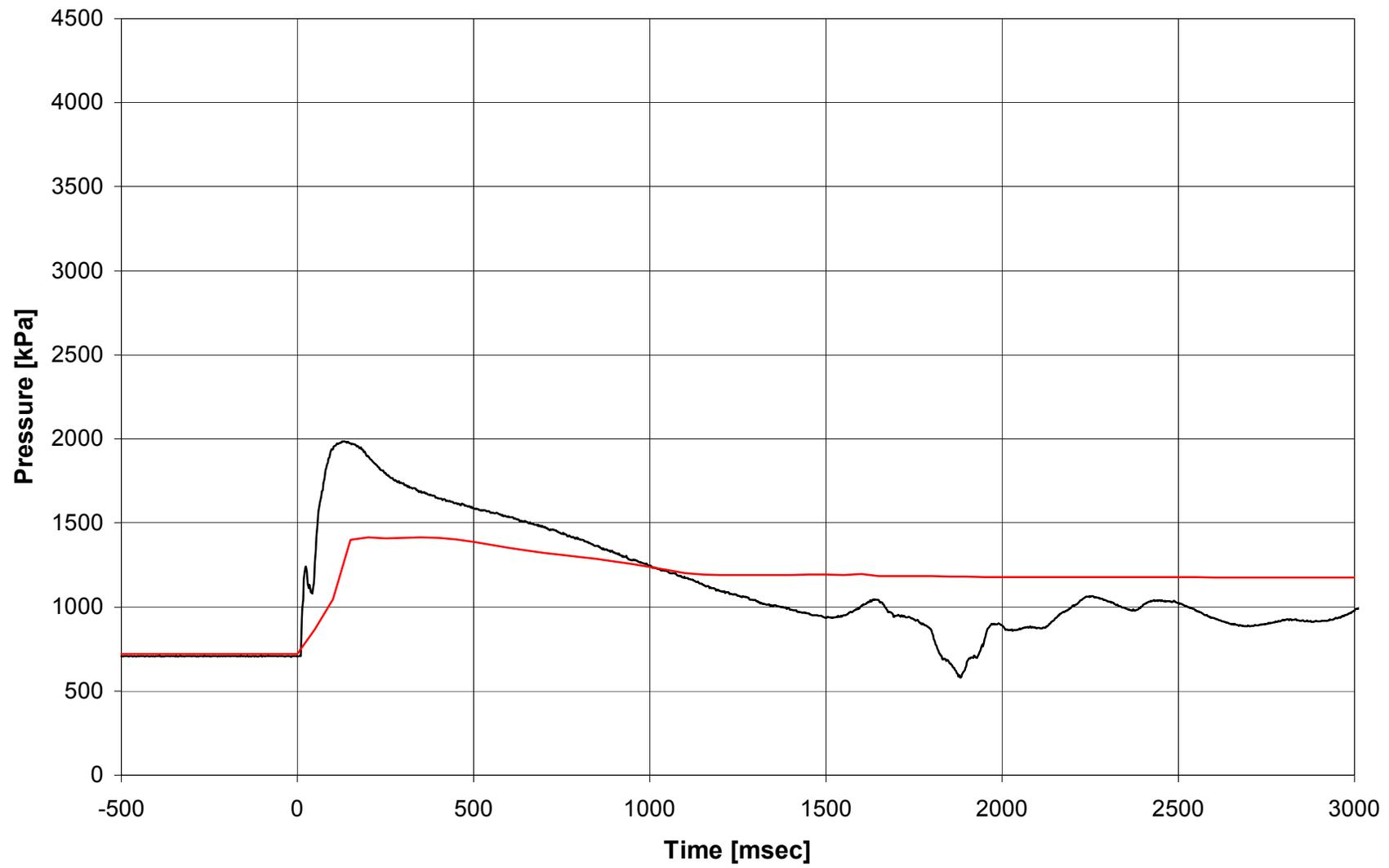


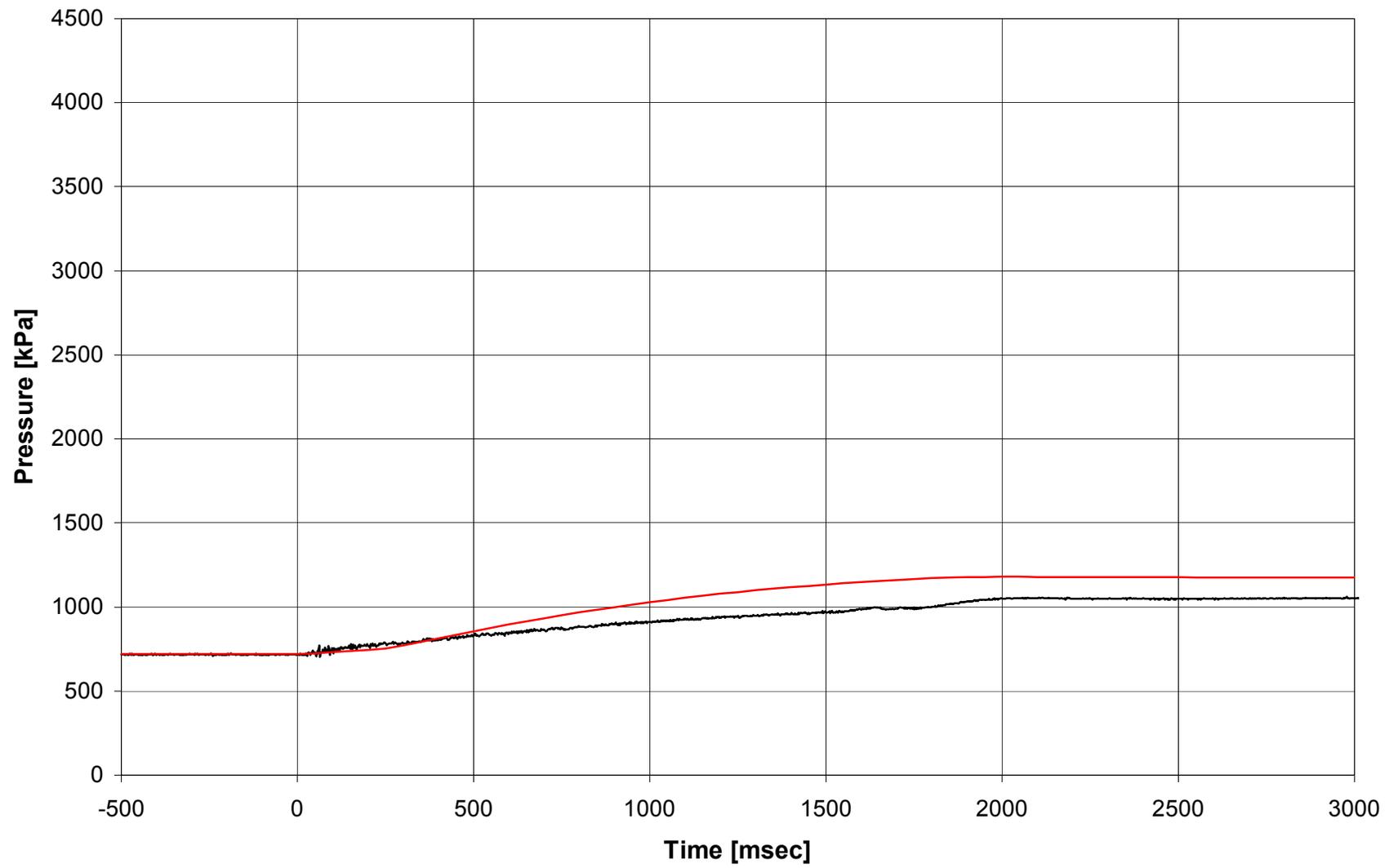












Run #4 with Code Prediction

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Straight Pipe

Source Vessel Initial Conditions: Fill Volume: 2370 milliliters
 Fluid Mass: 3.343 kg
 Pressure (Psvo): 4195 kPa
 Nitrogen Mass: 0.135 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 525 kPa

Initial System Temperature: 29° Celsius

Completion Date: 7/21/99

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

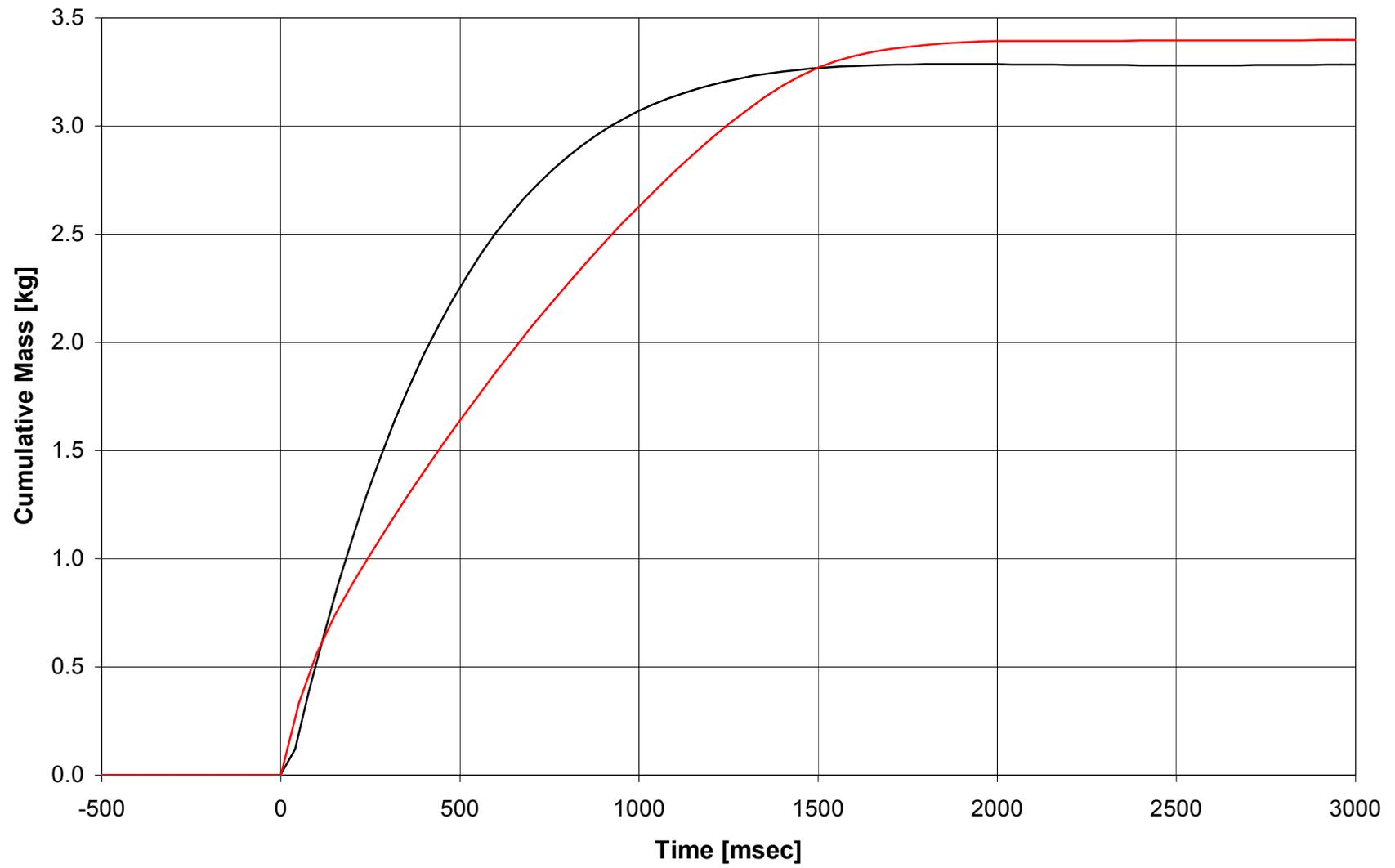
Graph 3: Source Vessel Pressure

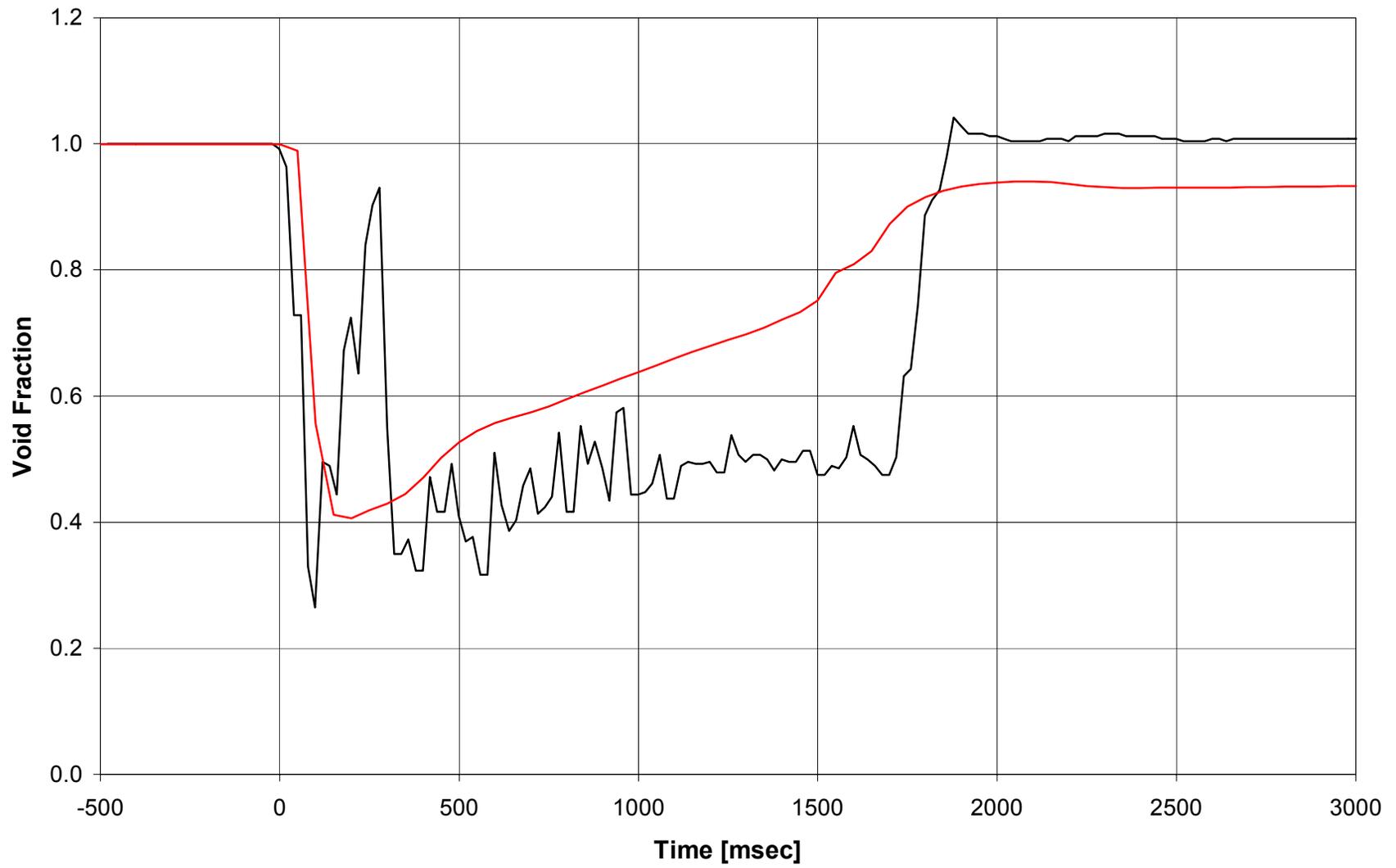
Graph 4: Pipe Position #1 Pressure

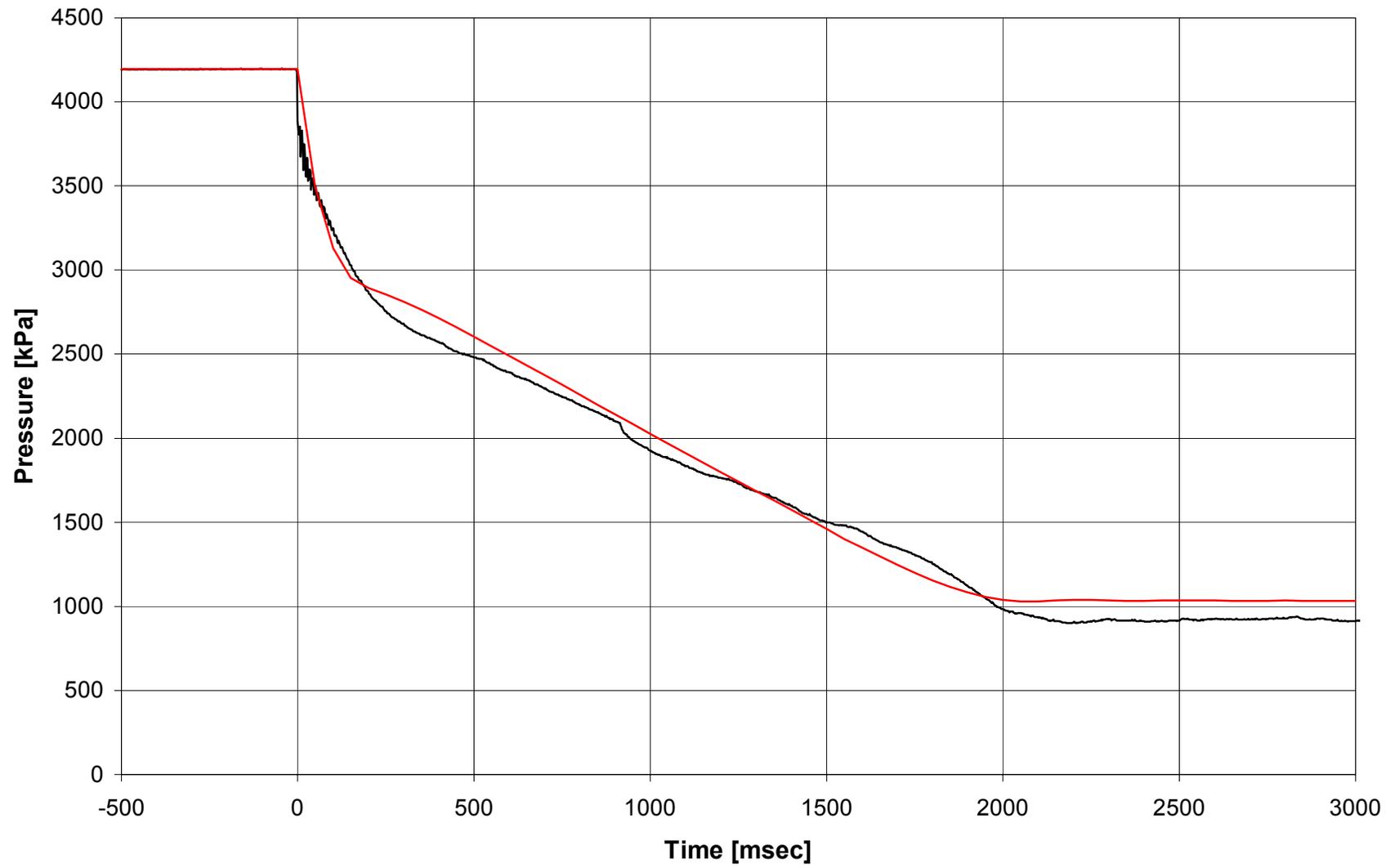
Graph 5: Pipe Position #2 Pressure

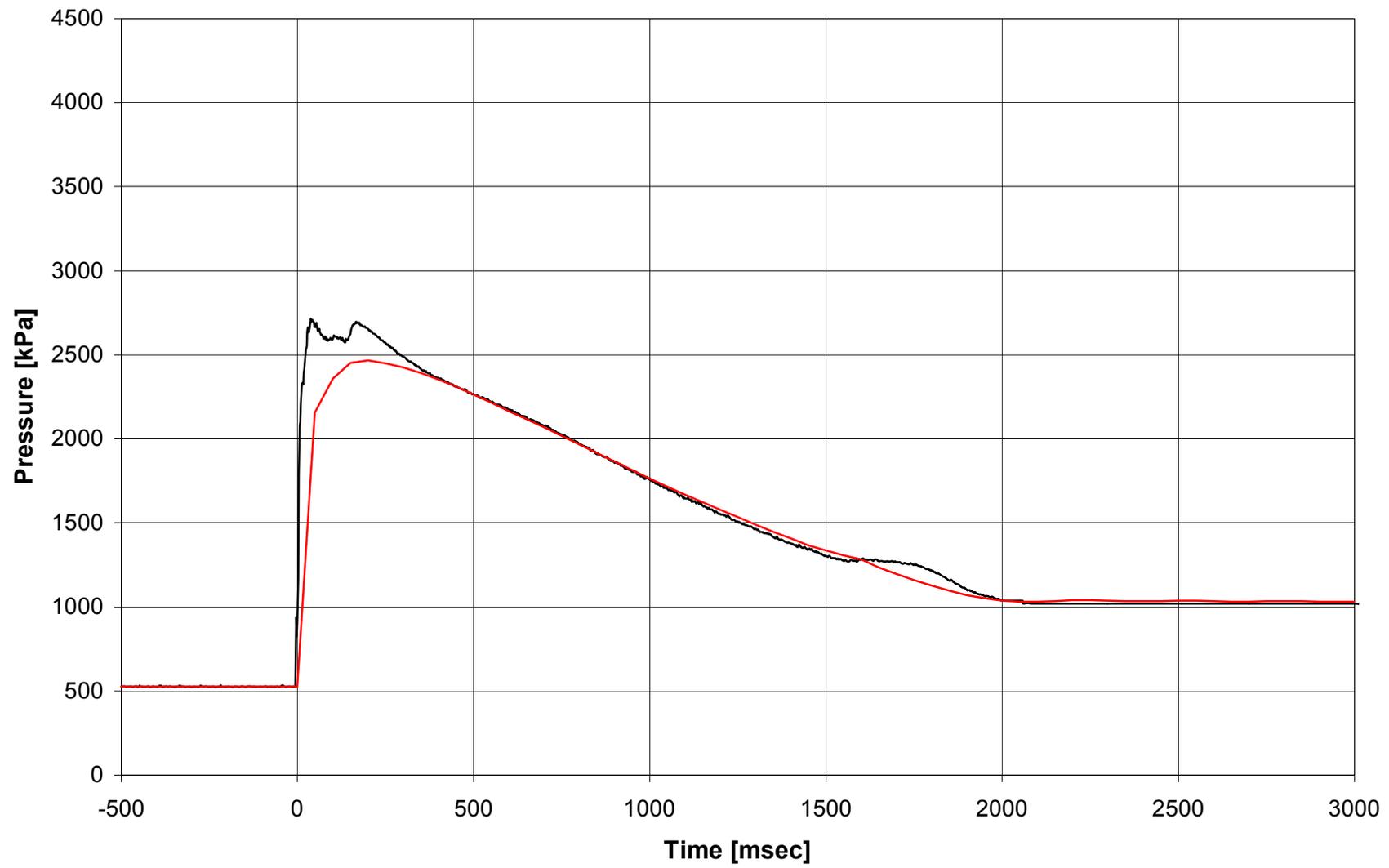
Graph 6: Pipe Position #3 Pressure

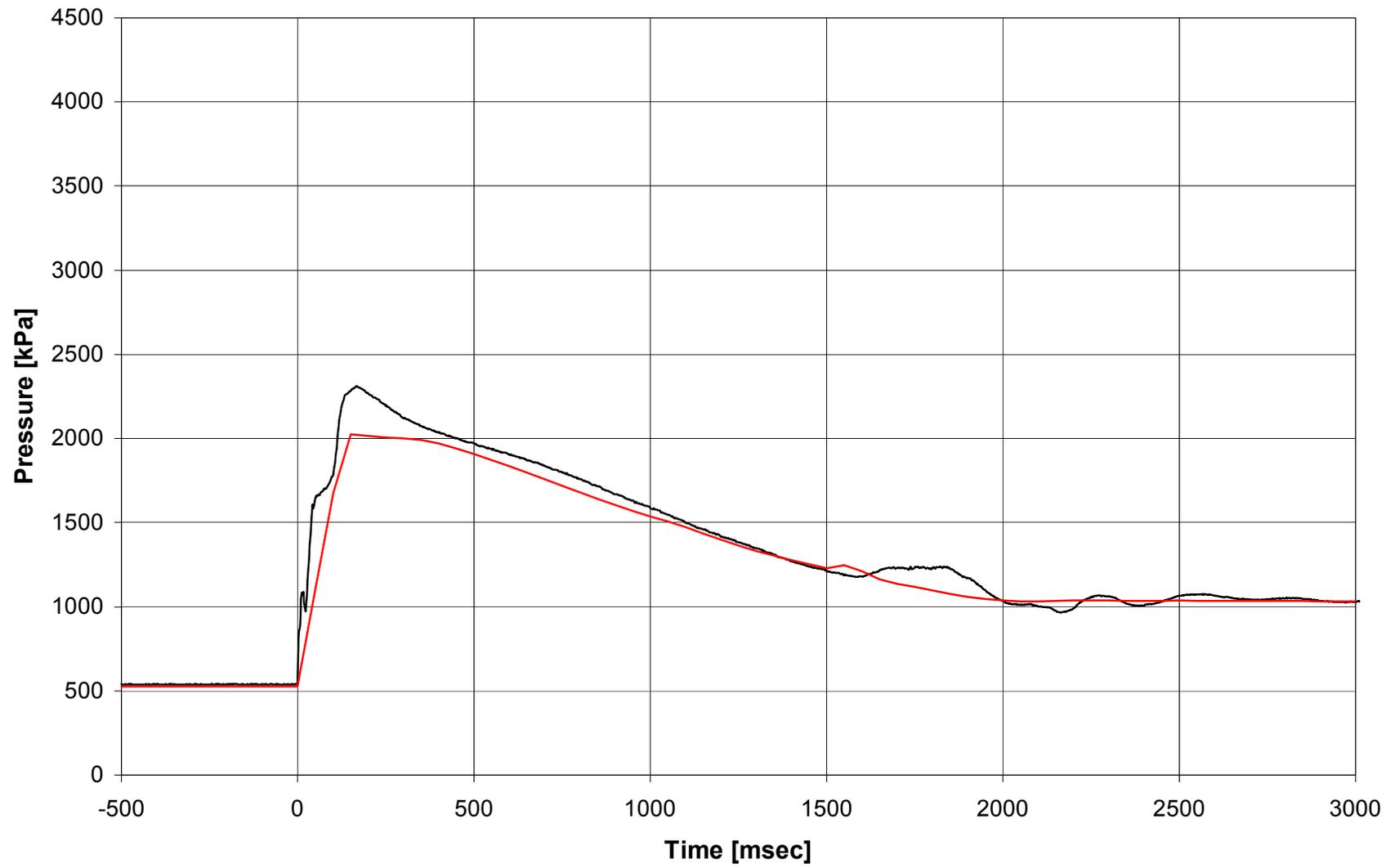
Graph 7: Collection Vessel Pressure

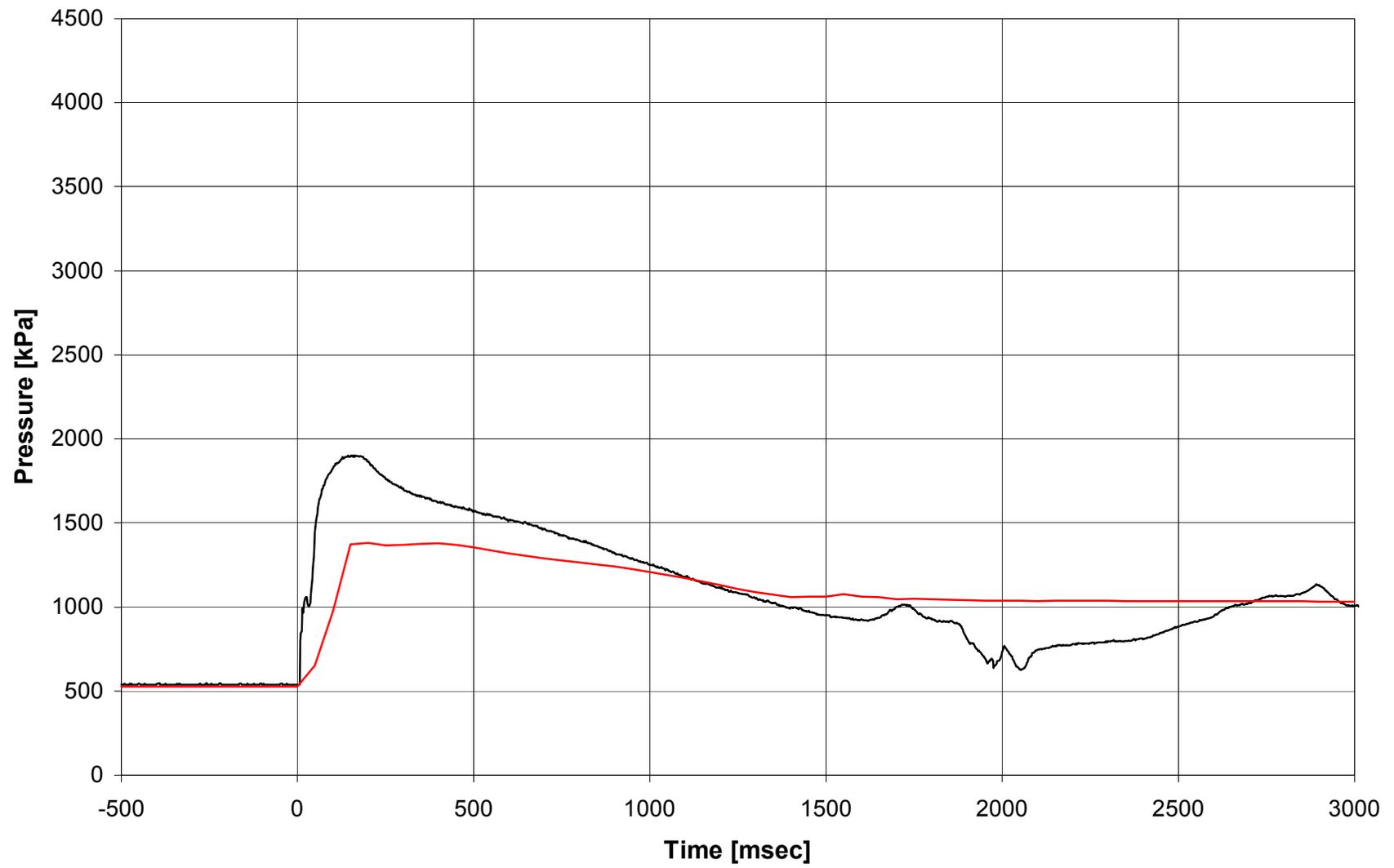


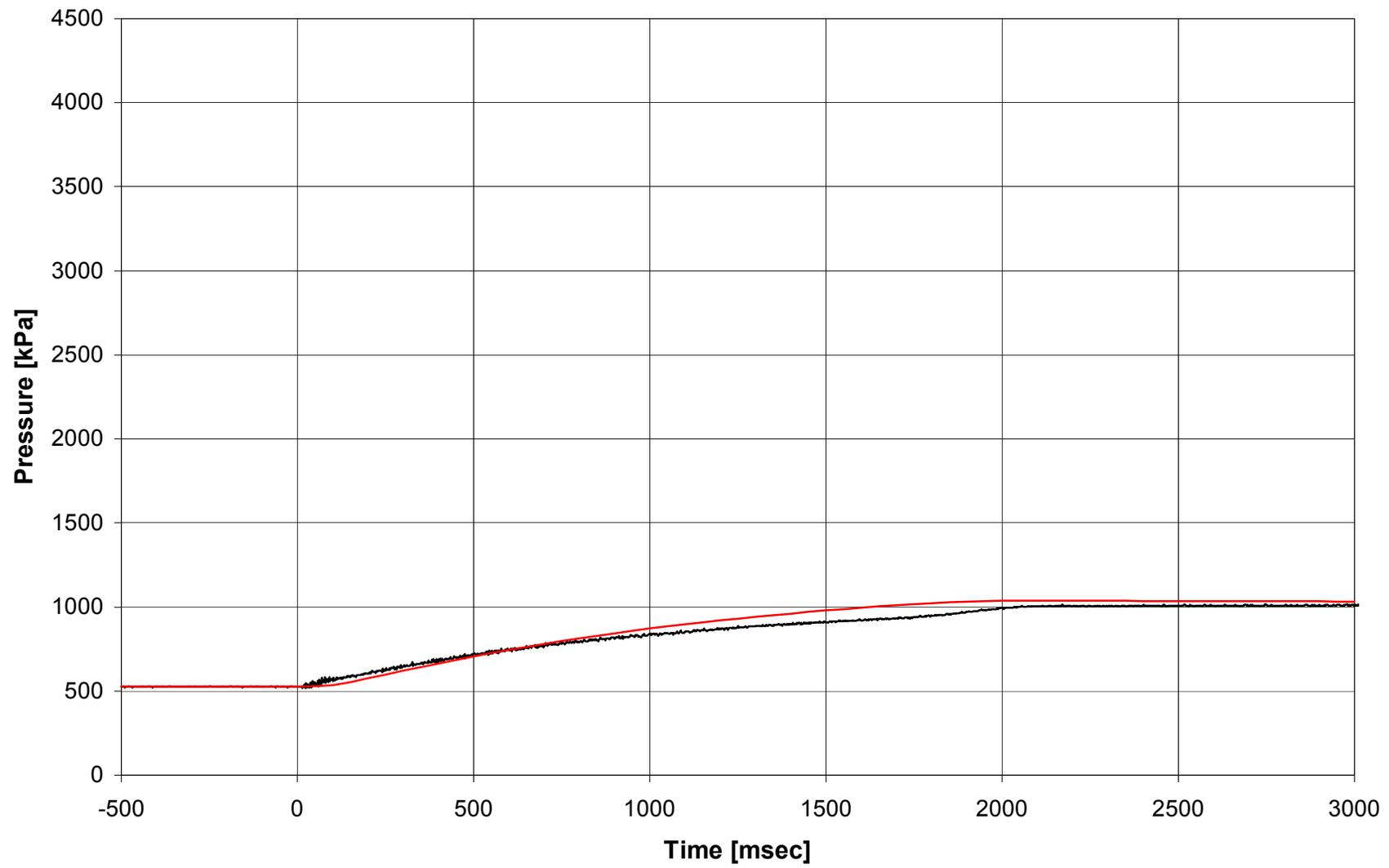












Run #5 with Code Prediction

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Straight Pipe

Source Vessel Initial Conditions: Fill Volume: 2388 milliliters
 Fluid Mass: 3.368 kg
 Pressure (Psvo): 4220 kPa
 Nitrogen Mass: 0.134 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 720 kPa

Initial System Temperature: 31° Celsius

Completion Date: 7/23/99

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

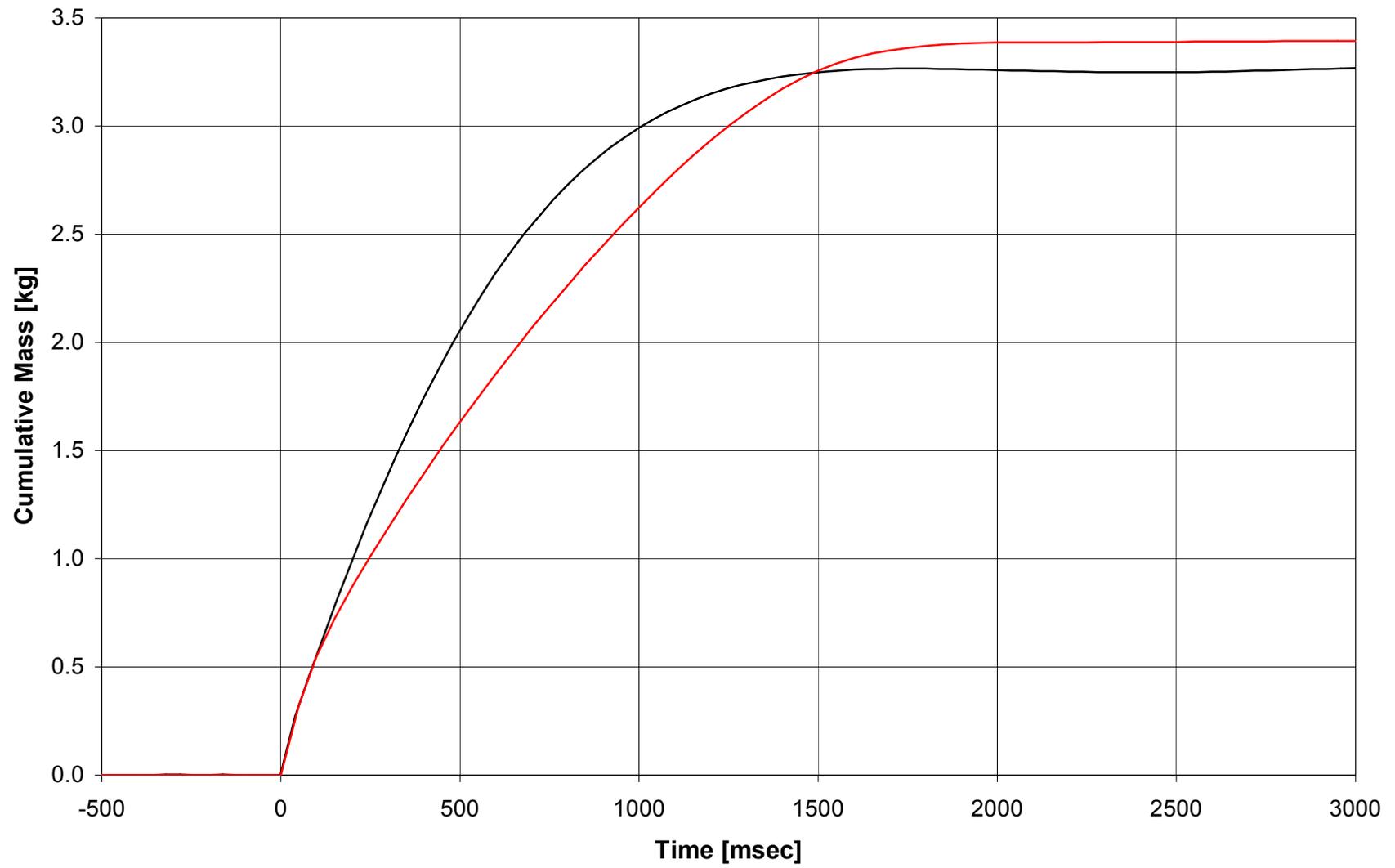
Graph 3: Source Vessel Pressure

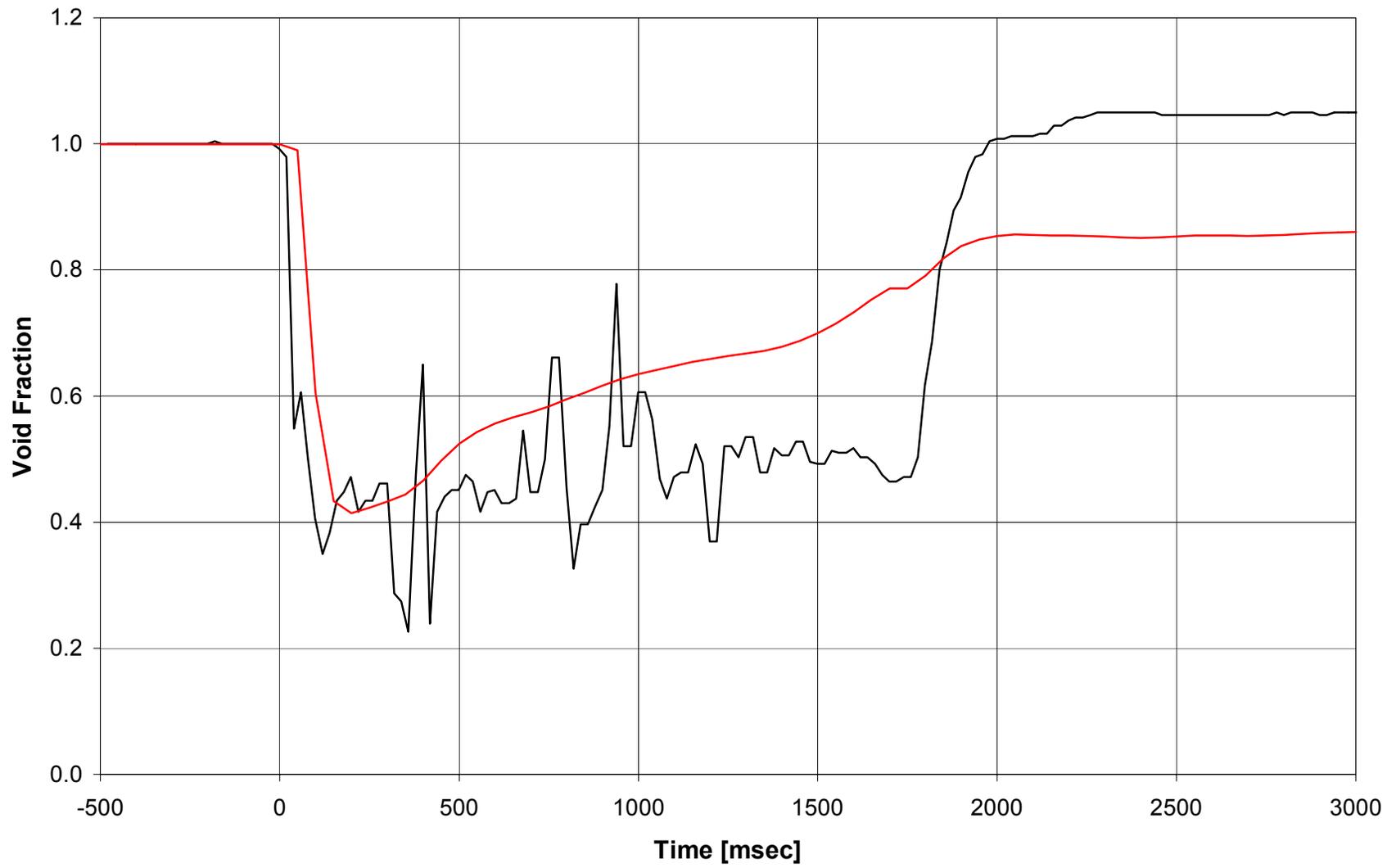
Graph 4: Pipe Position #1 Pressure

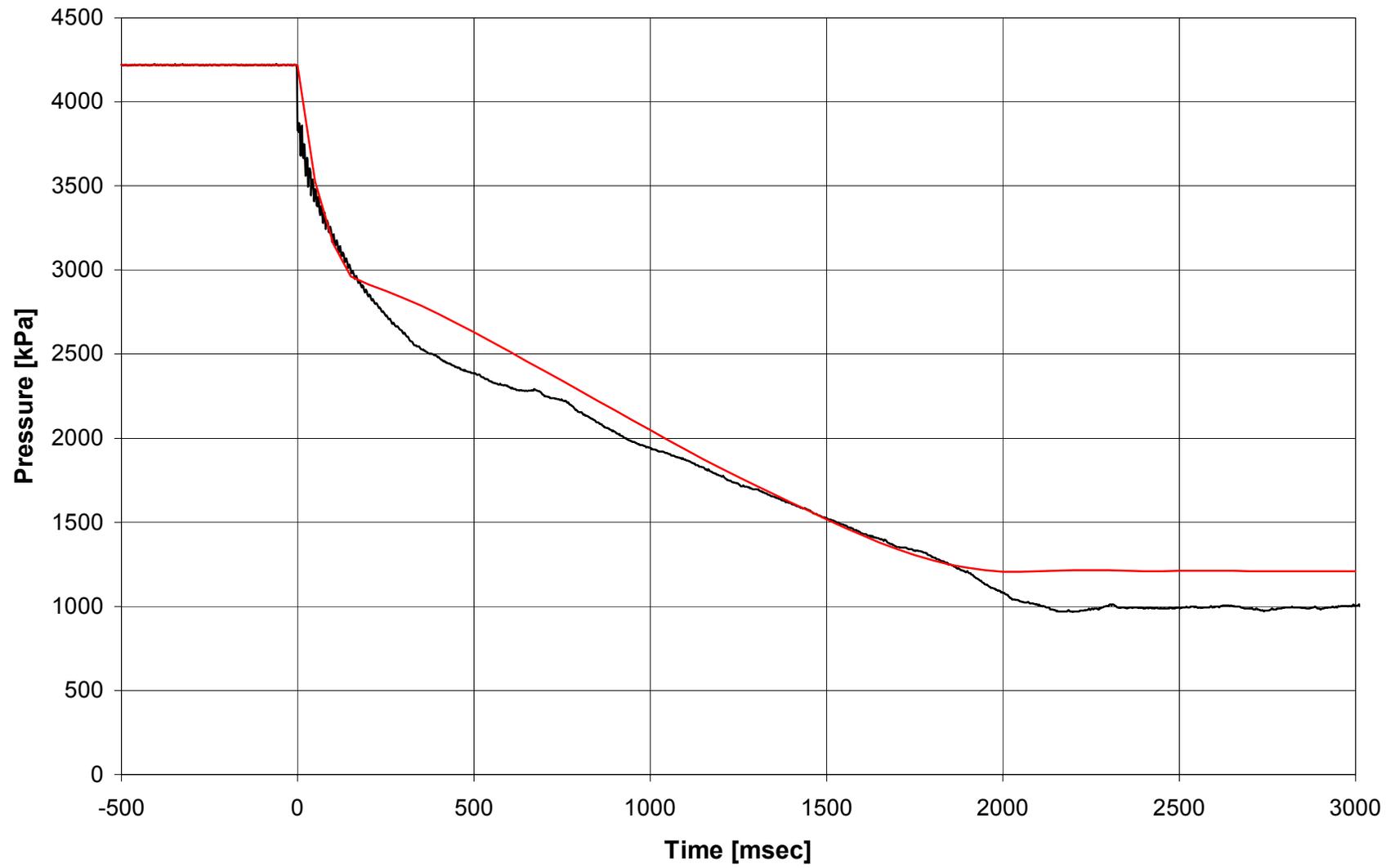
Graph 5: Pipe Position #2 Pressure

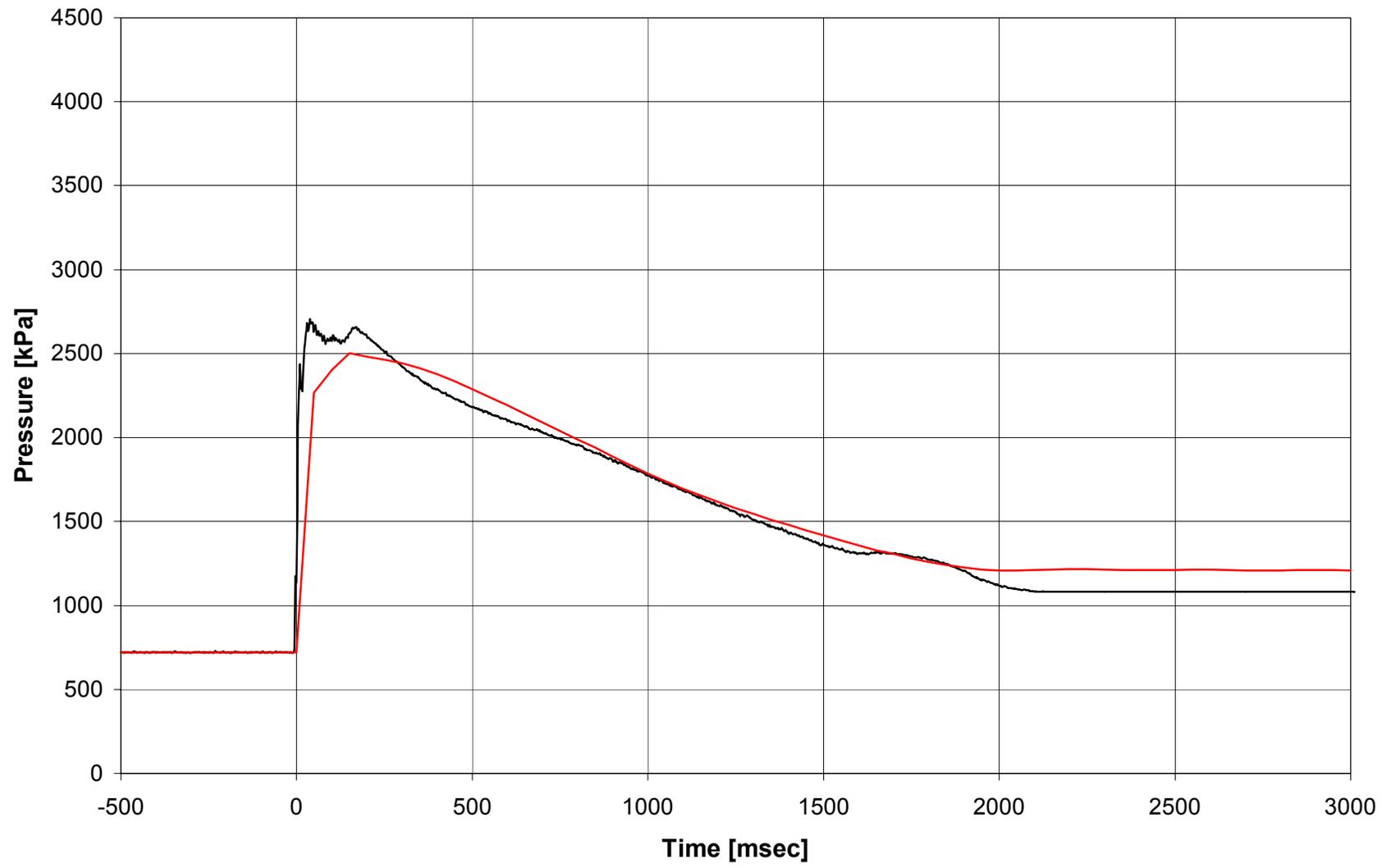
Graph 6: Pipe Position #3 Pressure

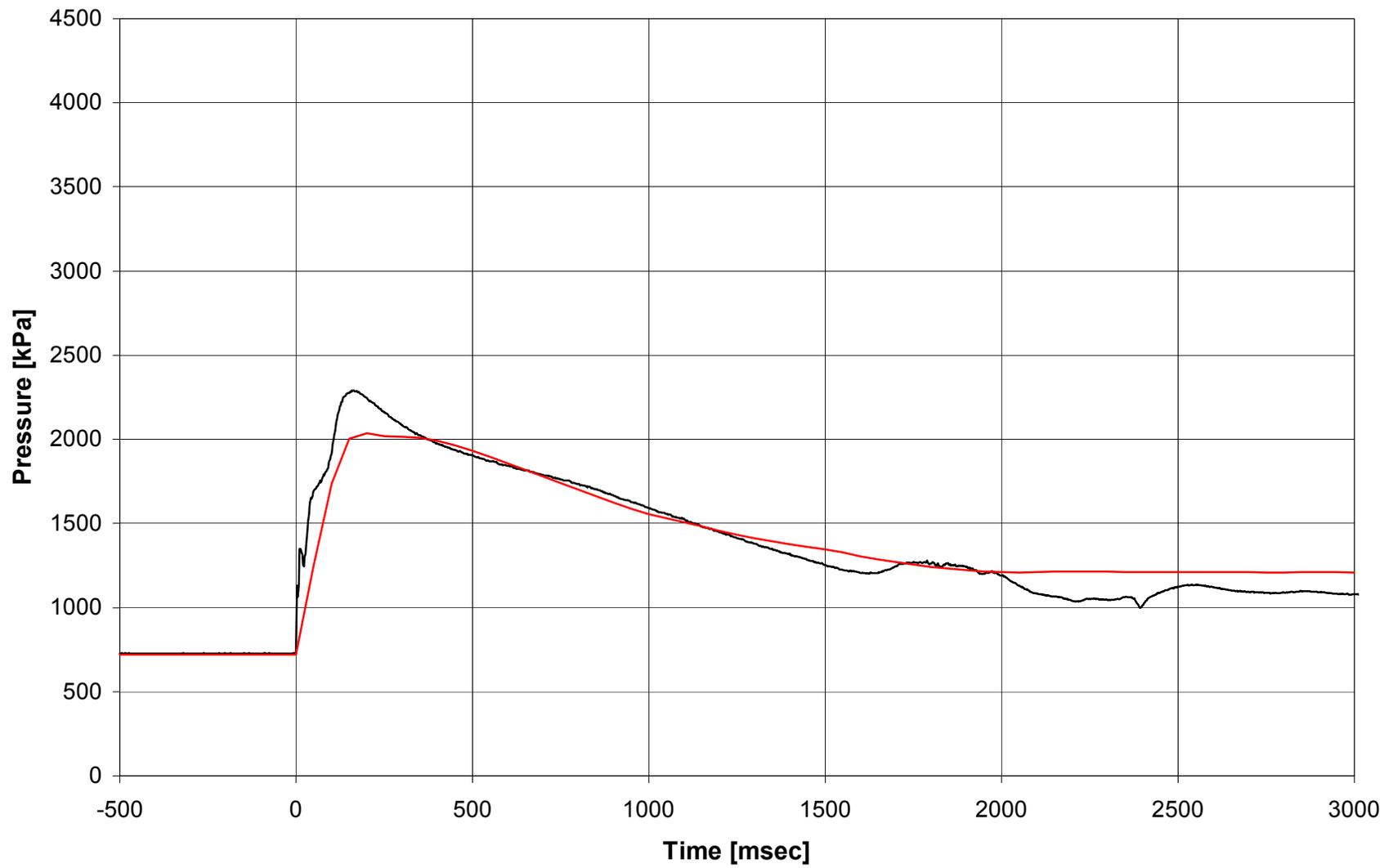
Graph 7: Collection Vessel Pressure

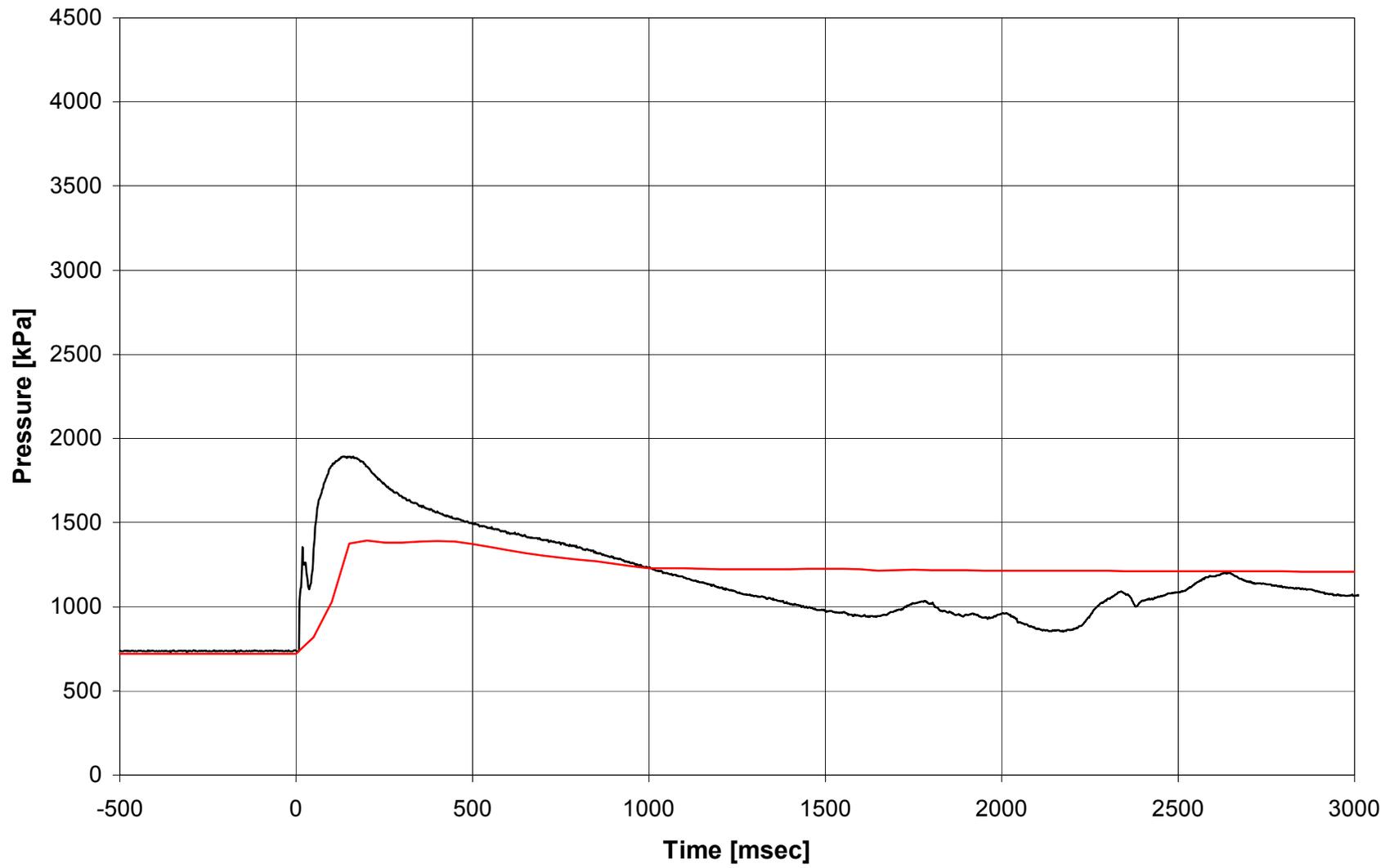


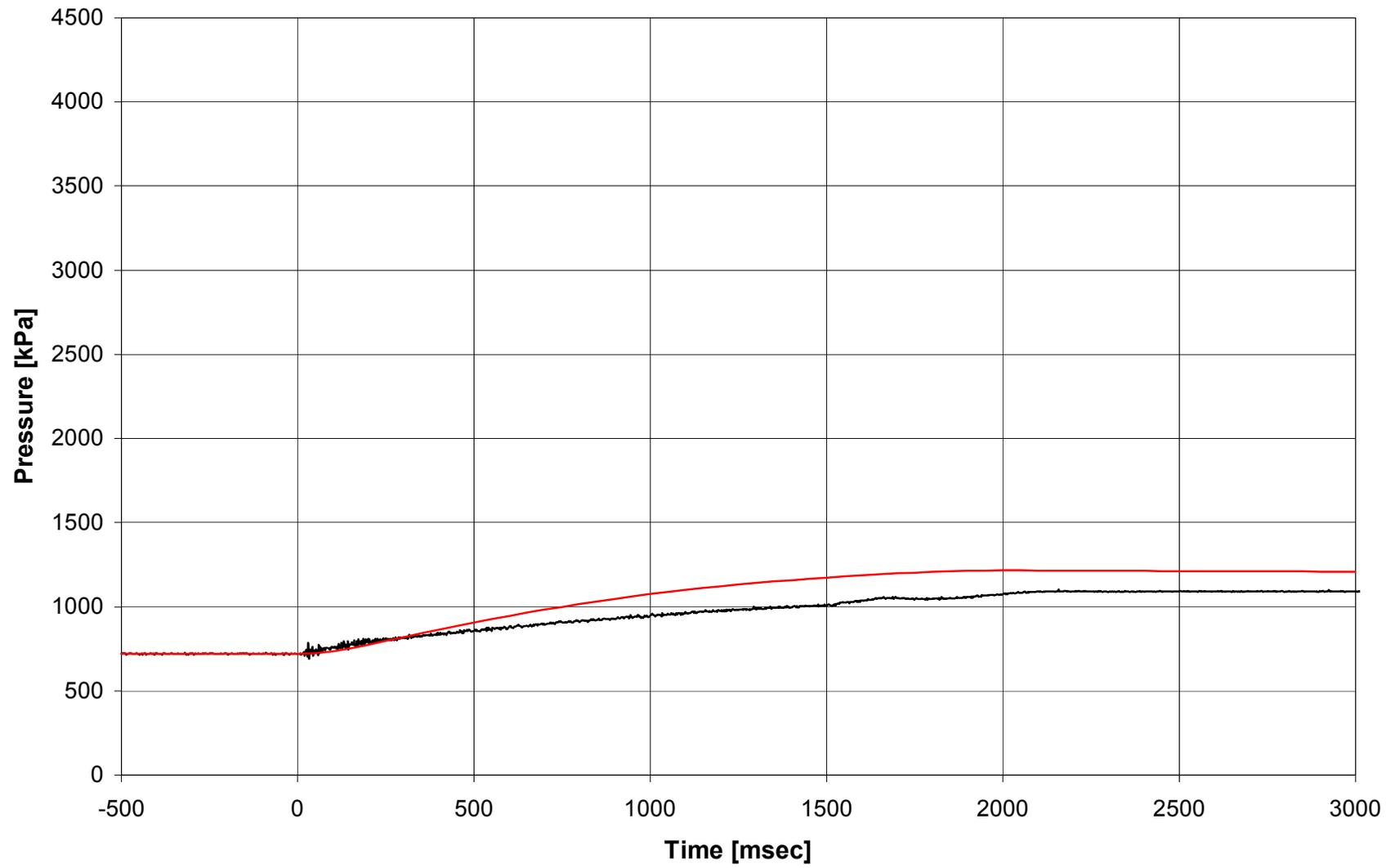












Run #6 with Code Prediction

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Straight Pipe

Source Vessel Initial Conditions: Fill Volume: 2150 milliliters
 Fluid Mass: 3.038 kg
 Pressure (Psvo): 4910 kPa
 Nitrogen Mass: 0.162 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 715 kPa

Initial System Temperature: 31° Celsius

Completion Date: 8/13/99

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

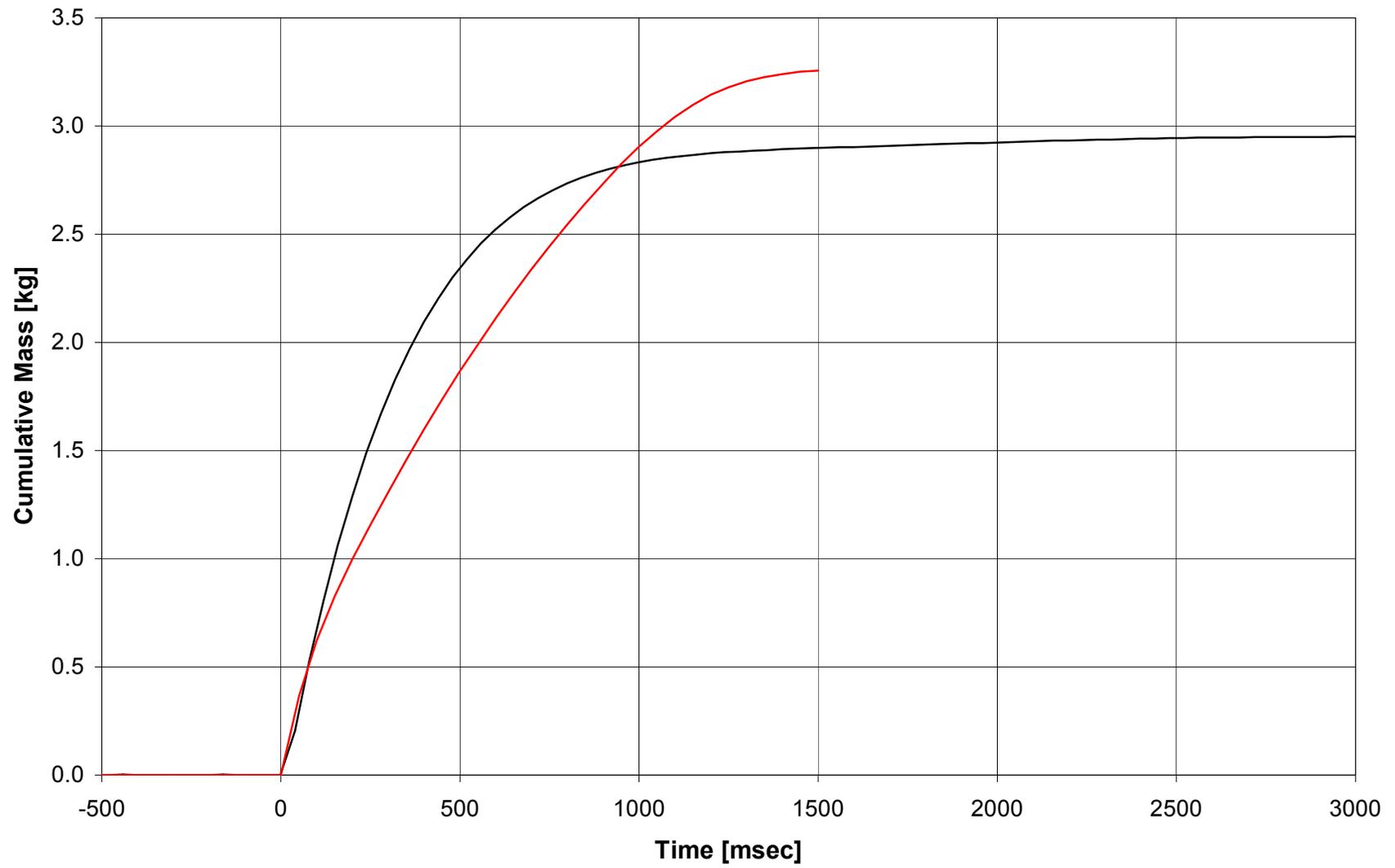
Graph 3: Source Vessel Pressure

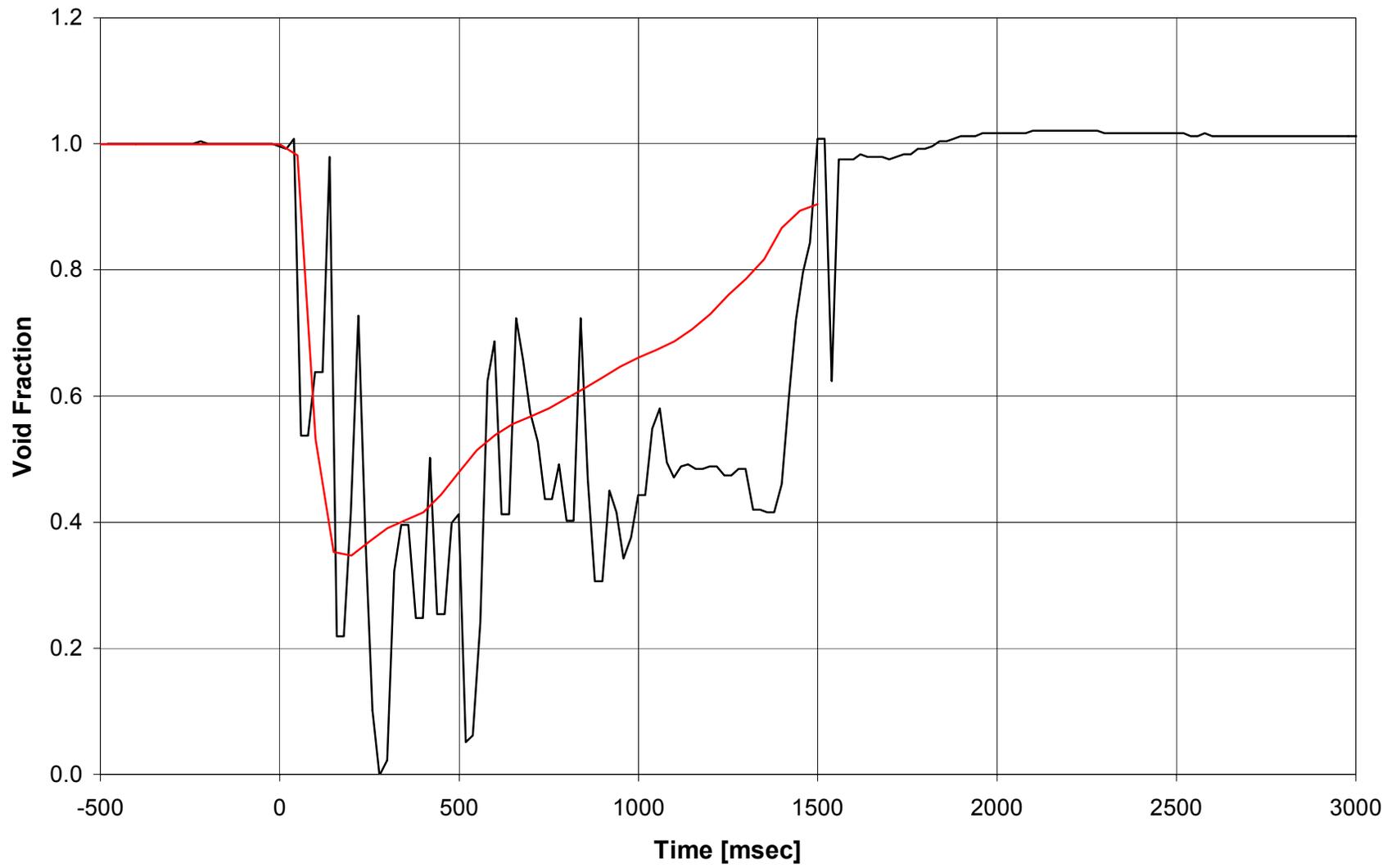
Graph 4: Pipe Position #1 Pressure

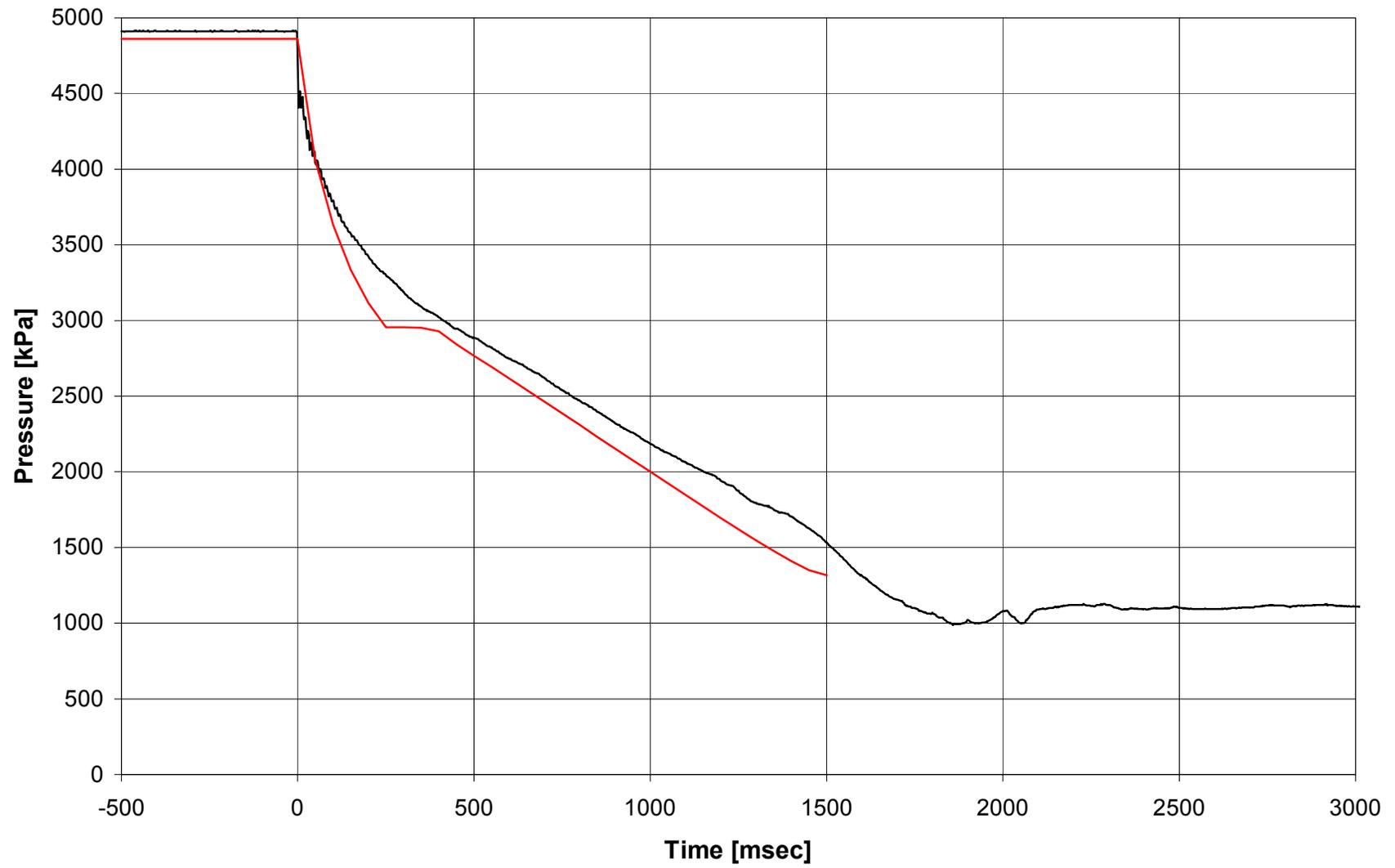
Graph 5: Pipe Position #2 Pressure

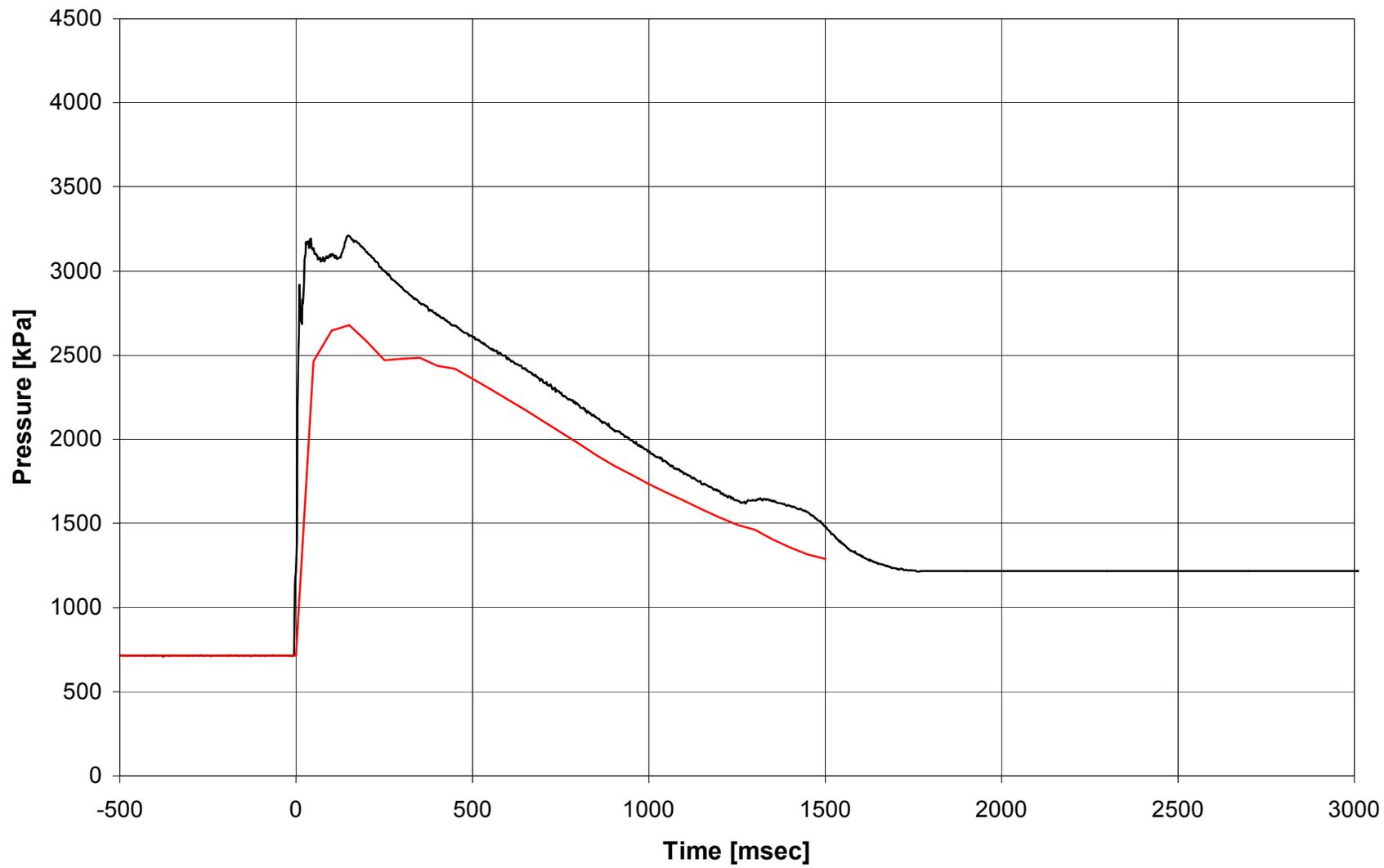
Graph 6: Pipe Position #3 Pressure

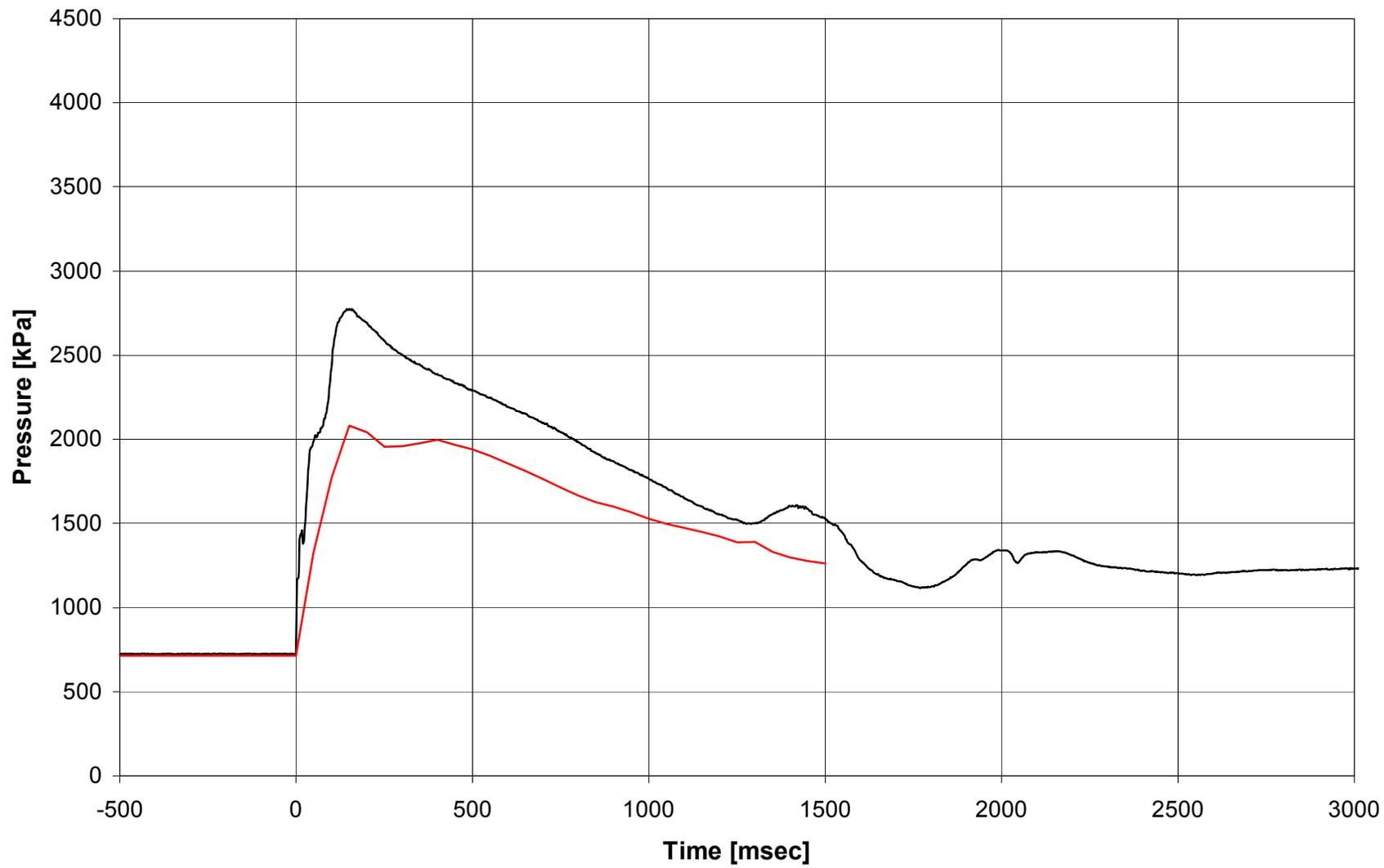
Graph 7: Collection Vessel Pressure

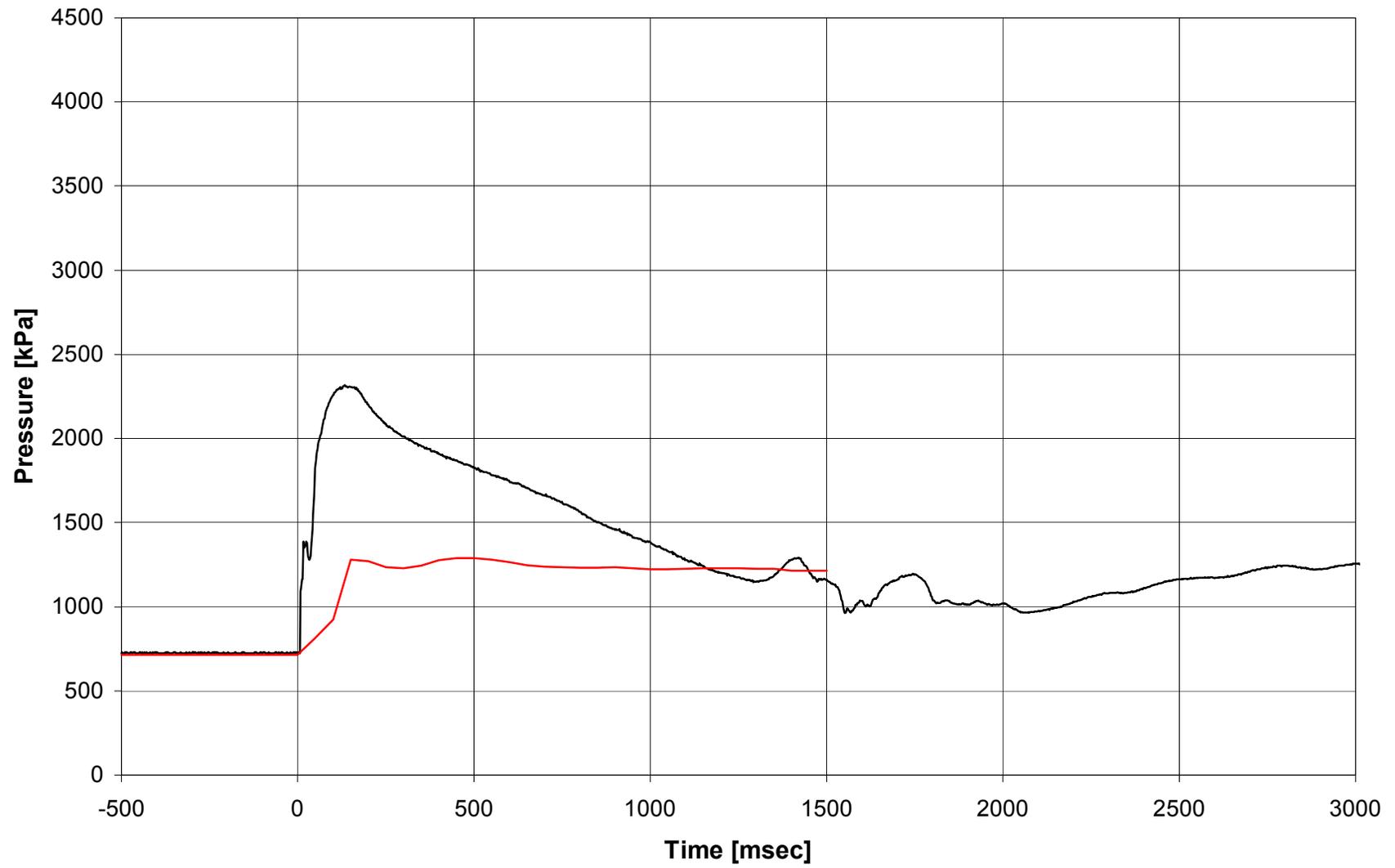


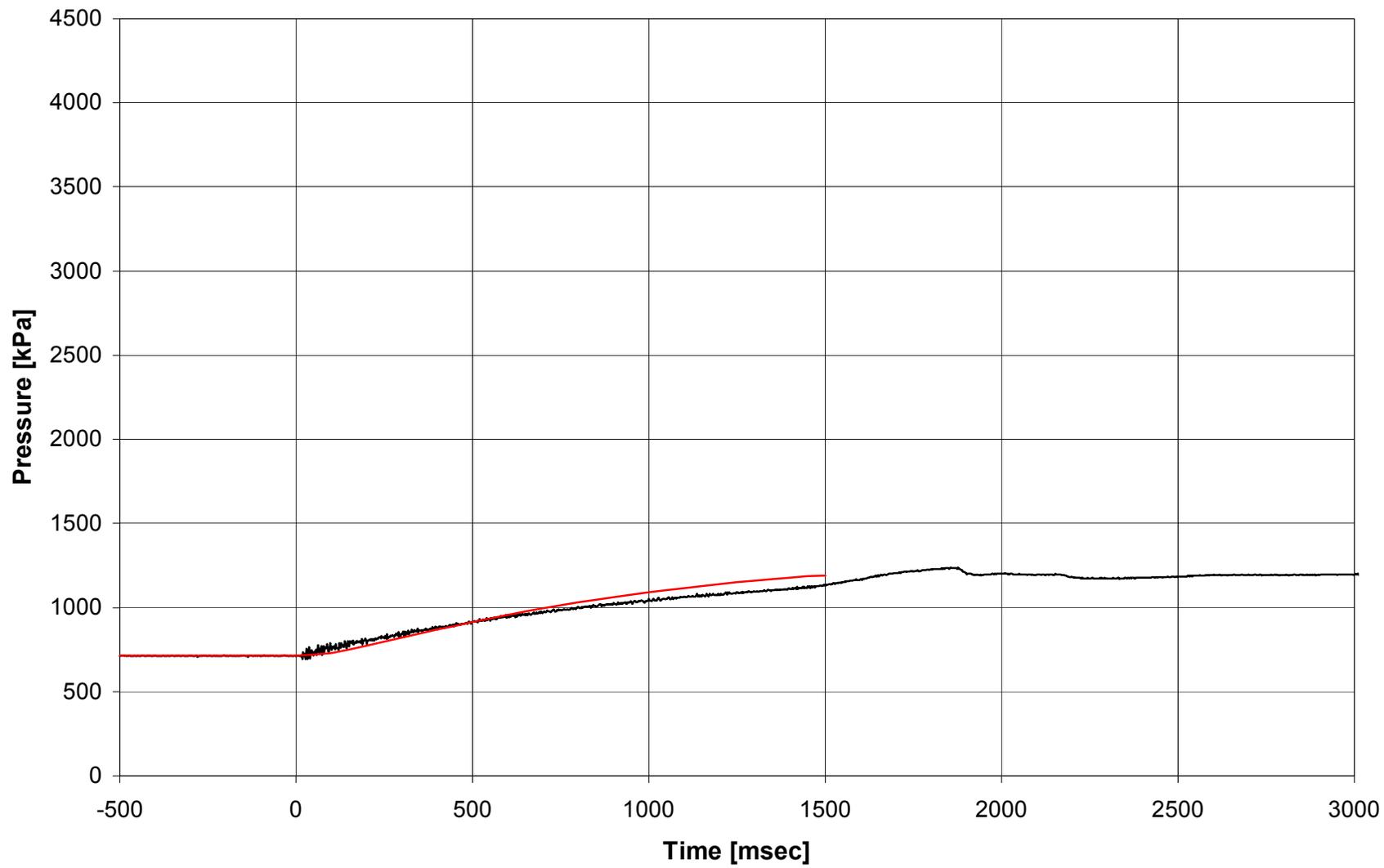












Run #7 with Code Prediction

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Straight Pipe w/ Hotspot @ 55° C

Source Vessel Initial Conditions: Fill Volume: 2200 milliliters
 Fluid Mass: 3.117 kg
 Pressure (Psvo): 4230 kPa
 Nitrogen Mass: 0.140 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 710 kPa

Initial System Temperature: 27° Celsius

Completion Date: 8/10/99

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

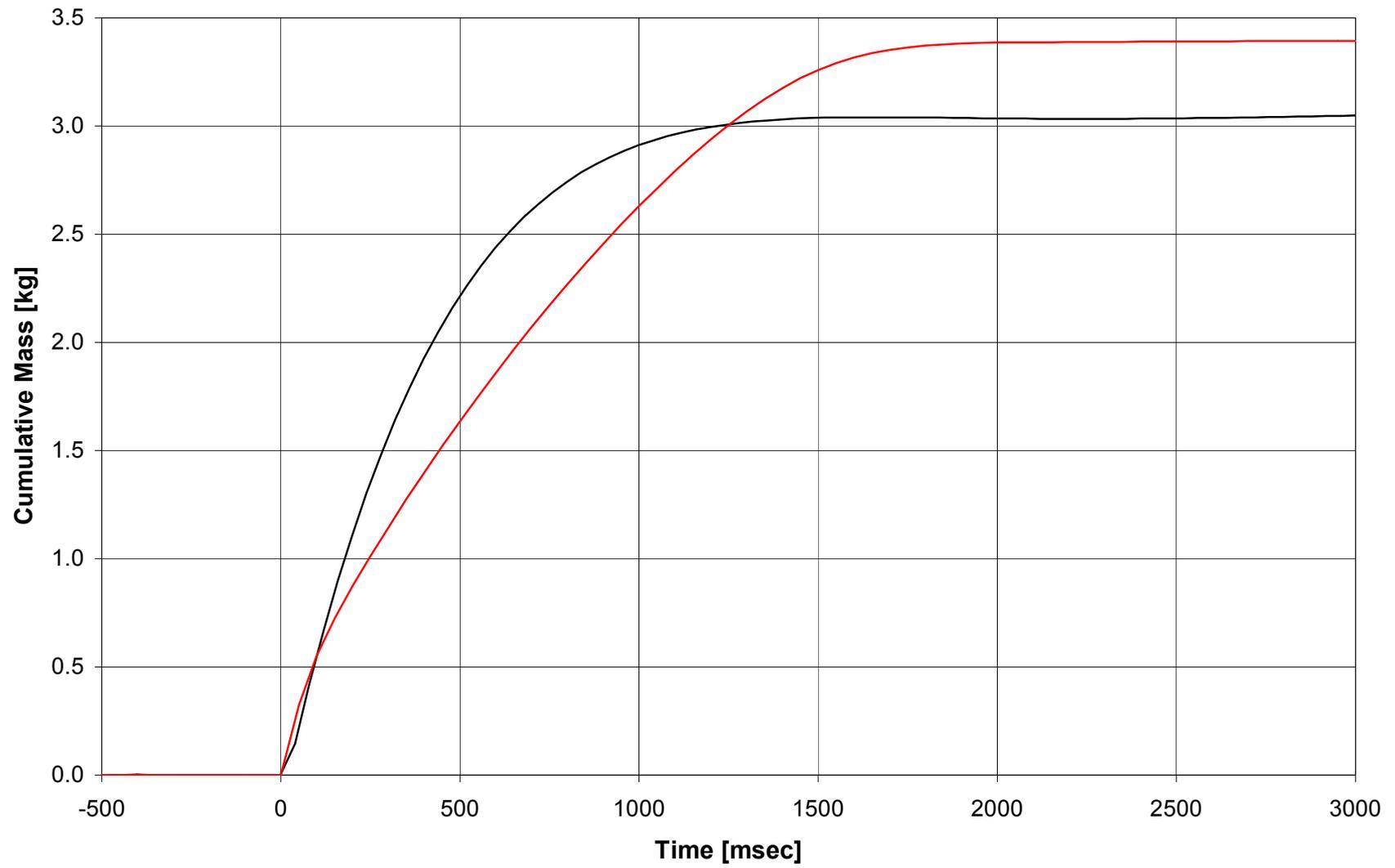
Graph 3: Source Vessel Pressure

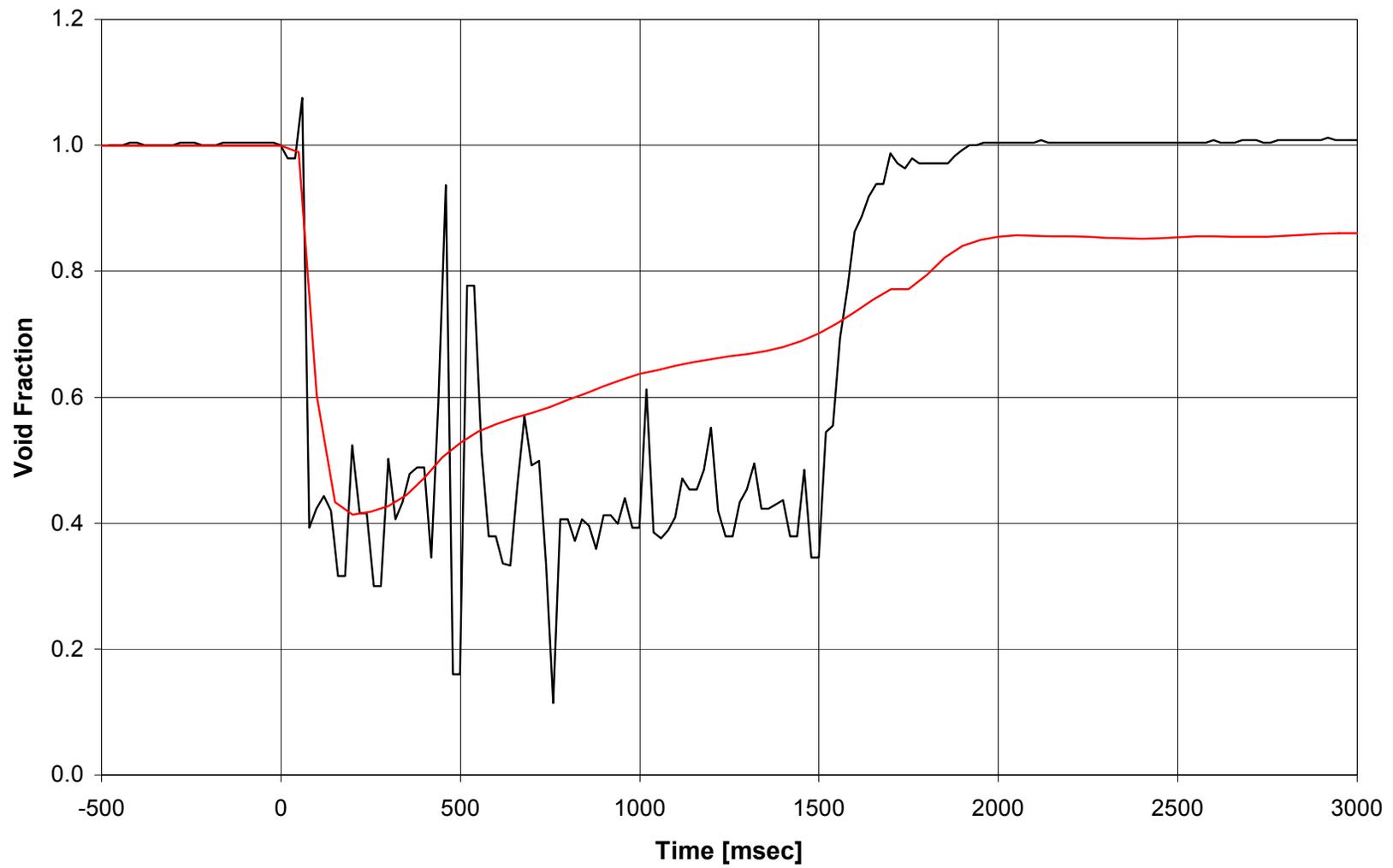
Graph 4: Pipe Position #1 Pressure

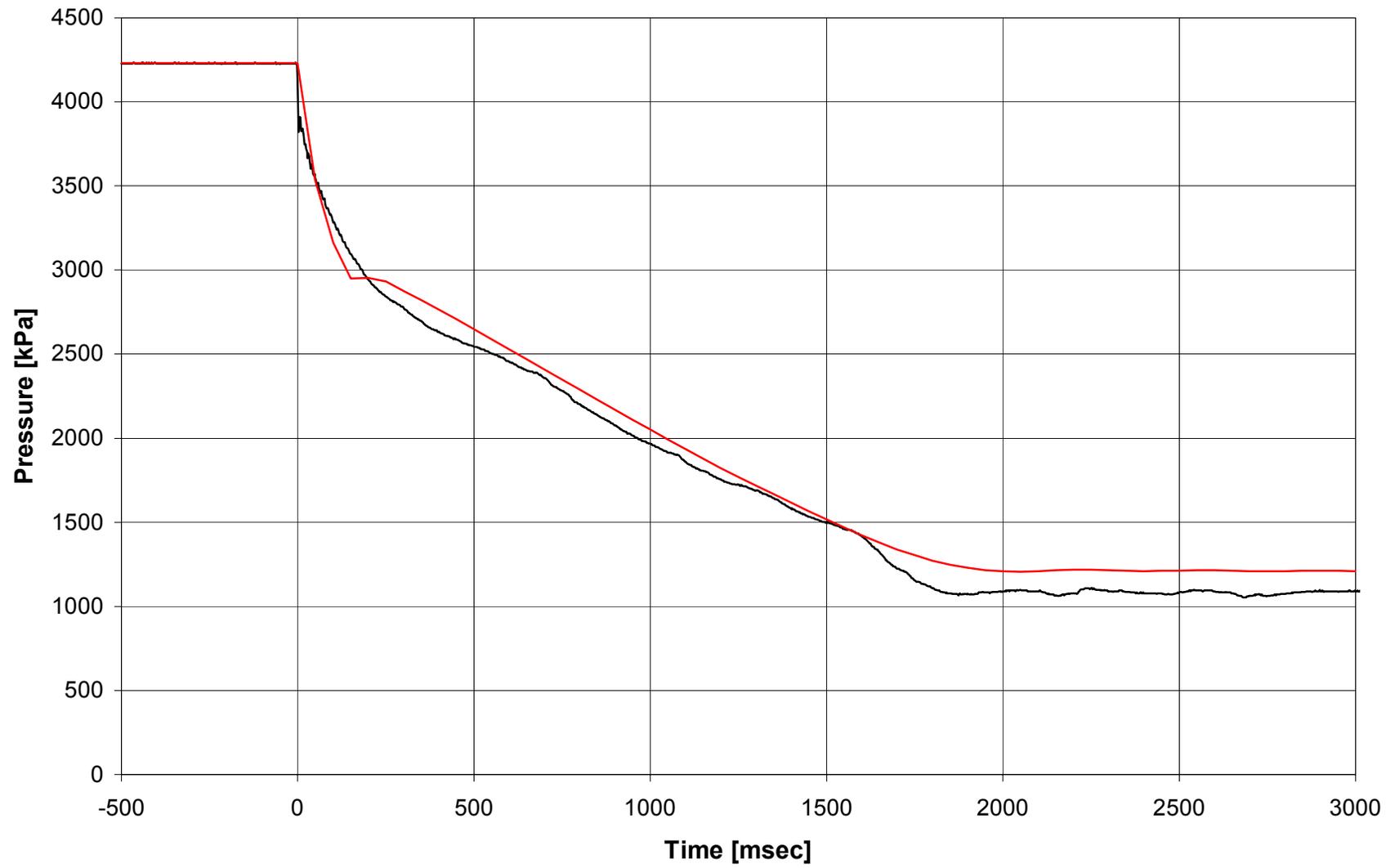
Graph 5: Pipe Position #2 Pressure

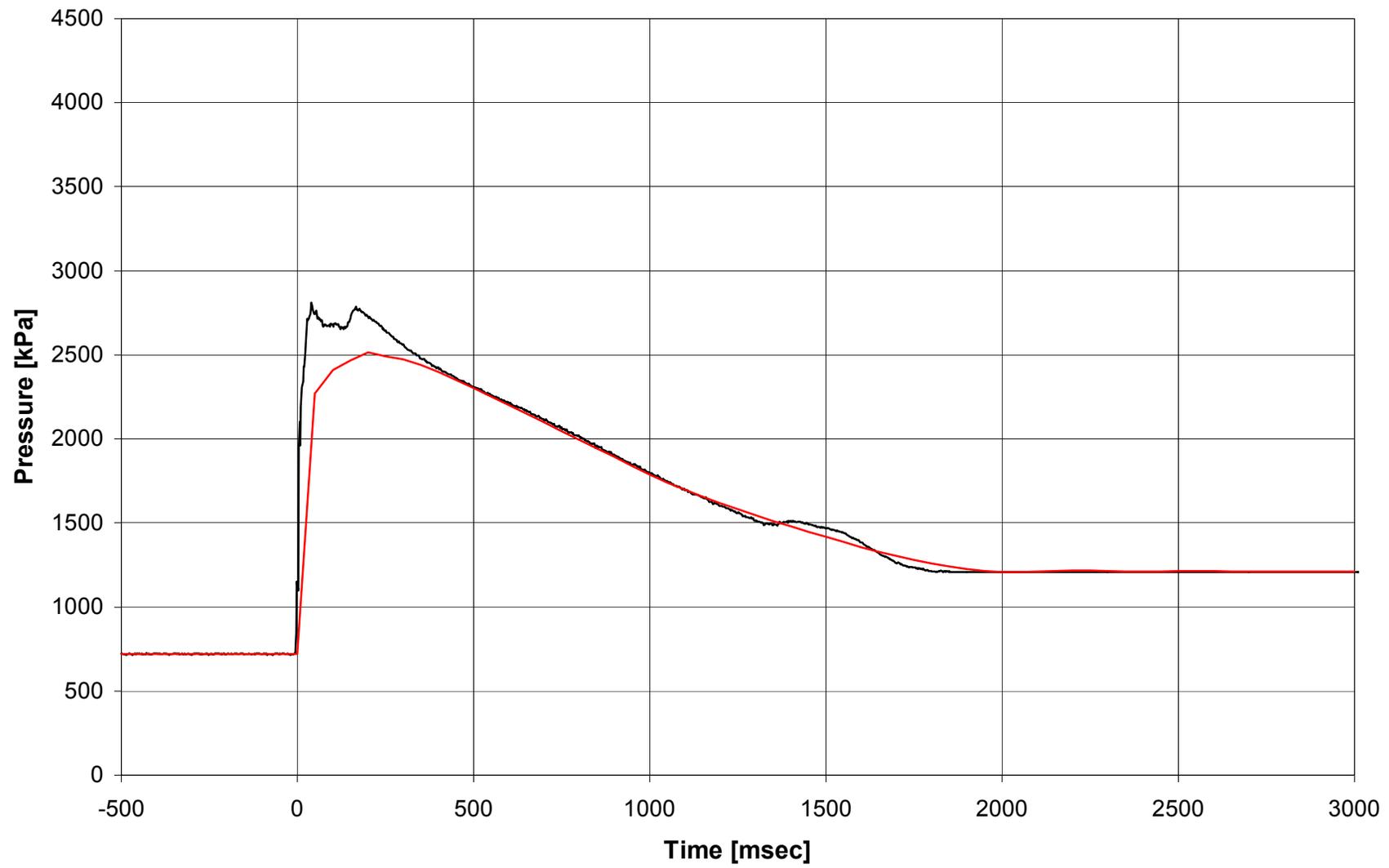
Graph 6: Pipe Position #3 Pressure

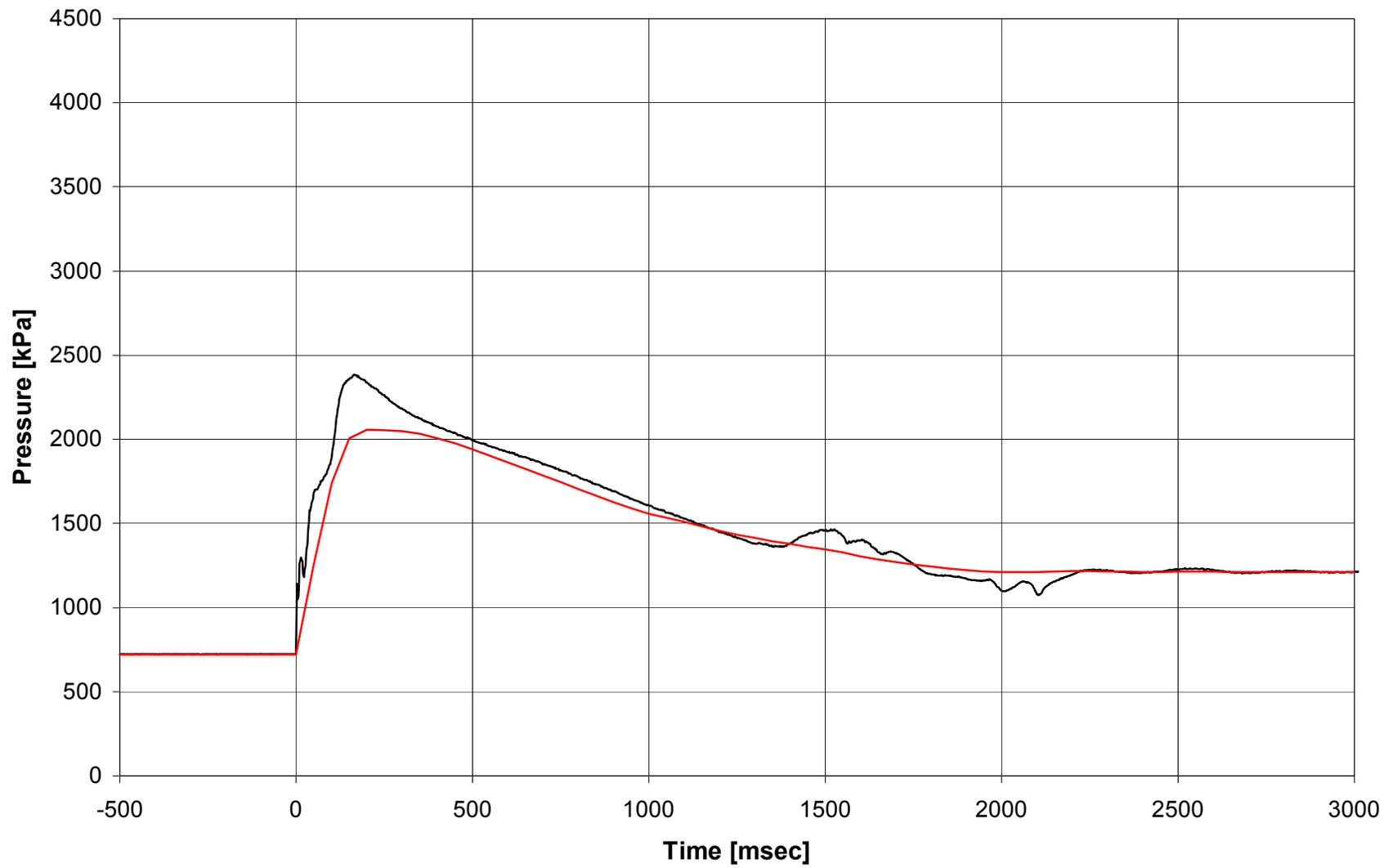
Graph 7: Collection Vessel Pressure

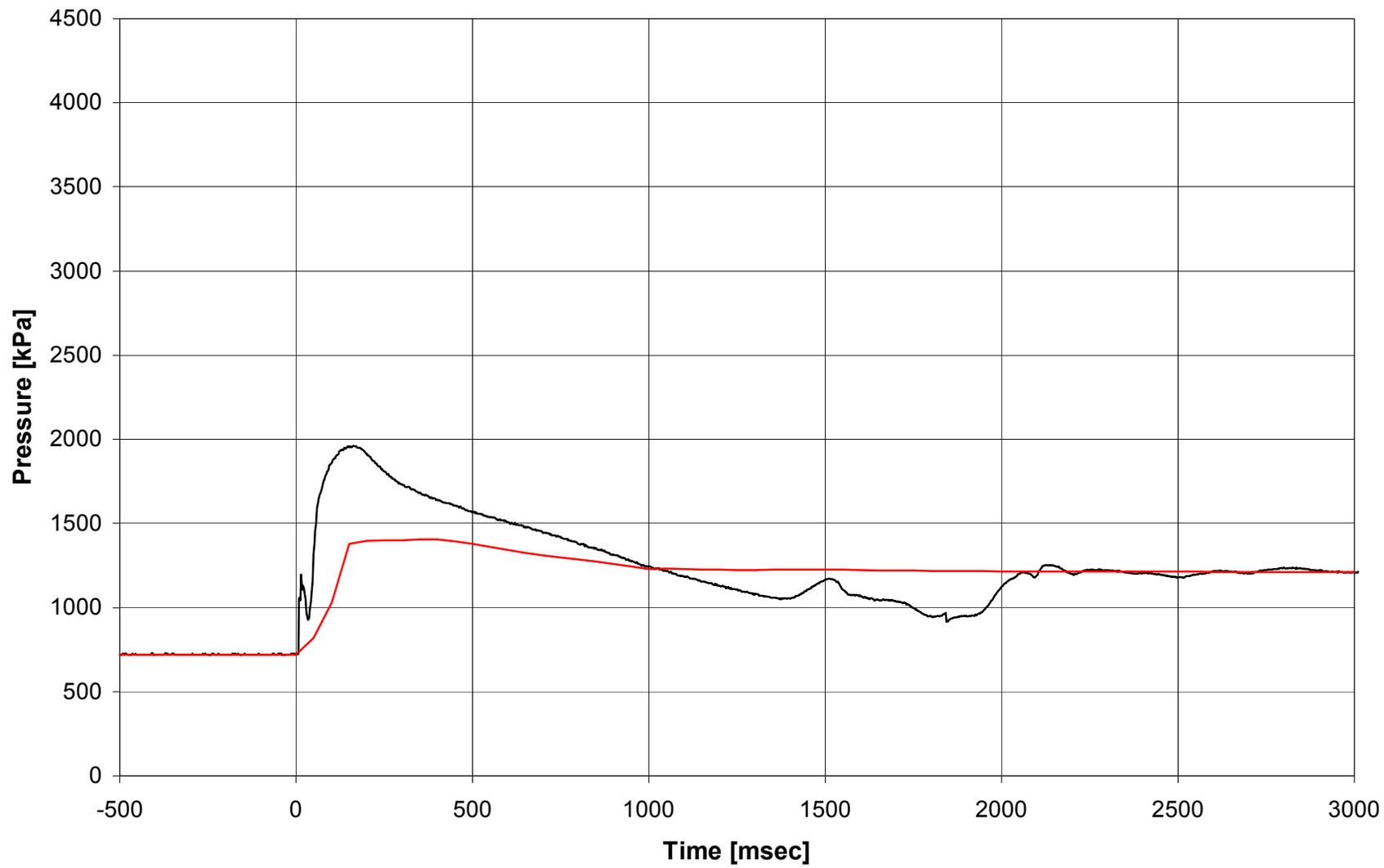


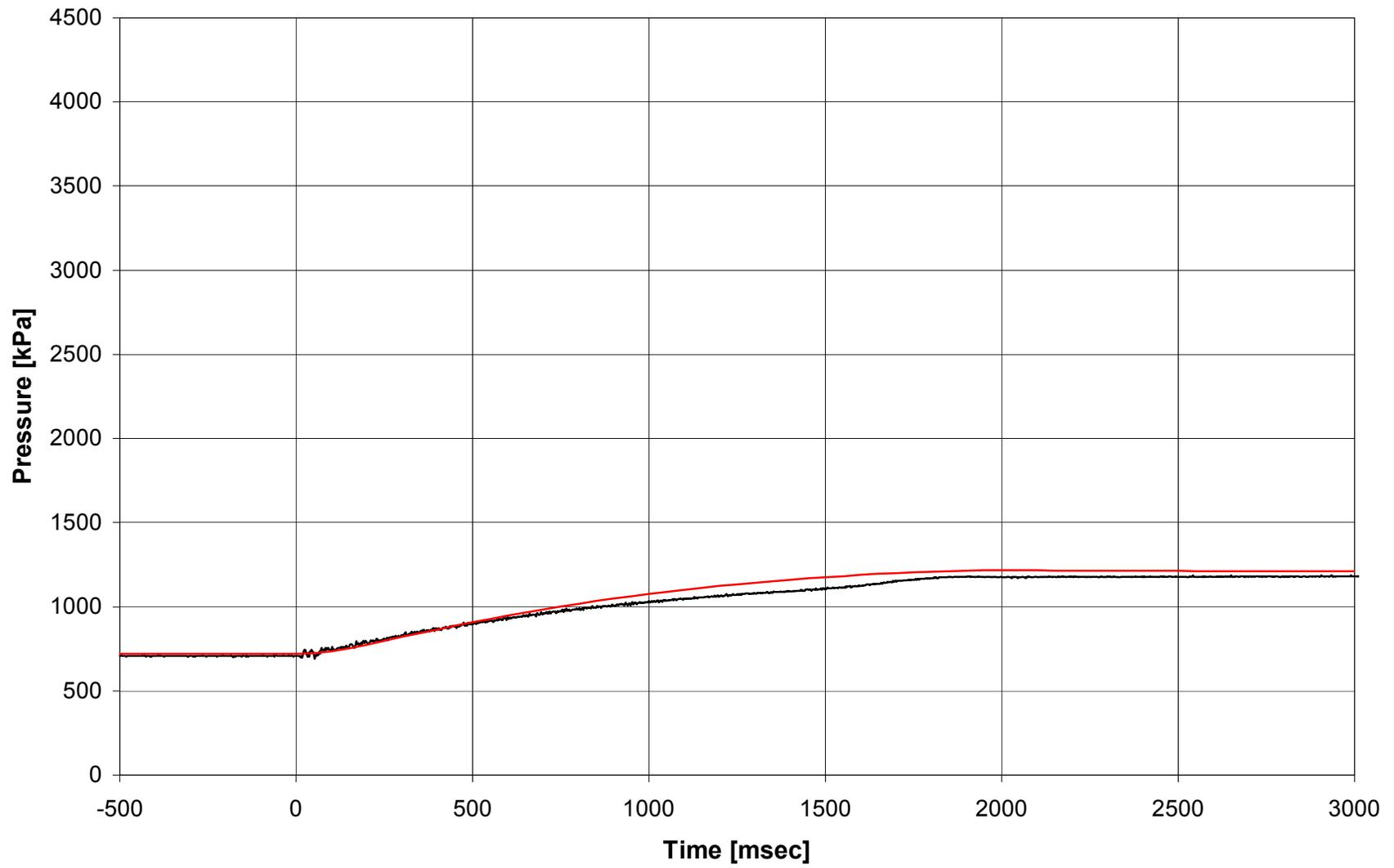












Run #8 with Code Prediction

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Capped Tee, 90° Elbow, Union, Two 45° Elbows, Capped Tee (Configuration #1)

Source Vessel Initial Conditions: Fill Volume: 3420 milliliters
 Fluid Mass: 4.851 kg
 Pressure (Psvo): 2120 kPa
 Nitrogen Mass: 0.058 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 125 kPa

Initial System Temperature: 21° Celsius

Completion Date: 1/19/00

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

Graph 3: Source Vessel Pressure

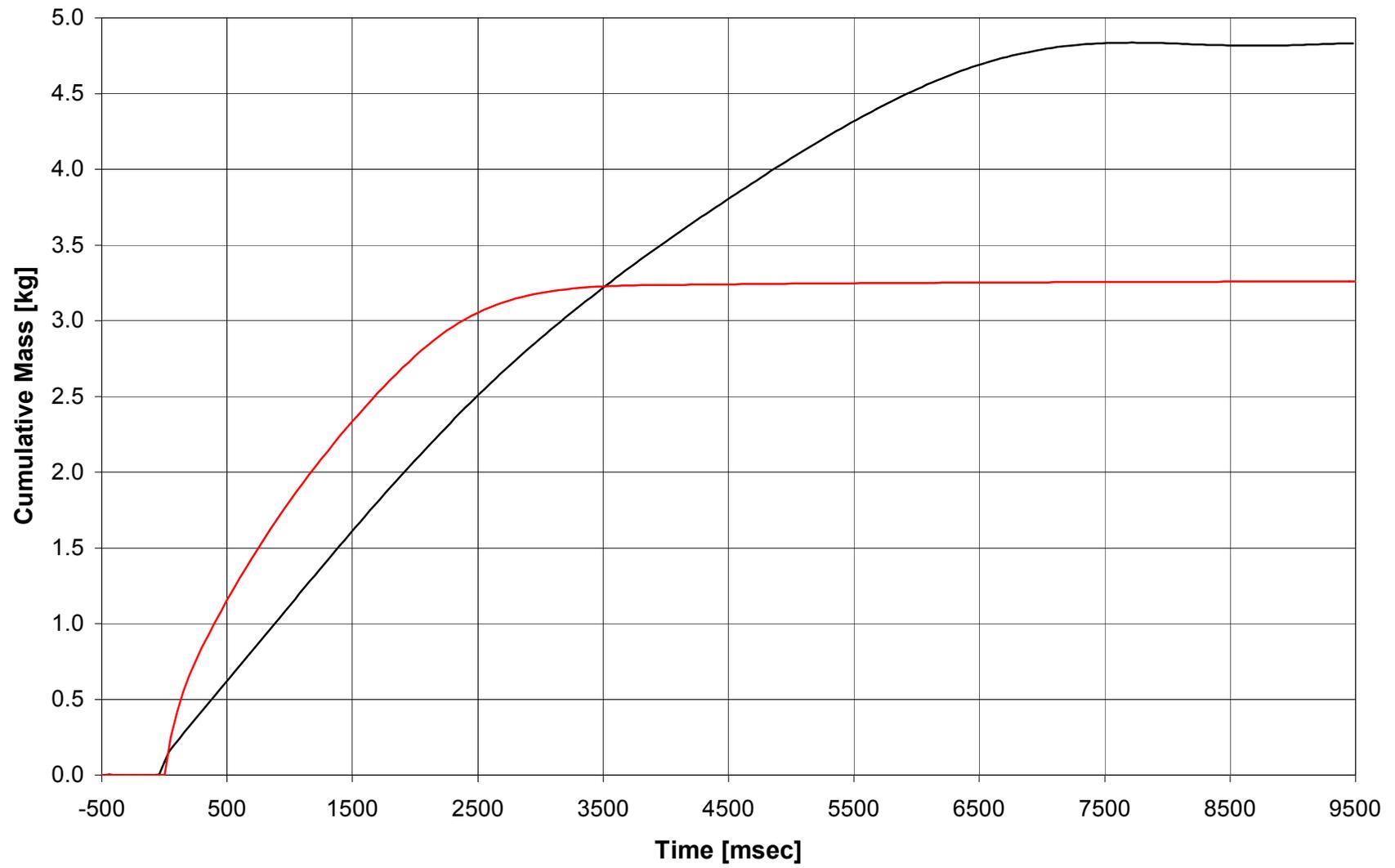
Graph 4: Pipe Position #1 Pressure

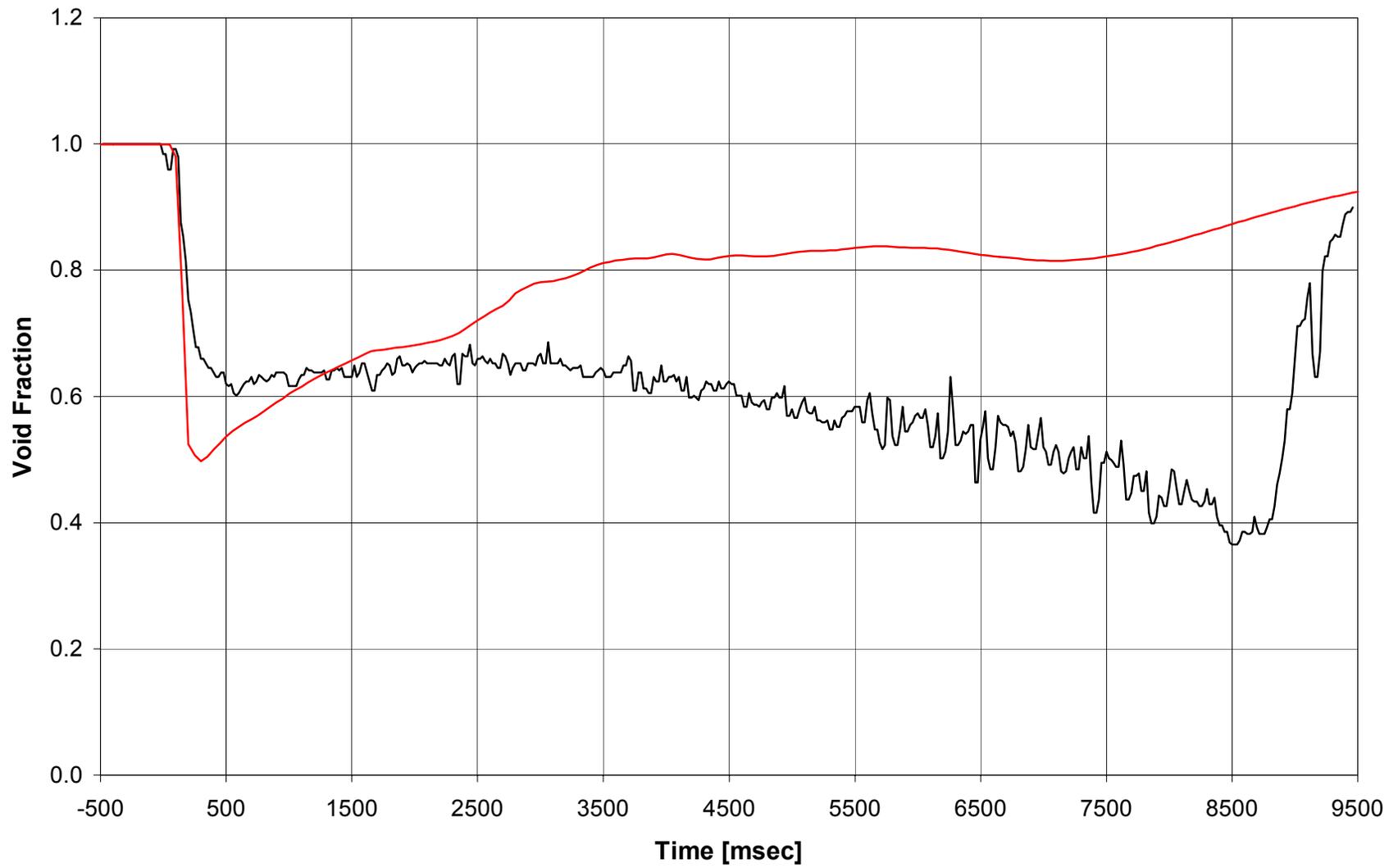
Graph 5: Collection Vessel Pressure

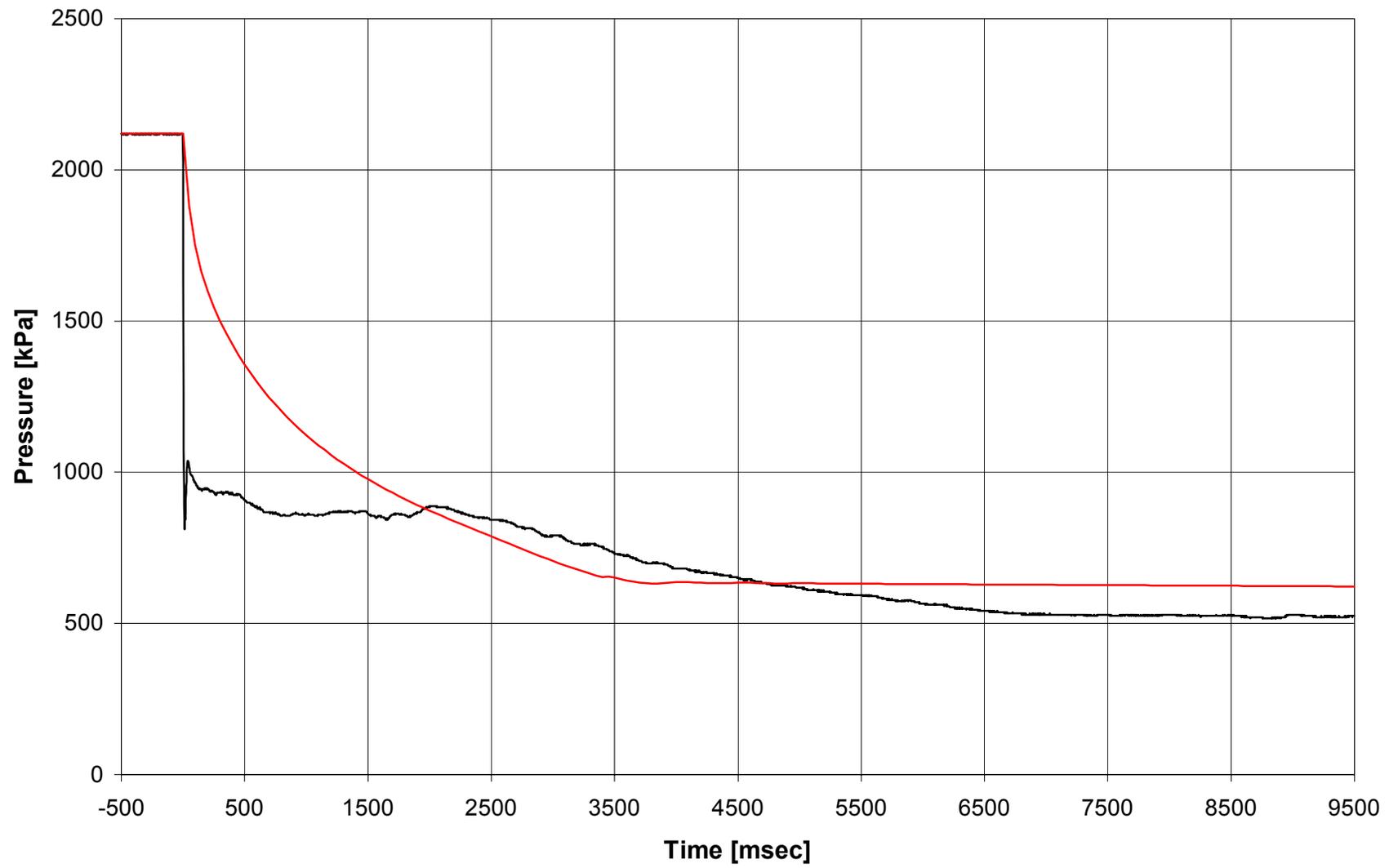
Graph 6: Pressure Drop Across Capped Tee

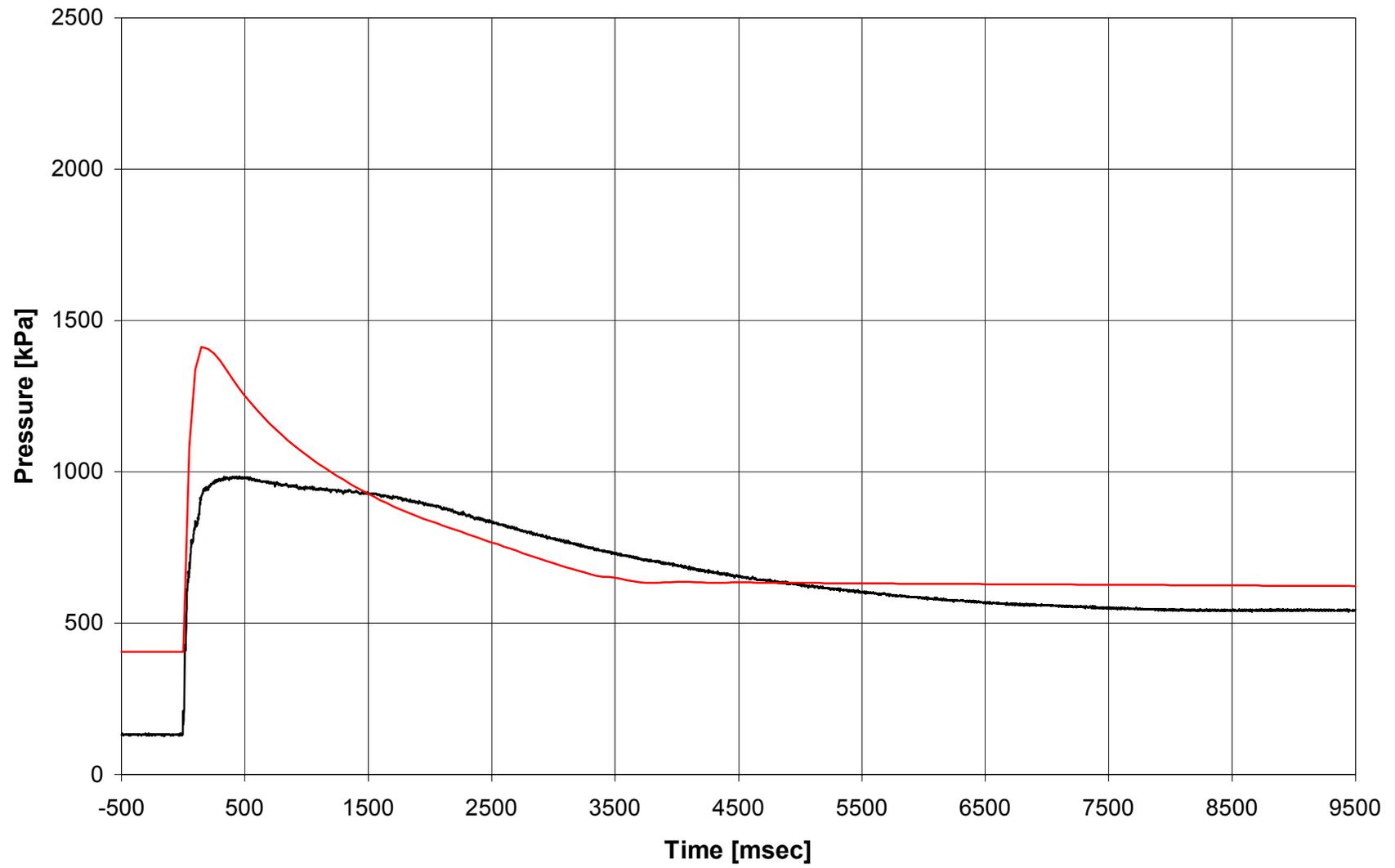
Graph 7: Pressure Drop Across 90° Elbow

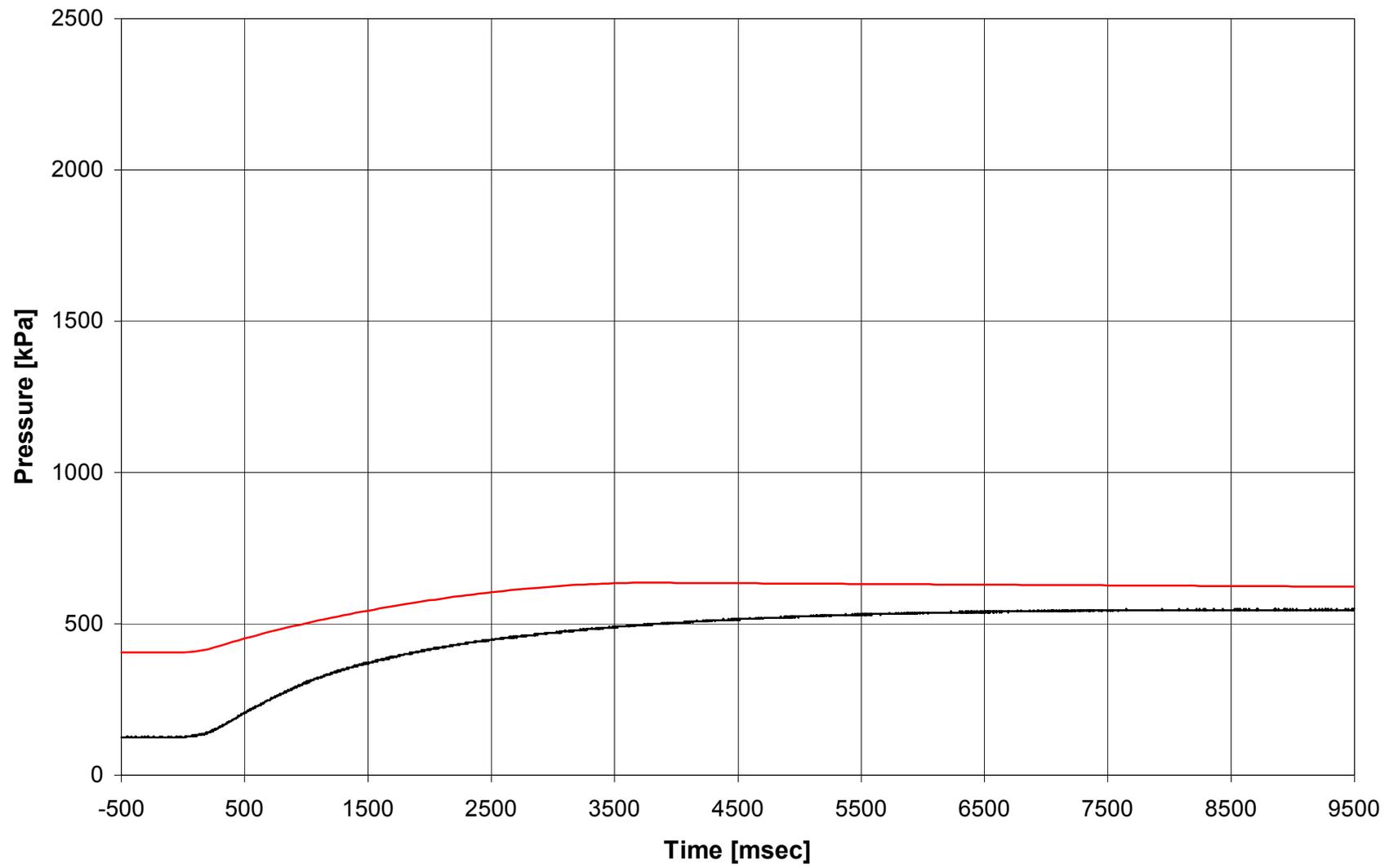
Graph 8: Pressure Drop Across Union

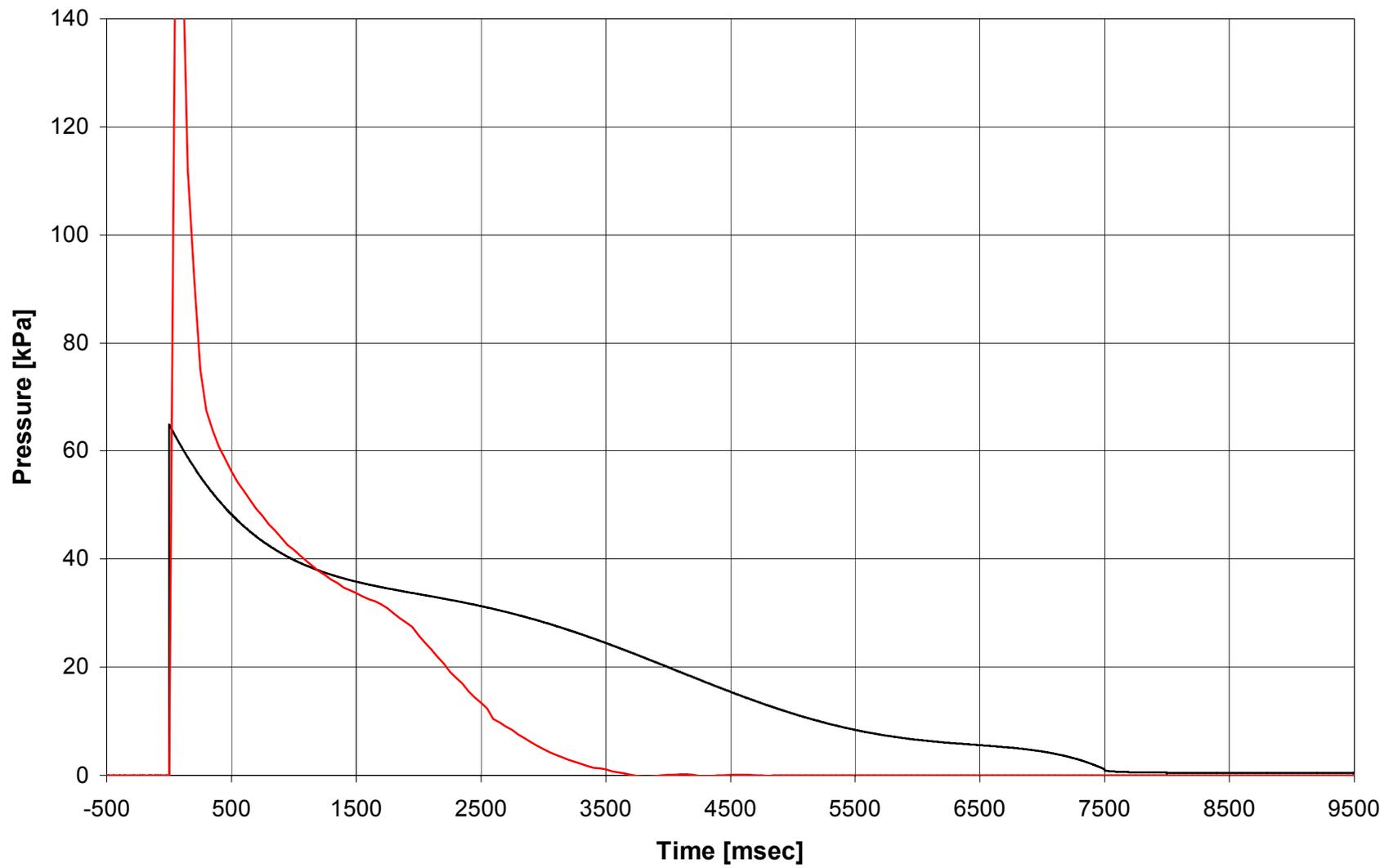


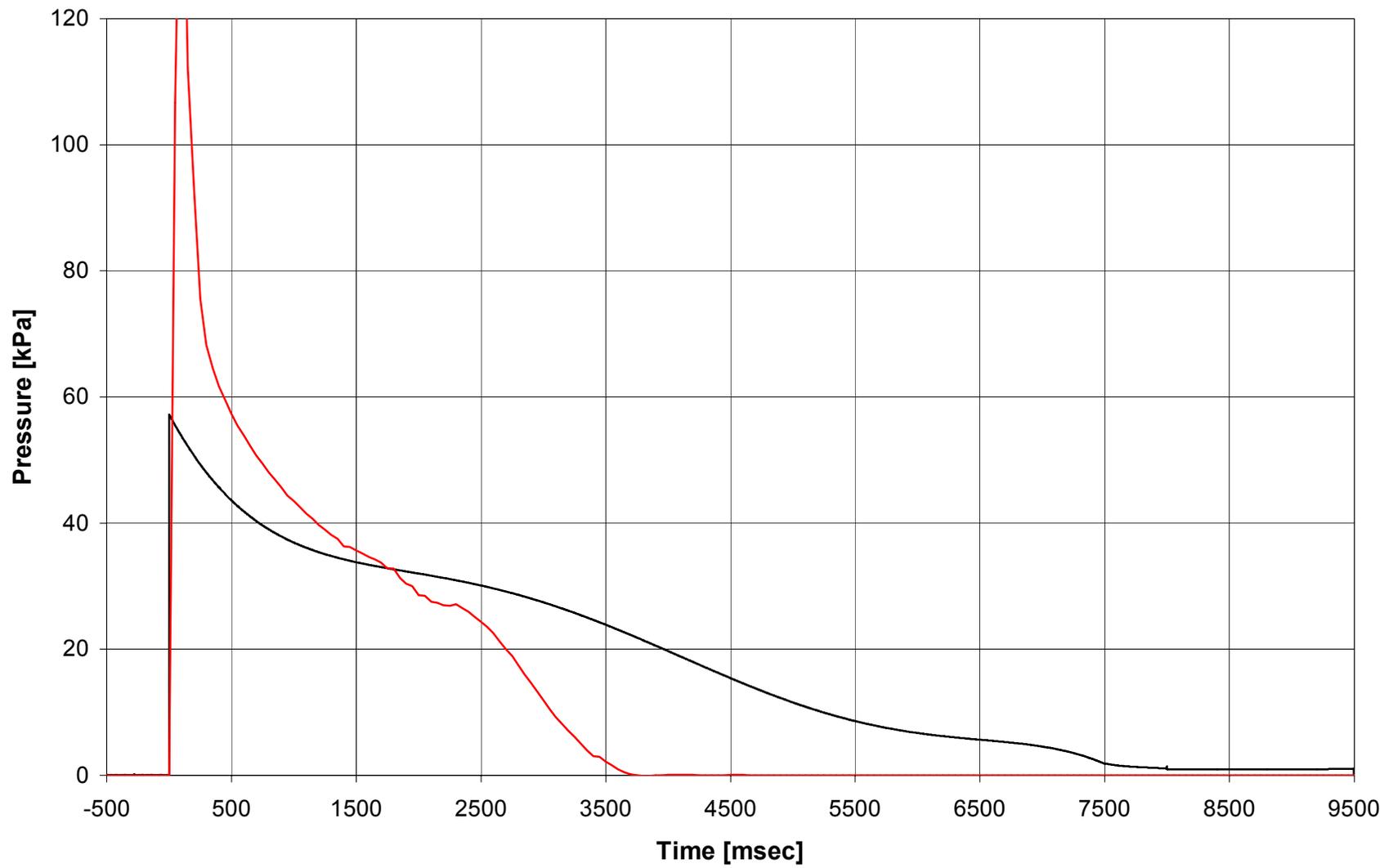


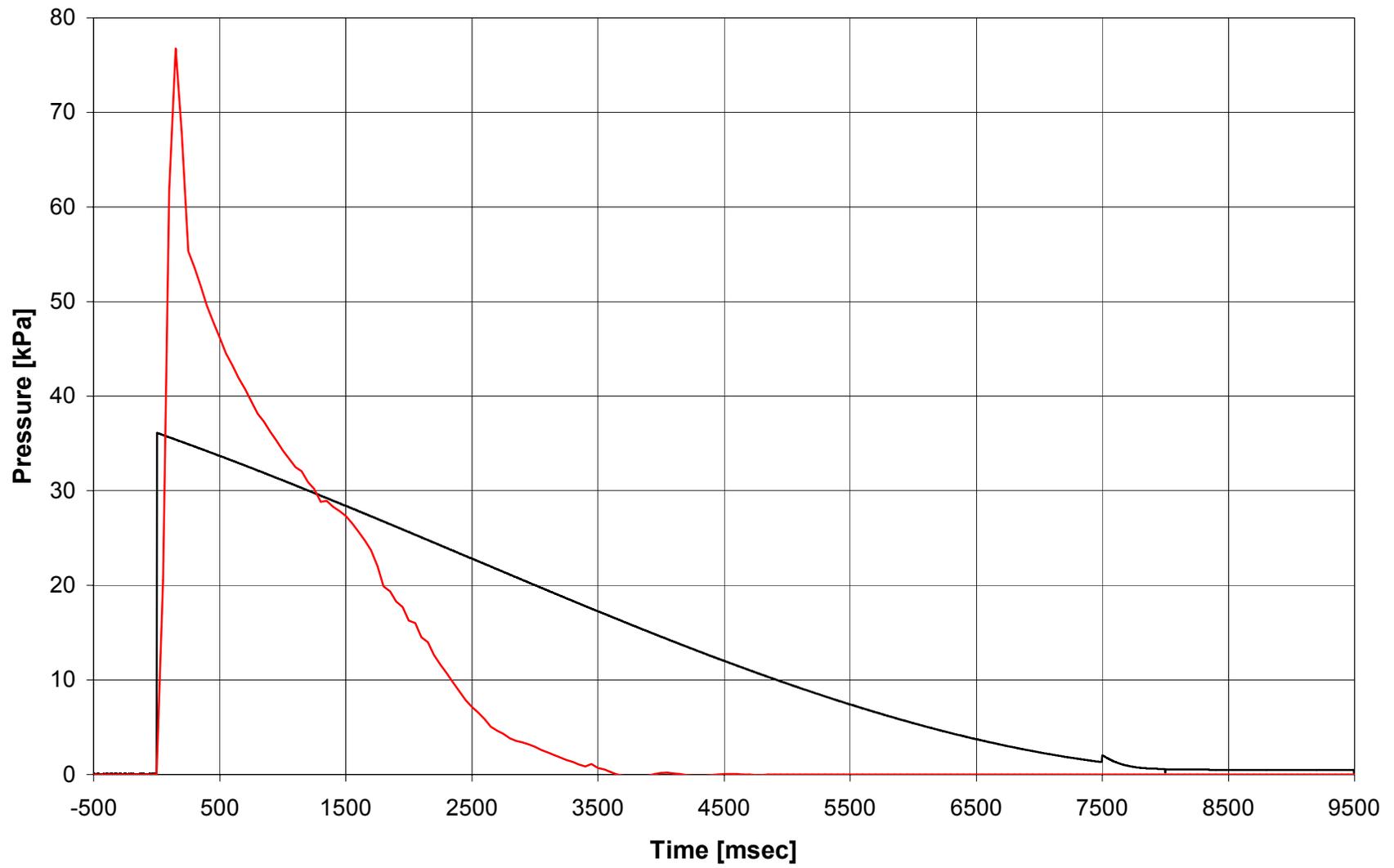












Run #9 with Code Prediction

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Capped Tee, 90° Elbow, Union, Two 45° Elbows, Capped Tee (Configuration #1)

Source Vessel Initial Conditions: Fill Volume: 2500 milliliters
 Fluid Mass: 3.568 kg
 Pressure (Psvo): 3915 kPa
 Nitrogen Mass: 0.127 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 575 kPa

Initial System Temperature: 24° Celsius

Completion Date: 2/7/00

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

Graph 3: Source Vessel Pressure

Graph 4: Pipe Position #1 Pressure

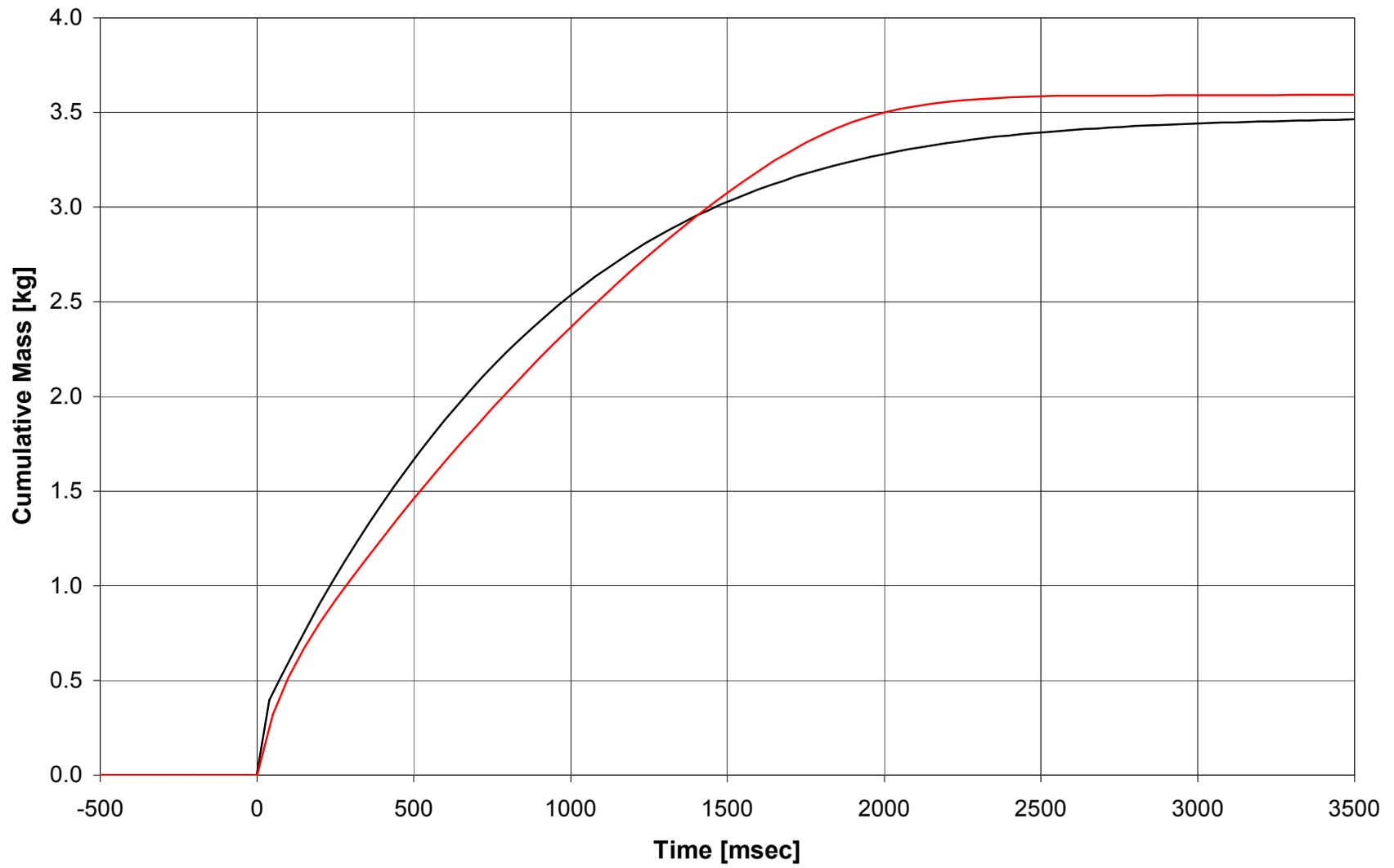
Graph 5: Pipe Position #3 Pressure

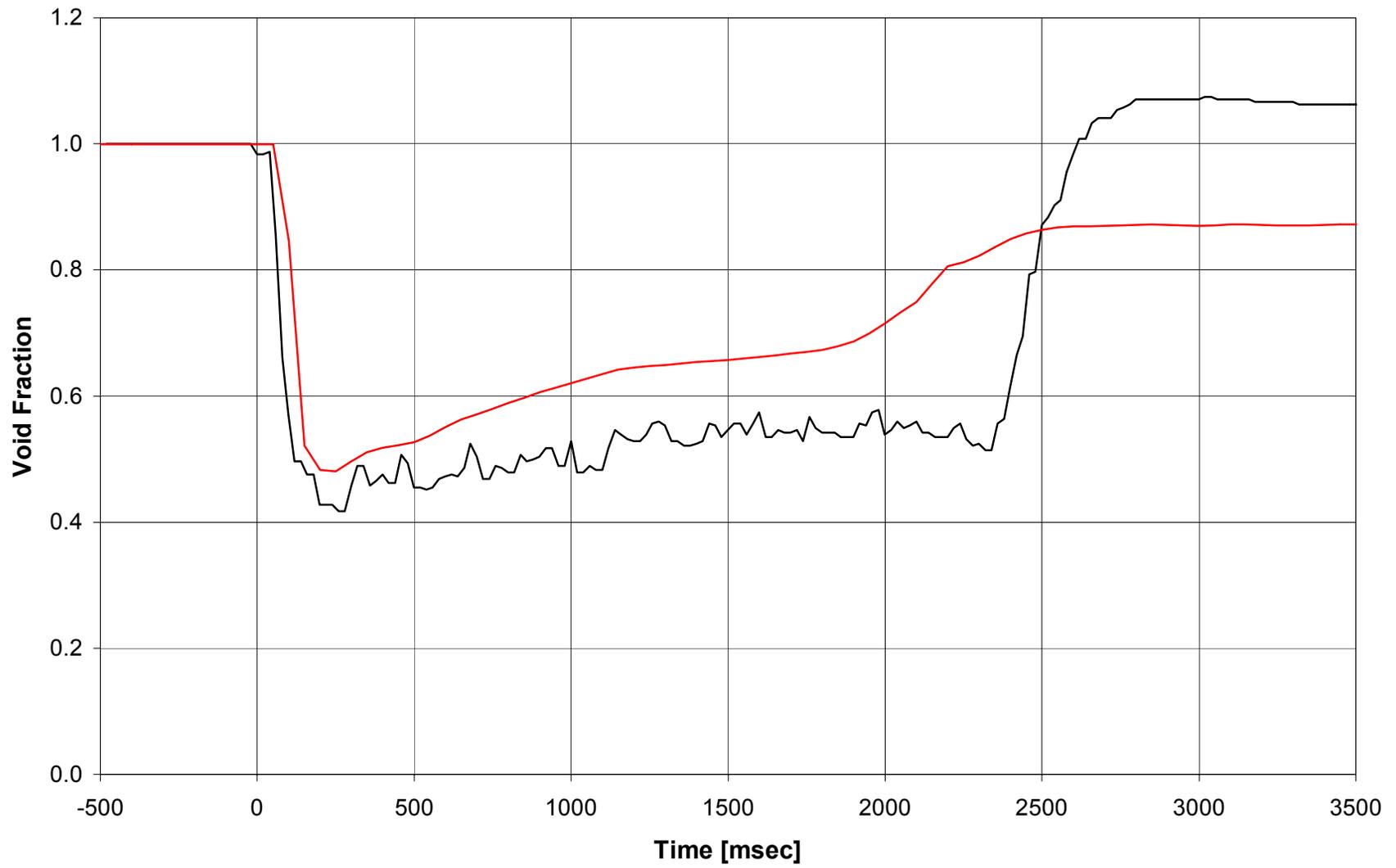
Graph 6: Collection Vessel Pressure

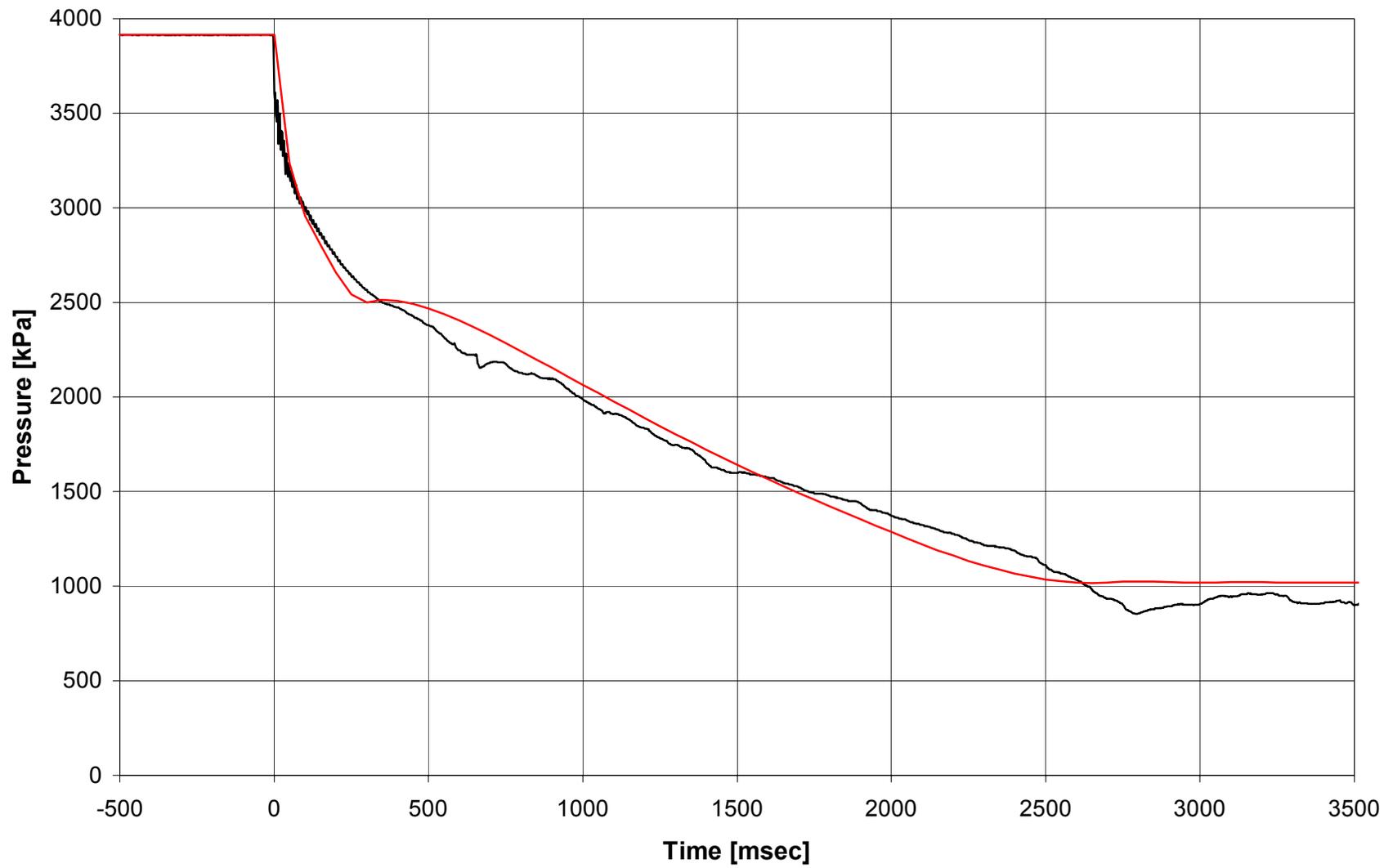
Graph 7: Pressure Drop Across Capped Tee

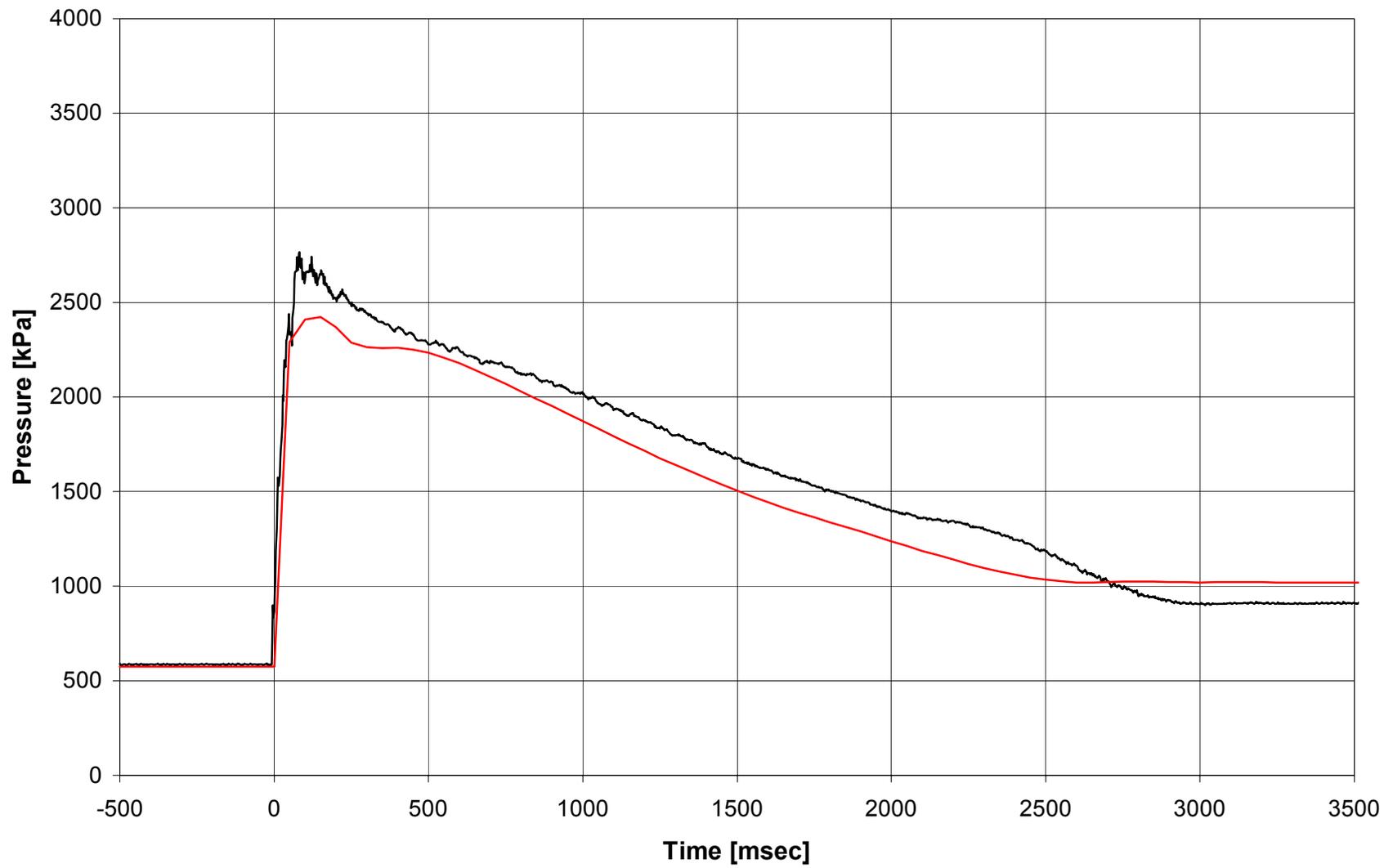
Graph 8: Pressure Drop Across 90° Elbow

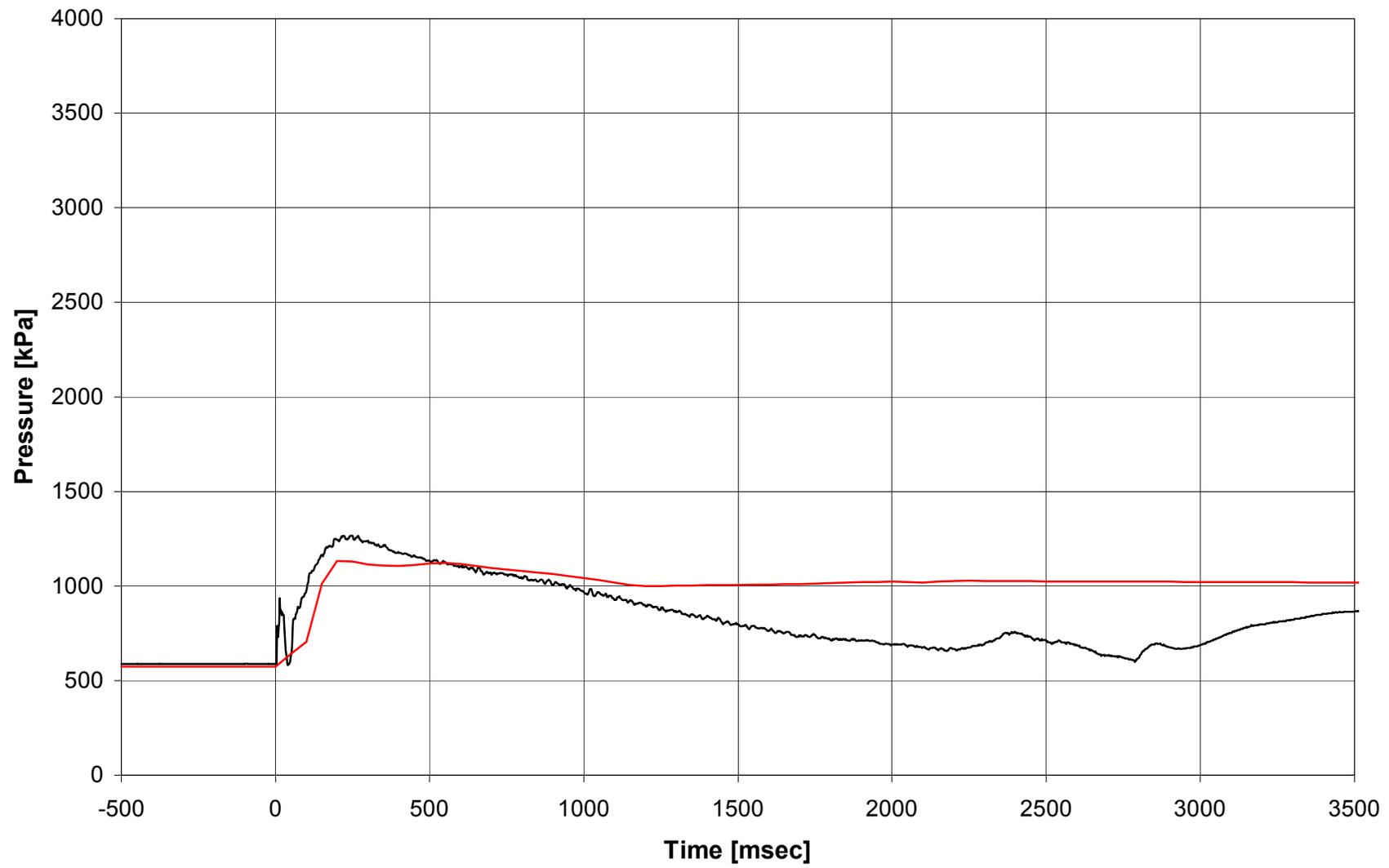
Graph 9: Pressure Drop Across Union

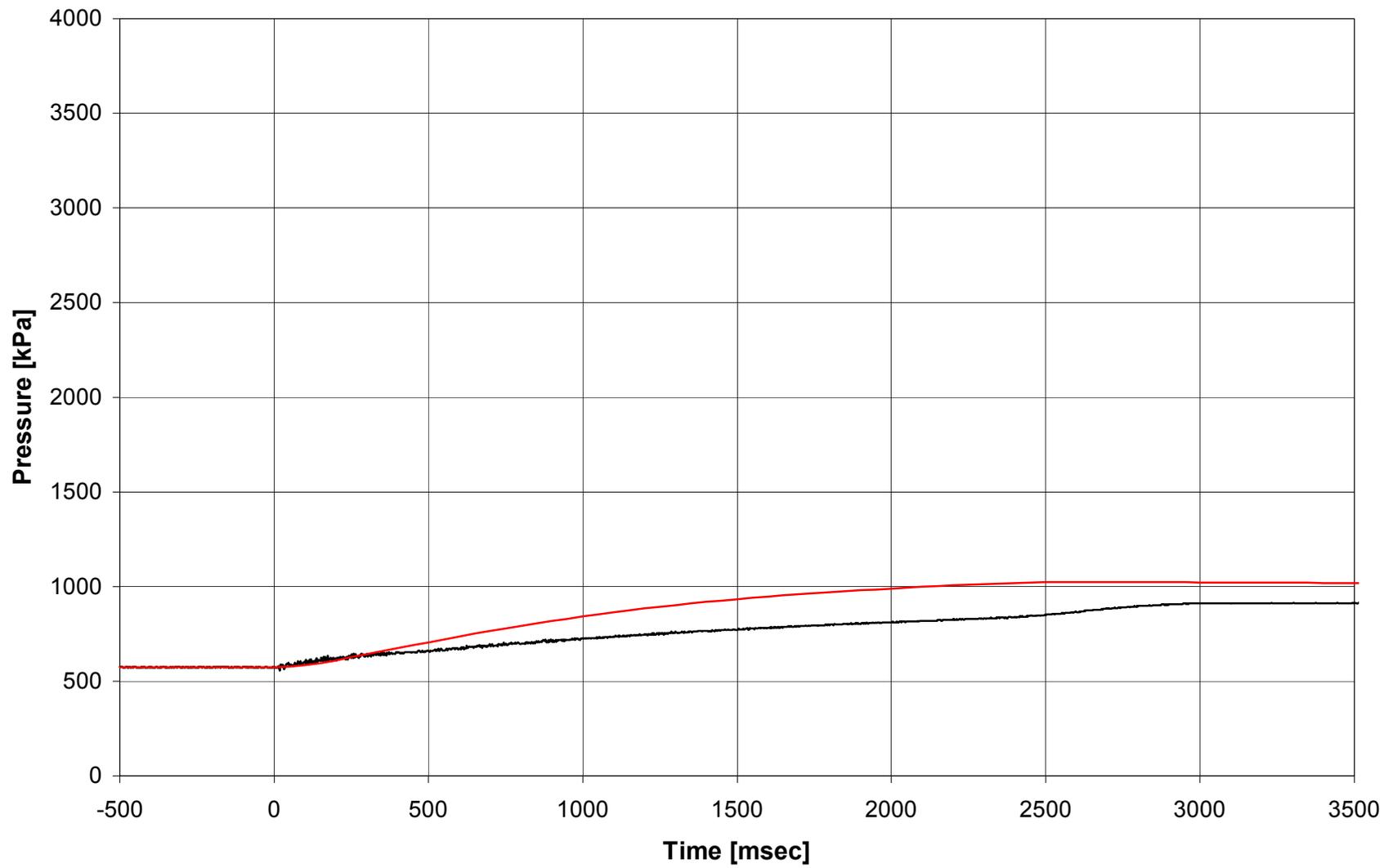


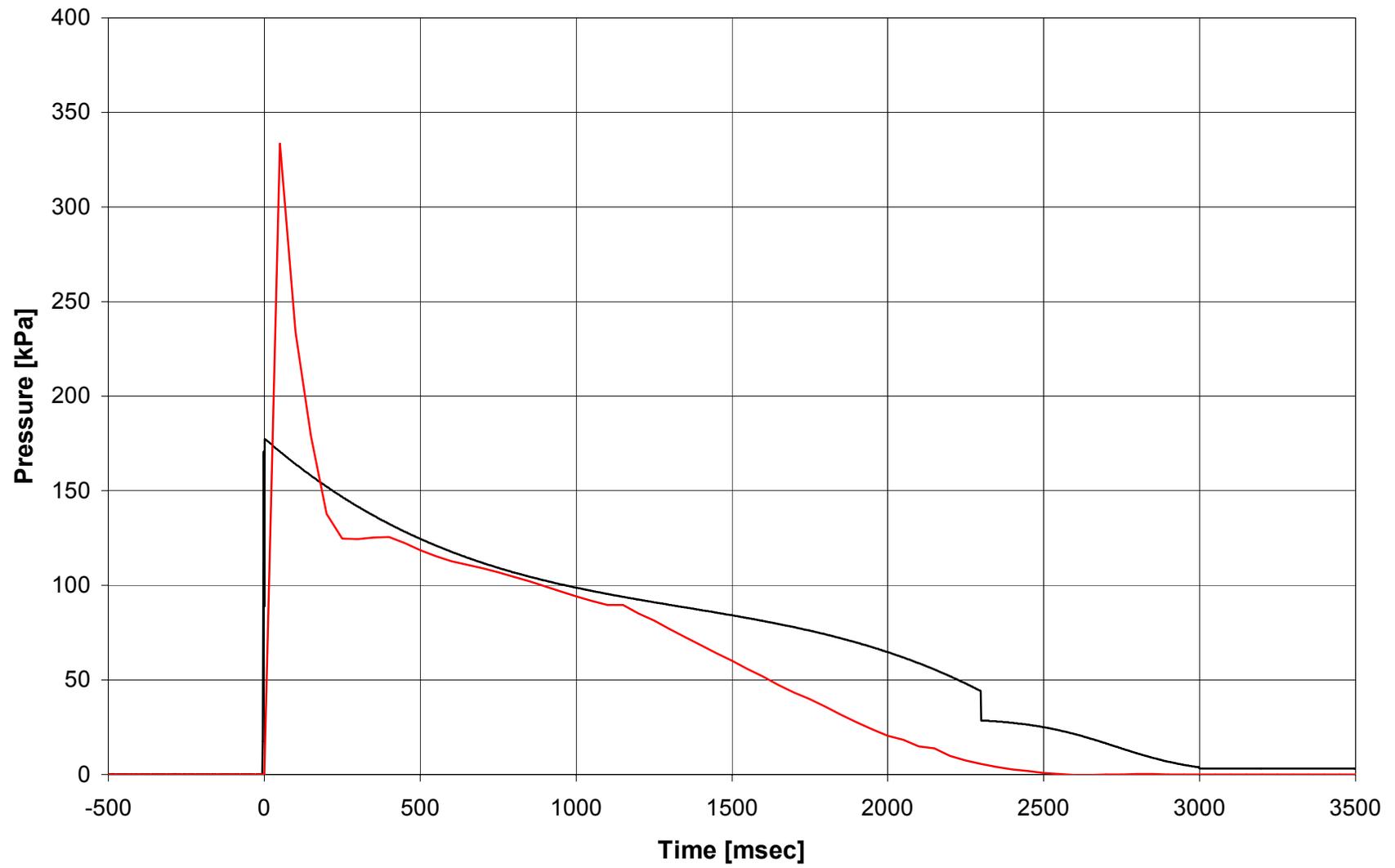


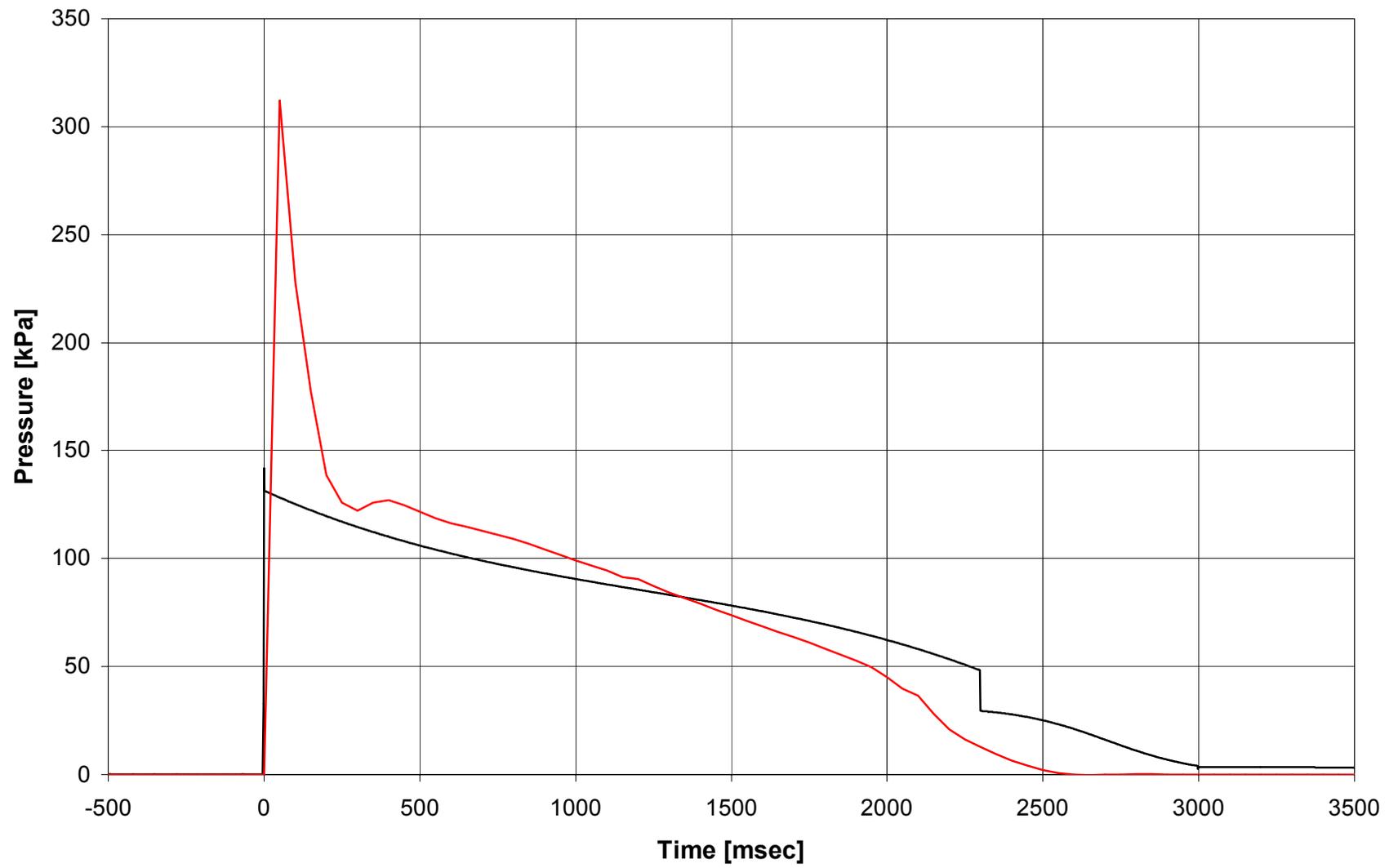


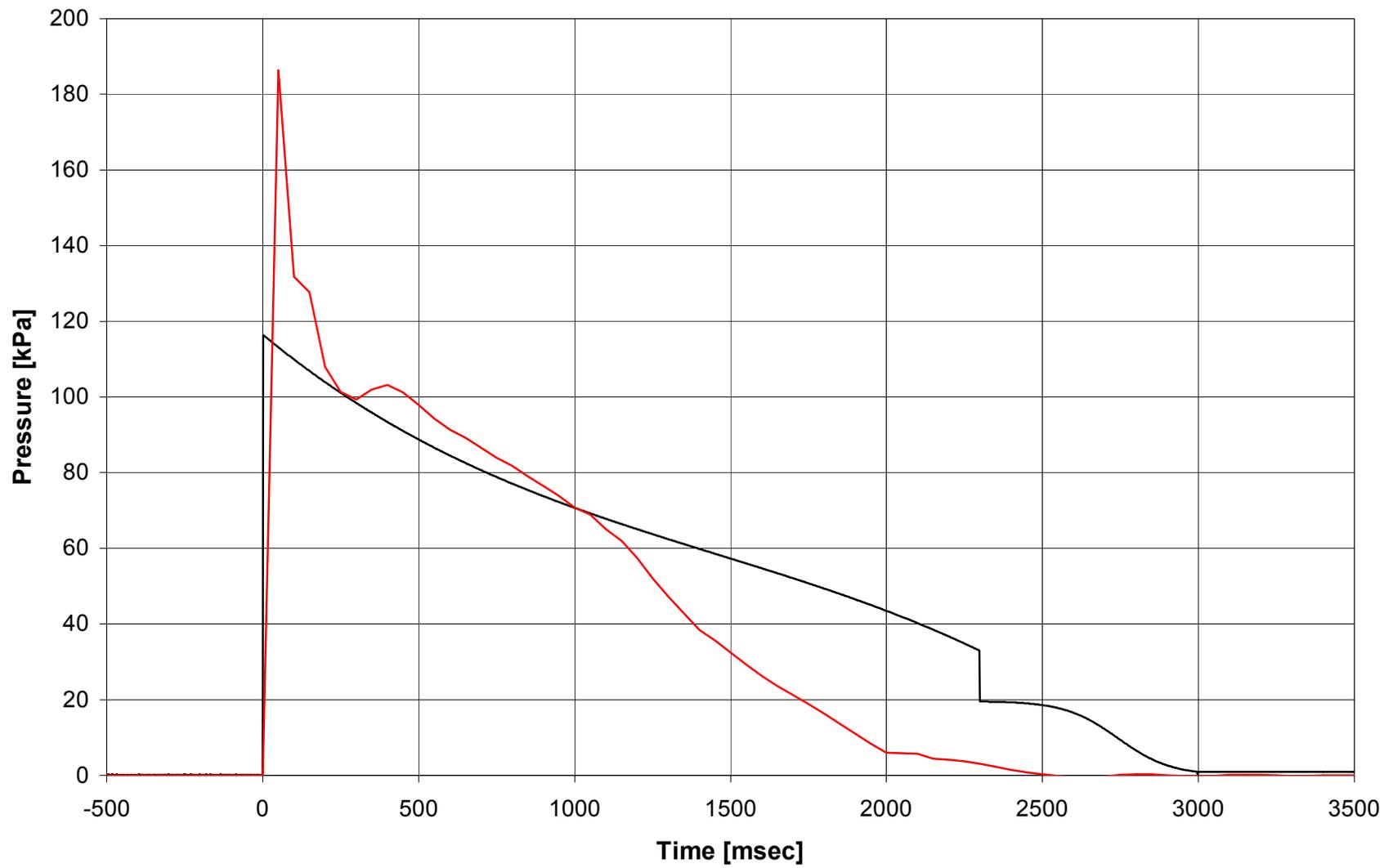












Run #10 with Code Prediction

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Capped Tee, 90° Elbow, Union, Two 45° Elbows, Capped Tee (Configuration #1)

Source Vessel Initial Conditions: Fill Volume: 2450 milliliters
 Fluid Mass: 3.512 kg
 Pressure (Psvo): 4910 kPa
 Nitrogen Mass: 0.163 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 615 kPa

Initial System Temperature: 25° Celsius

Completion Date: 2/11/00

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

Graph 3: Source Vessel Pressure

Graph 4: Pipe Position #1 Pressure

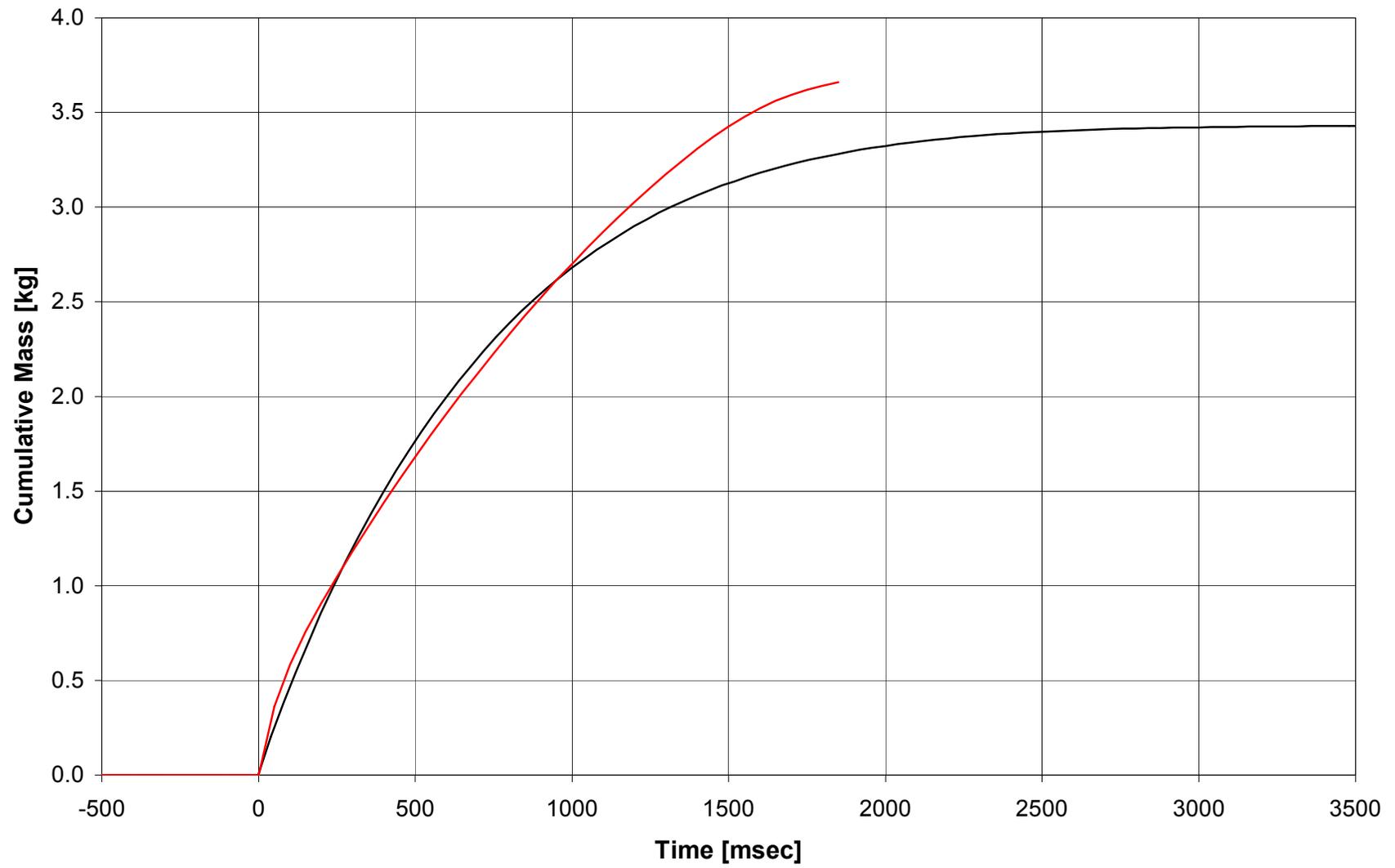
Graph 5: Pipe Position #3 Pressure

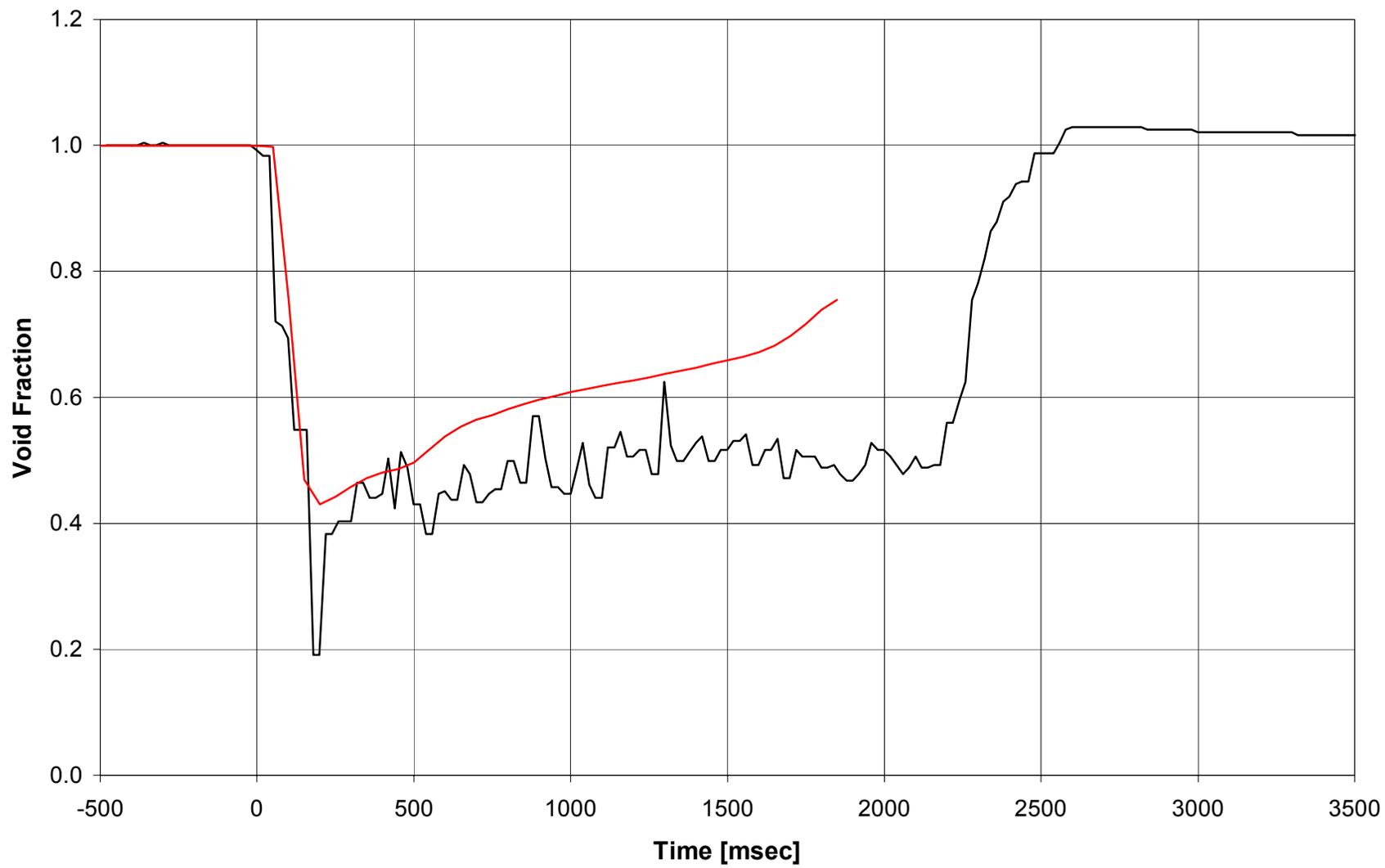
Graph 6: Collection Vessel Pressure

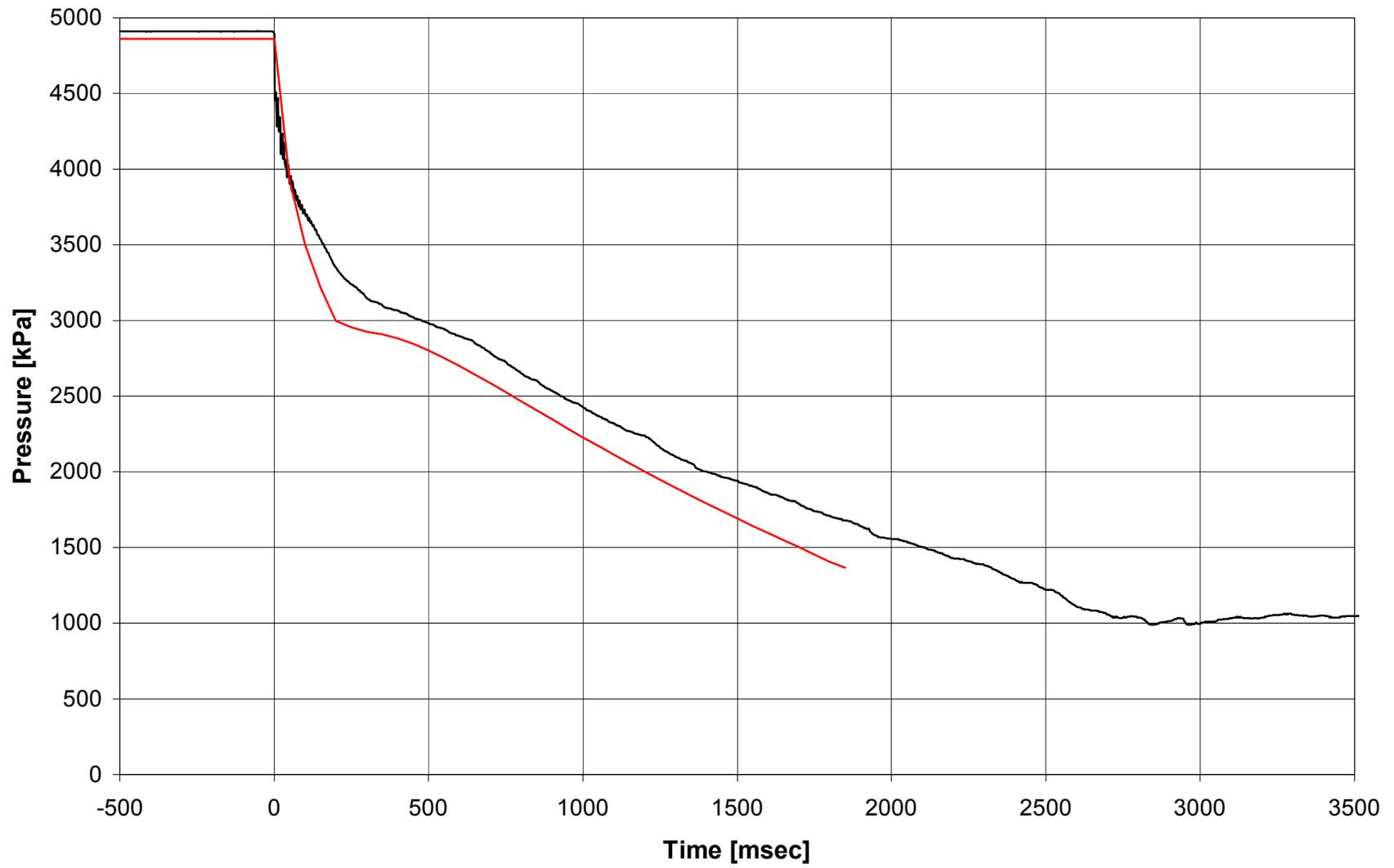
Graph 7: Pressure Drop Across Capped Tee

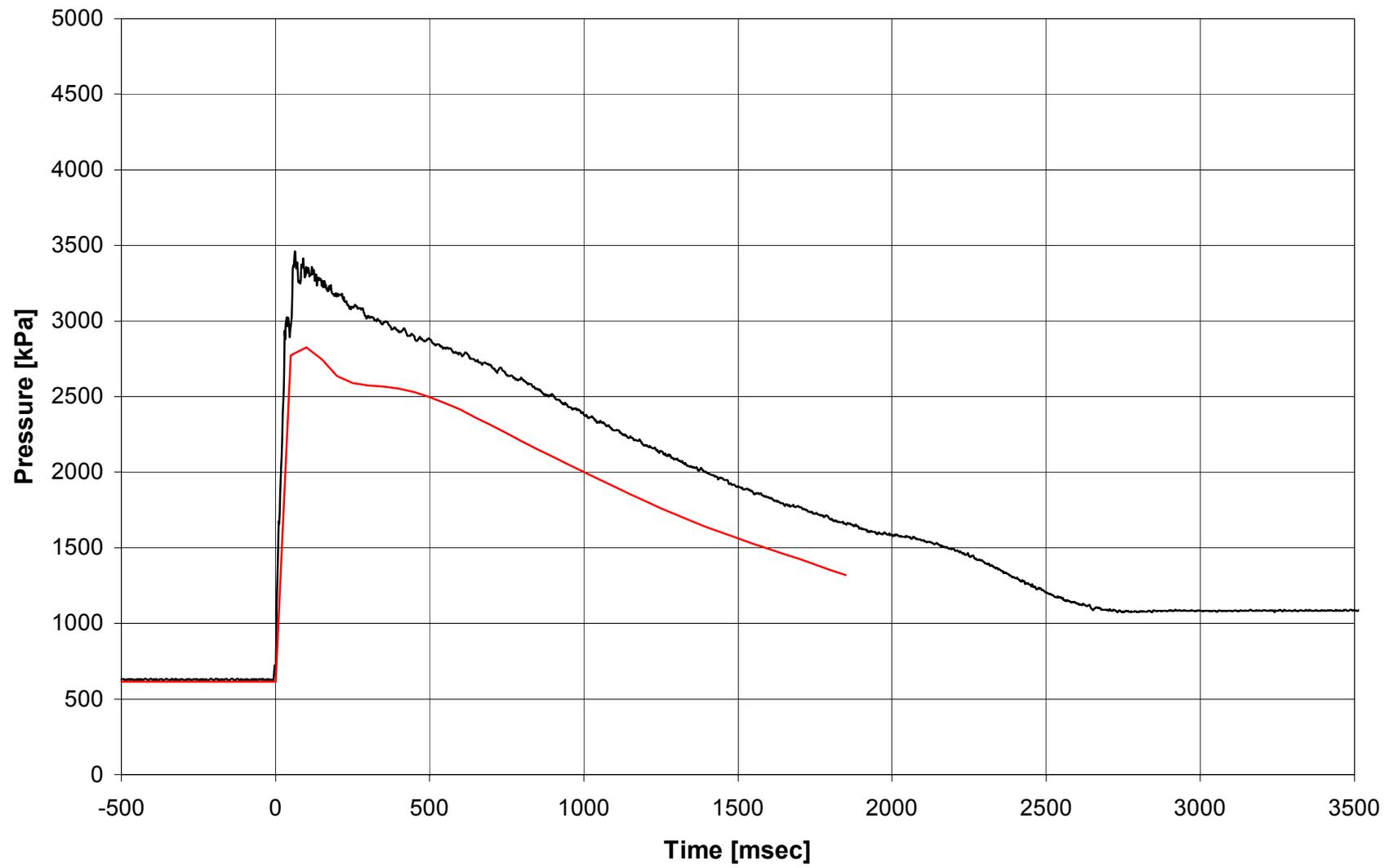
Graph 8: Pressure Drop Across 90° Elbow

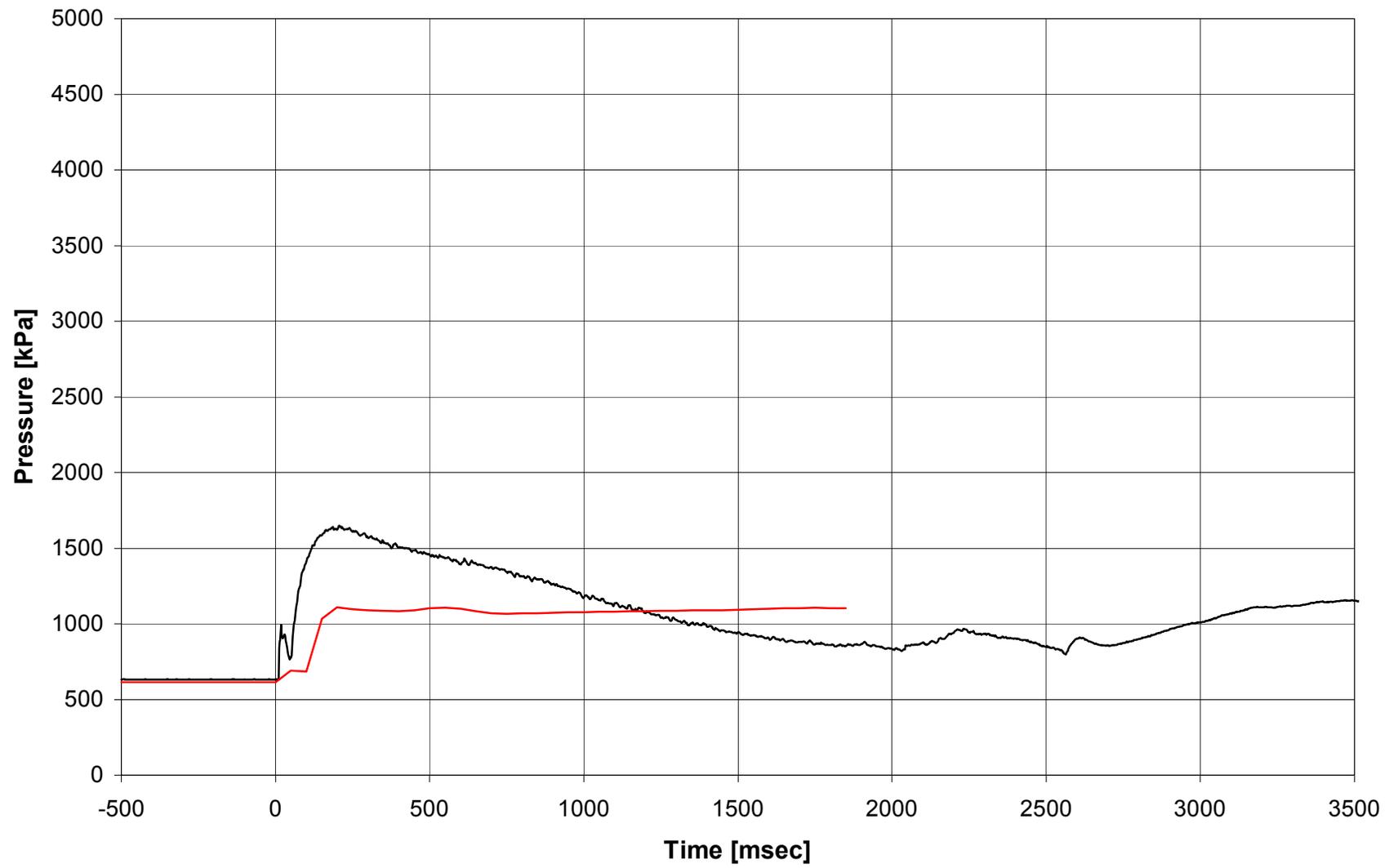
Graph 9: Pressure Drop Across Union

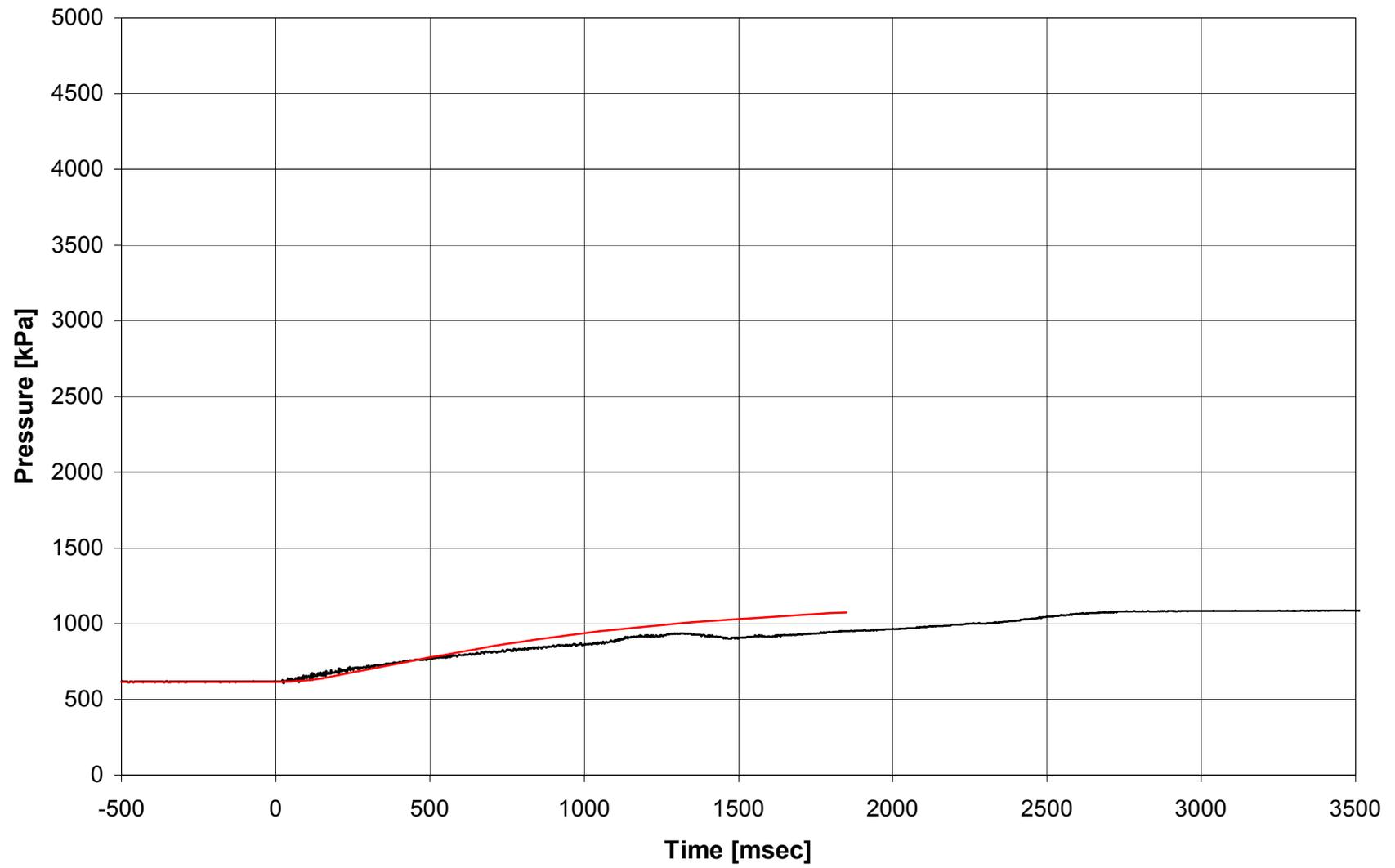


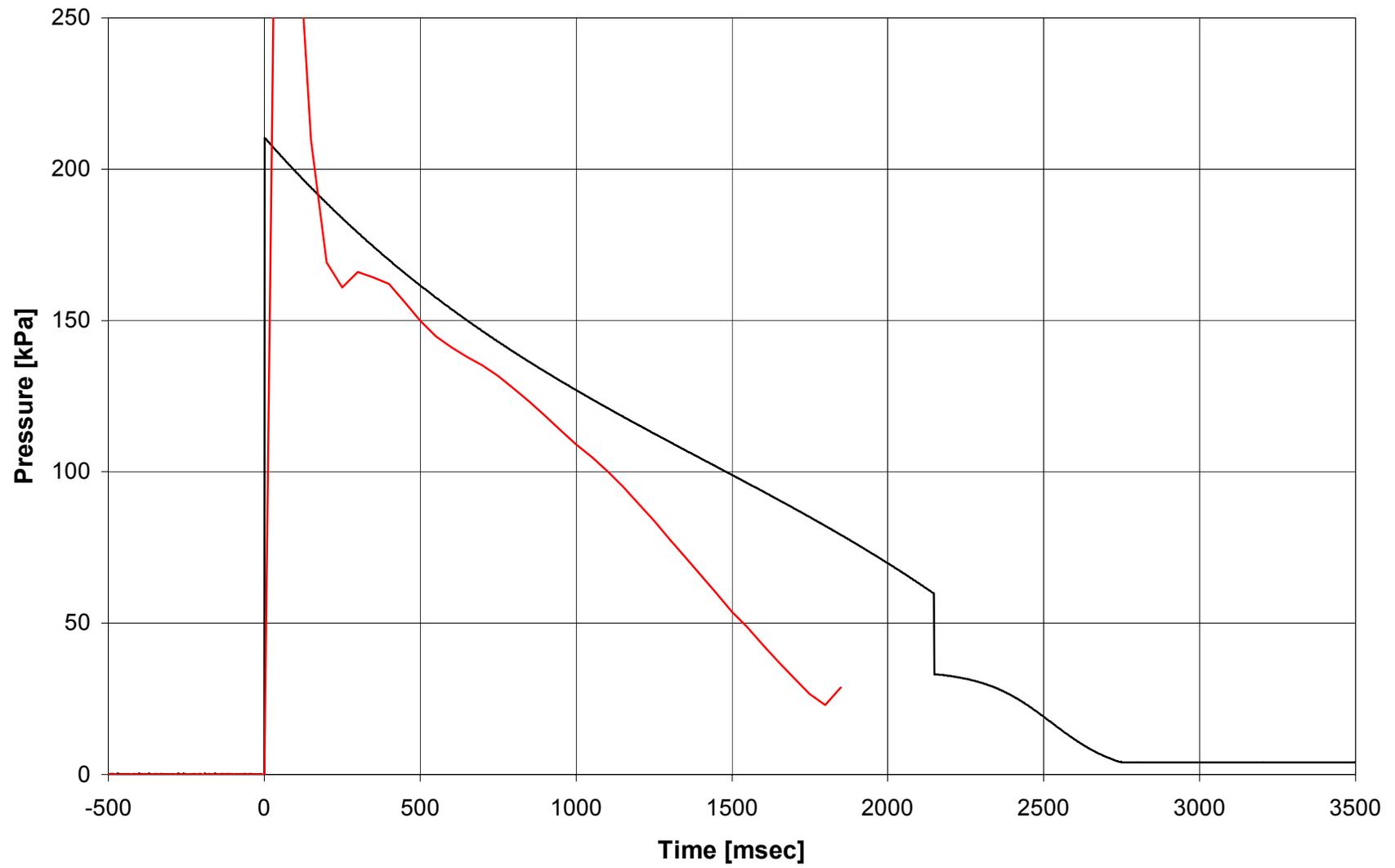


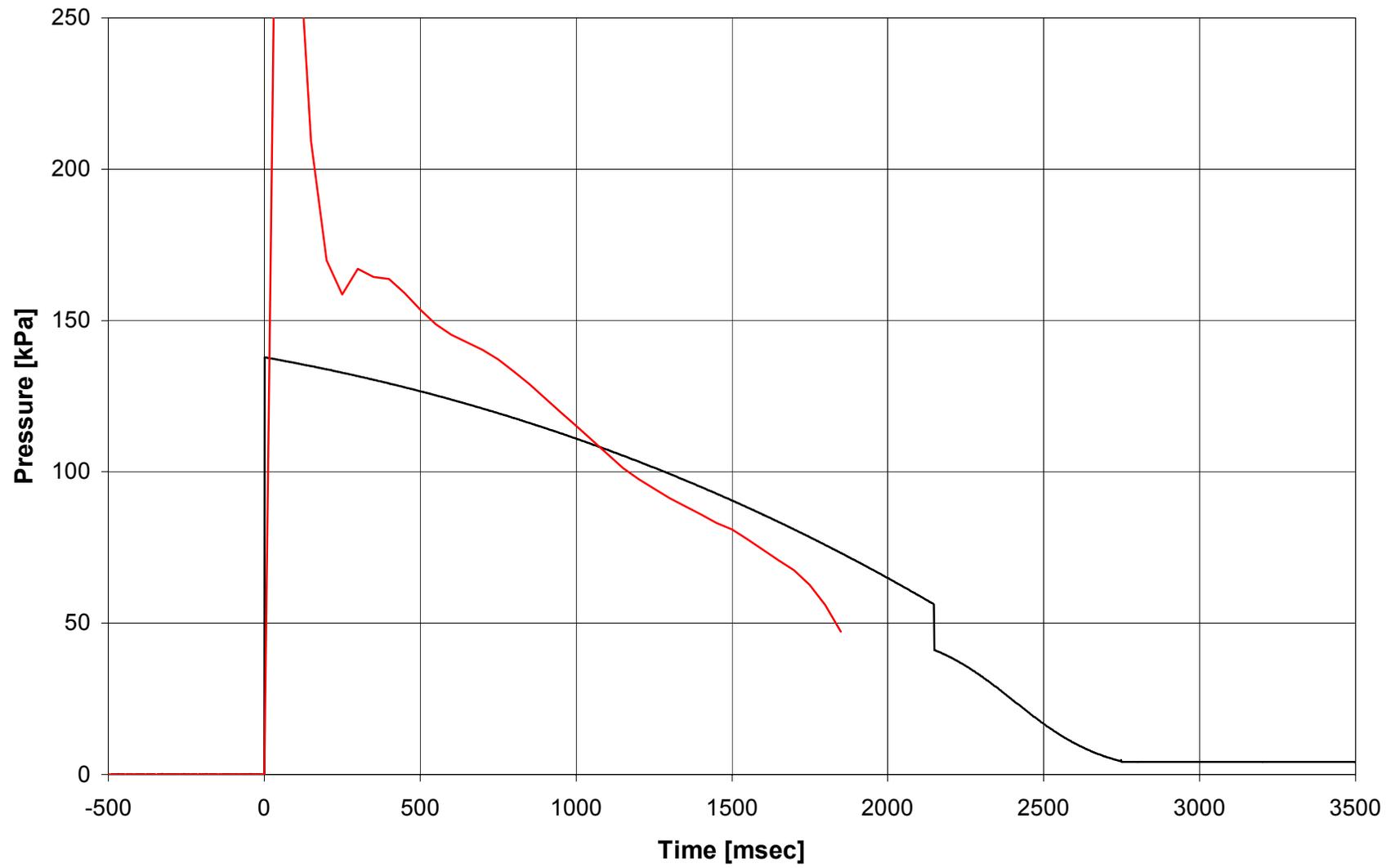


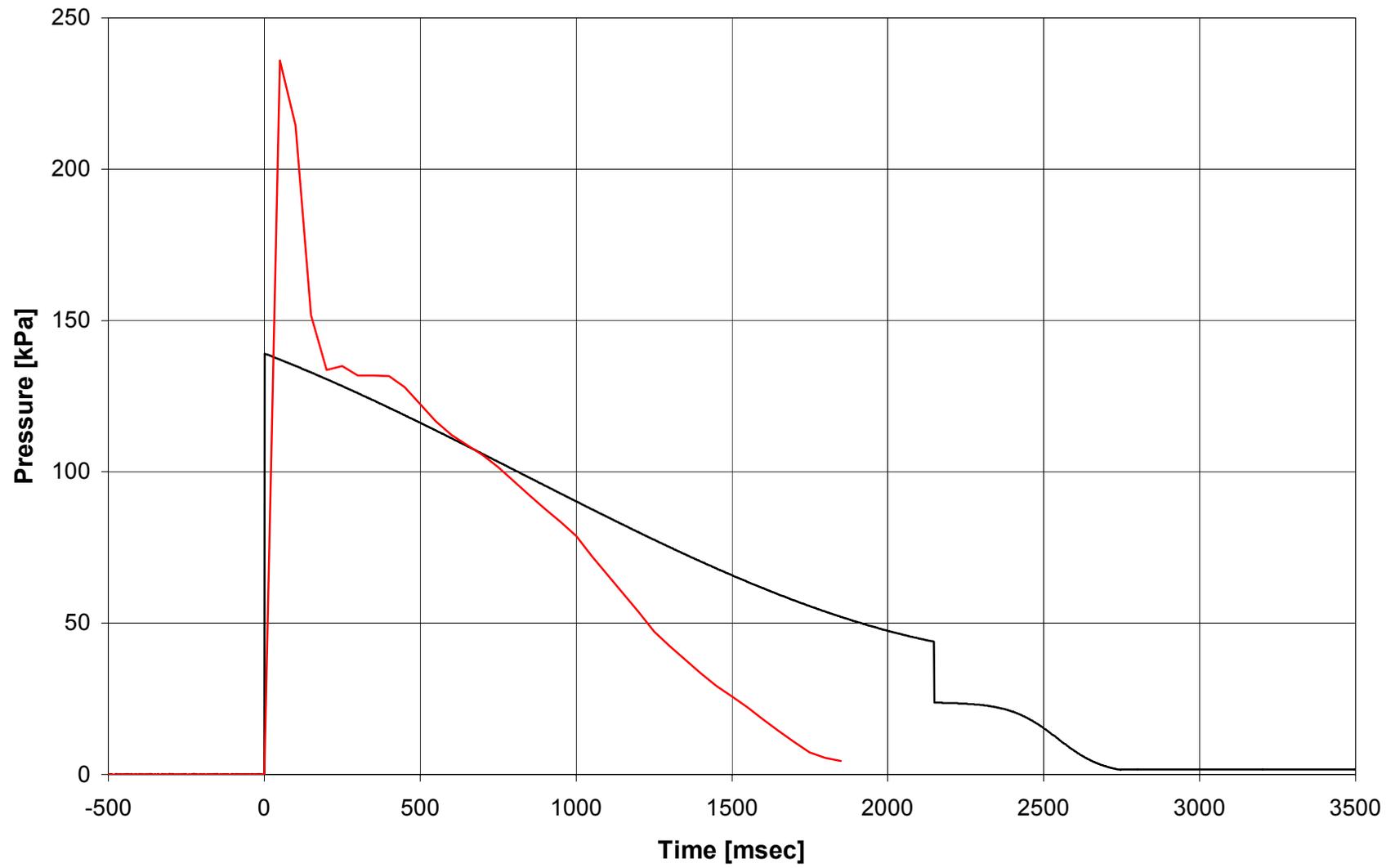












Run #11 with Code Prediction

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Vertical Tee branching into a 90° Elbow, Union, and Two 45° Elbows (Configuration #2)

Source Vessel Initial Conditions: Fill Volume: 3507 milliliters
 Fluid Mass: 4.938 kg
 Pressure (Psvo): 2140 kPa
 Nitrogen Mass: 0.055 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 600 kPa

Initial System Temperature: 26° Celsius

Completion Date: 2/22/00

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

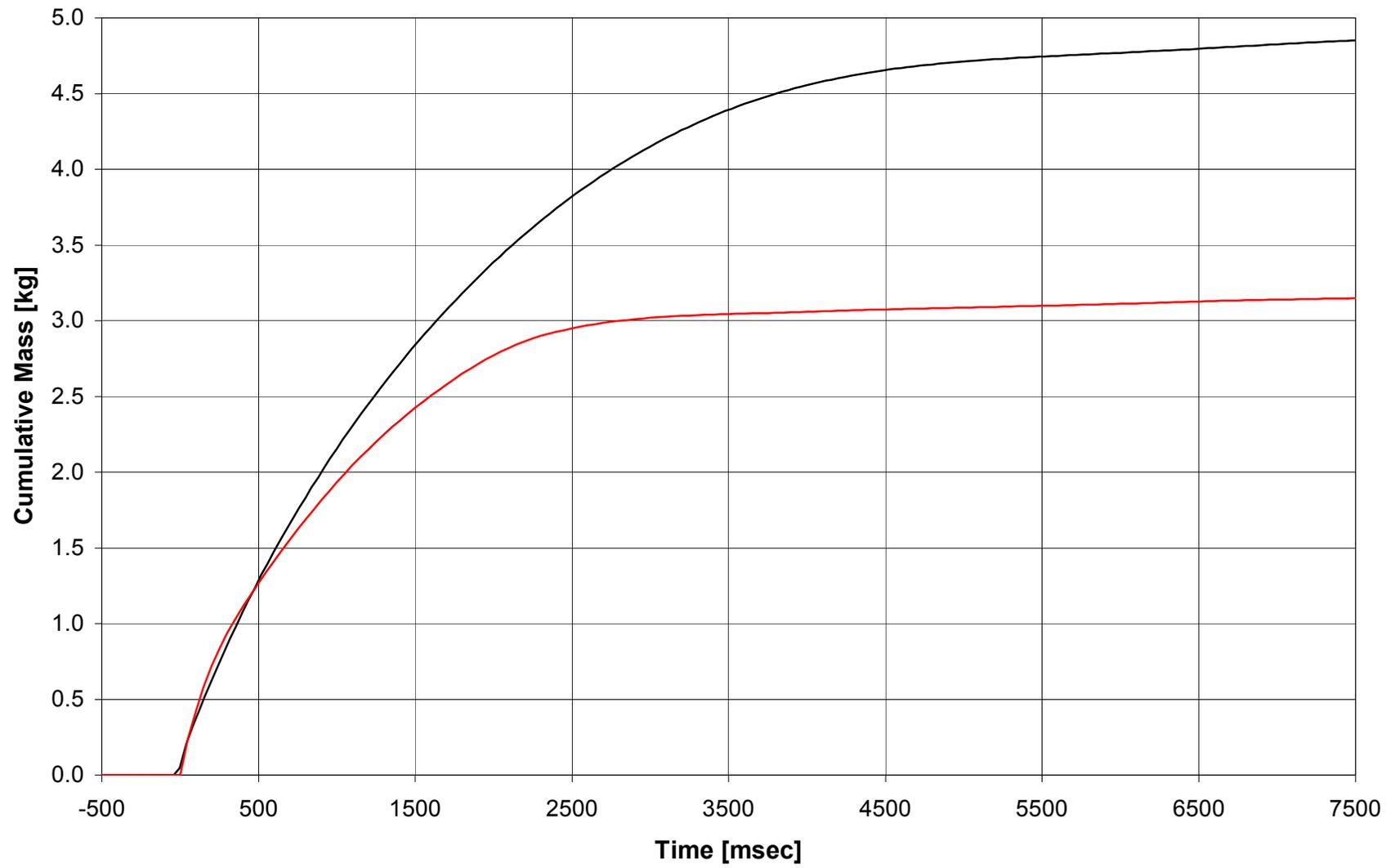
Graph 3: Source Vessel Pressure

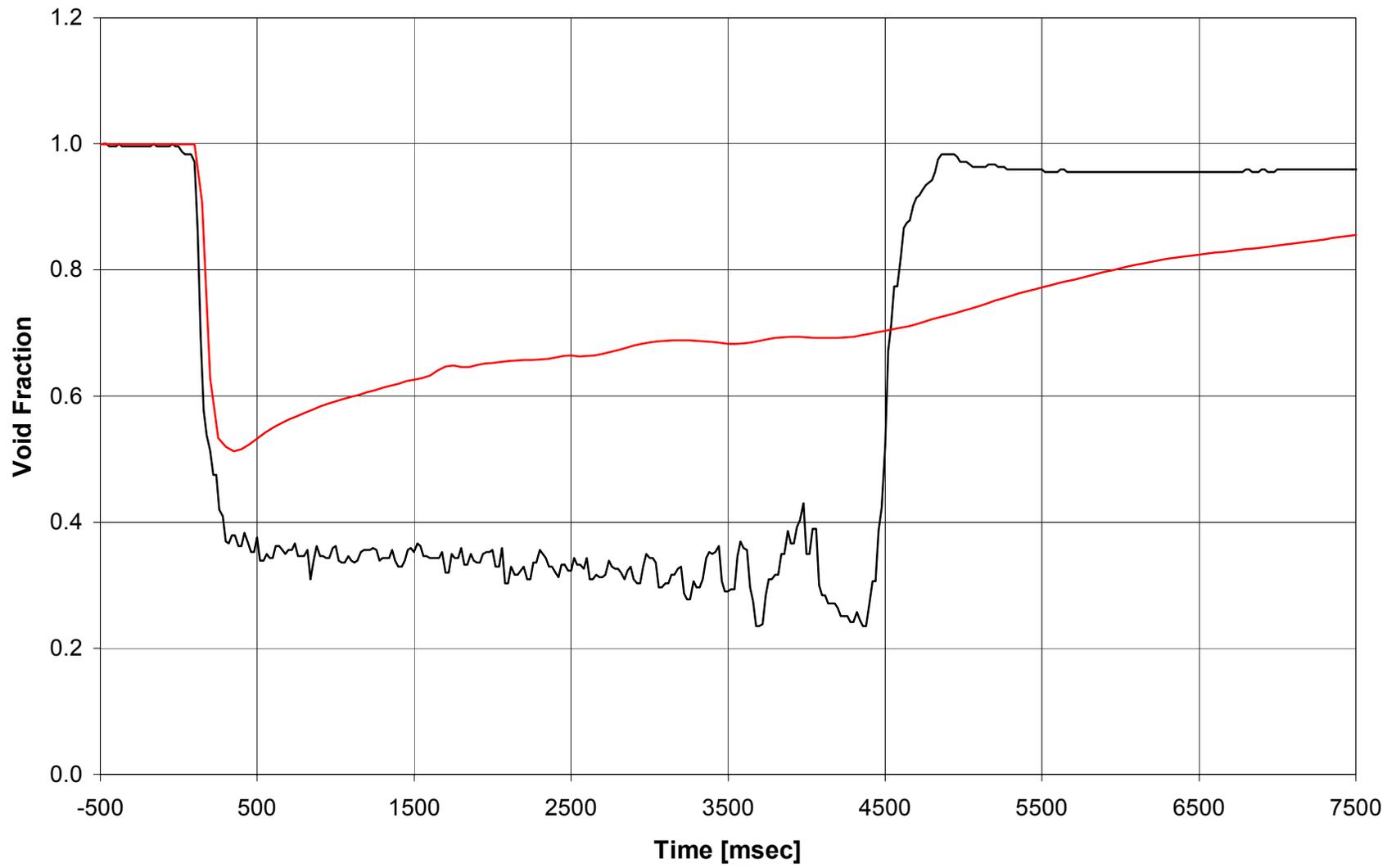
Graph 4: Pipe Position #1 Pressure

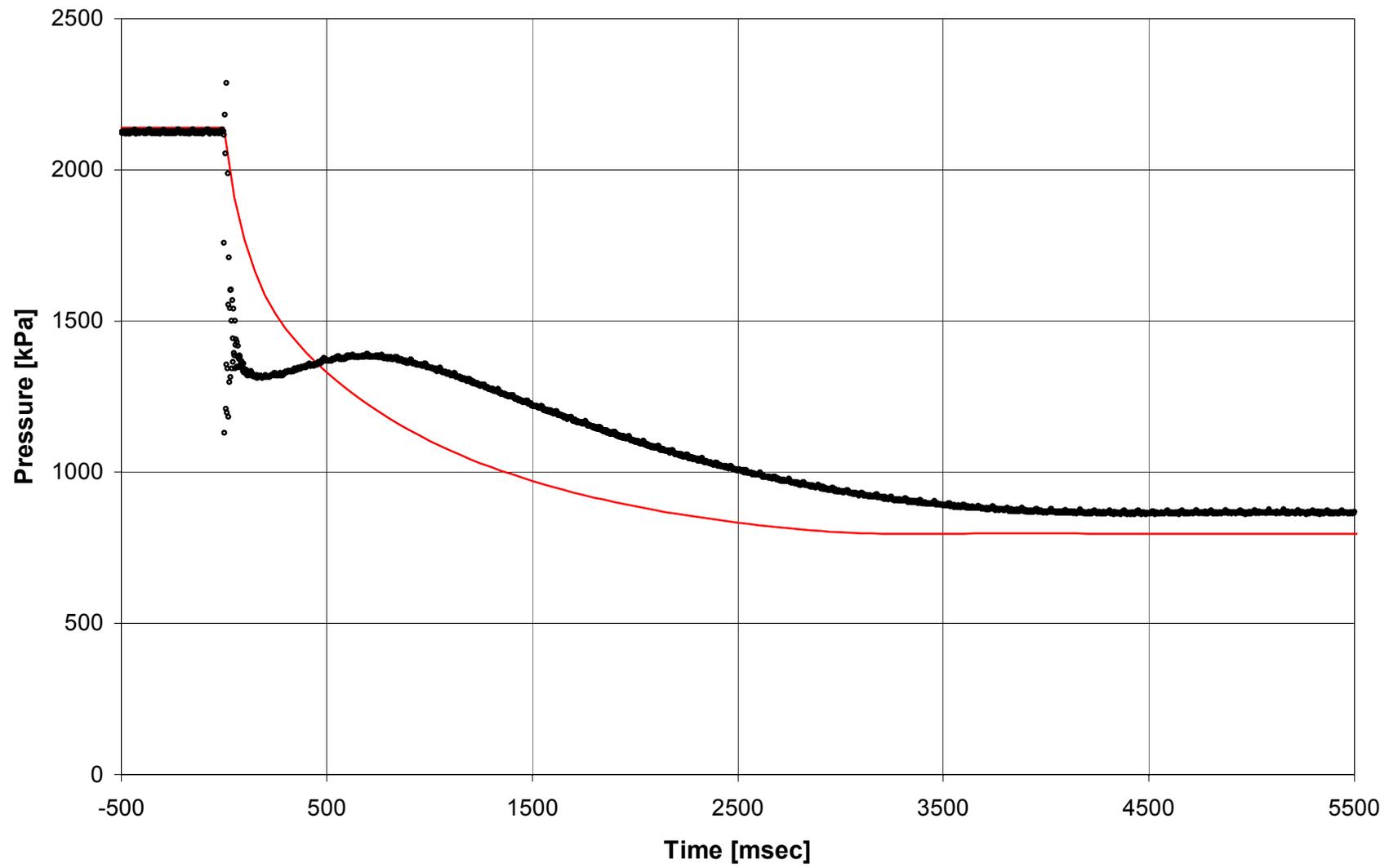
Graph 5: Collection Vessel Pressure

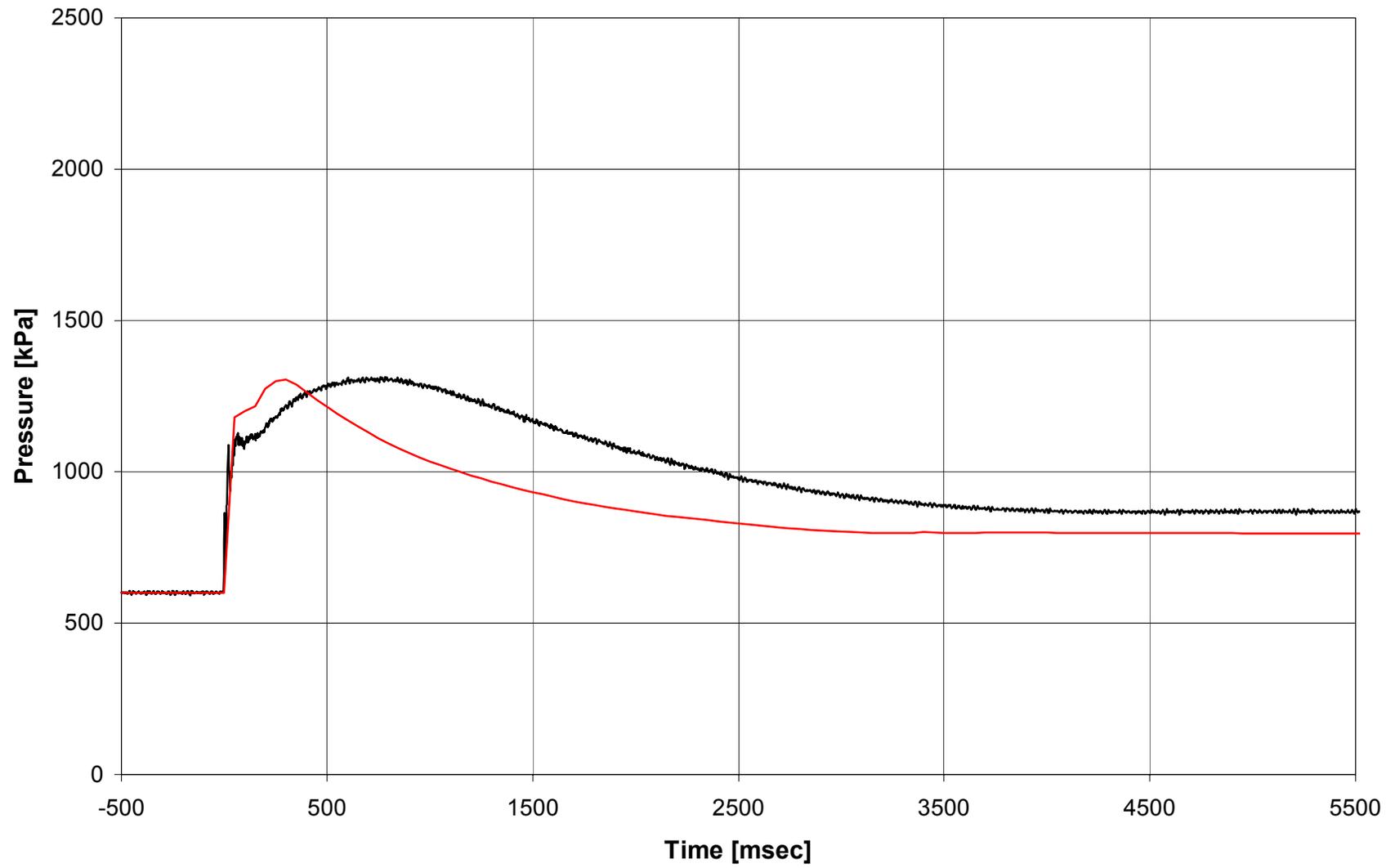
Graph 6: Pressure Drop Across Top Branch

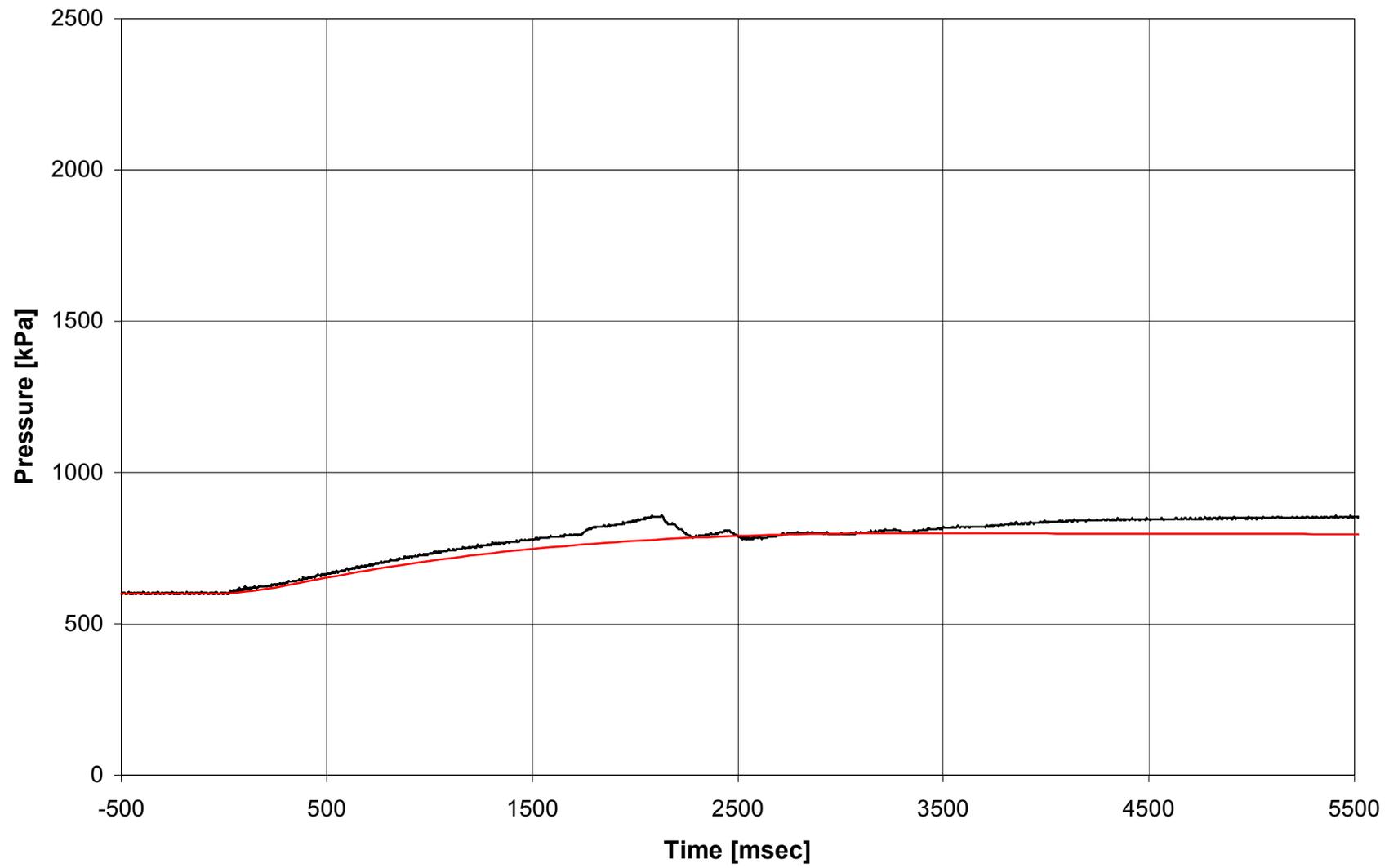
Graph 7: Pressure Drop Across Bottom Branch

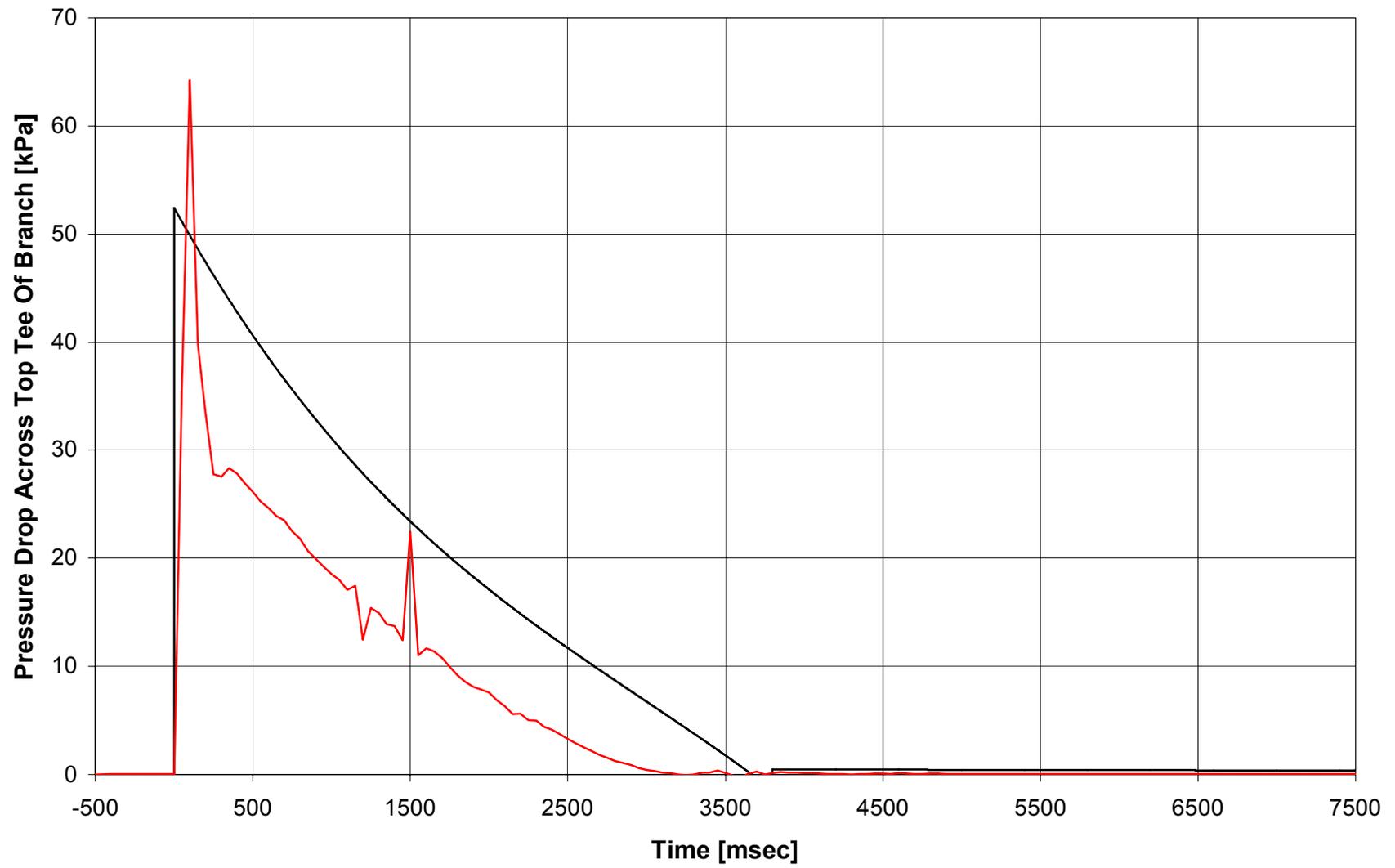


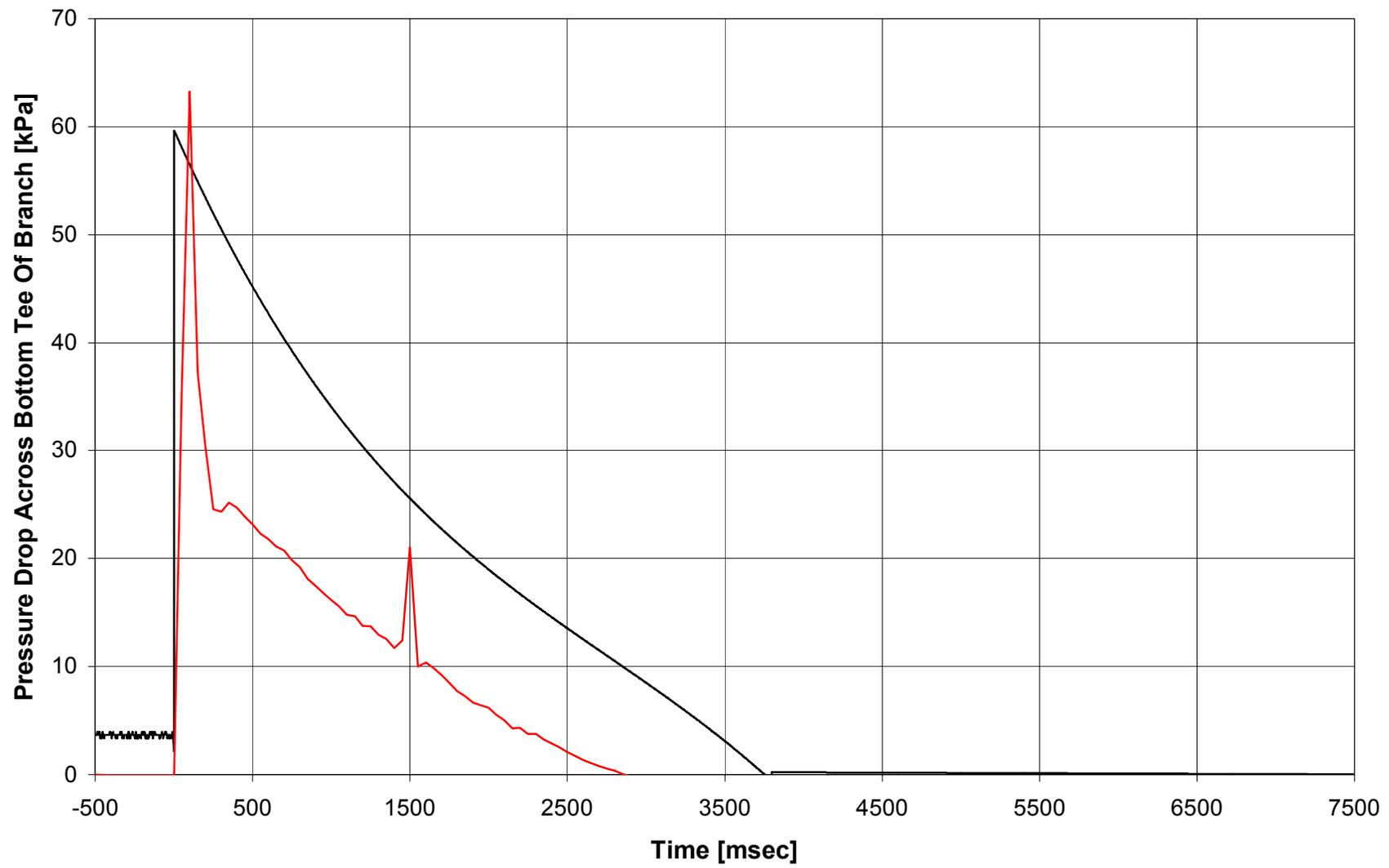












Run #12 with Code Prediction

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Vertical Tee branching into a 90° Elbow, Union, and Two 45° Elbows (Configuration #2)

Source Vessel Initial Conditions: Fill Volume: 2400 milliliters
 Fluid Mass: 3.421 kg
 Pressure (Psvo): 3935 kPa
 Nitrogen Mass: 0.129 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 655 kPa

Initial System Temperature: 24° Celsius

Completion Date: 2/28/00

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

Graph 3: Source Vessel Pressure

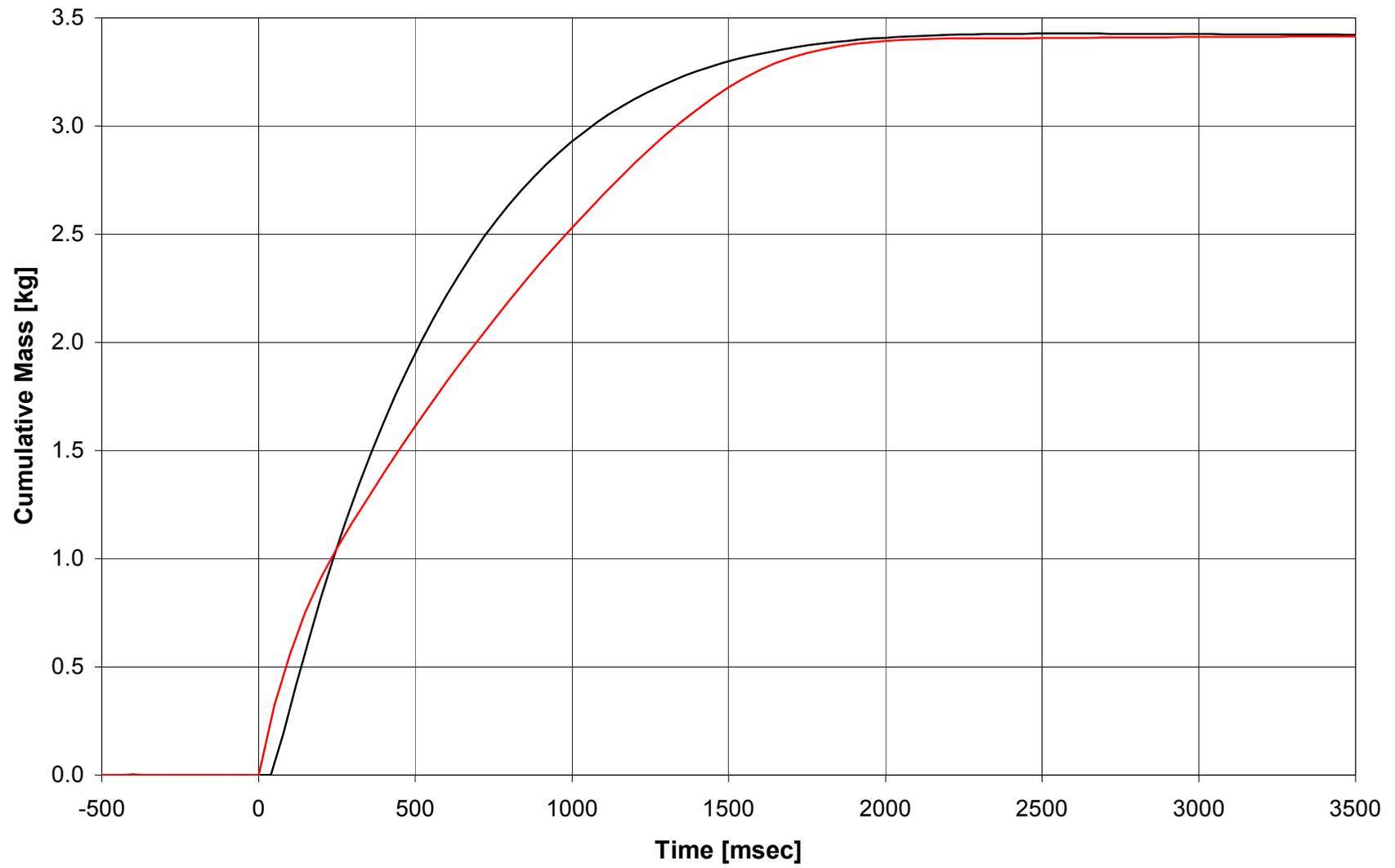
Graph 4: Pipe Position #1 Pressure

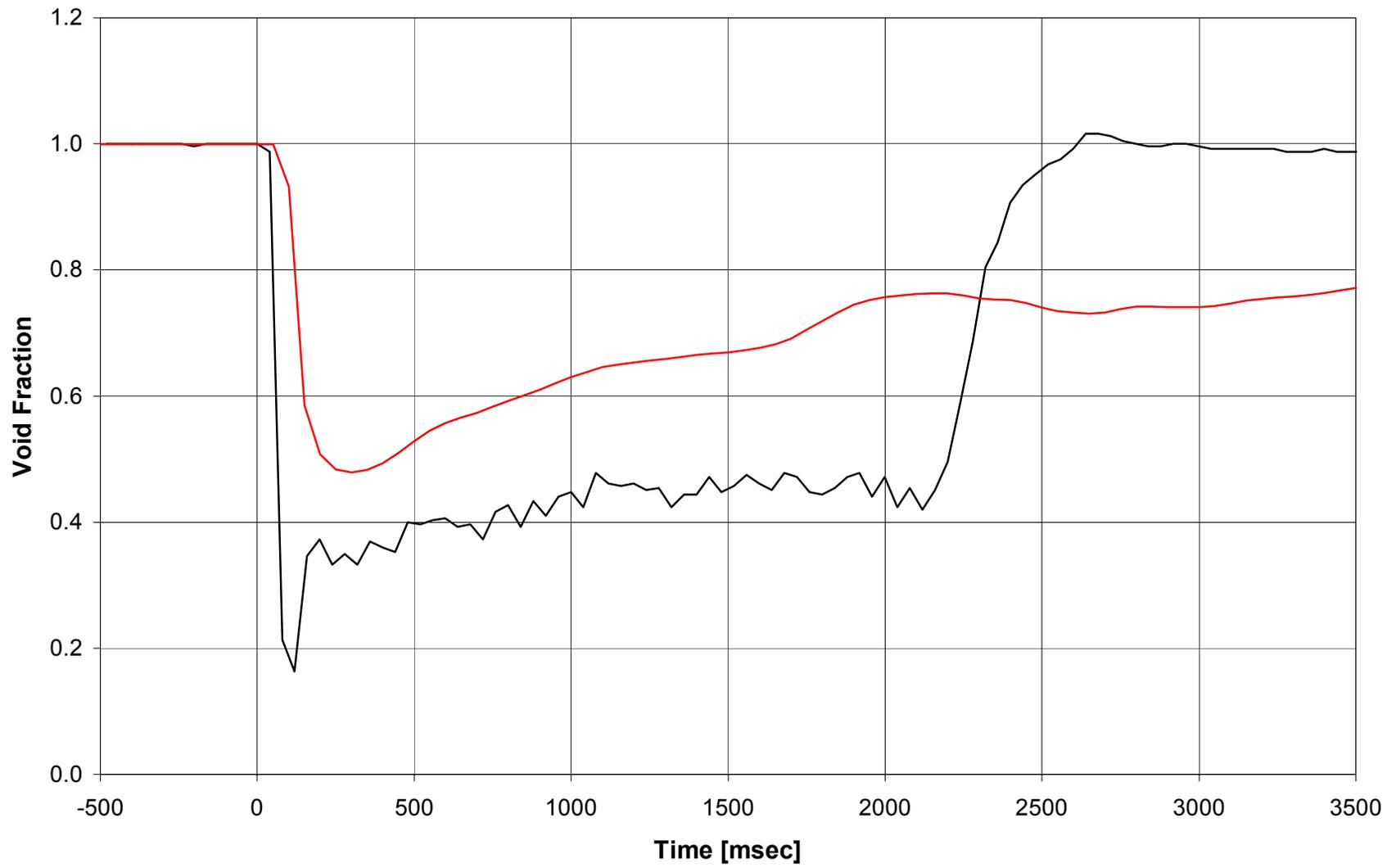
Graph 5: Pipe Position #3 Pressure

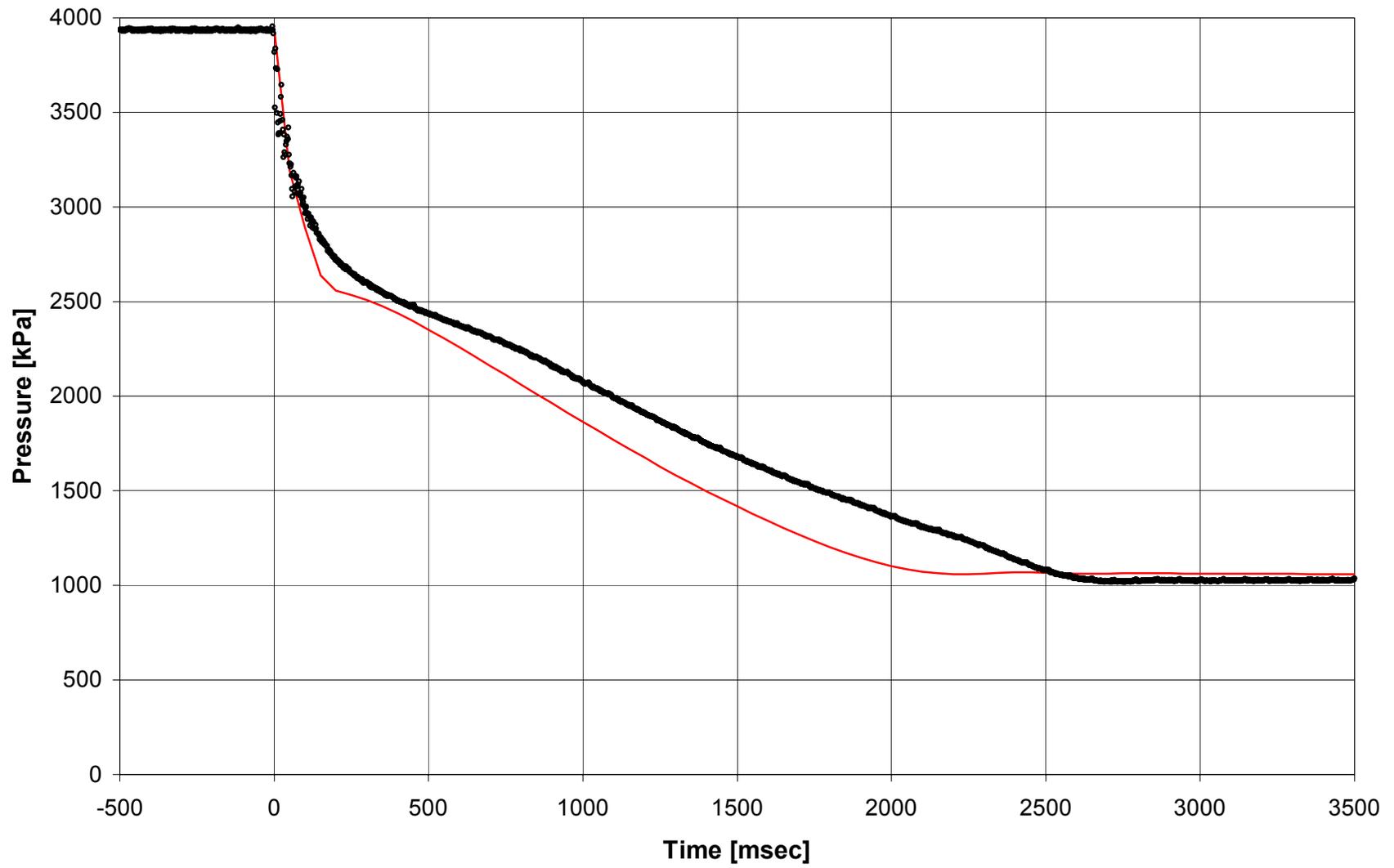
Graph 6: Collection Vessel Pressure

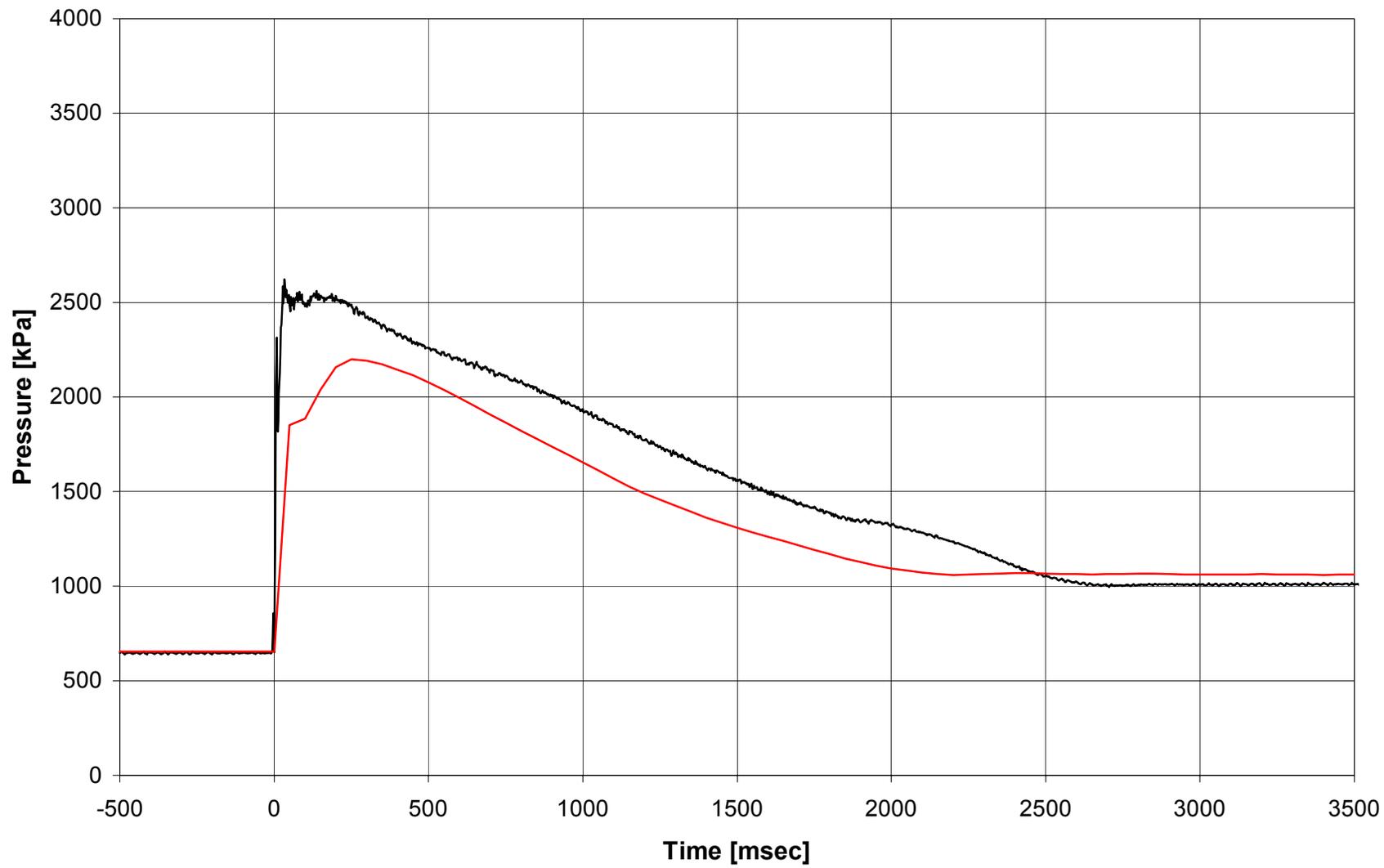
Graph 7: Pressure Drop Across Top Branch

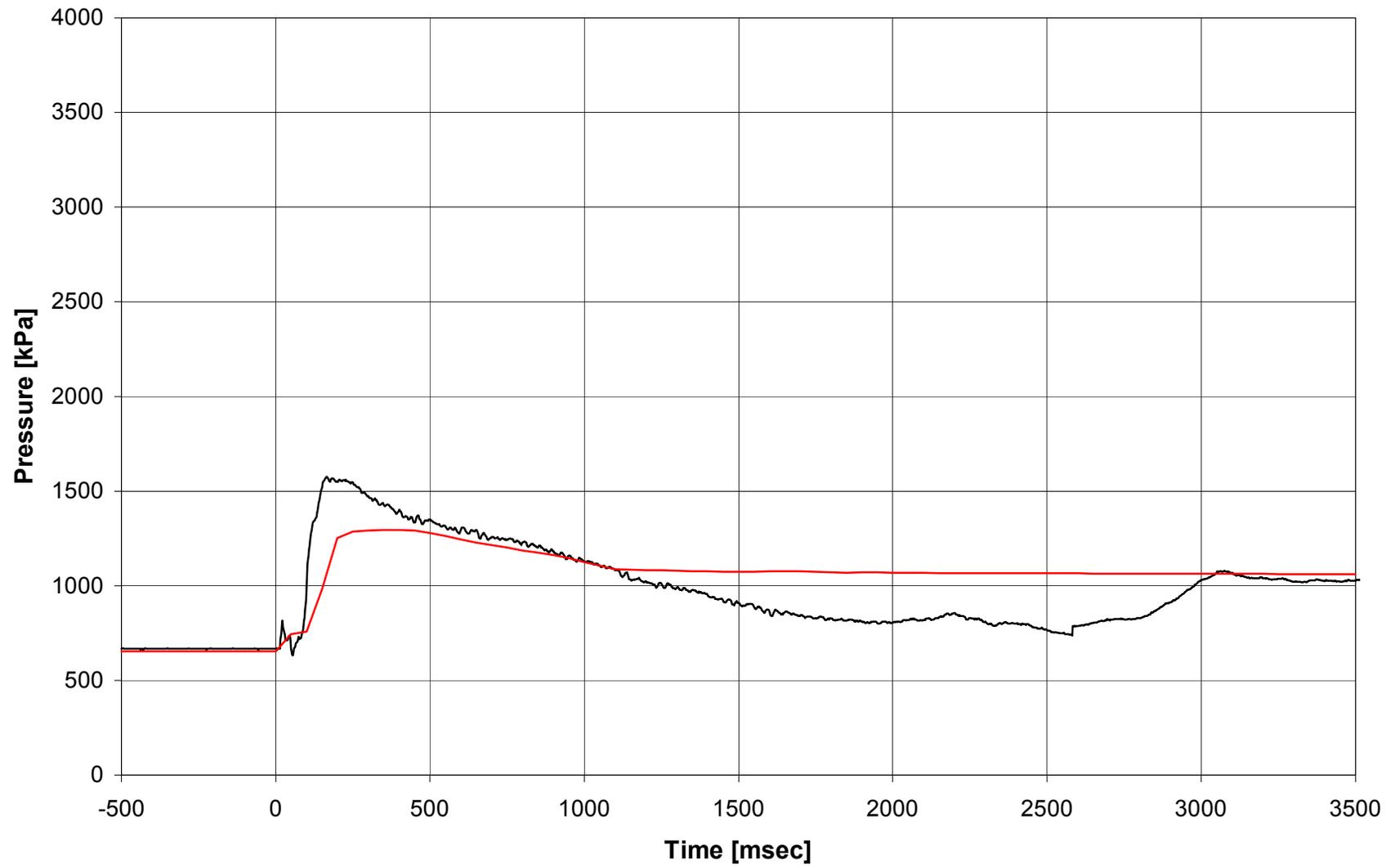
Graph 8: Pressure Drop Across Bottom Branch

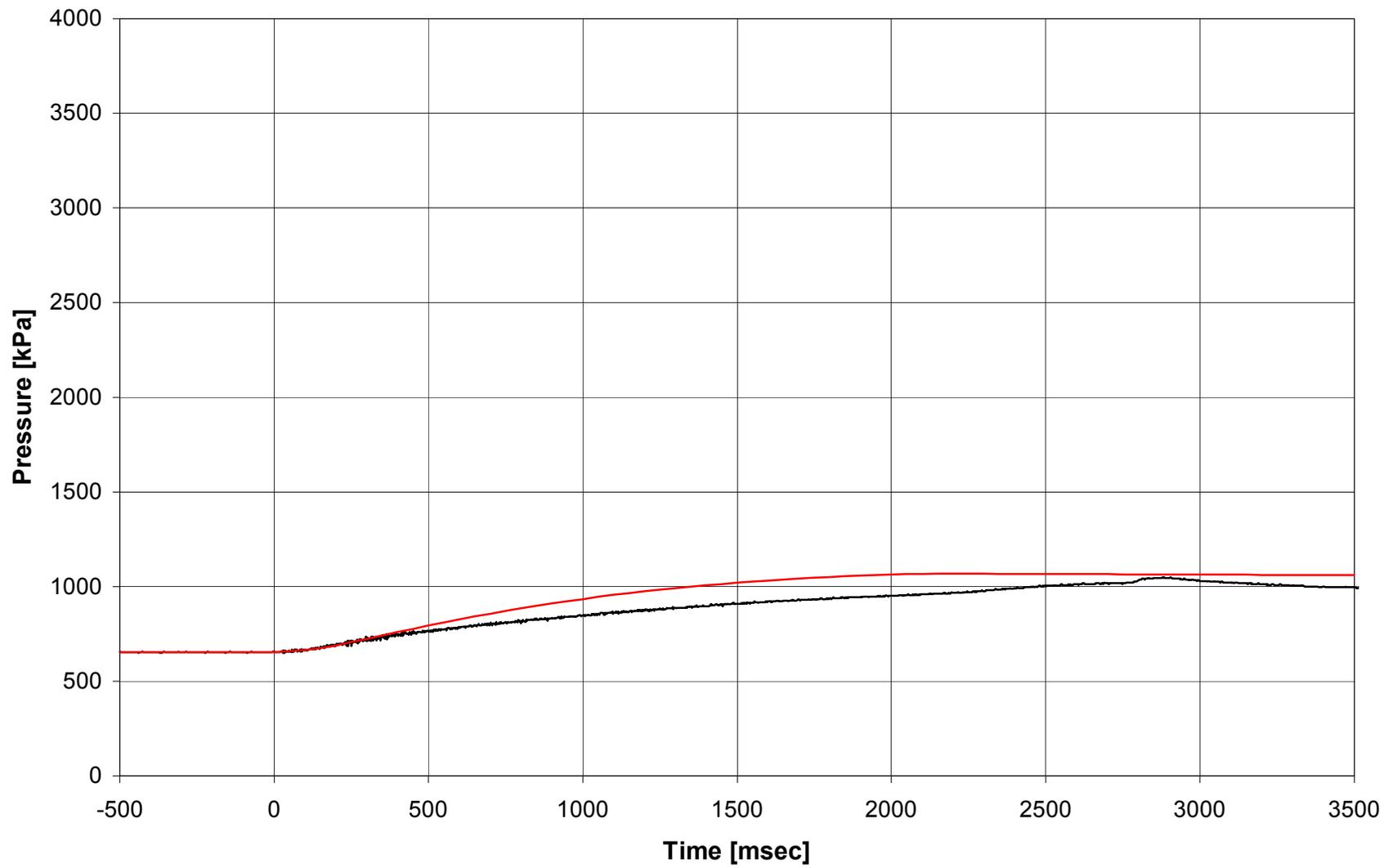


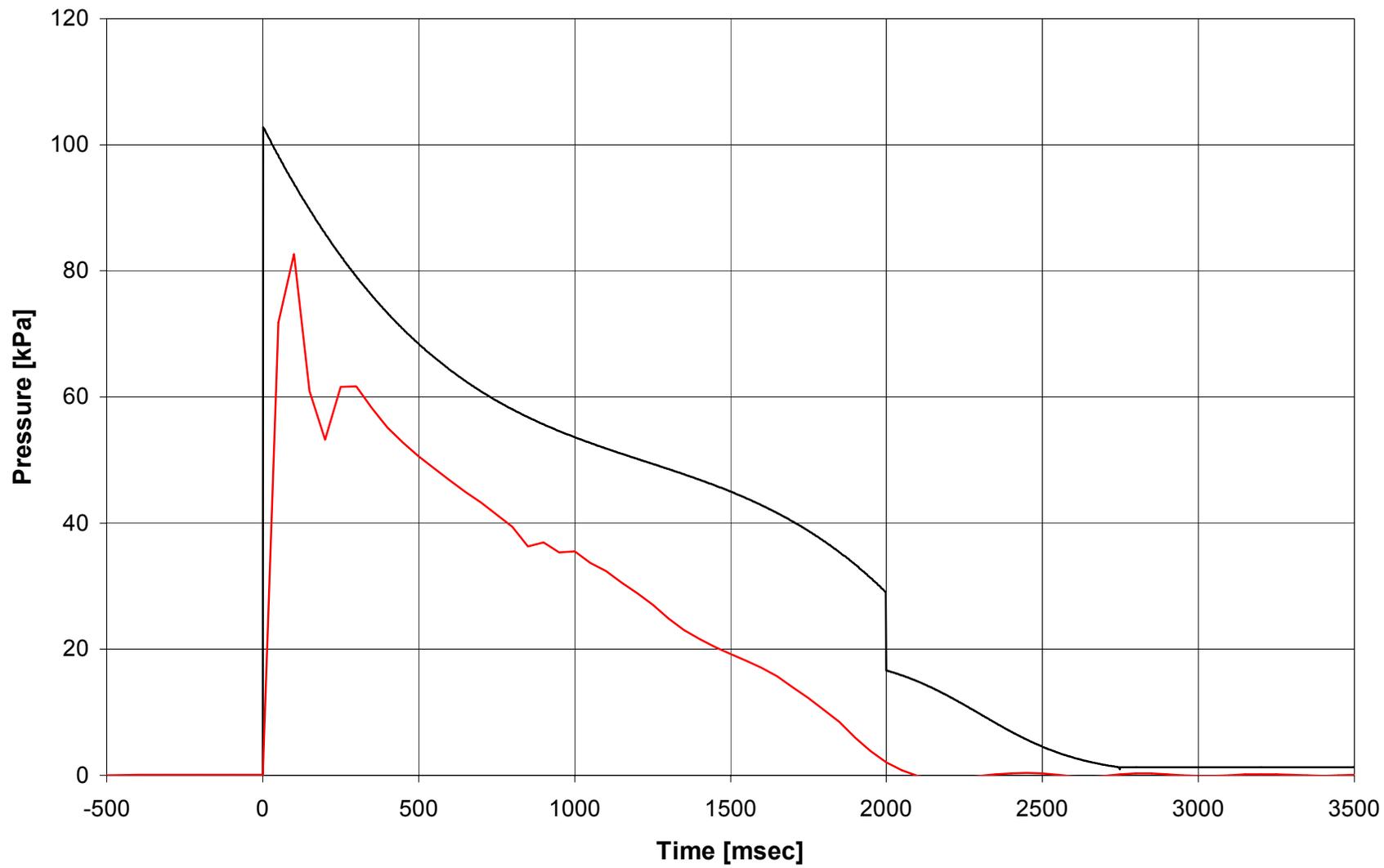


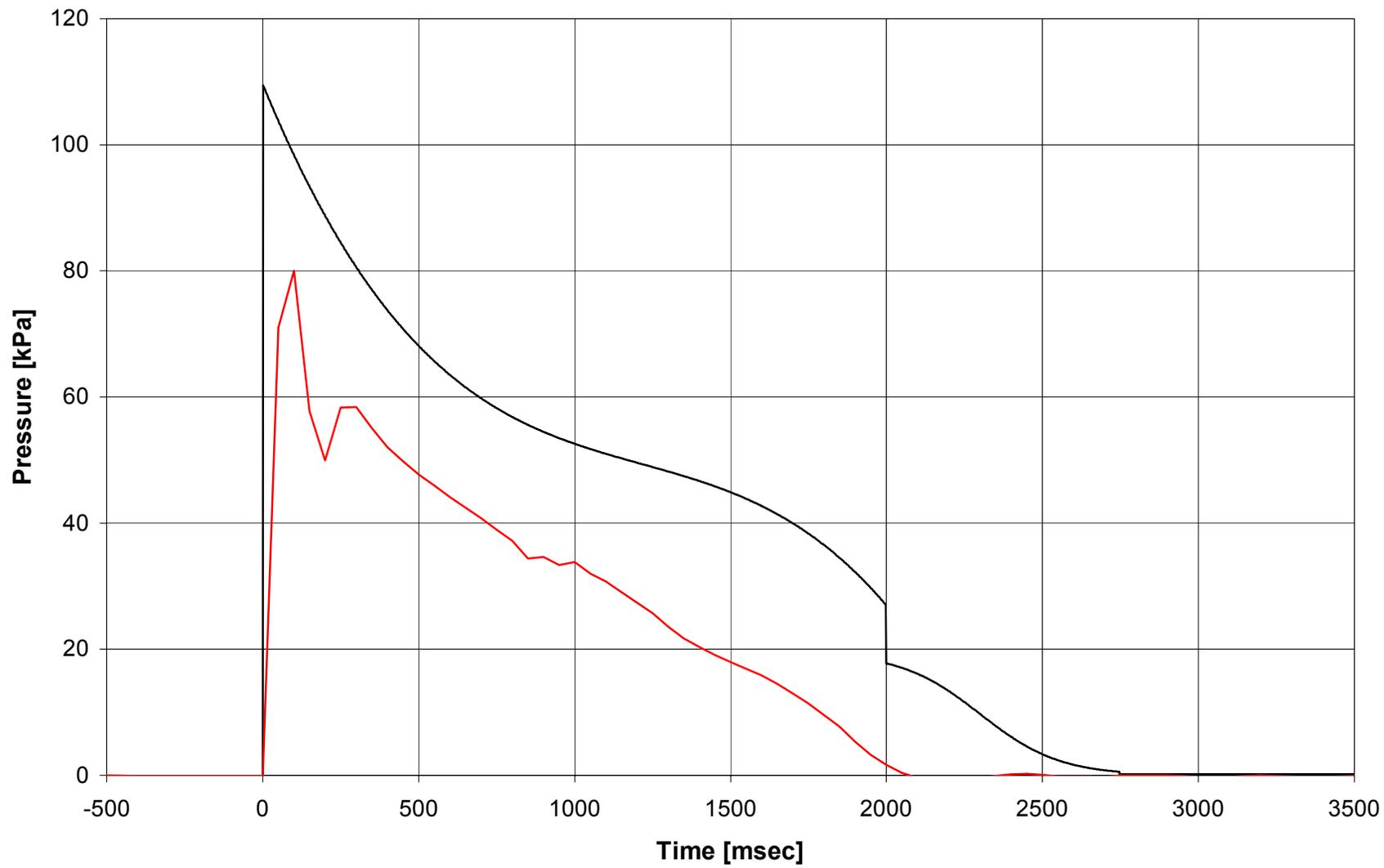












Run #13 with Code Prediction

Test Fluid: 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea)
CAS #: 431-89-0
Molecular Weight: 170.04

System Piping Configuration: Vertical Tee branching into a 90° Elbow, Union, and Two 45° Elbows (Configuration #2)

Source Vessel Initial Conditions: Fill Volume: 2460 milliliters
 Fluid Mass: 3.520 kg
 Pressure (Psvo): 4910 kPa
 Nitrogen Mass: 0.163 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 615 kPa

Initial System Temperature: 25° Celsius

Completion Date: 3/3/00

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

Graph 3: Source Vessel Pressure

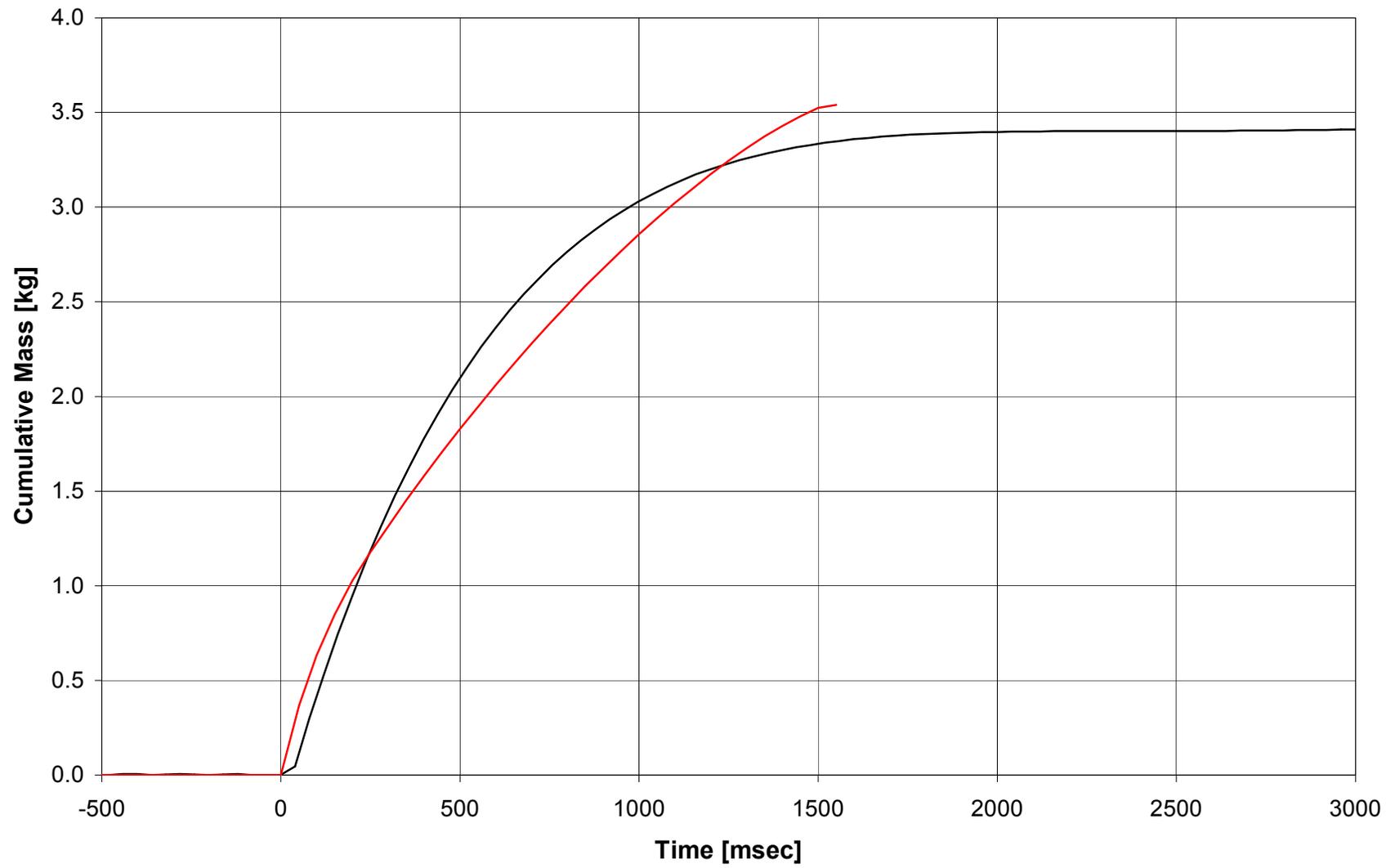
Graph 4: Pipe Position #1 Pressure

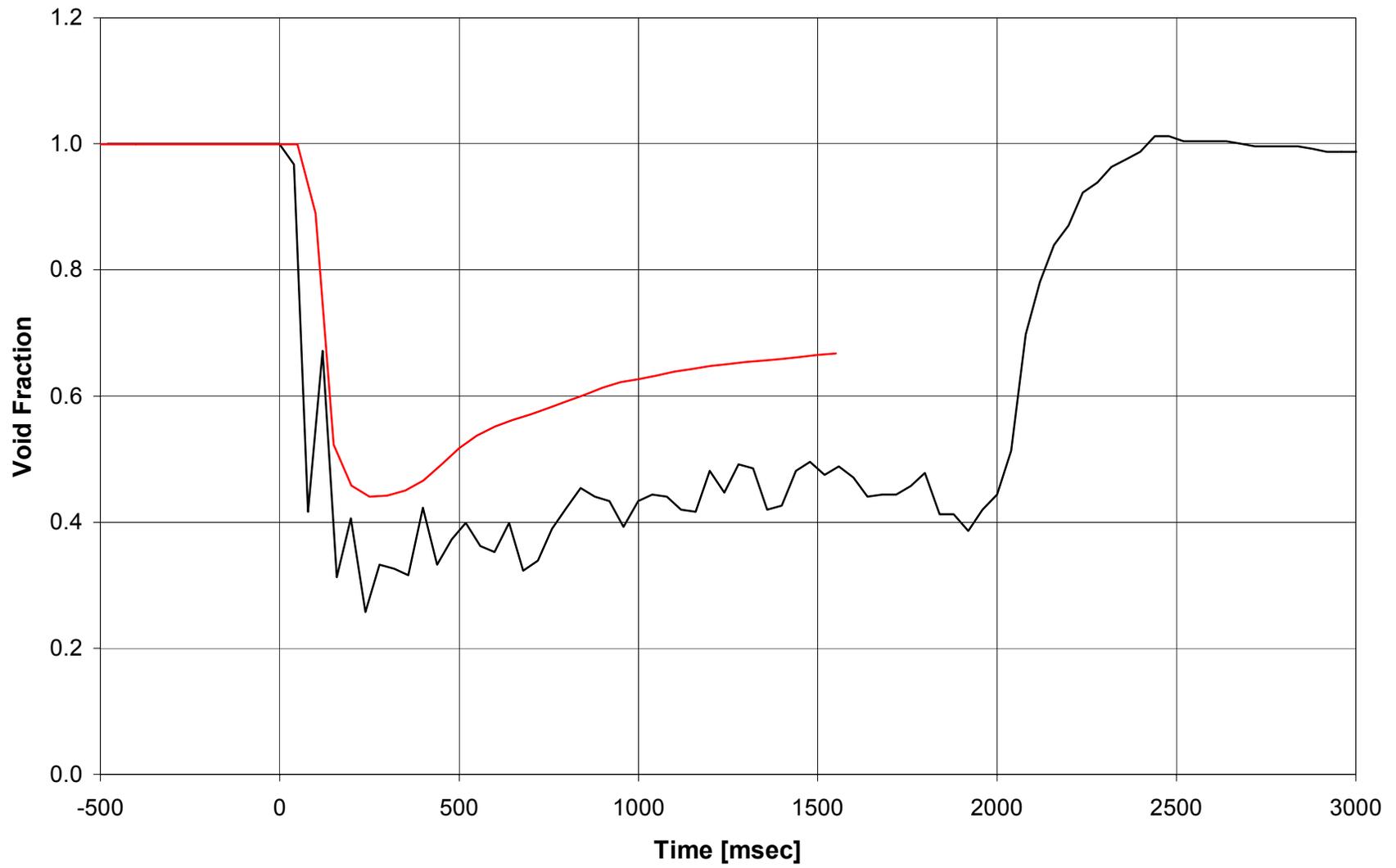
Graph 5: Pipe Position #3 Pressure

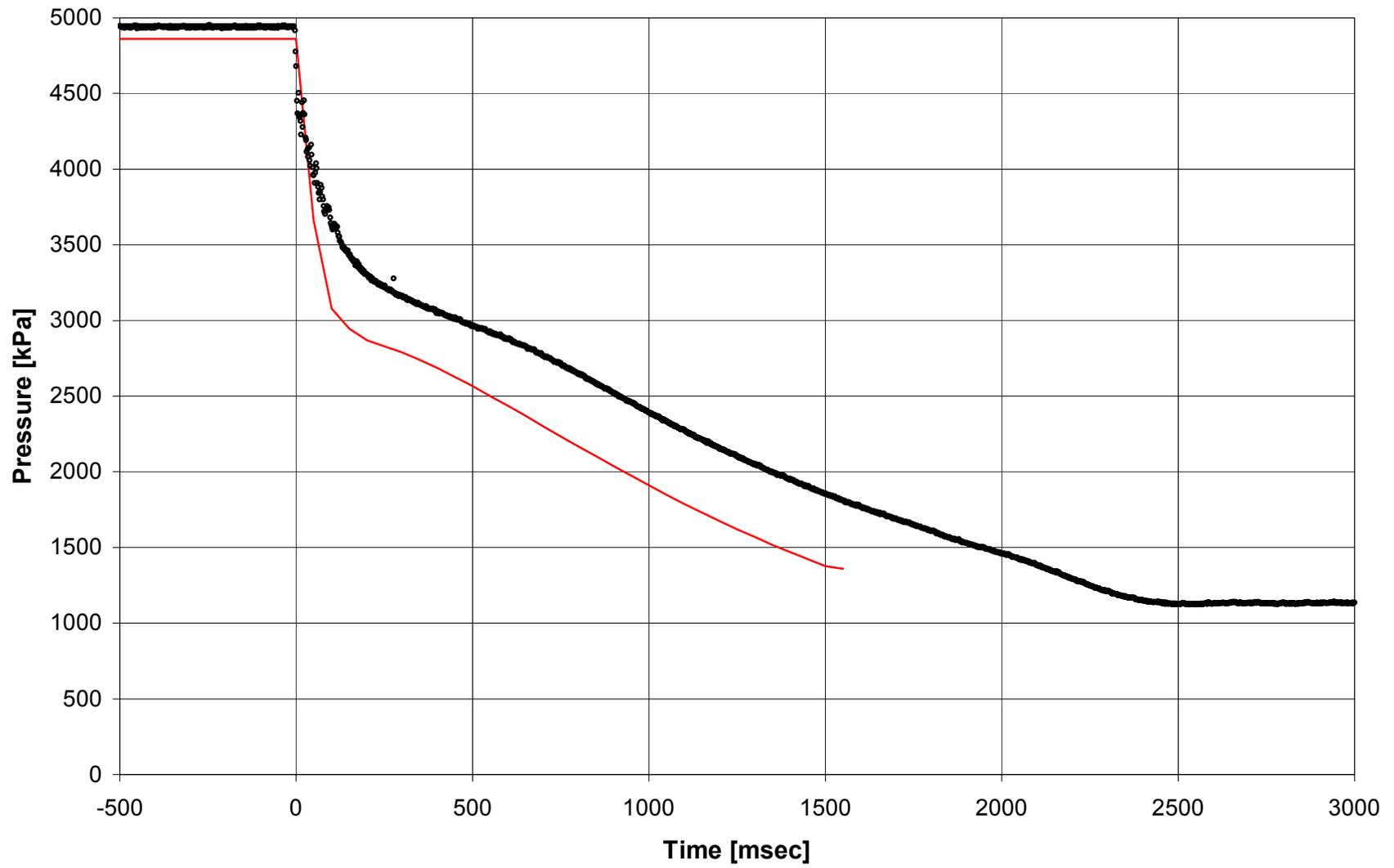
Graph 6: Collection Vessel Pressure

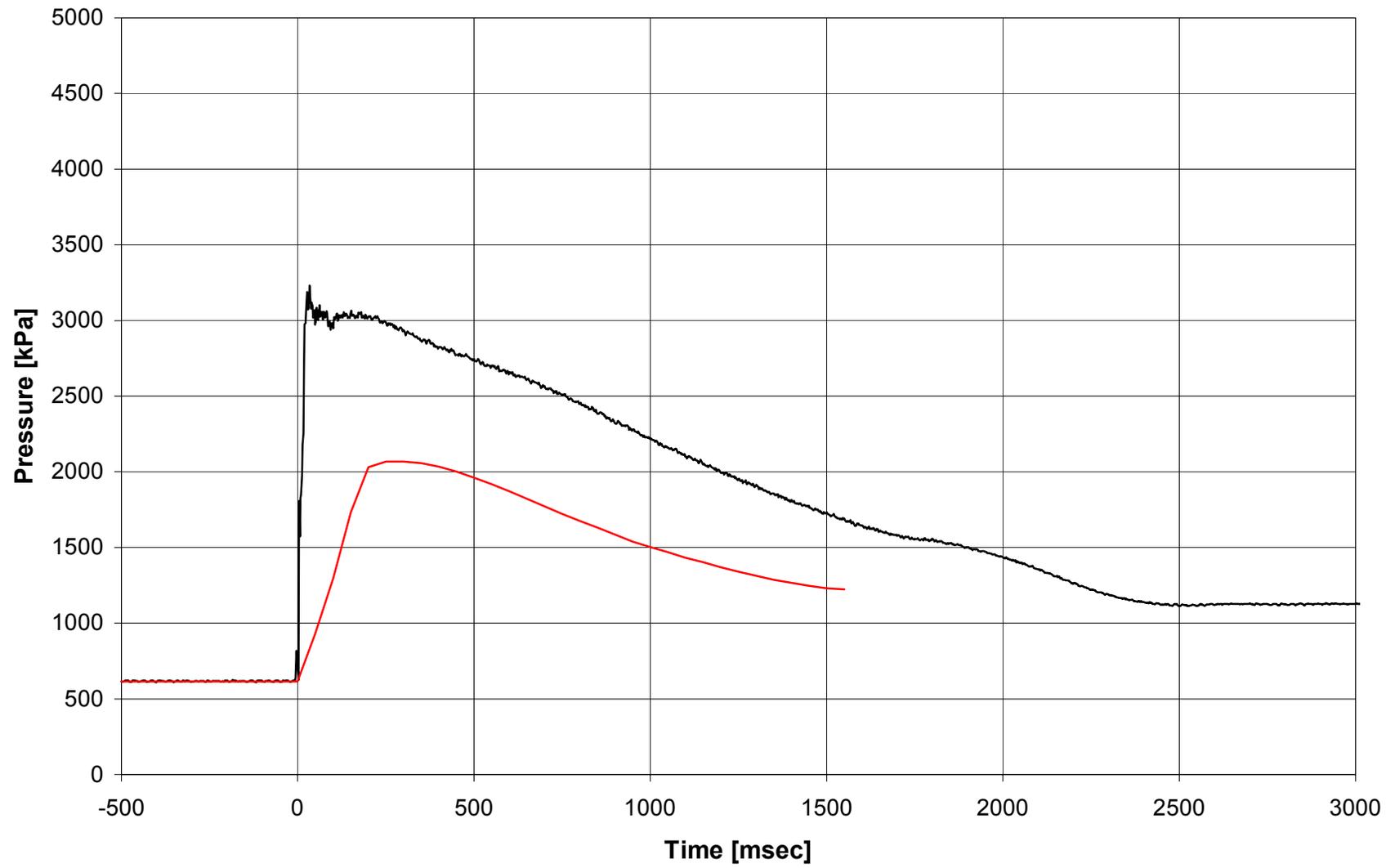
Graph 7: Pressure Drop Across Top Branch

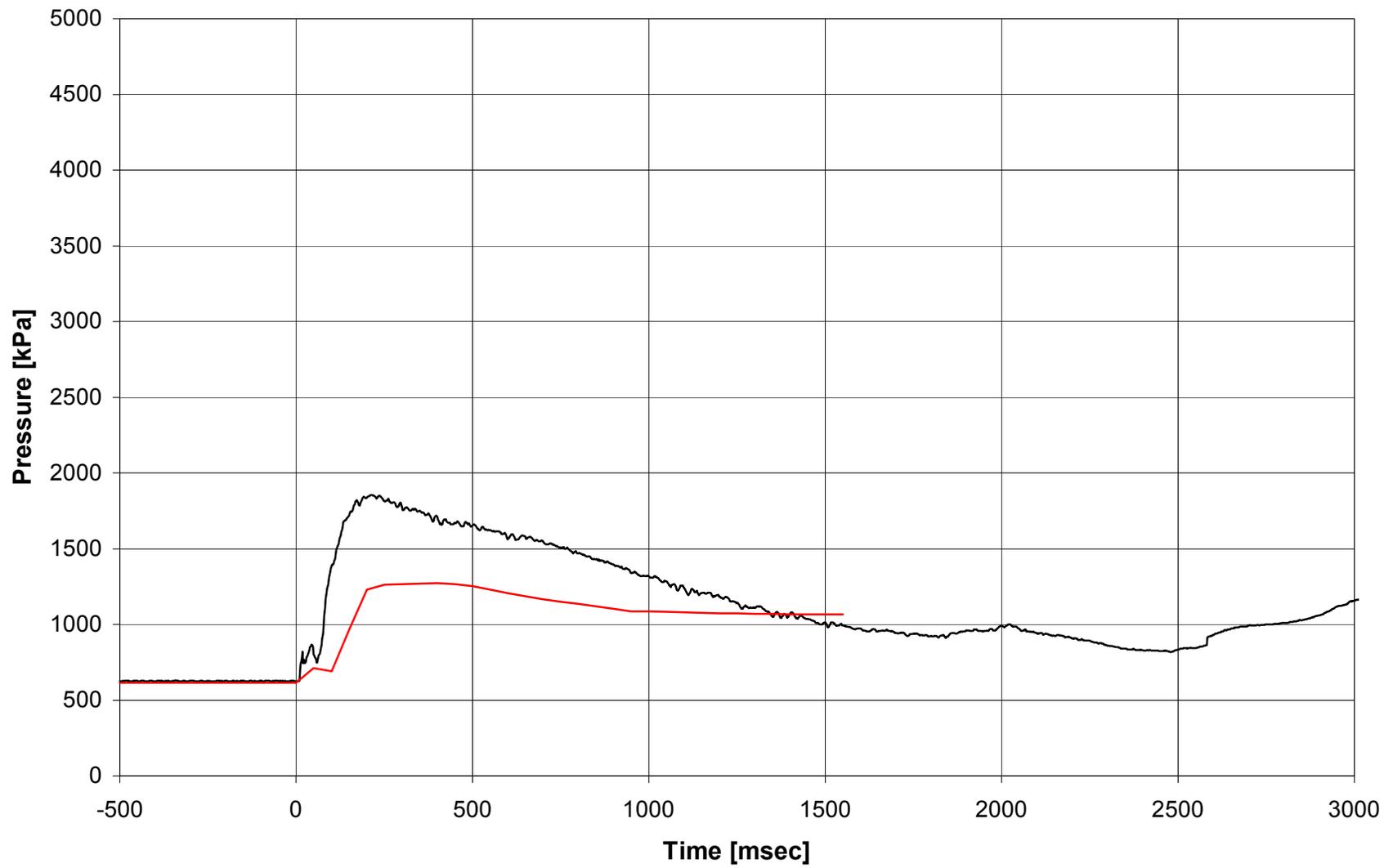
Graph 8: Pressure Drop Across Bottom Branch

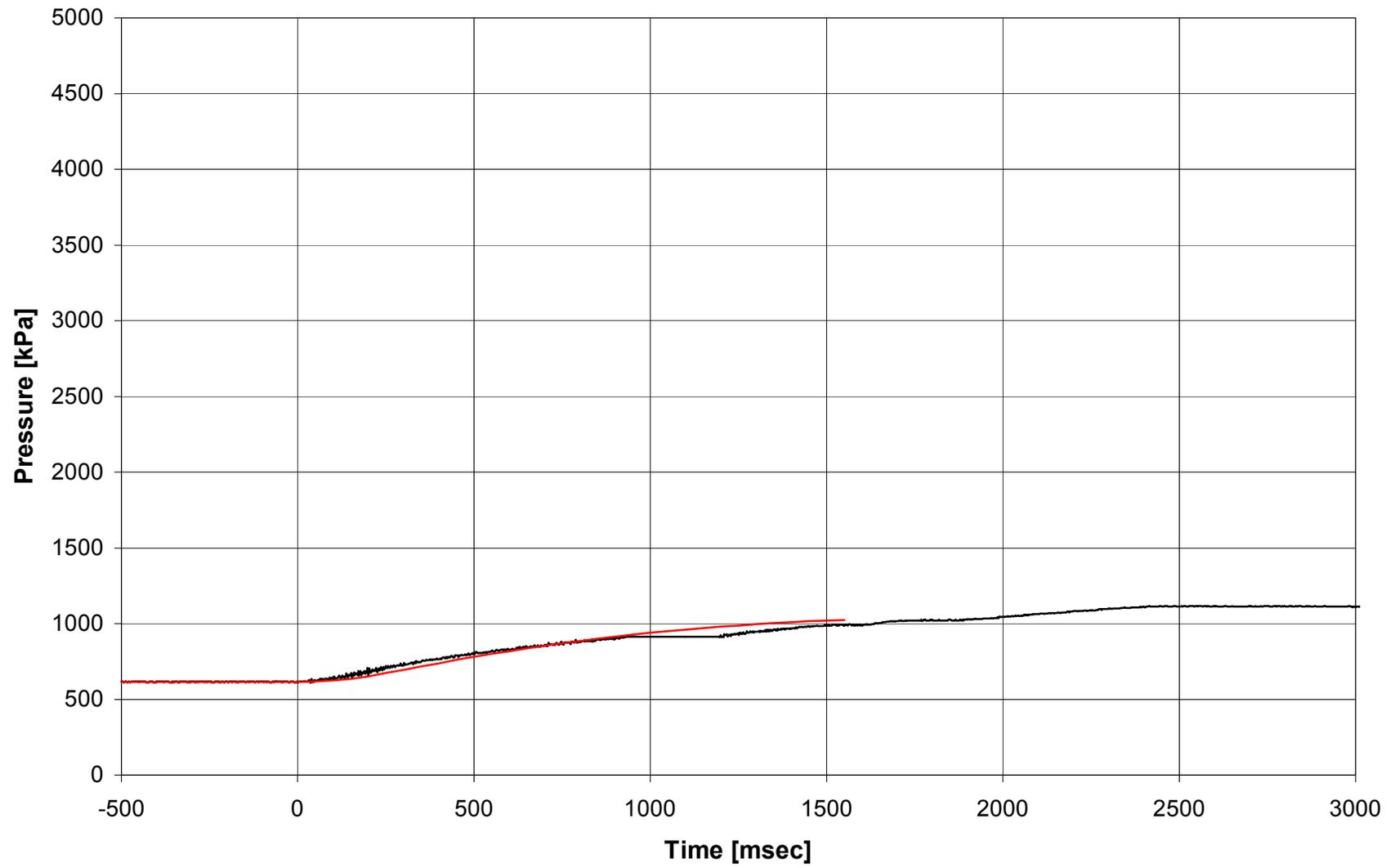


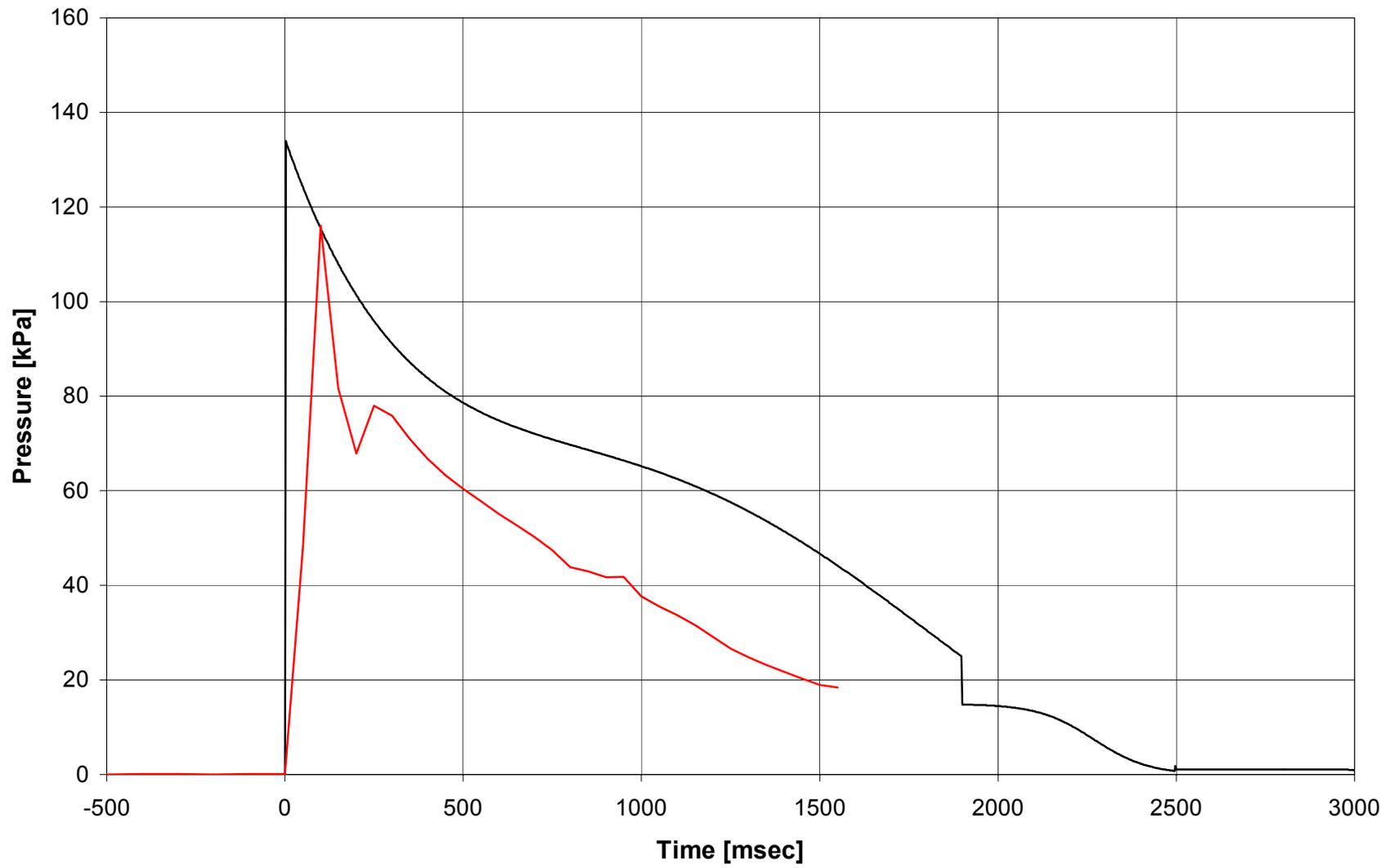


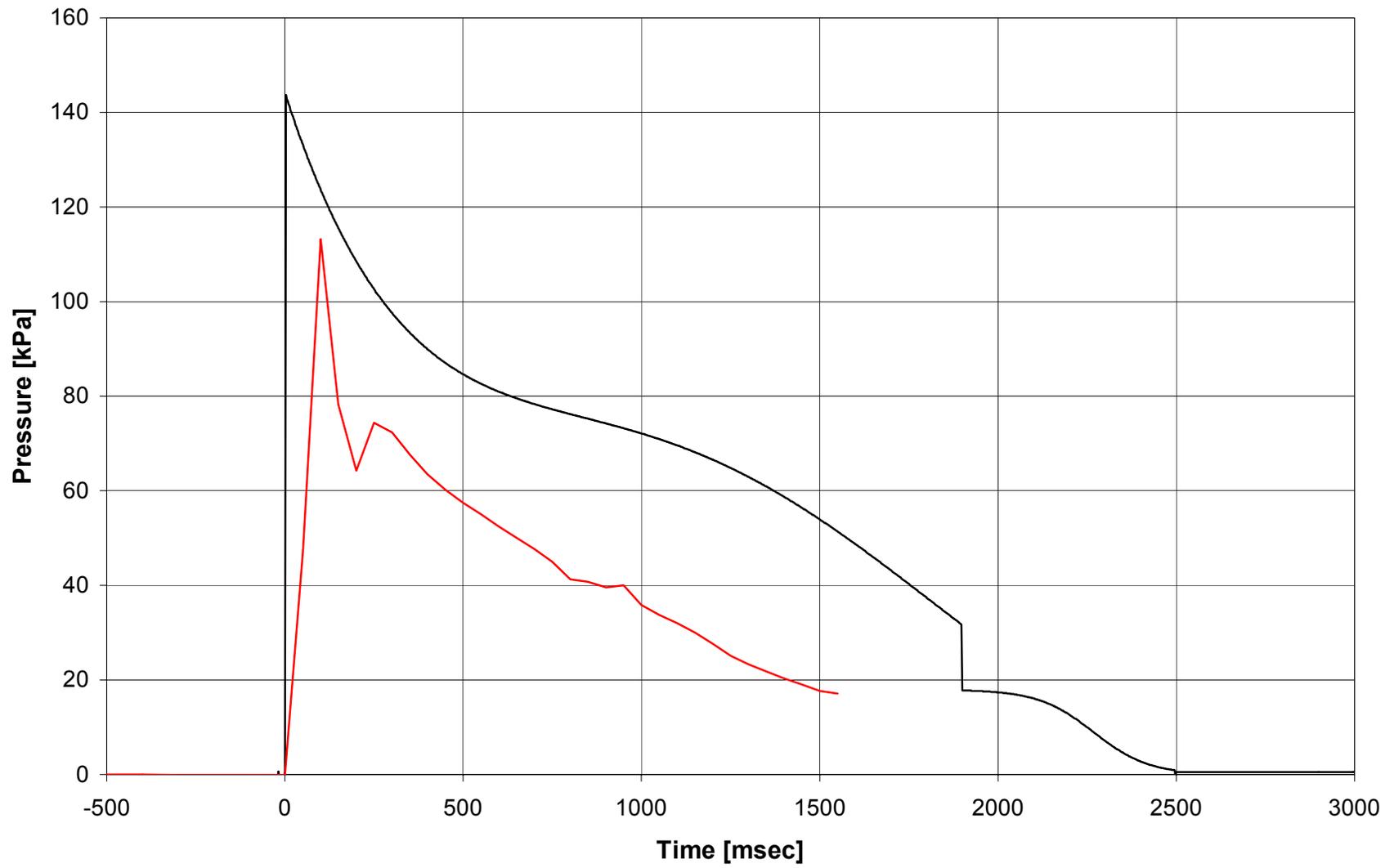












Run #14 with Code Prediction

Test Fluid: C2HF5 Pentafluoroethane (HFC-125)
CAS #: 354-33-6
Molecular Weight: 120.3

System Piping Configuration: Straight Pipe

Source Vessel Initial Conditions: Fill Volume: 2900 milliliters
 Fluid Mass: 3.459 kg
 Pressure (Psvo): 2050 kPa
 Nitrogen Mass: 0.026 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 110 kPa

Initial System Temperature: 26° Celsius

Completion Date: 4/3/00

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

Graph 3: Source Vessel Pressure

Graph 4: Pipe Position #1 Pressure

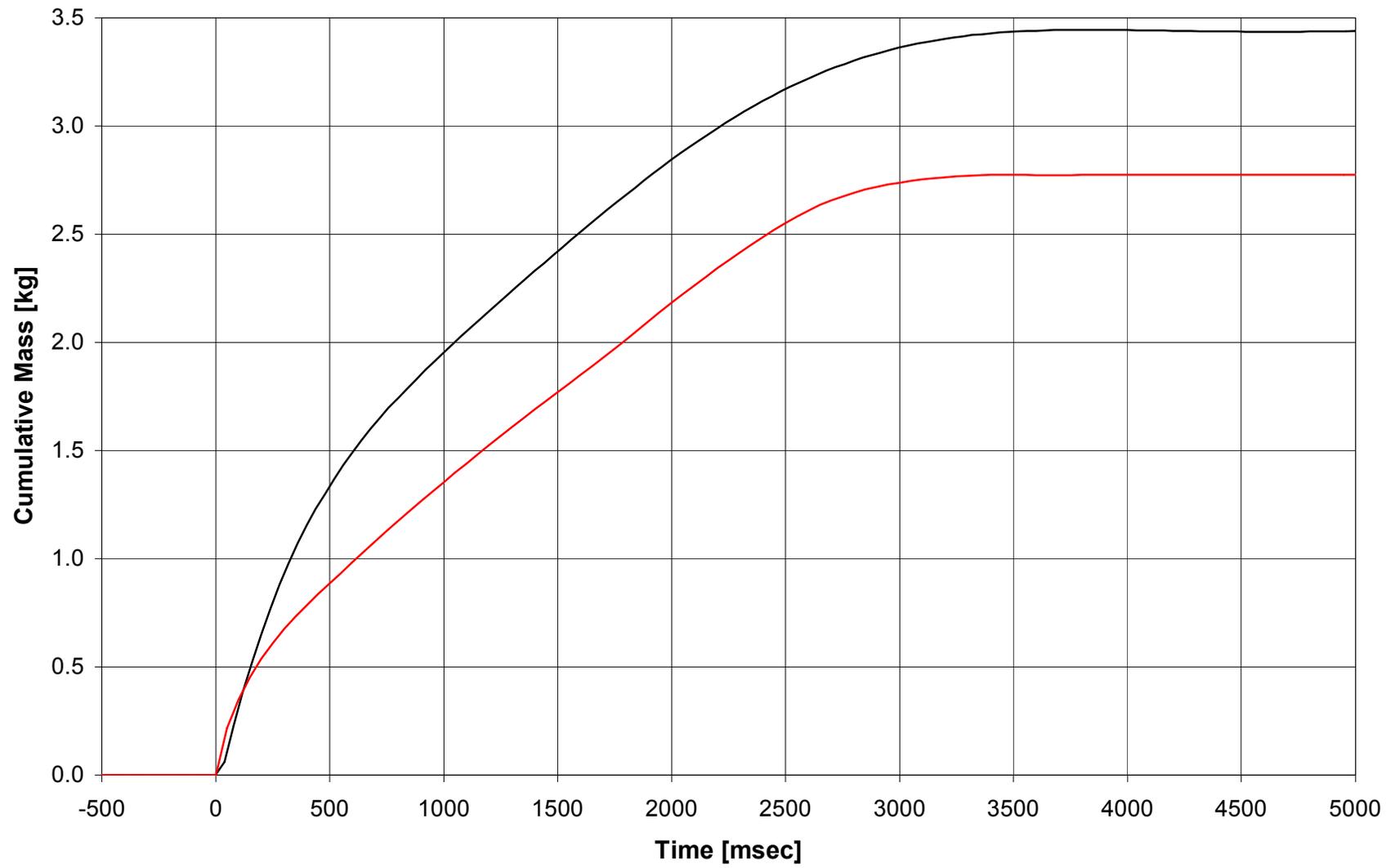
Graph 5: Pipe Position #2 Pressure

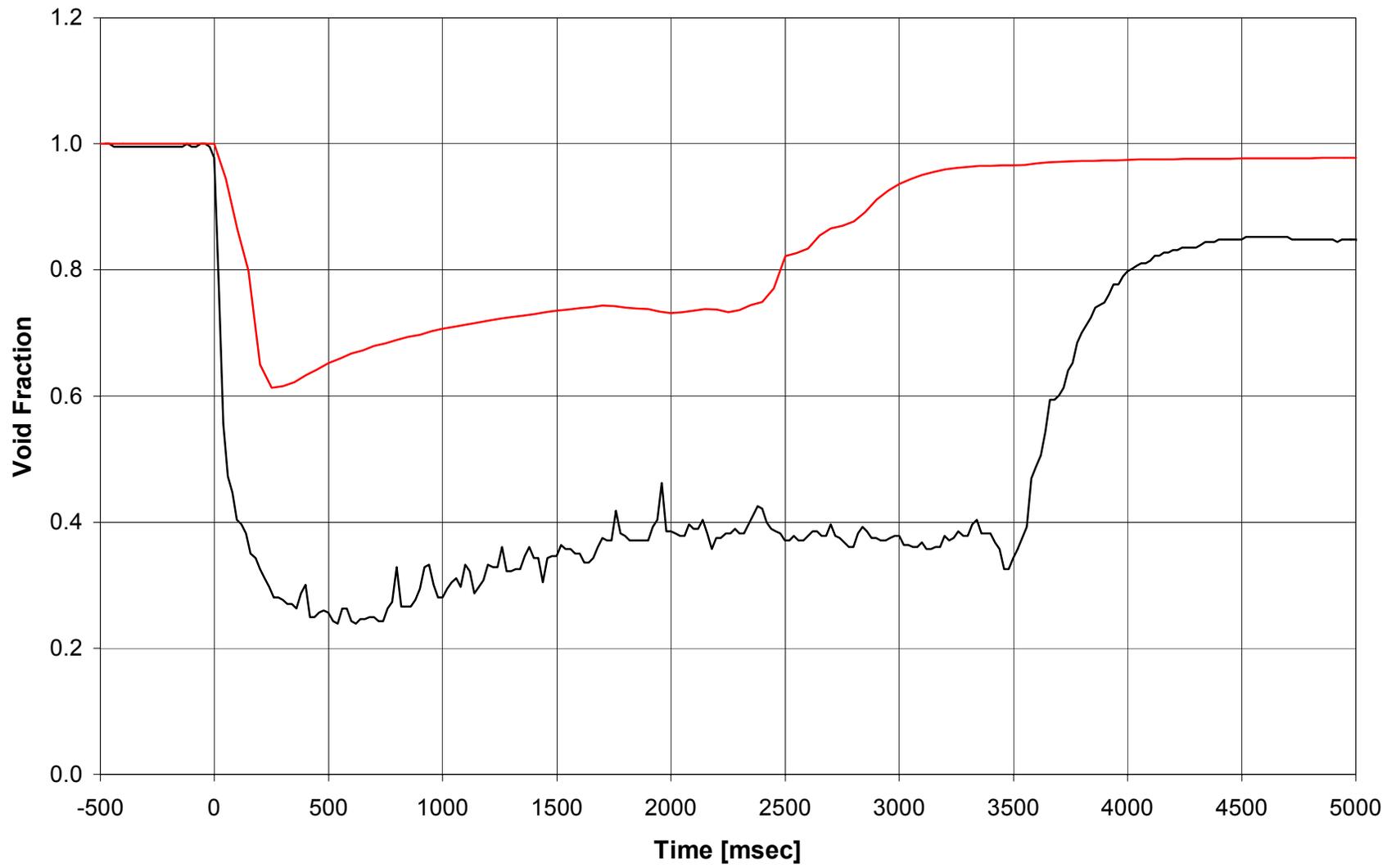
Graph 6: Pipe Position #3 Pressure

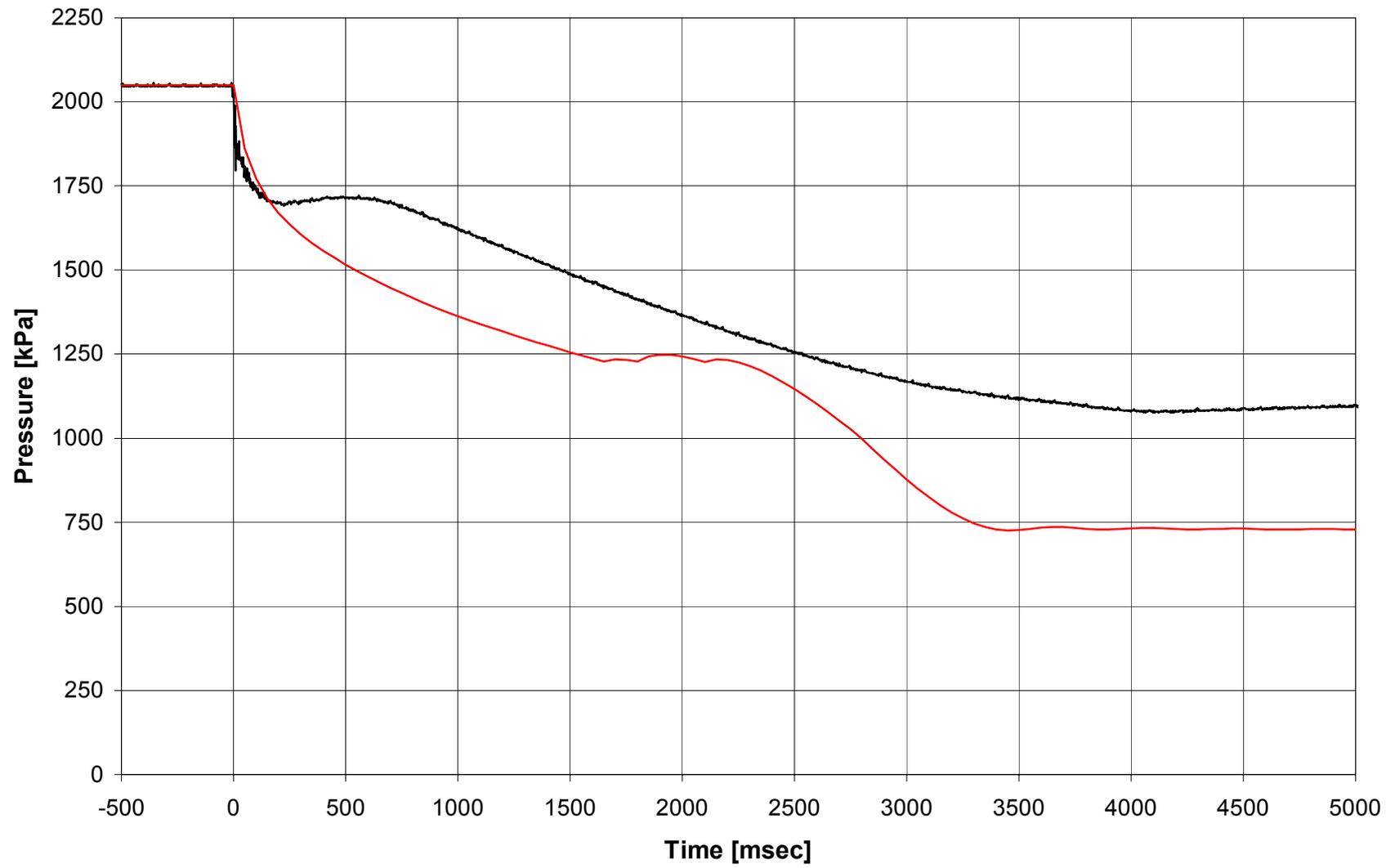
Graph 7: Collection Vessel Pressure

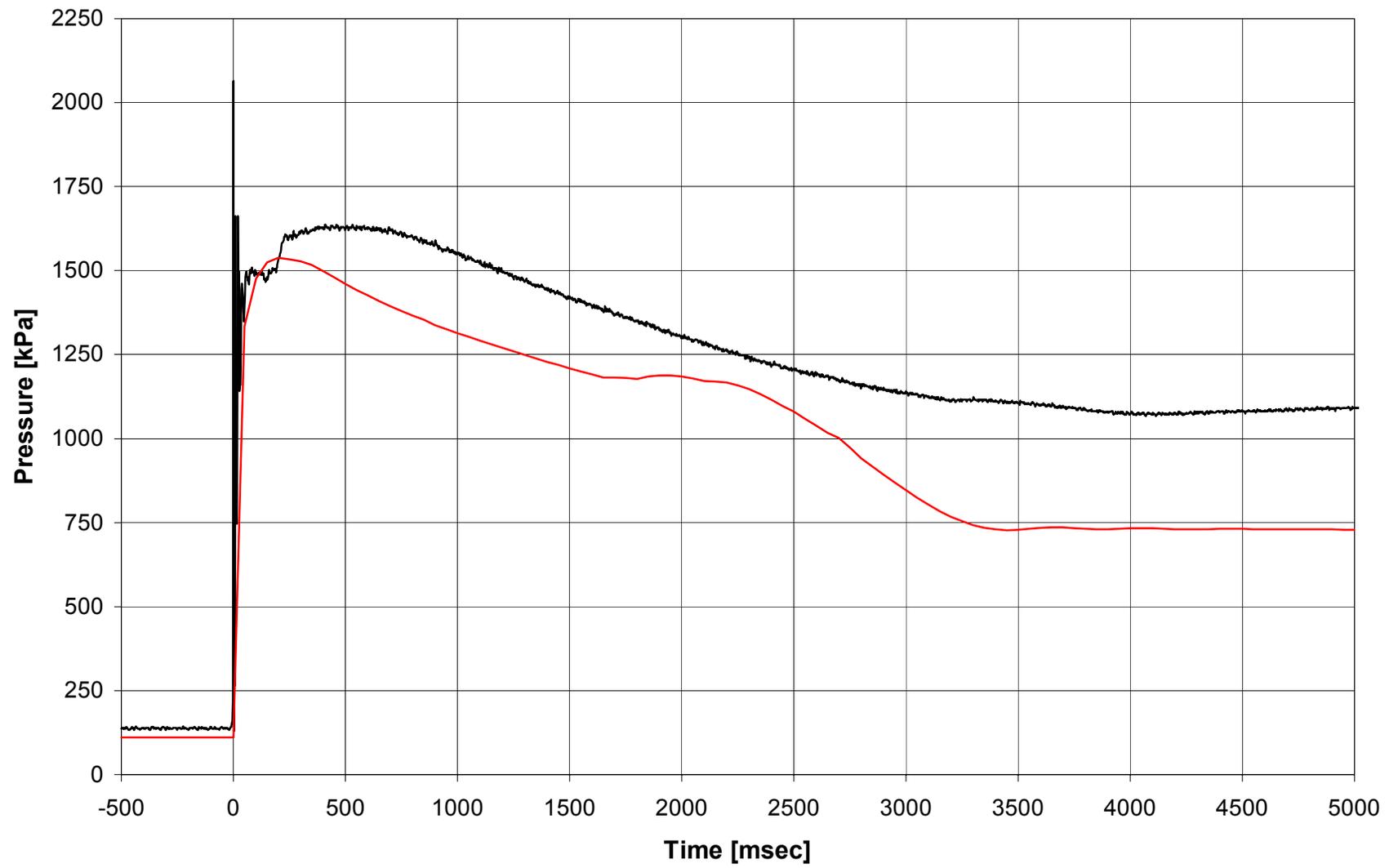
Graph 8: Gas Temperature in Source Vessel

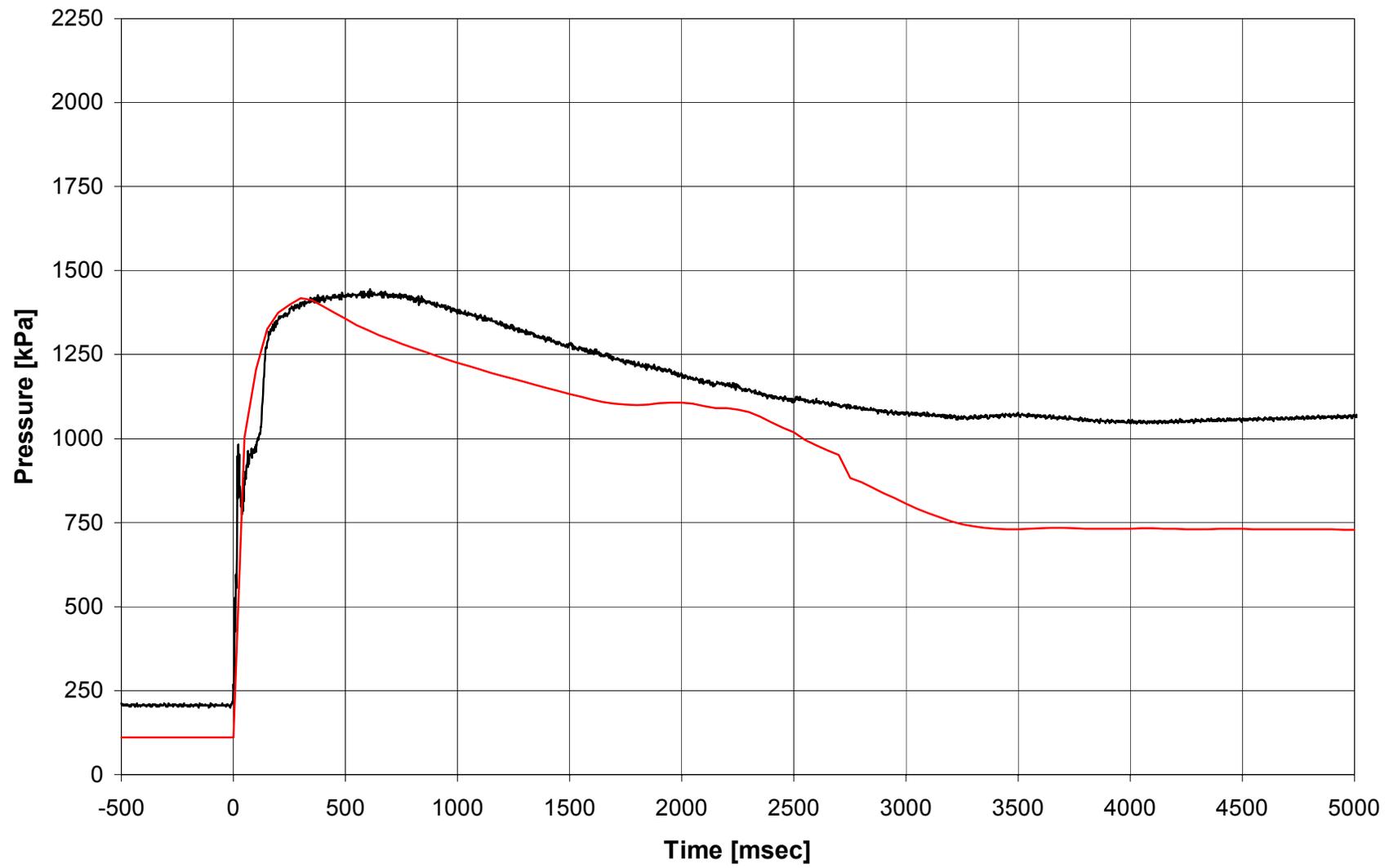
Graph 9: Gas Temperature in Collection Vessel

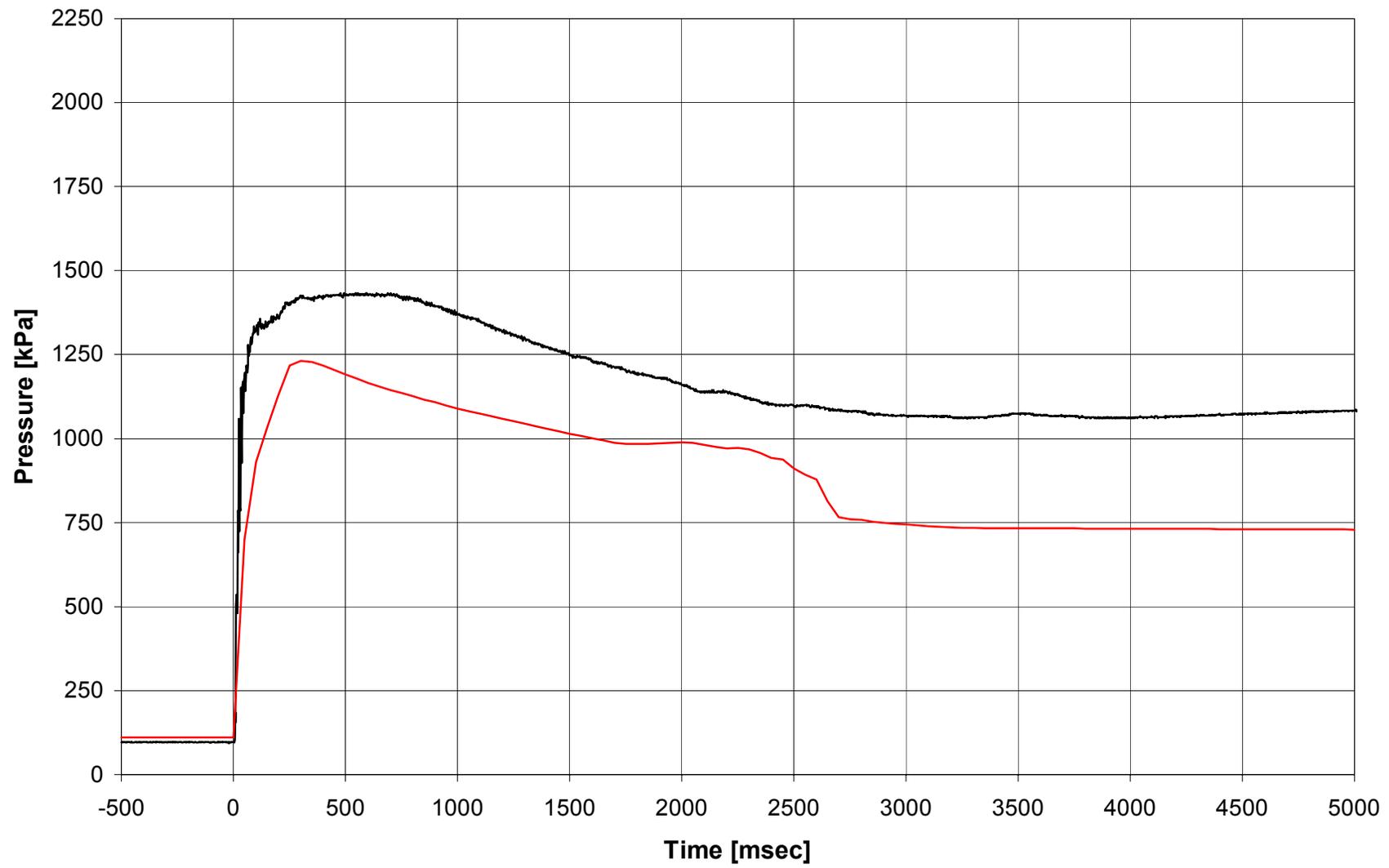


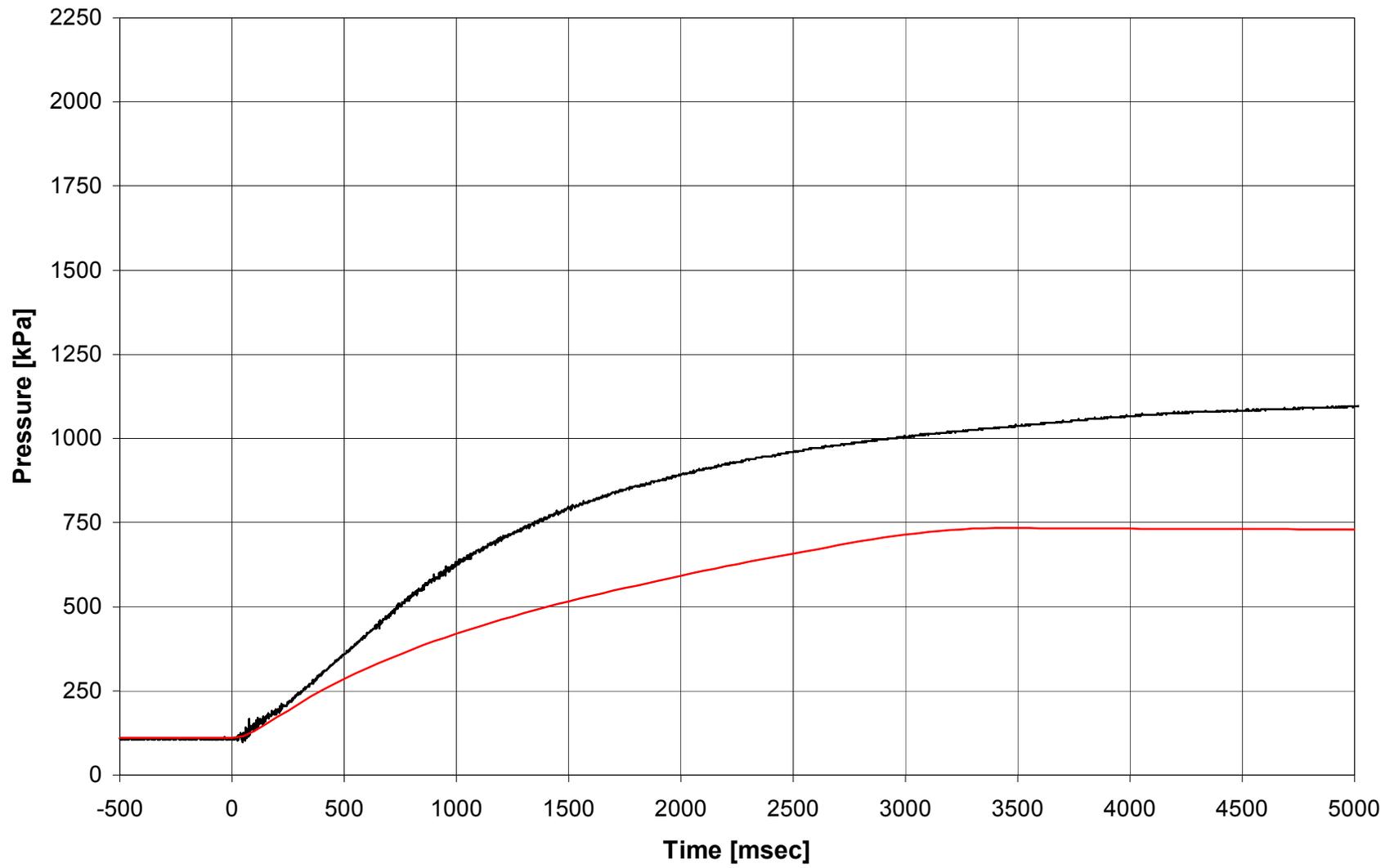


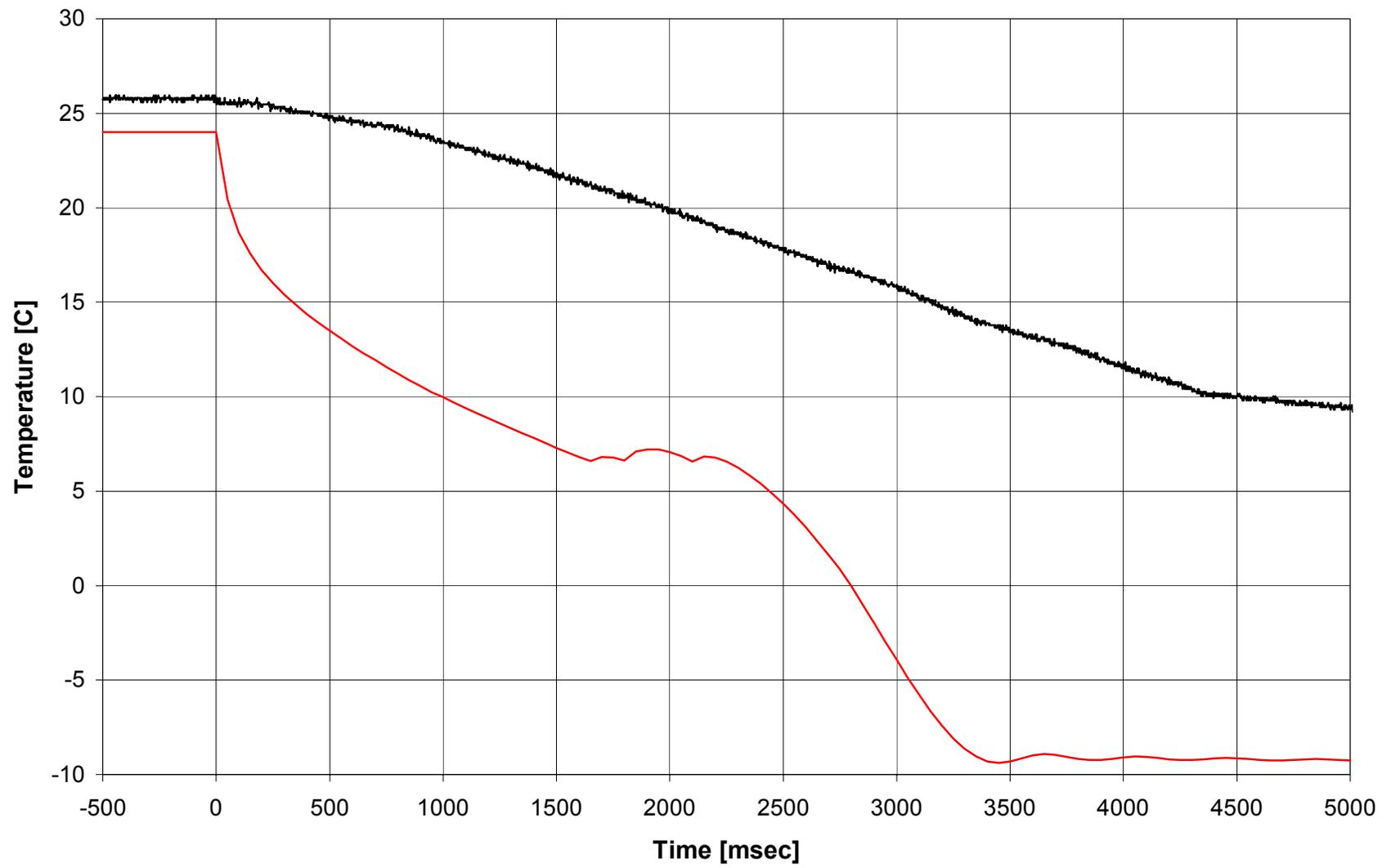


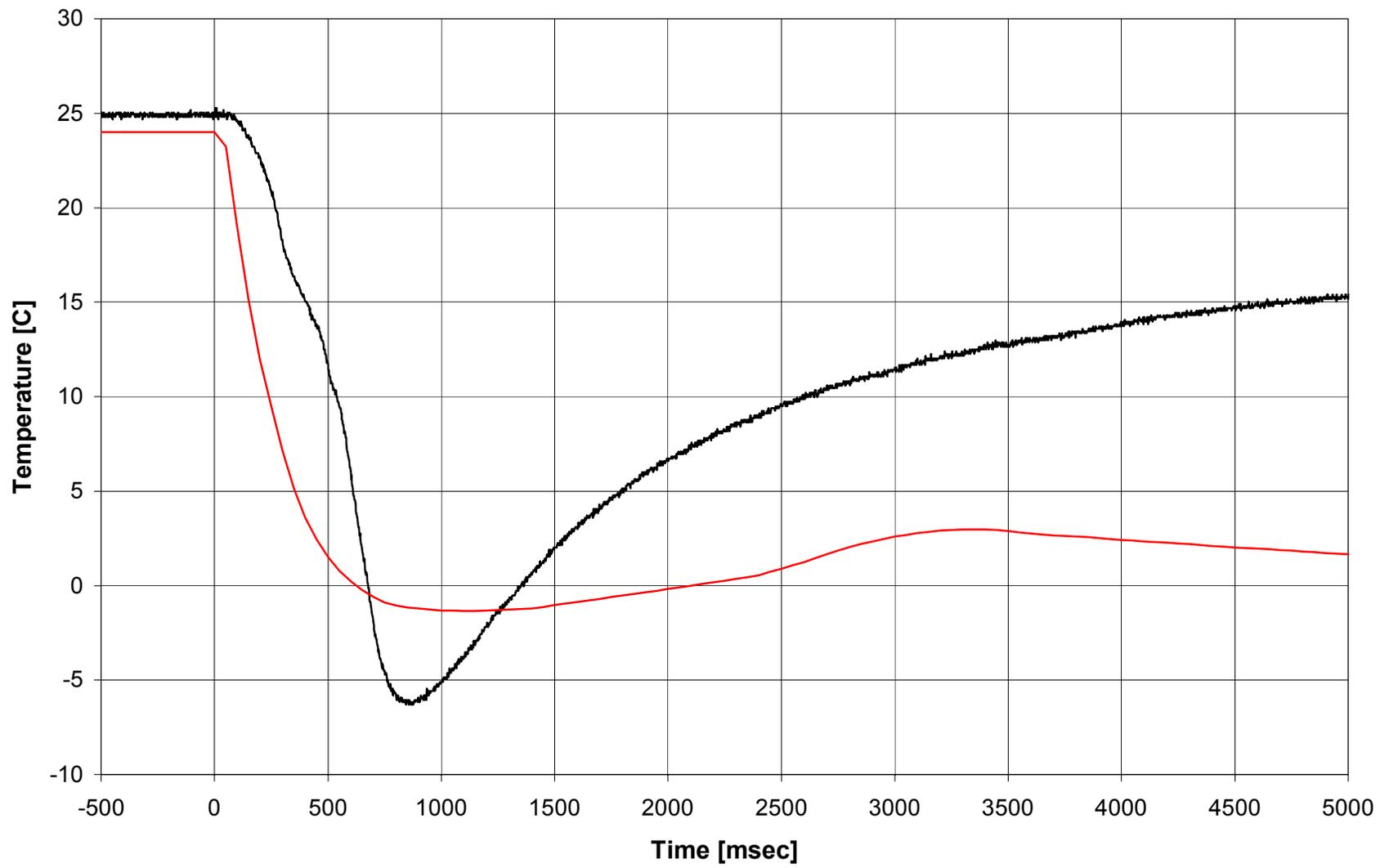












Run #15 with Code Prediction

Test Fluid: C2HF5 Pentafluoroethane (HFC-125)
CAS #: 354-33-6
Molecular Weight: 120.3

System Piping Configuration: Straight Pipe

Source Vessel Initial Conditions: Fill Volume: 2363 milliliters
 Fluid Mass: 2.868 kg
 Pressure (Psvo): 3635 kPa
 Nitrogen Mass: 0.092 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 175 kPa

Initial System Temperature: 26° Celsius

Completion Date: 4/6/00

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

Graph 3: Source Vessel Pressure

Graph 4: Pipe Position #1 Pressure

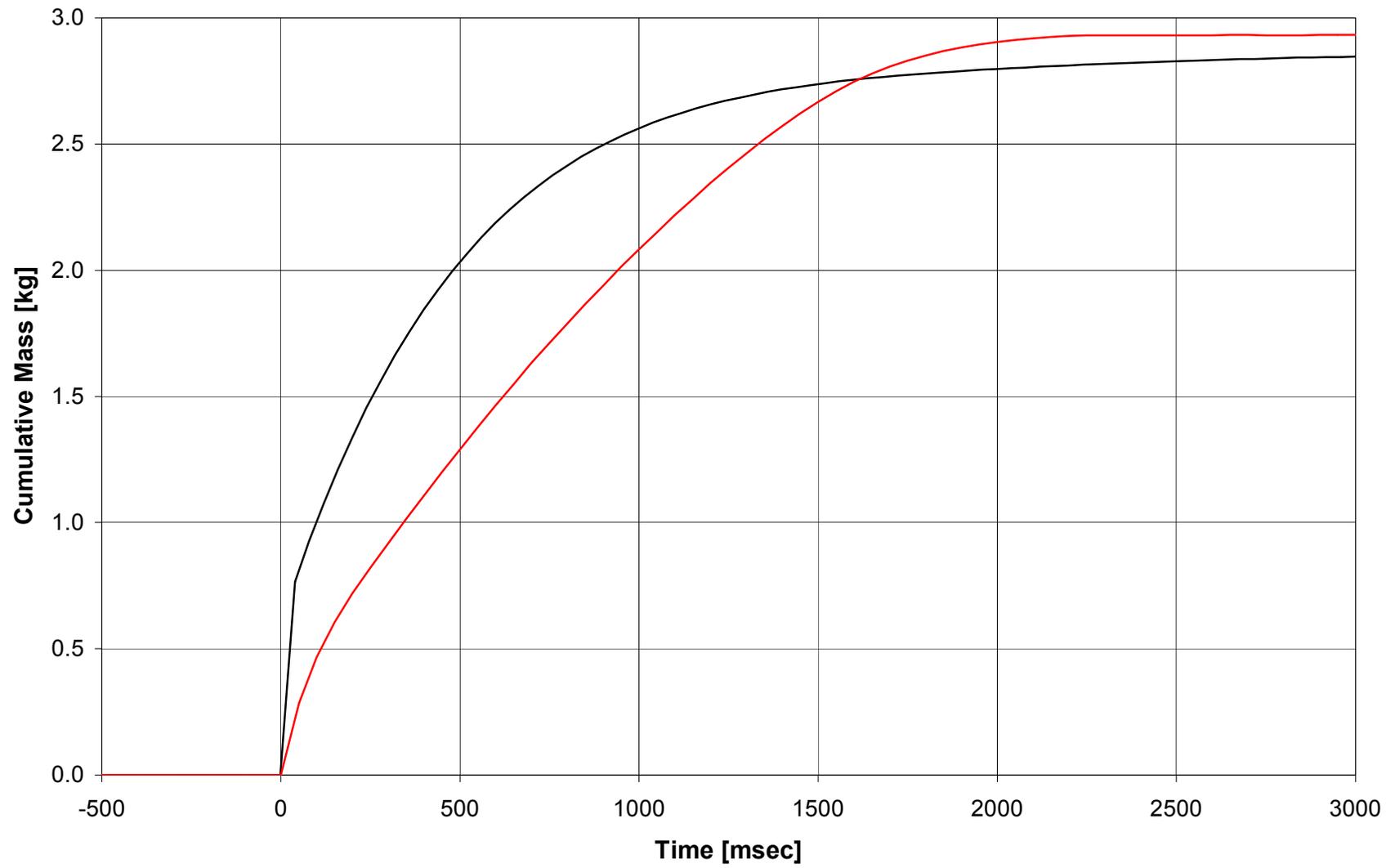
Graph 5: Pipe Position #2 Pressure

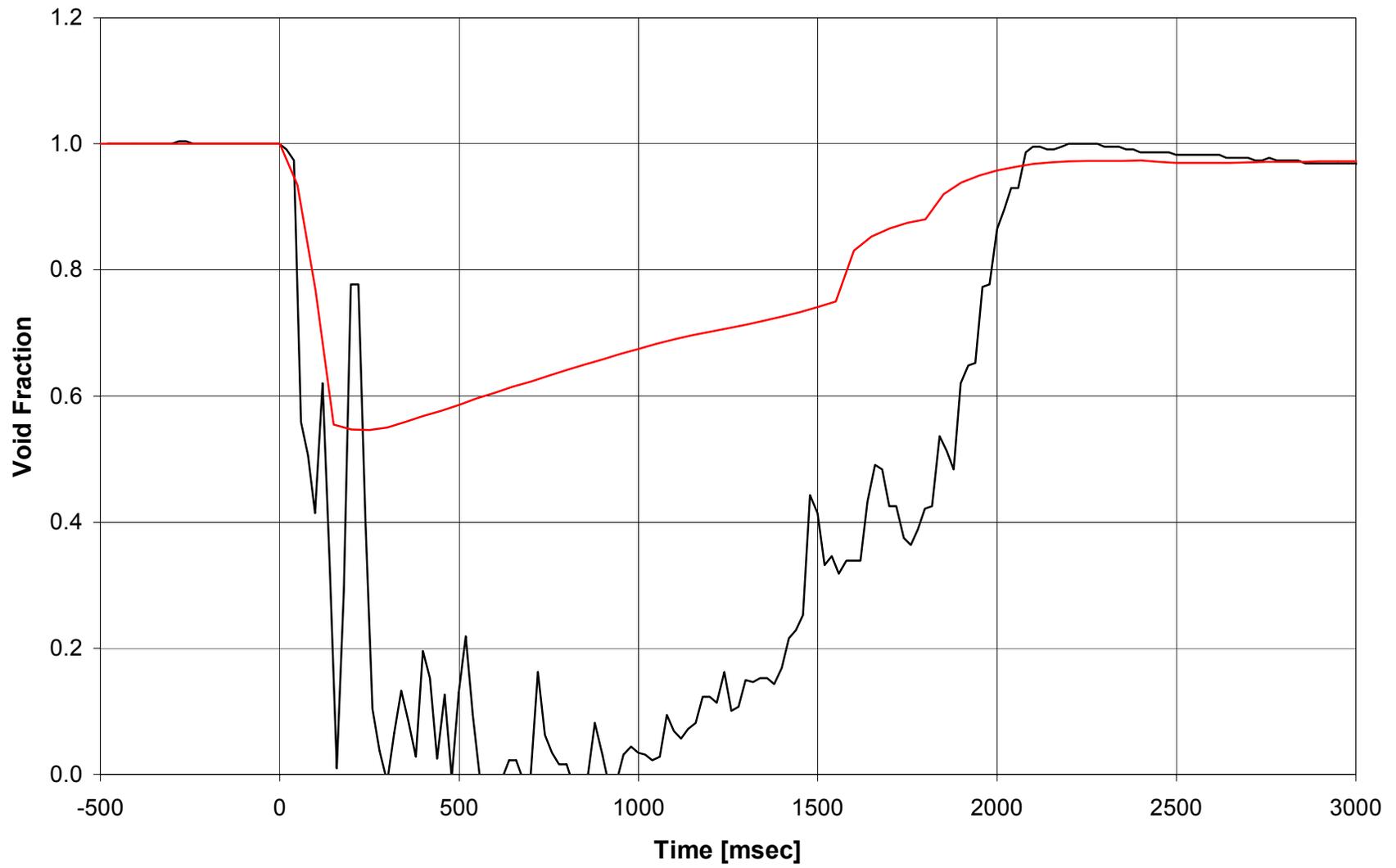
Graph 6: Pipe Position #3 Pressure

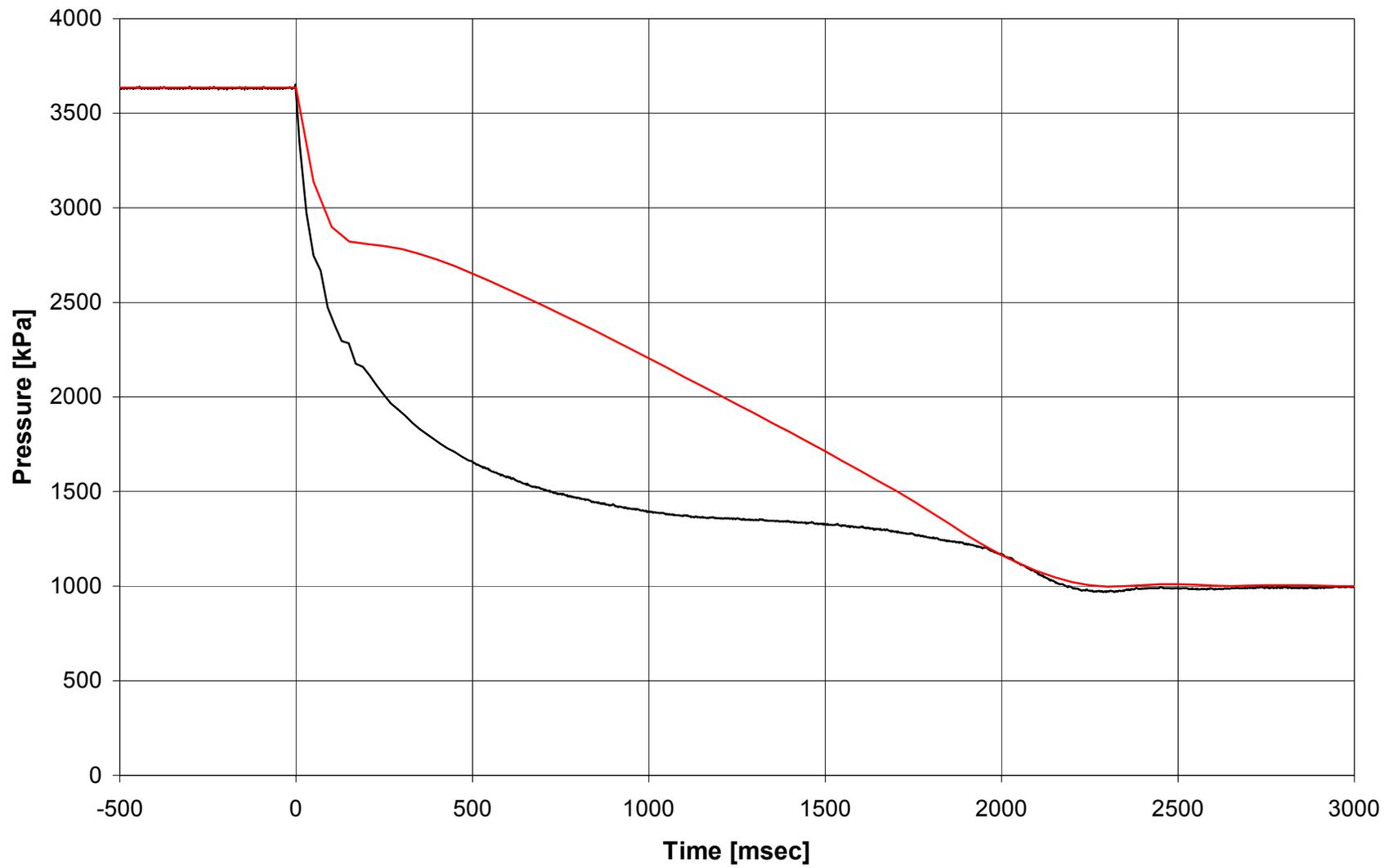
Graph 7: Collection Vessel Pressure

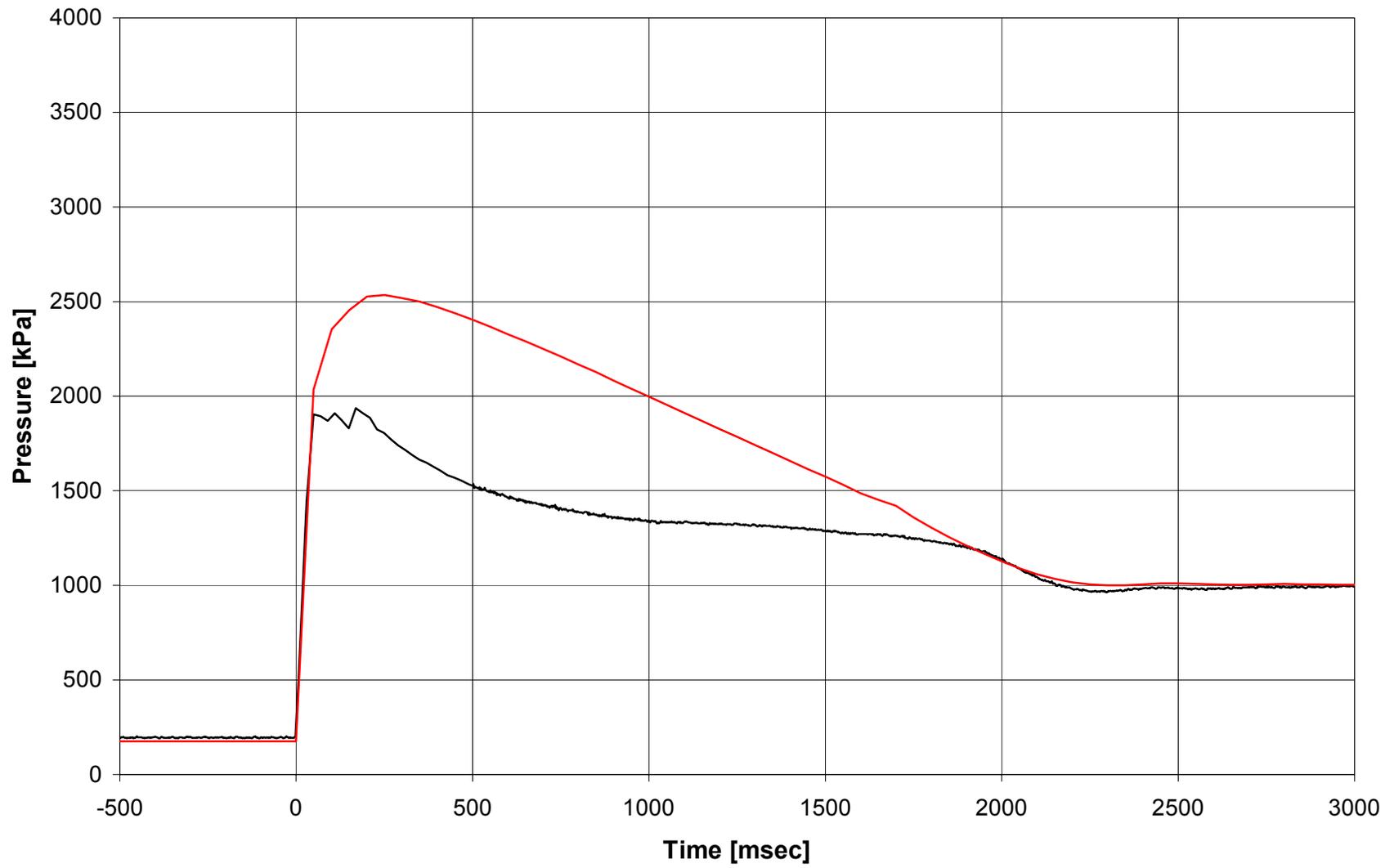
Graph 8: Gas Temperature in Source Vessel

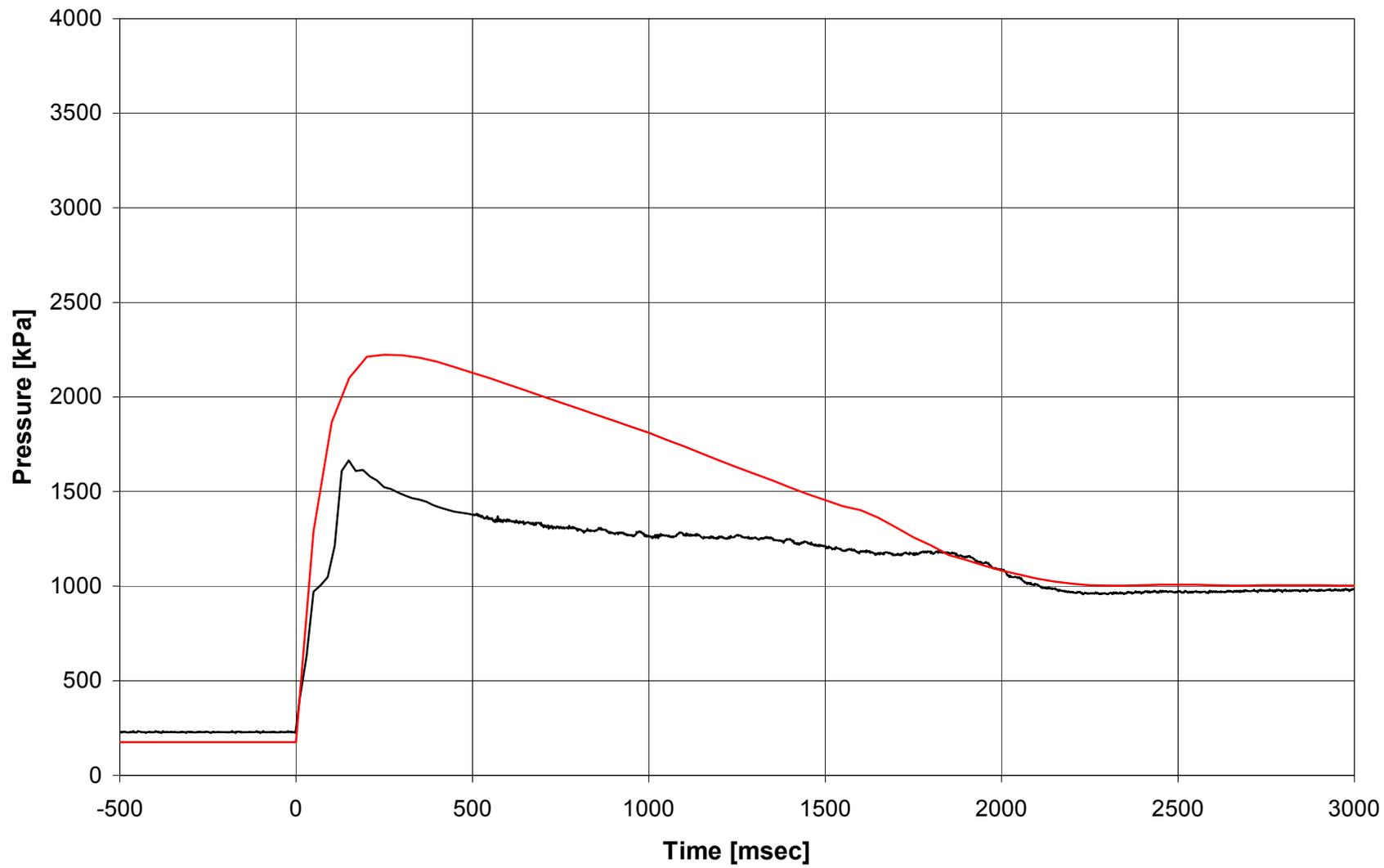
Graph 9: Gas Temperature in Collection Vessel

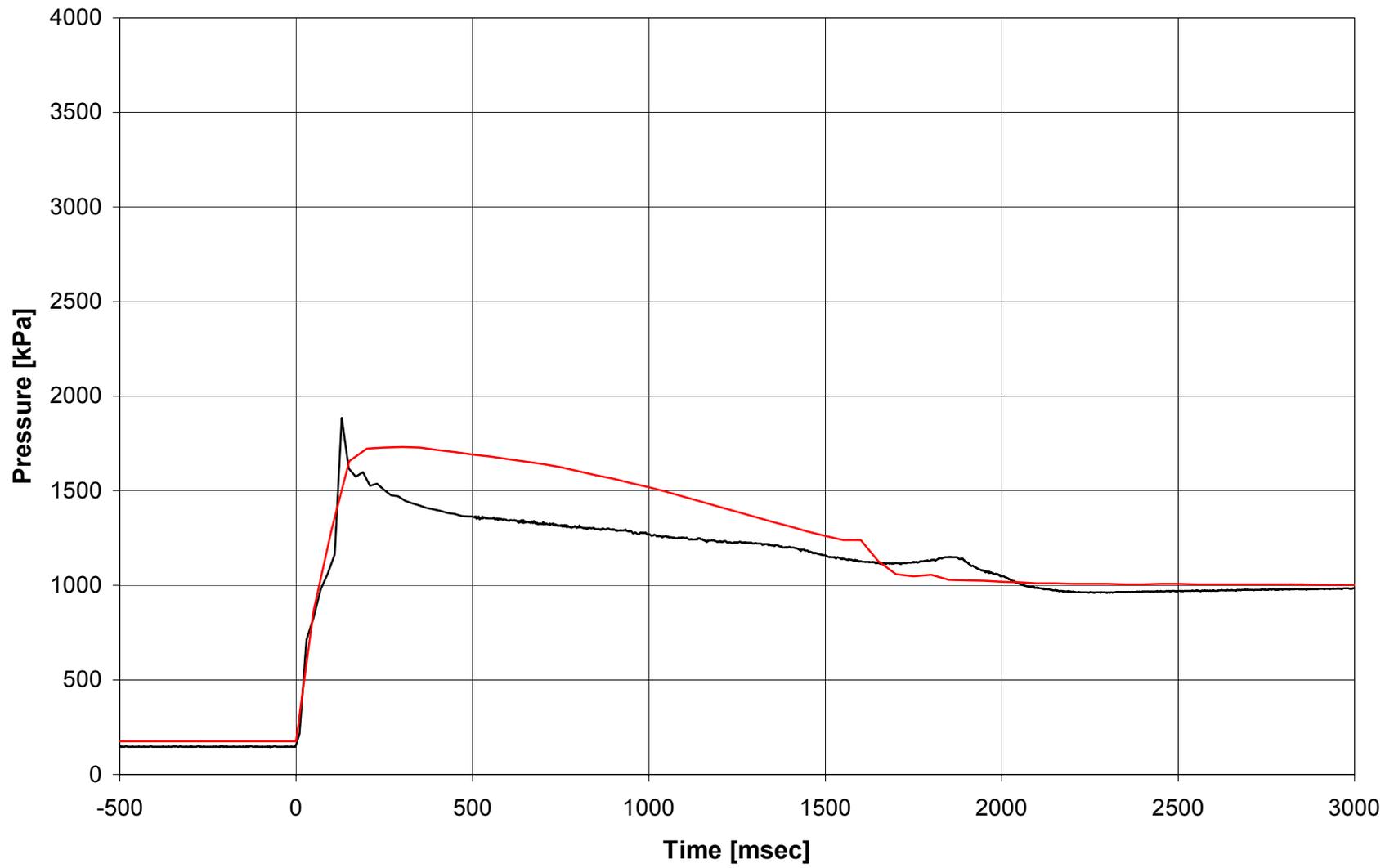


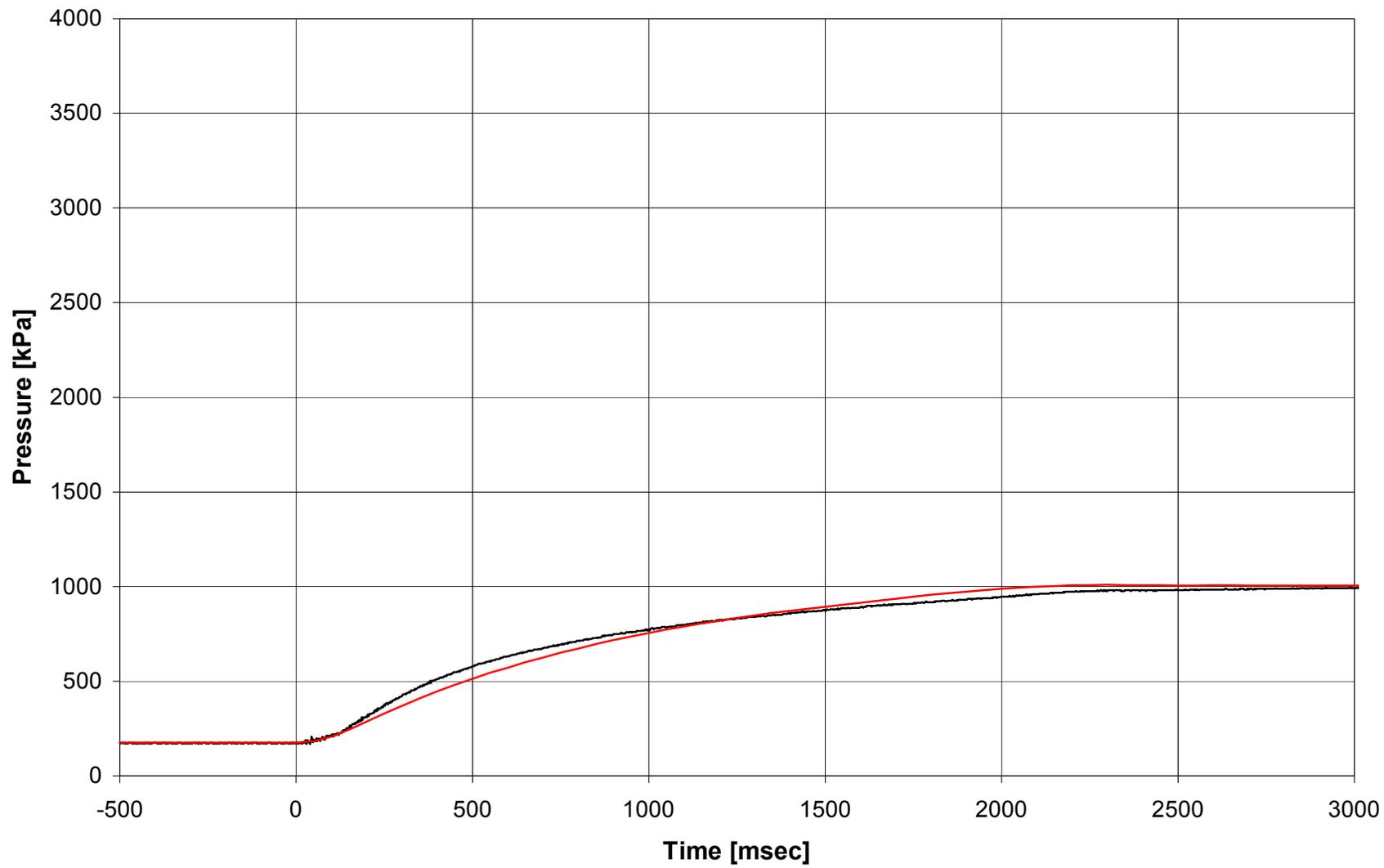


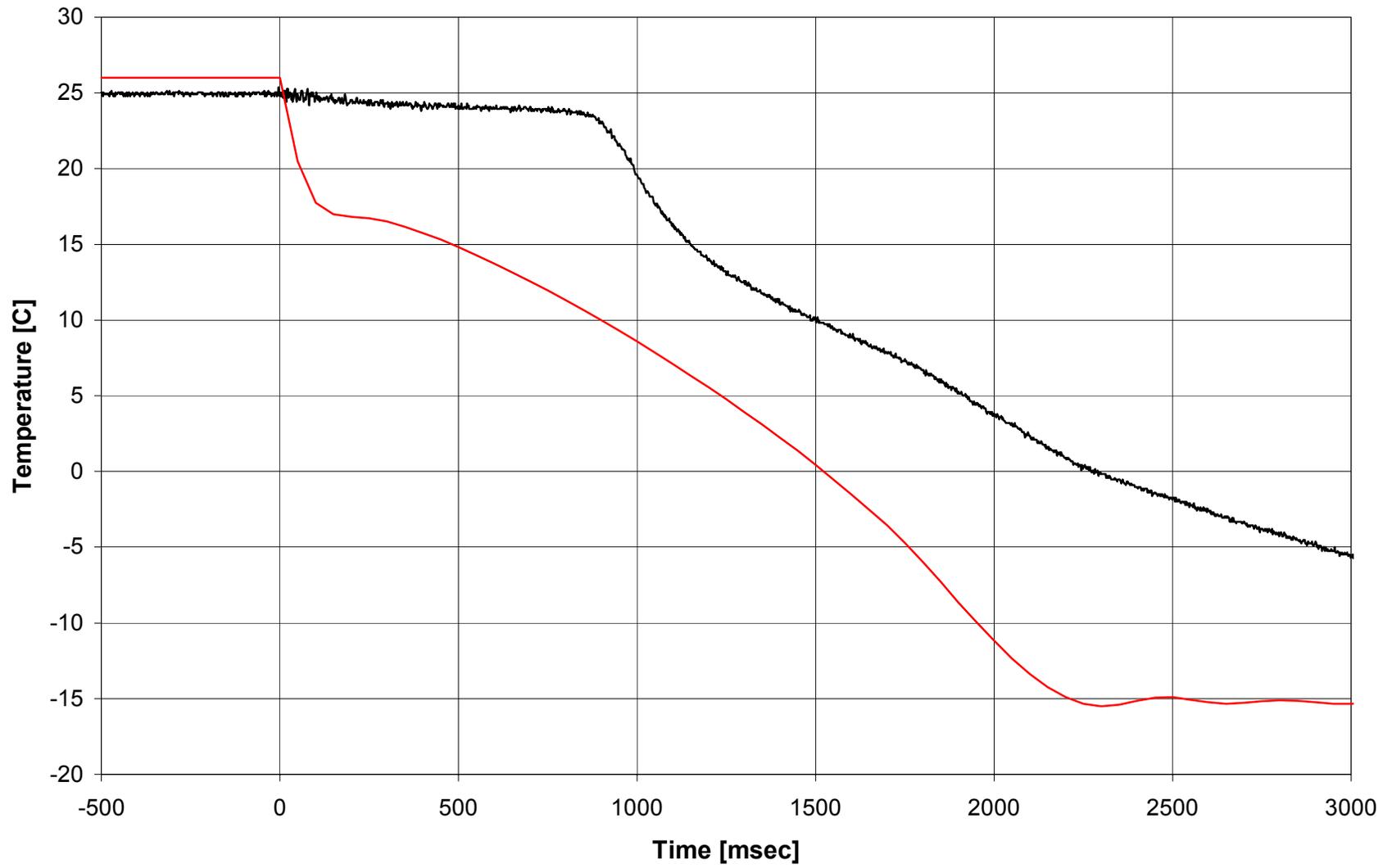


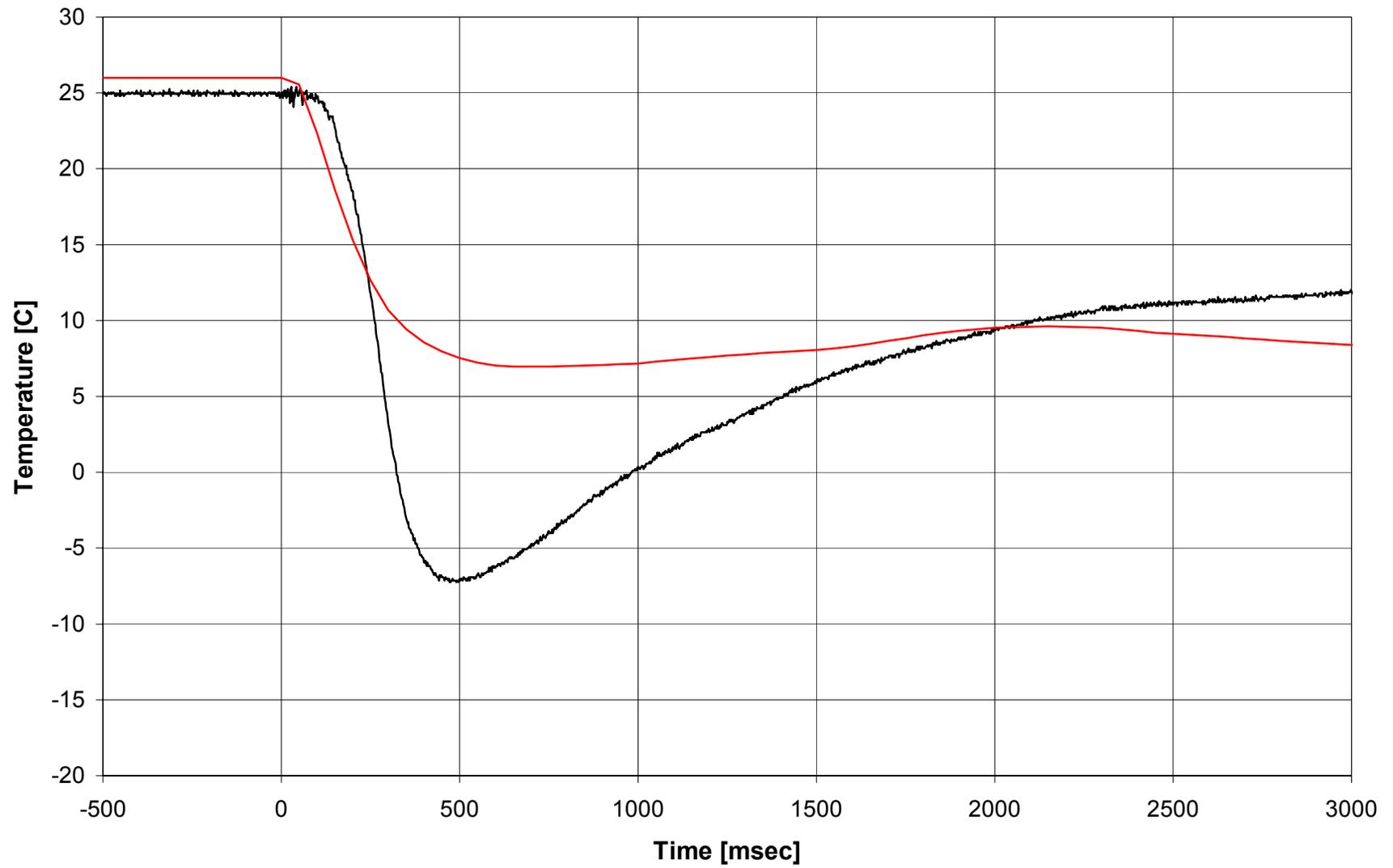












Run #16 with Code Prediction

Test Fluid: C2HF5 Pentafluoroethane (HFC-125)
CAS #: 354-33-6
Molecular Weight: 120.3

System Piping Configuration: Straight Pipe

Source Vessel Initial Conditions: Fill Volume: 2400 milliliters
 Fluid Mass: 2.936 kg
 Pressure (Psvo): 4245 kPa
 Nitrogen Mass: 0.118 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 165 kPa

Initial System Temperature: 26° Celsius

Completion Date: 4/4/00

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

Graph 3: Source Vessel Pressure

Graph 4: Pipe Position #1 Pressure

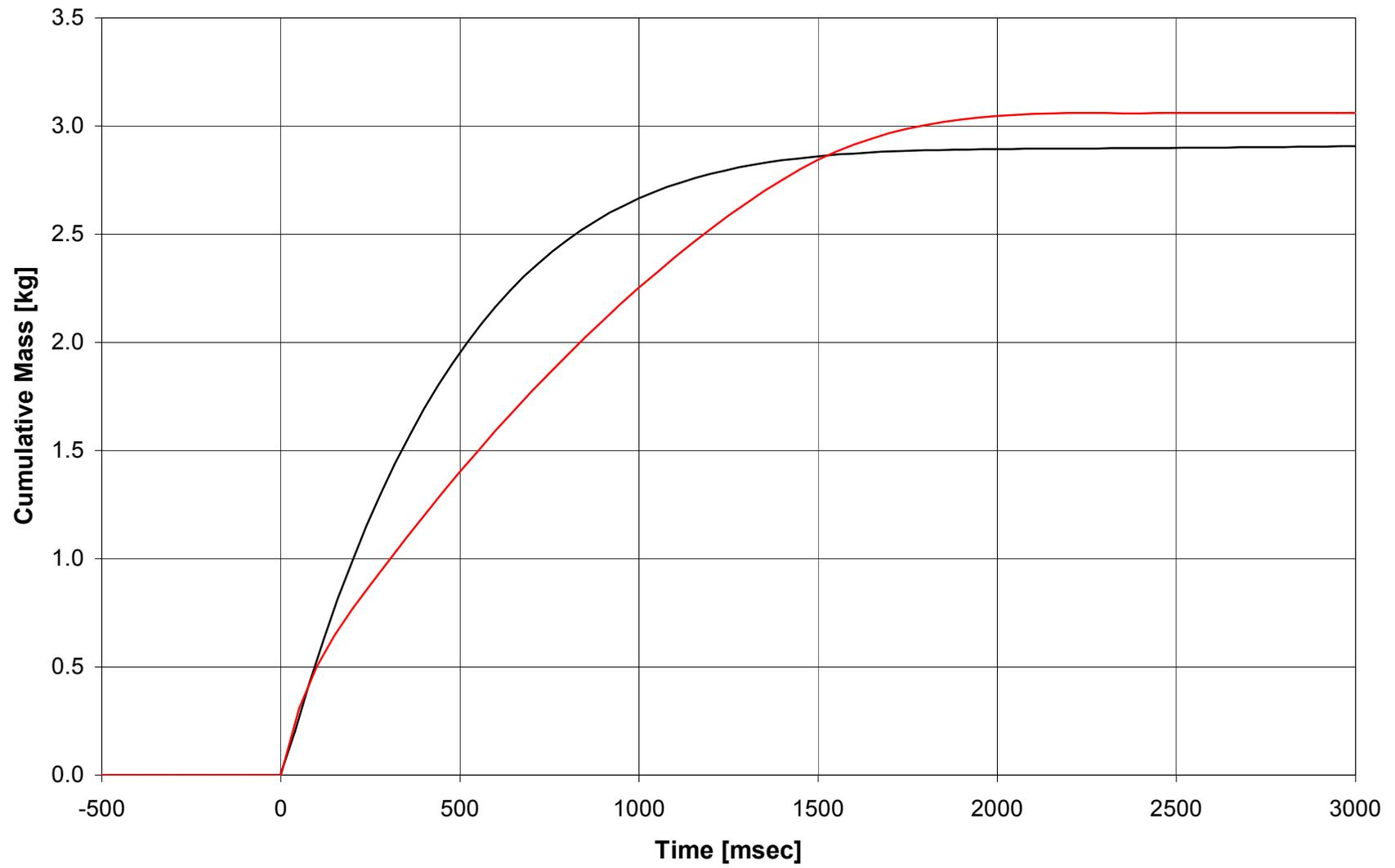
Graph 5: Pipe Position #2 Pressure

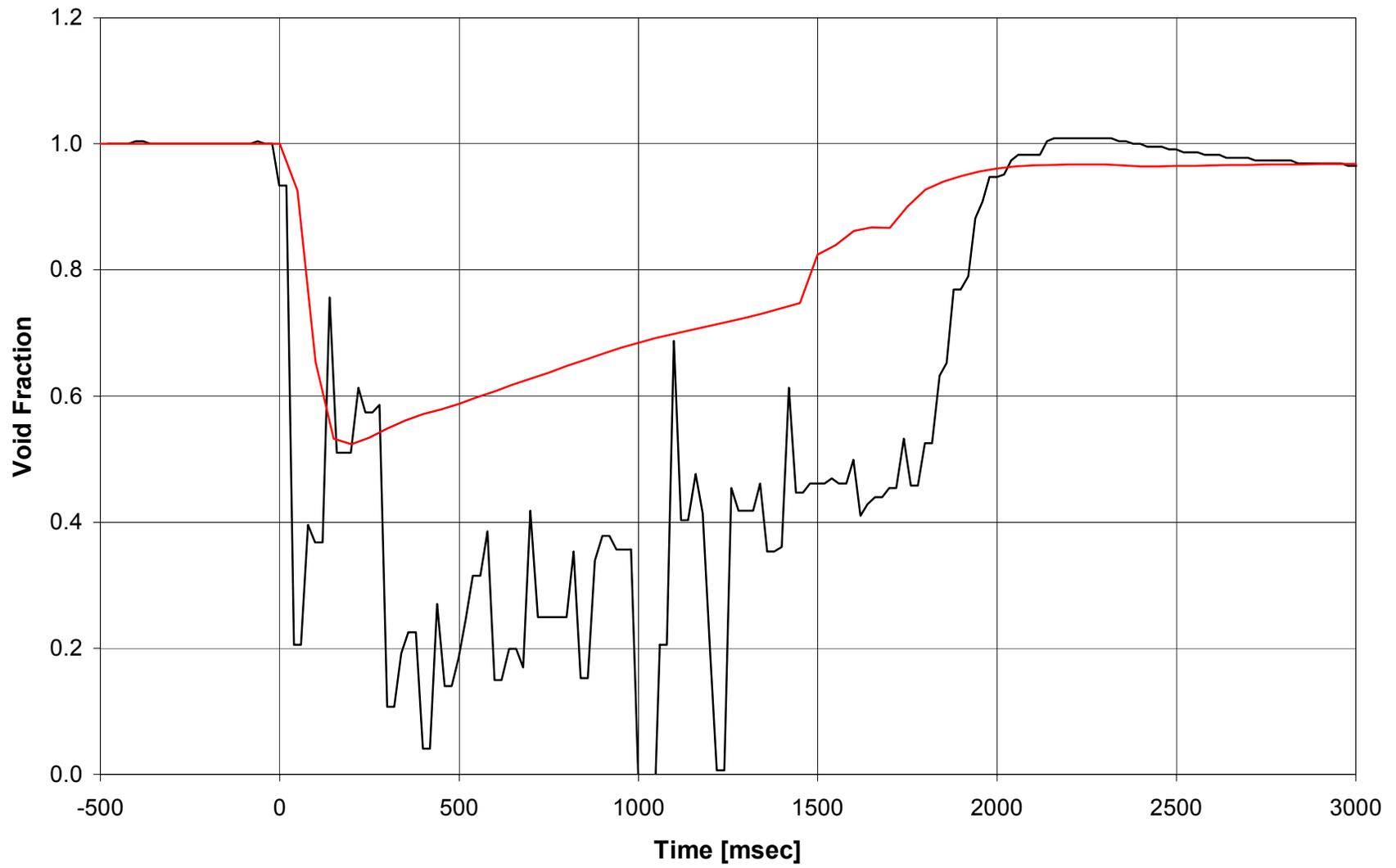
Graph 6: Pipe Position #3 Pressure

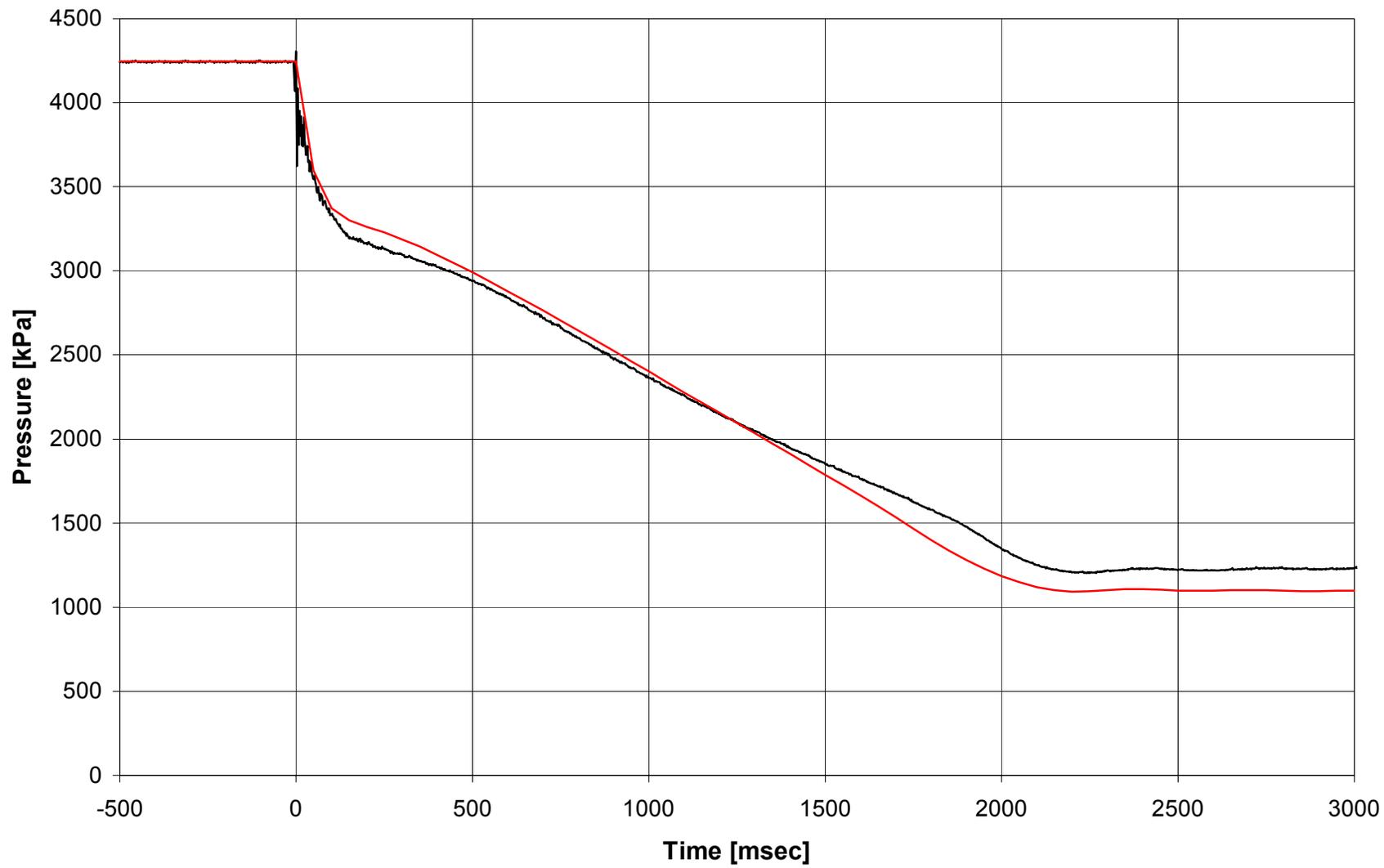
Graph 7: Collection Vessel Pressure

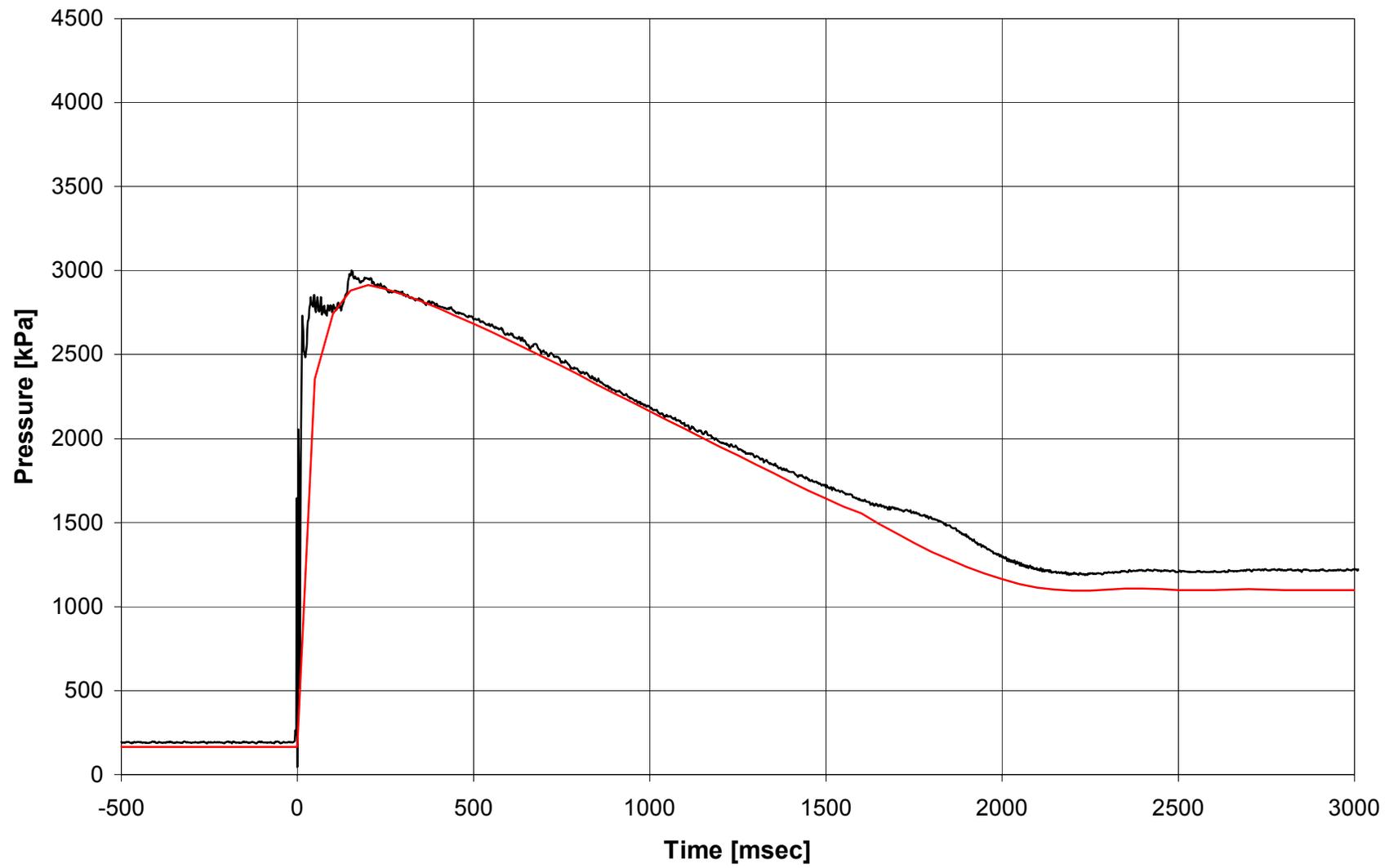
Graph 8: Gas Temperature in Source Vessel

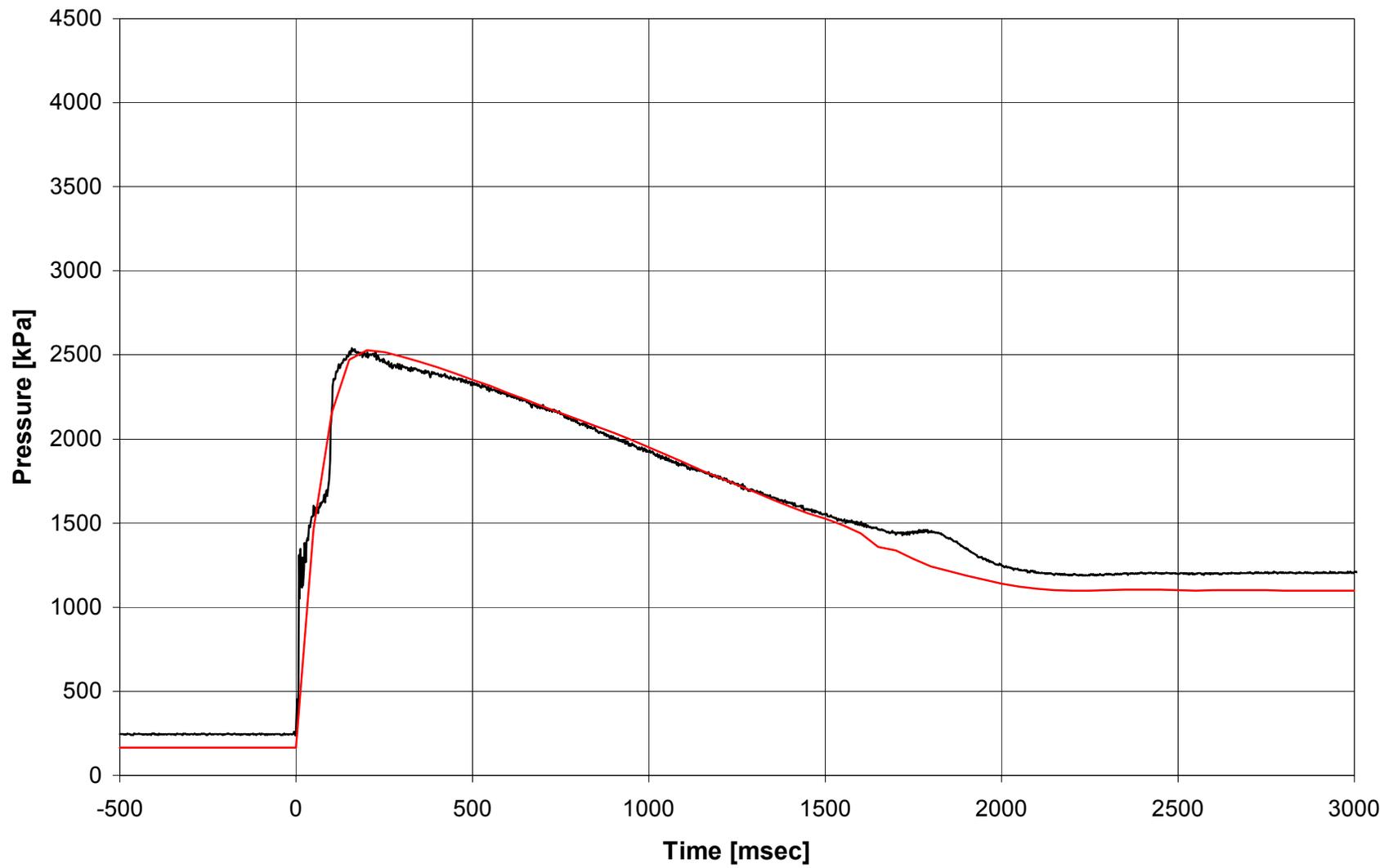
Graph 9: Gas Temperature in Collection Vessel

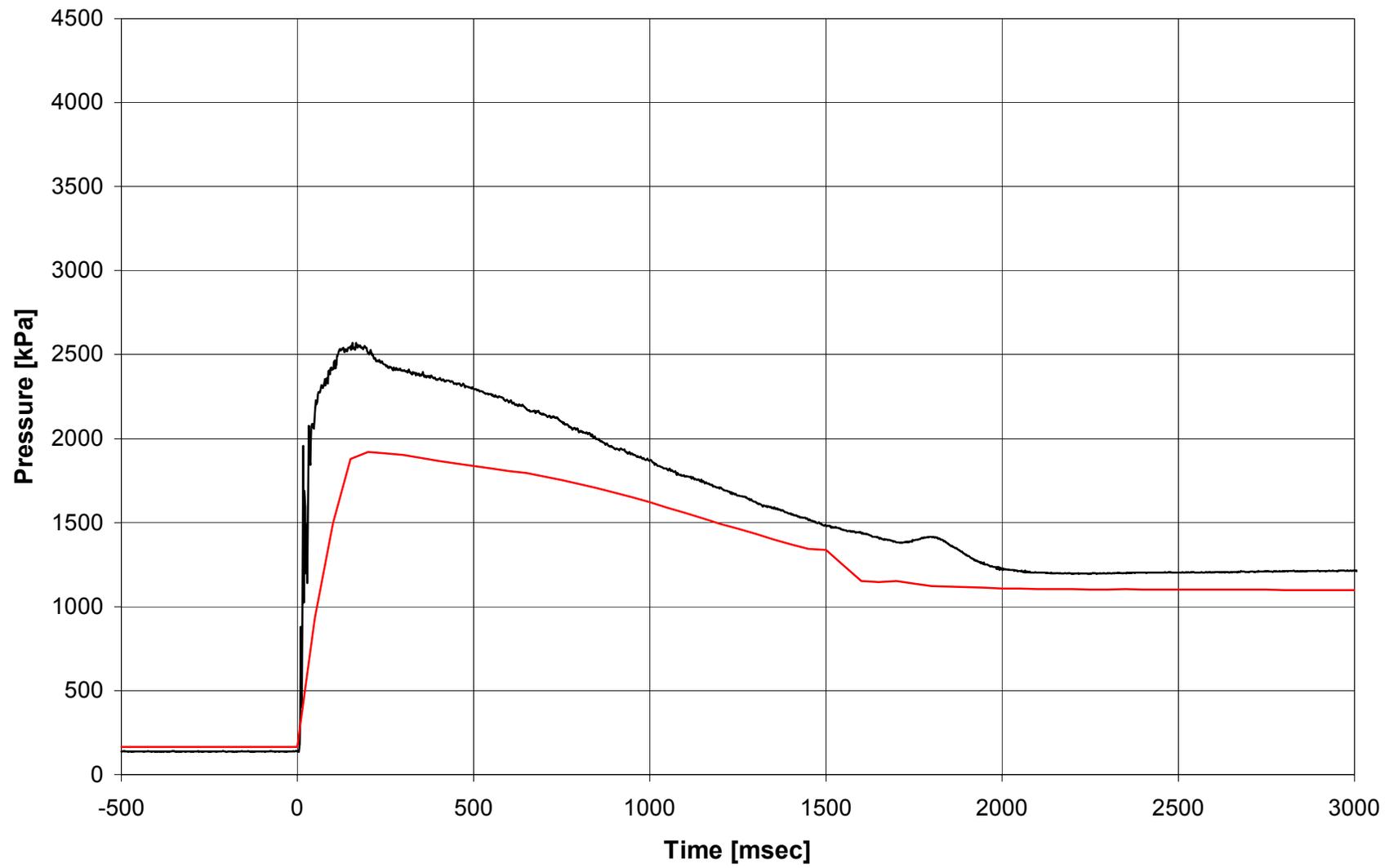


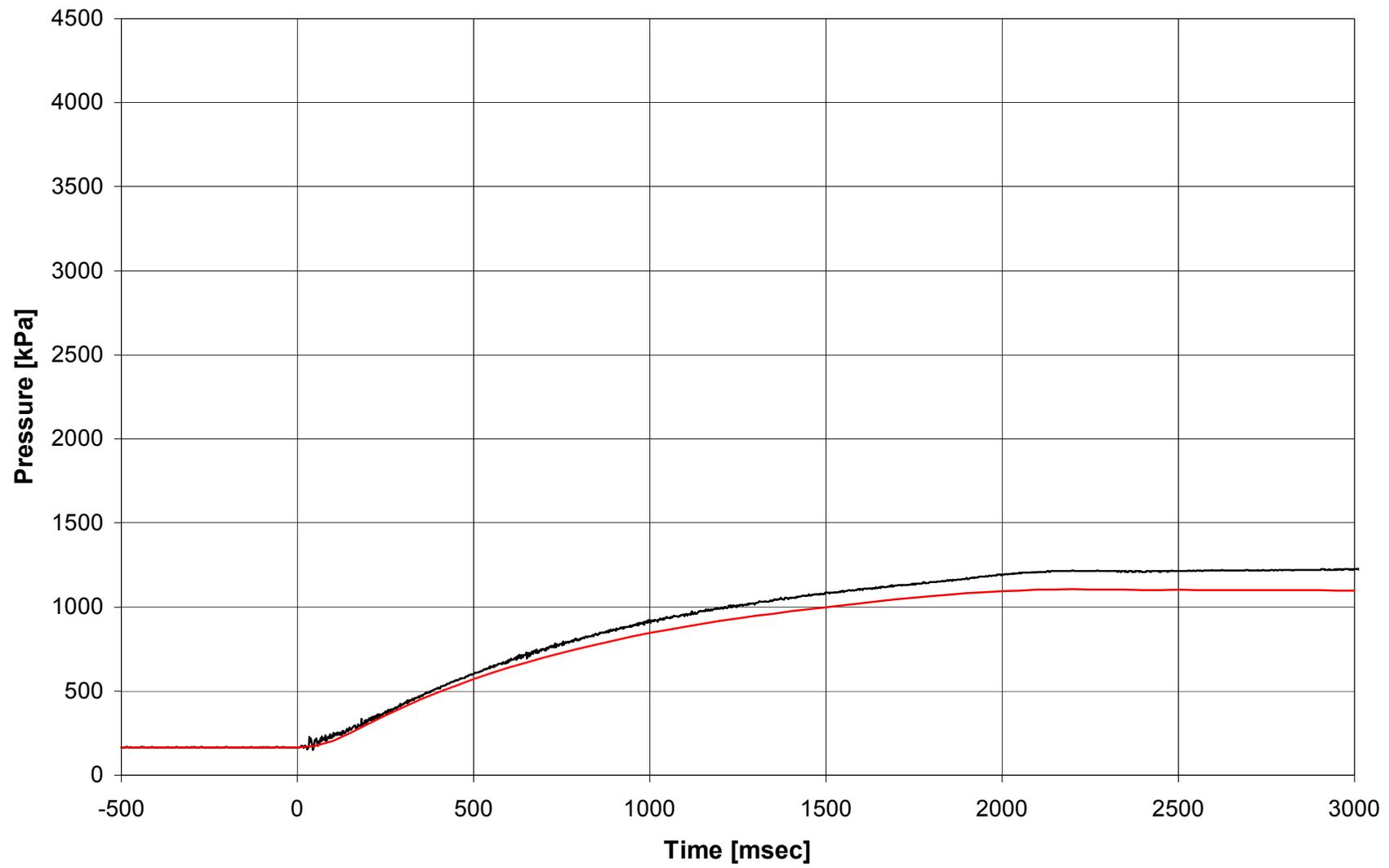


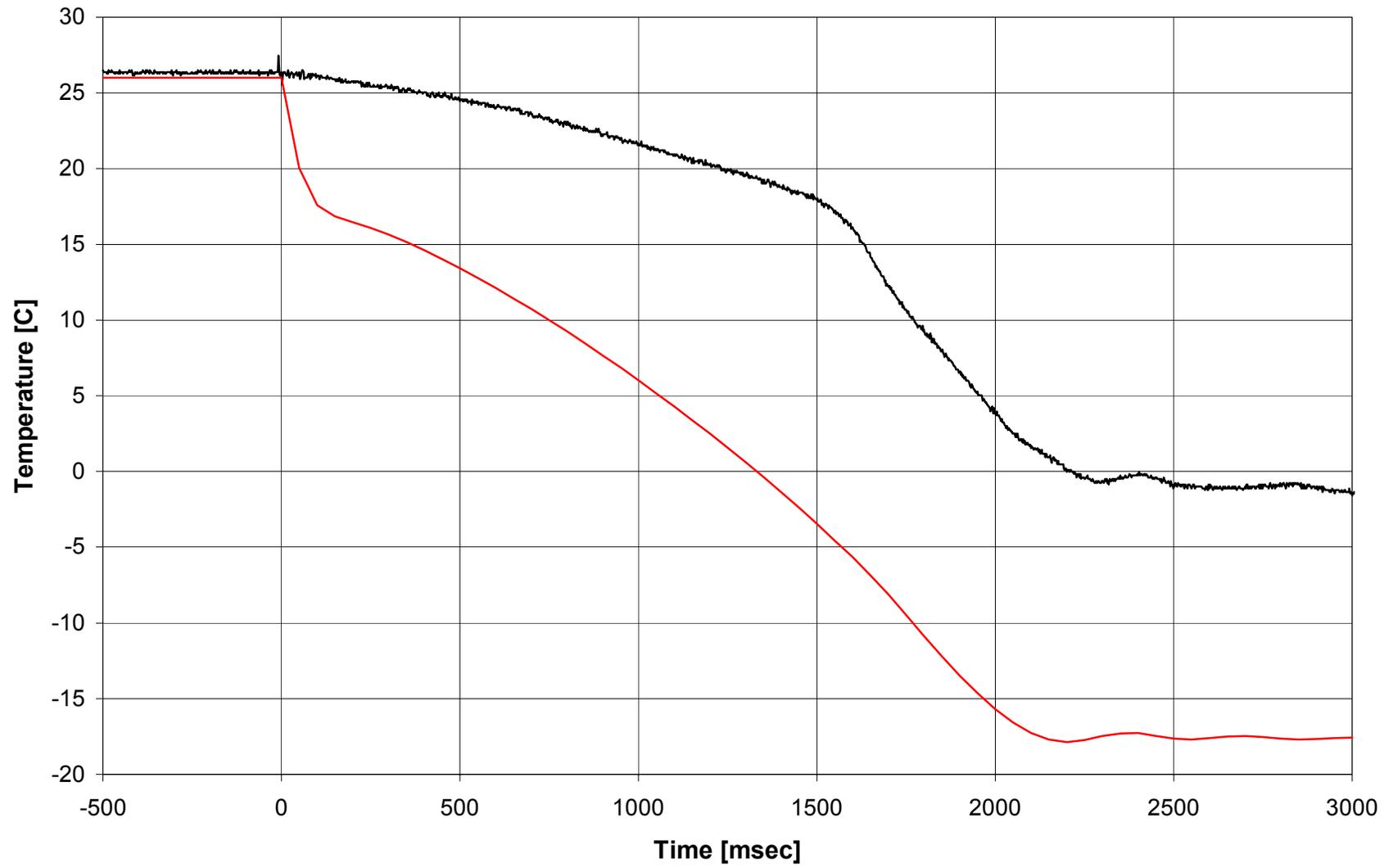


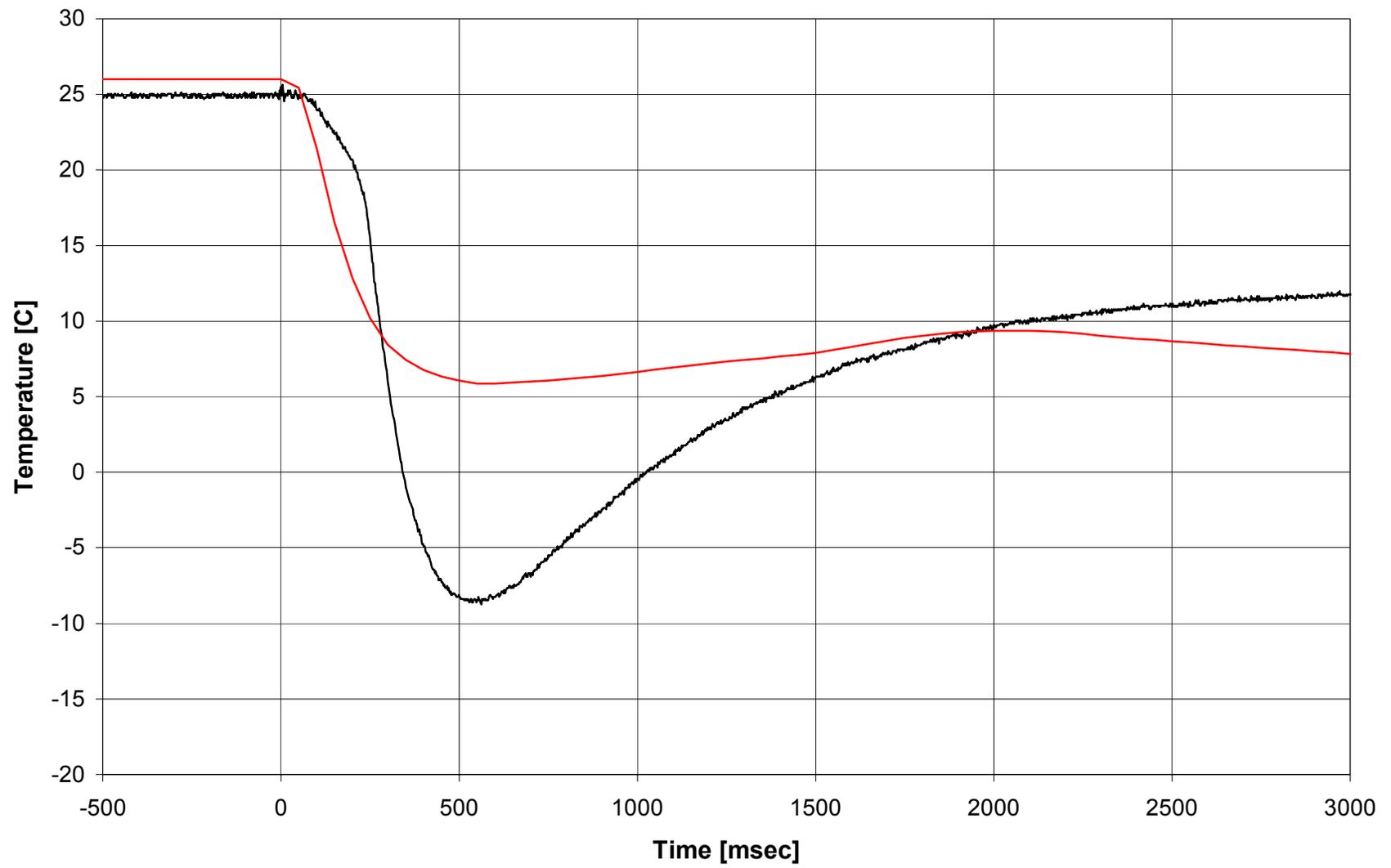












Run #17 with Code Prediction

Test Fluid: C2HF5 Pentafluoroethane (HFC-125)
CAS #: 354-33-6
Molecular Weight: 120.3

System Piping Configuration: Straight Pipe

Source Vessel Initial Conditions: Fill Volume: 2467 milliliters
Fluid Mass: 3.066 kg
Pressure (Psvo): 5000 kPa
Nitrogen Mass: 0.152 kg

Initial Collection Vessel & Piping Pressure (Pcvo): 125 kPa

Initial System Temperature: 24° Celsius

Completion Date: 4/10/00

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Void Fraction

Graph 3: Source Vessel Pressure

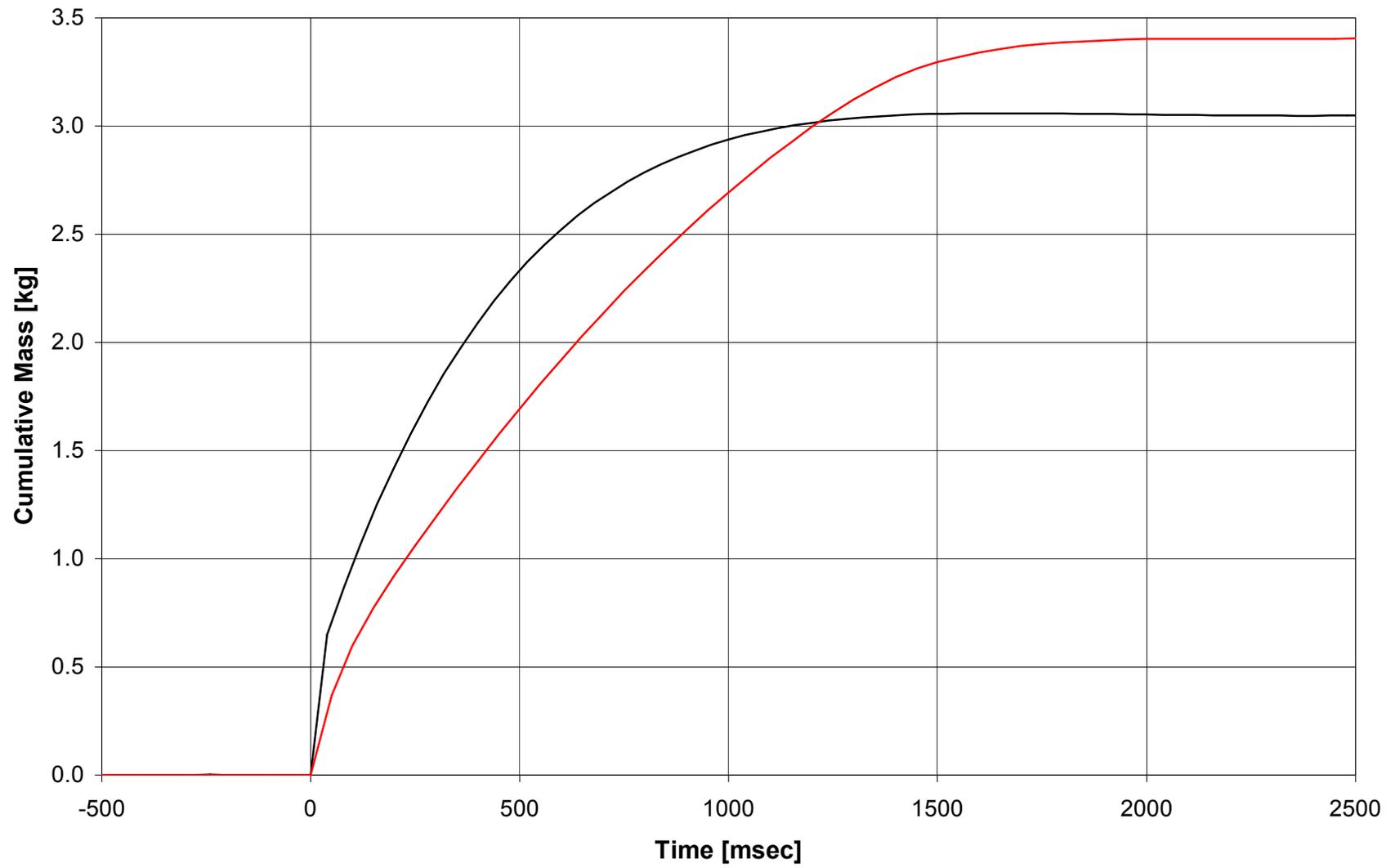
Graph 4: Pipe Position #1 Pressure

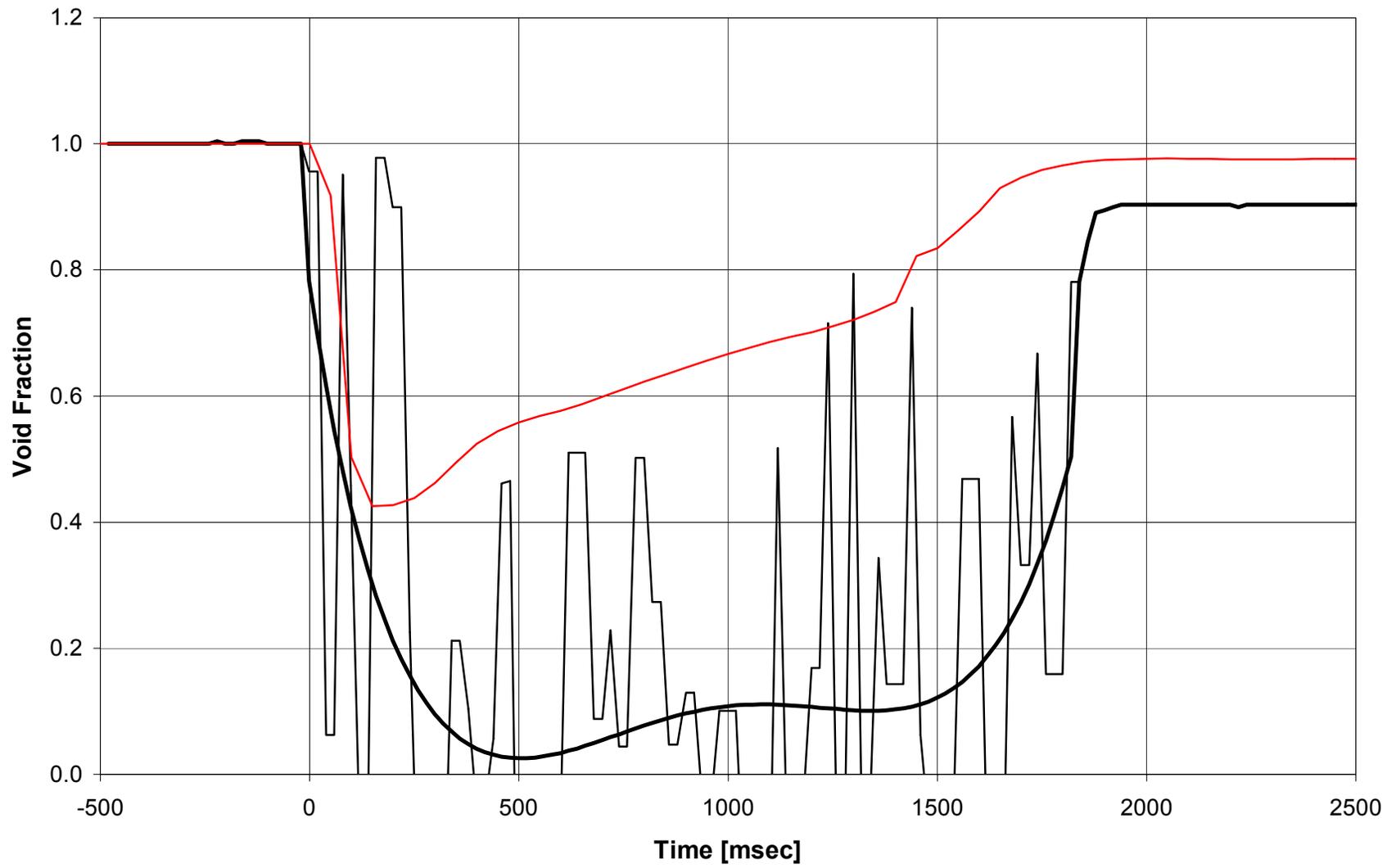
Graph 5: Pipe Position #2 Pressure

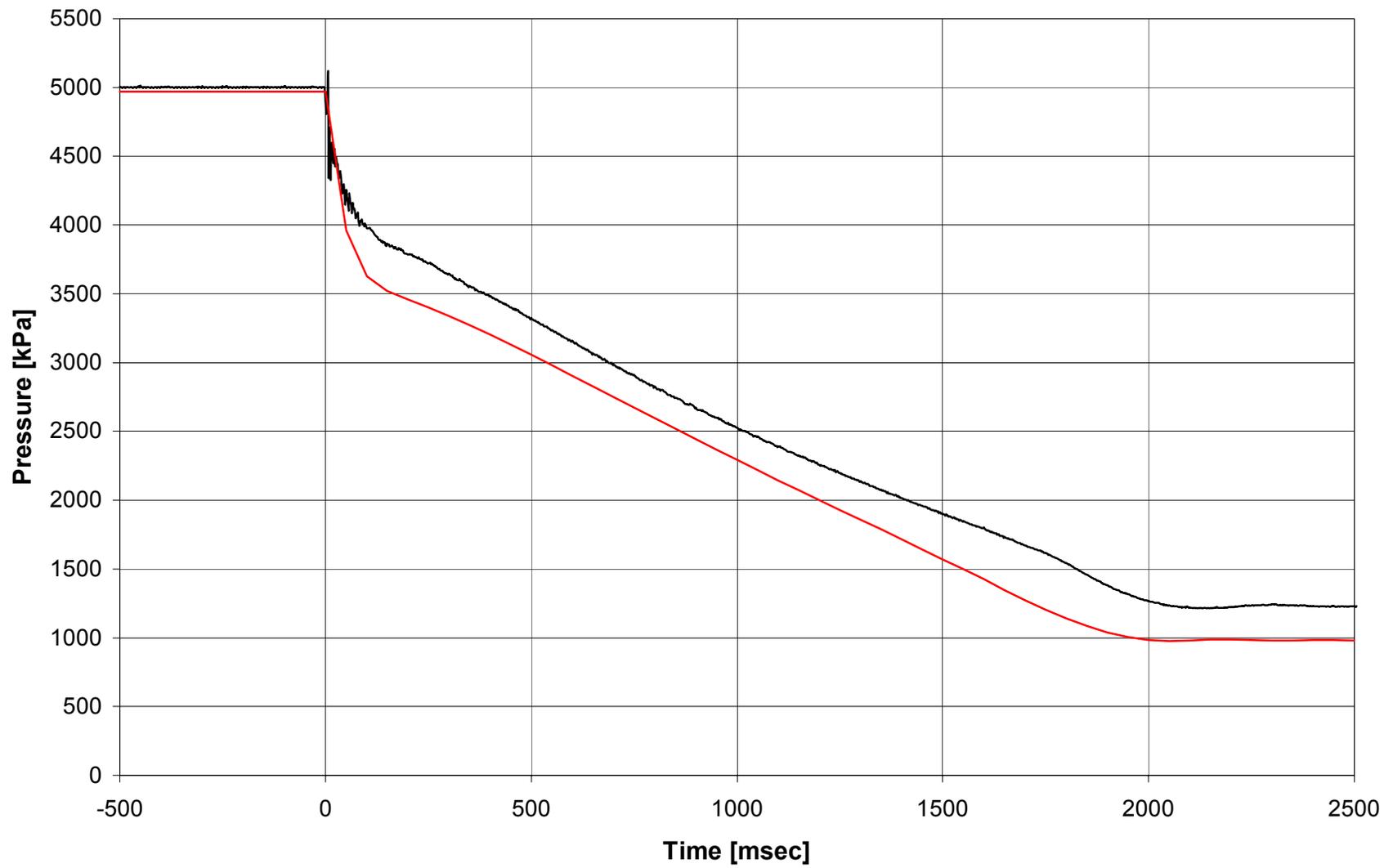
Graph 6: Pipe Position #3 Pressure

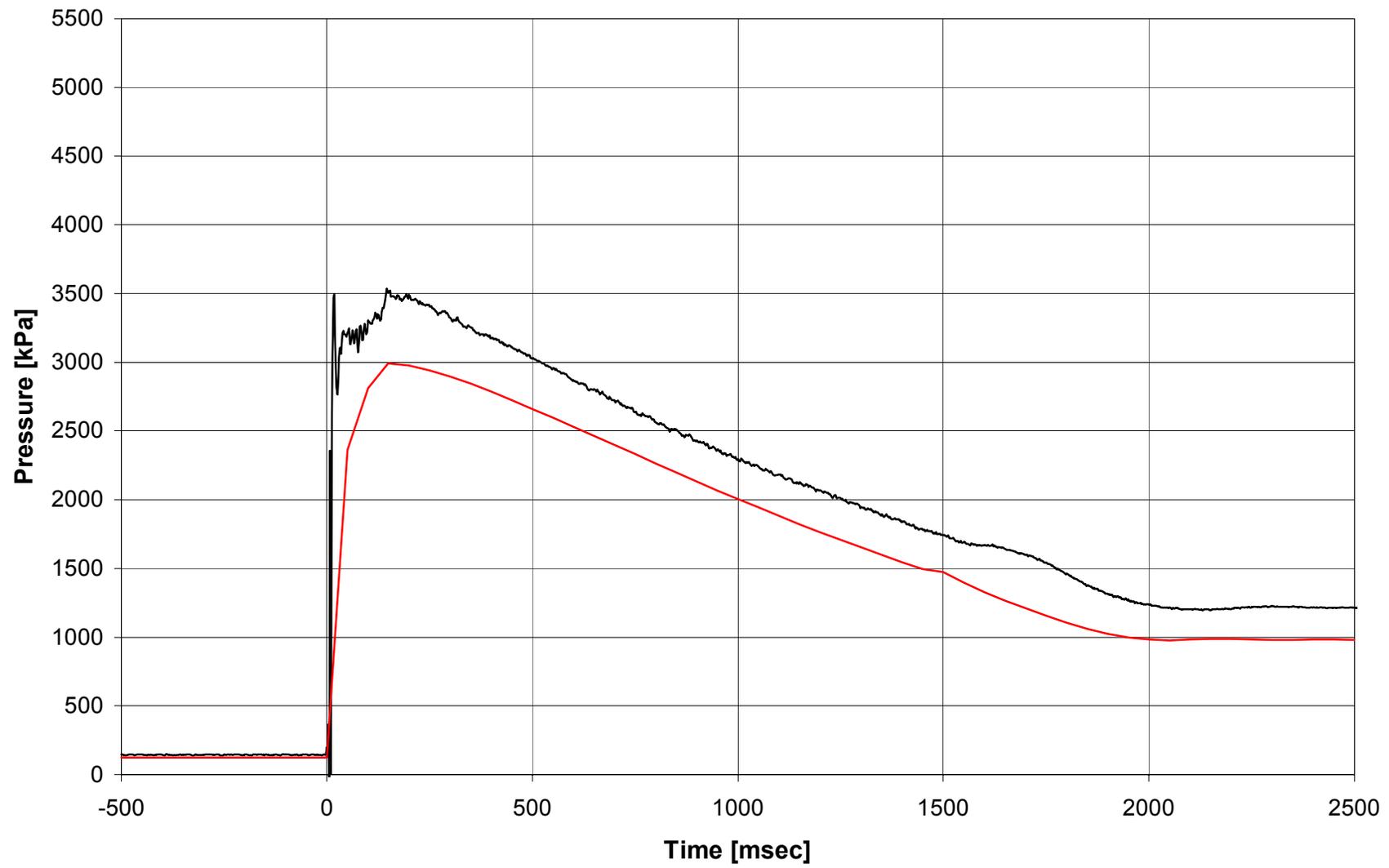
Graph 7: Collection Vessel Pressure

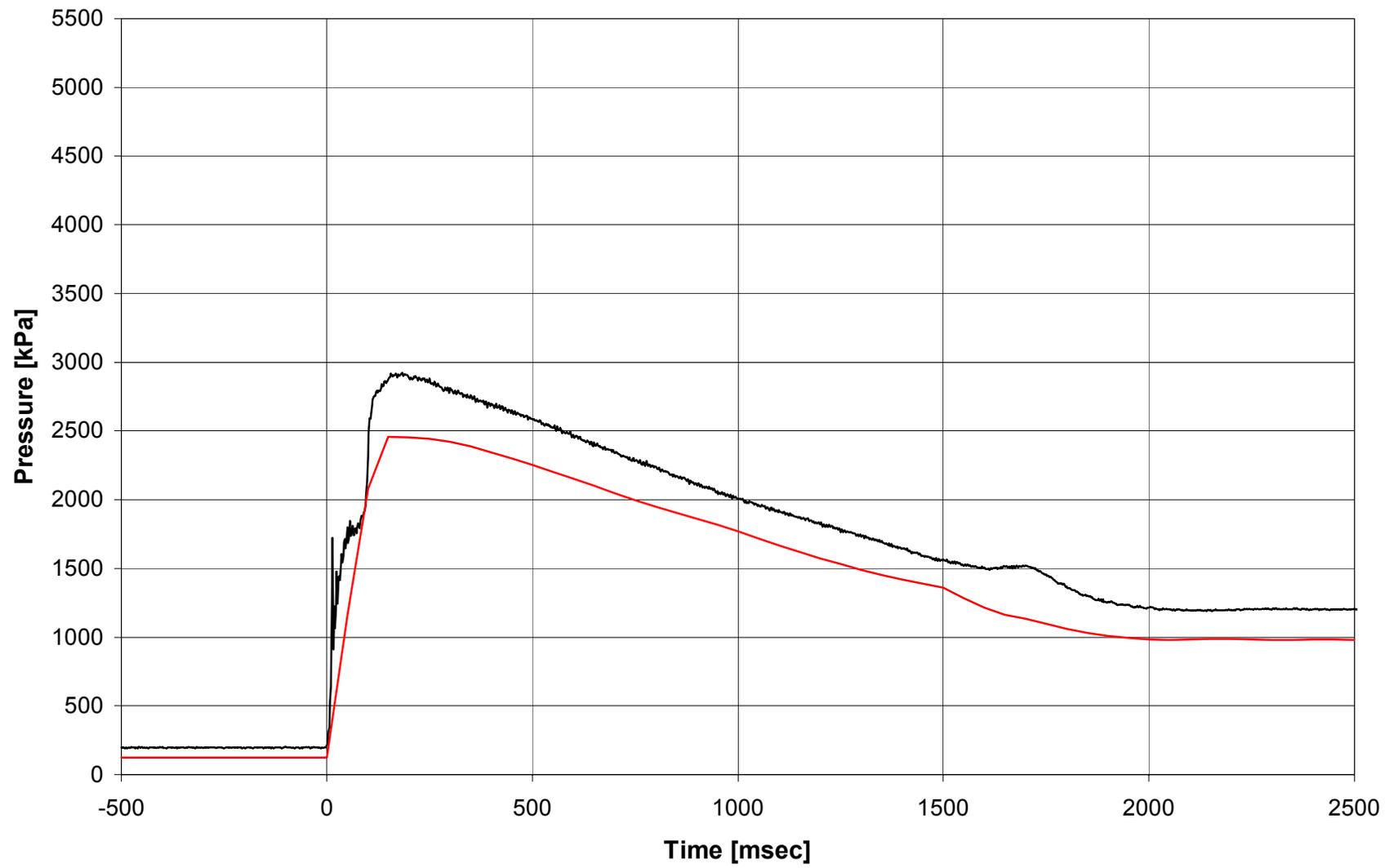
Graph 8: Gas Temperature in Collection Vessel

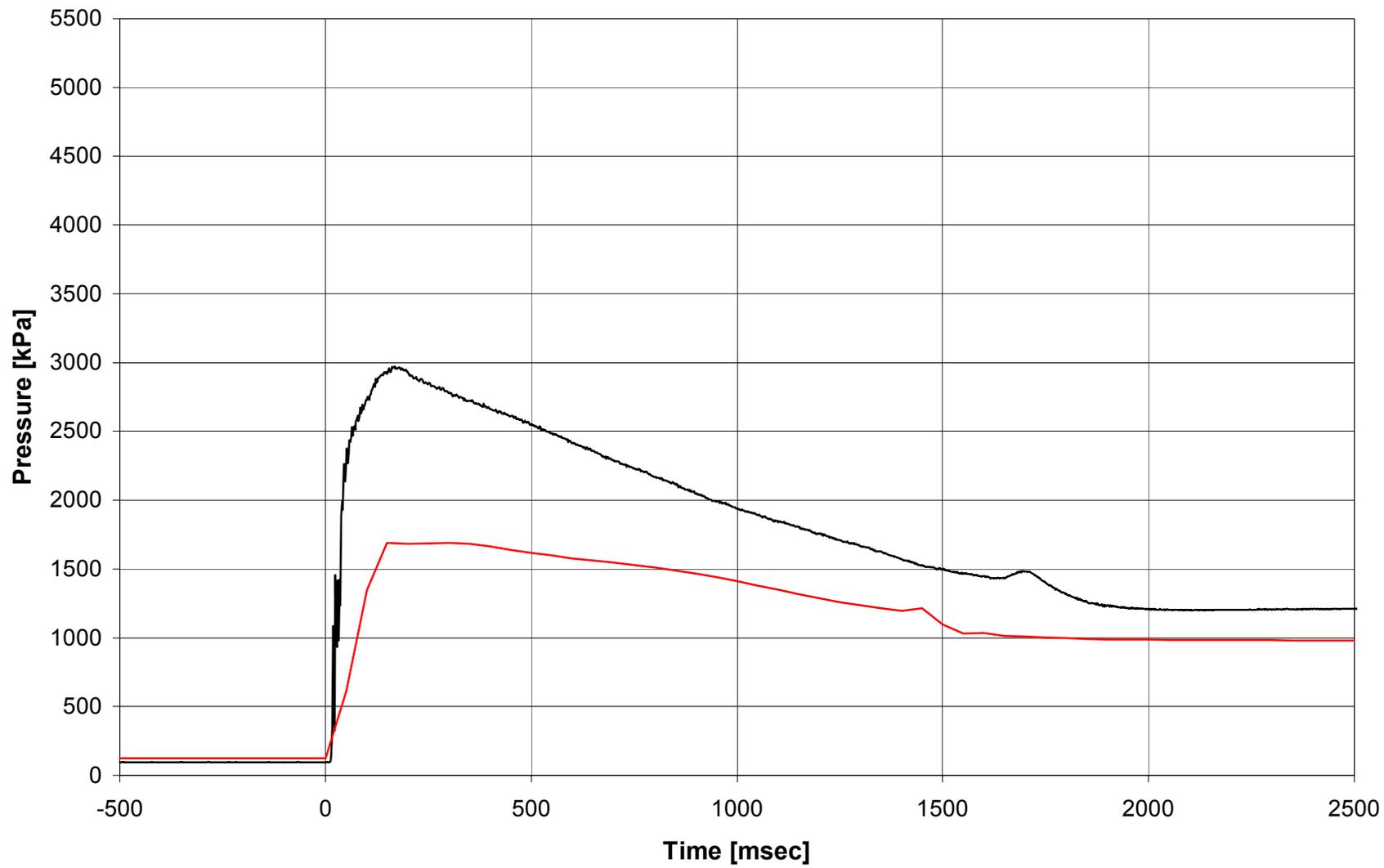


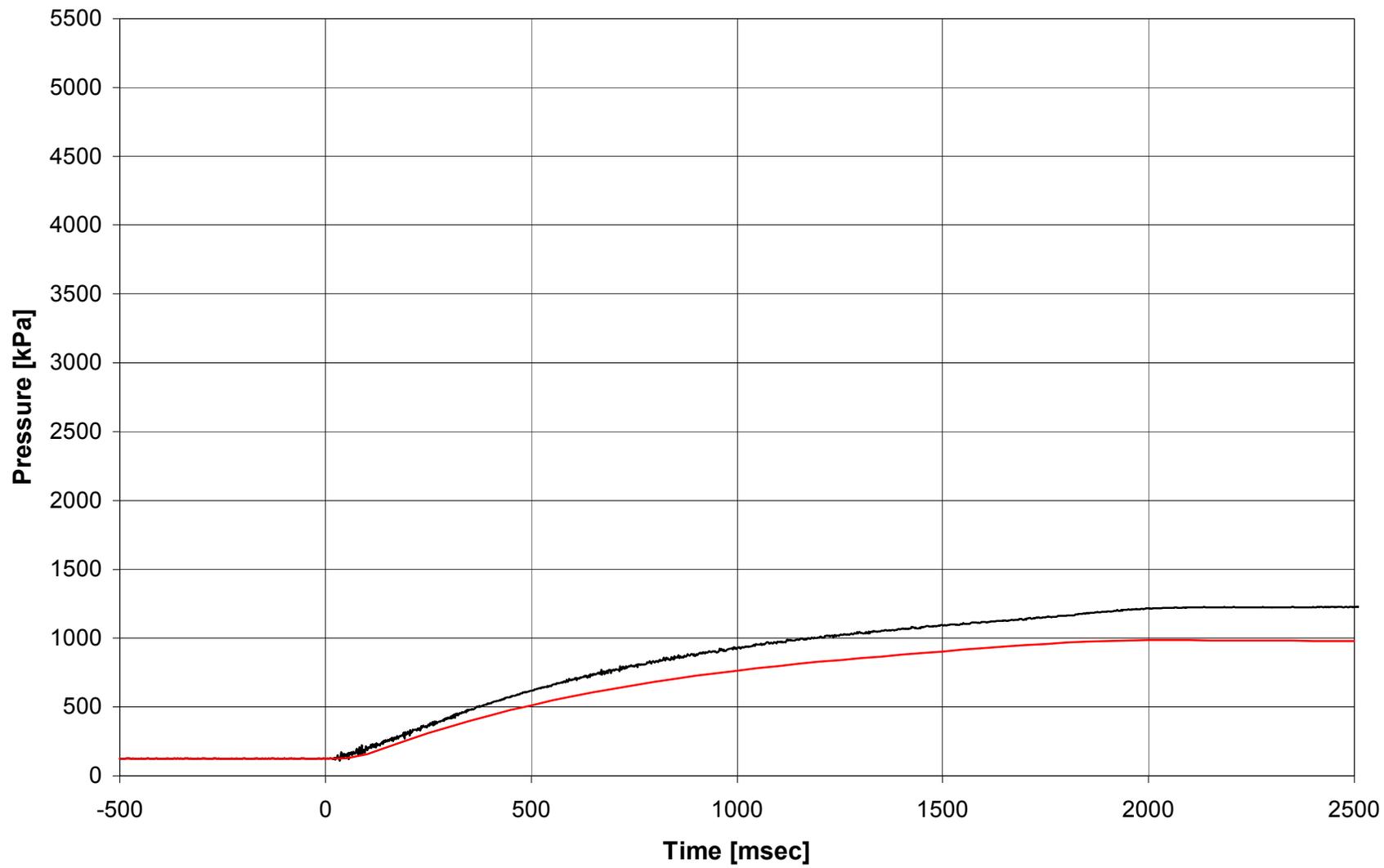


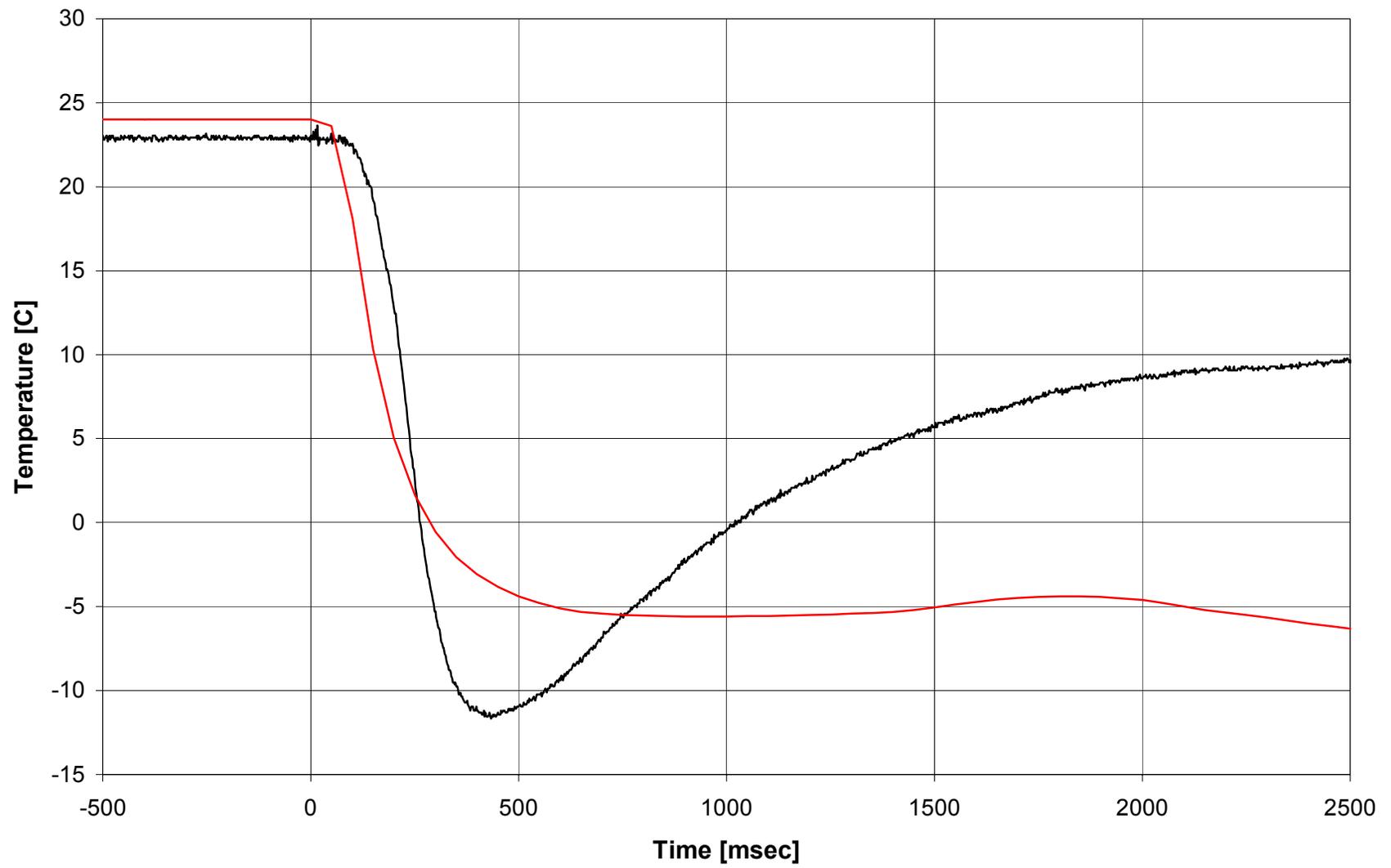












Run #18 with Code Prediction

Test Fluid: Water

System Piping Configuration: Straight Pipe

Source Vessel Initial Conditions: Fill Volume: 3585 milliliters
 Fluid Mass: 3.585 kg
 Pressure (Psvo): 2875 kPa

Initial Collection Vessel & Piping Pressure (Pcvo): 120 kPa

Initial System Temperature: 28° Celsius

Completion Date: 7/1/99

Legend

Black Line = Experimental Results

Red Line = Code Predicted Results

Graph 1: Cumulative Mass

Graph 2: Source Vessel Pressure

Graph 3: Pipe Position #1 Pressure

Graph 4: Gas Temperature in Source Vessel

