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INSC International Nuclear Safety Center

RELAP5/MOD3.2 Analysis of INSC Standard Problem INSCSP-R7: Void Fraction Distribution over RBMK Fuel Channel Height for Experiments Performed in the ENTEK BM Test Facility

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ABSTRACT

The RELAP5/MOD3.2 computer program has been used to analyze a series of tests investigating void fraction distribution over height in RBMK fuel channels performed in Facility BM at the ENTEK. This is RBMK Standard Problem 7 in Joint Project 6, which is the investigation of Computer Code Validation for Transient Analysis of RBMK and VVER Reactors, between the United States and Russian Minatom International Nuclear Safety Centers. The experiment facility and data, RELAP5 nodalization, and results are shown for all tests. Agreement between RELAP5 and the experiment data is reasonable.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols

C_p	specific heat capacity at constant pressure [J/kg·K]
G	mass flow rate [kg/s]
N	heat generation rate [W]
P	pressure [Pa]
T	temperature [K]
X_{re}	relative enthalpy [-]
Z	height above bottom of HRZ [m]
λ	thermal conductivity [W/m·K]
ρ	density [kg/m^3]
ν	void (vapor volume) fraction [-]

Subscripts

cal	calculated
err	error (calculated minus experiment)
ex	exit of HRZ
exp	experiment
in	inlet of HRZ

Superscripts

avg	average
max	maximum
min	minimum

Abbreviations

ANL	Argonne National Laboratory
ENTEK	see RDIPE
HRZ	Heat Release Zone
INEEL	Idaho National Engineering and Environmental Laboratory
INSP	International Nuclear Safety Program
NIKIET	see RDIPE
RBMK	transliteration of Russian characters for graphite-moderated boiling-water-cooled channel-type reactor
RDIPE	Research and Development Institute of Power Engineering (a.k.a., ENTEK, NIKIET)
RMINSC	Russian Minatom International Nuclear Safety Center
SAR	Safety Analysis Report
SP	Standard Problem
USDOE	United States Department of Energy
USINSC	United States International Nuclear Safety Center
USNRC	United States Nuclear Regulatory Commission
VVER	transliteration of Russian characters for water-moderated water-cooled reactor

1. Introduction

RBMK reactors were designed in the 1970s, before the current Russian licensing requirements were issued. Hence, the Safety Analysis Reports (SAR) for these reactors do not completely satisfy current requirements. These reactors continue to operate in Russia and Lithuania, generating a significant share of the total energy source in these countries. Since these reactors are expected to continue operating for many more years, up-to-date SARs are being established which require verification and use of best-estimate codes like RELAP5.

The RBMK design and operating conditions (e.g., channelized flow with boiling coolant) are distinctly different from other reactor types in the world; therefore, it is not possible to use worldwide experience and data to the extent that is possible for the VVER type reactors (which have many similarities to the pressurized water reactors used in many countries). There are Russian experiment data applicable to RBMK reactors, although most of these experiments were performed in the 1970s and 1980s and are not fully suitable for current-day code validation activities. RELAP5 validation for RBMK reactors is an important issue but is a more difficult task compared with validation for VVER reactors.

A joint US/Russian project has been established to address RELAP5 validation issues for both RBMK and VVER reactors. The technical work involves participation by staff from many US and Russian organizations. The work is coordinated by each country's International Nuclear Safety Center (i.e., USINSC in the US and RMINSC in Russia under Minatom). The work is funded by the United States Department of Energy (USDOE) through its International Nuclear Safety Program (INSP). Work has proceeded in parallel for both RBMK and VVER reactors; only the RBMK work is mentioned here. Phase 1 of this project (Reference 1) was the identification of the phenomena expected to be important in RBMK safety analysis, identification of experiment facilities and data relevant to these phenomena, prioritizing the phenomena on the basis of their importance to the safety analysis process, and categorizing the experiment data as to their relevance to the validation process. A set of guidelines (Reference 2) was prepared during Phase 1 describing how Standard Problems (SP) would be defined and analyzed. During Phase 1, one set of RBMK experiment data was analyzed by both Russian and US teams using RELAP5 as an example of the process to be followed in subsequent SPs: i.e., preparation of a data report by the data owner, analysis and its reporting by each team, preparation of a joint analysis report summarizing the results from all teams, and storing all of the information in such a manner that it is accessible via the internet. During Phase 2, the list of potential Standard Problems was reduced to those having a high impact on safety and for which experiment data were both available and suitable for analysis using RELAP5; the list was then prioritized (Reference 3) resulting in a set of 12 SPs for RBMK; Phase 2 also showed there are some phenomena for which there are insufficient Russian experiment data to define SPs for analysis. Phase 3 of the project is the analysis of the first six SPs for each of these two reactor designs. (Much of the preceding three paragraphs was extracted from Reference 4.)

The present report is the US analysis of INSC Standard Problem RBMK Number 7 (INSC SP-R7). This is the fourth RBMK SP to be analyzed chronologically (INSC SP-R1 was analyzed during Phase 1, and R5 and R2 were analyzed previously in Phase 3), even though its "R7" identifier would indicate the seventh problem. Identifiers (i.e., R1-R12) were assigned to the SPs during Phase 2, and the numeric part of the identifier indicates the analysis order based on the

prioritization process; since that time, data availabilities have required the problems to be analyzed in a different order than originally planned.

Sections 2 and 3 of this report describe the experiment facility and the tests, respectively, which examine the axial distribution of coolant void in an RBMK coolant channel at steady state. Section 4 provides a brief description of the RELAP5 code. Section 5 presents the results of applying RELAP5 to these experiment conditions. Conclusions from this analysis are shown in Section 6. The appendices include RELAP5 input files, results plots for all RELAP5 cases, and a set of review comments for the input file. A similar report is being prepared by the Russian analysis team. These two reports will be used to prepare a comparative analysis report covering the work of both teams.

2. Description of ENTEK Facility BM

The BM Facility at the Research and Development Institute of Power Engineering (RDIPE; a.k.a., ENTEK and NIKIET) models the forced circulation circuit of RBMK type reactors (Reference 5). The facility includes simulated fuel channels (two), steam separator, condenser, pump, and connecting piping; there are several different flow configurations. For the void distribution tests being studied, only a single fuel channel was used and the facility was at steady state. Several views of the facility relevant to the current experiments are shown in Figures 2.1 through 2.2.

Figure 2.1 provides an overall flow diagram of the single loop, showing component lengths. Coolant flow enters the simulated flow channel horizontally in the region labeled “8”, travels upward through the Heat Release Zone (HRZ; i.e., fuel rod simulators) between points “B” and “C”, and exits horizontally just below the upper flange labeled “10”.

Figure 2.2 provides a cross-section view of the HRZ, where diameters are shown in millimeters. The HRZ contains a 7-rod bundle; the stainless steel (X18H10T) rods are hollow, having an outer diameter of 13.5 mm, a 1.25 mm wall thickness, and a 7 m length. The bundle is contained within a stainless steel pressure tube (80 mm outer diameter and 5 mm wall thickness), which is lined with a set of talcum chlorate thimbles (49 mm inner diameter and 10.5 mm wall thickness). The coolant flow area is 8.84×10^{-4} m^2 and the hydraulic diameter is 7.84 mm. Copper tips (“7” in Figure 2.1) are welded to the end of the fuel pin simulators to supply current; these are connected to the supply flanges (“9” and “10” in Figure 2.1) by flexible conductors (“8” in Figure 2.1). Electrical heating is stated to be uniform over rod height and over fuel assembly radius. There are 20 honeycomb-type pin spacing grids along the length of the HRZ, starting 30 mm from the beginning of the HRZ and repeated every 350 mm; these are similar to the spacers in the RBMK-1000 and have a hydraulic loss coefficient of 0.4 based on measurements.

The test section was surrounded by an asbestos overcoat. The thickness and properties of this overcoat were not specified. The intent was to keep the exterior surface temperature below 313 K. Heat loss from the facility was measured during a series of constant-temperature experiments. The loss from the heat-release zone was 4.5 kW at 436 K, 6.9 kW at 475 K, 9 kW at 515 K, and 11.2 kW at 535 K.

The specifics of the rest of the facility are not important for the current set of experiments.

Properties of X18H10T stainless steel were given as follows: density (ρ) of 6400 kg/m^3 and specific heat capacity (C_p) of 490 J/kg·K as constant from 300 to 2000 K, and thermal conductivity (λ) values of 15.0, 17.0, 19.8, 26.6, 27.8, and 29.4 W/m·K at 300, 400, 600, 1000, 1500, and 2000 K. Properties of talcum chlorate were given as follows: density of 2790 kg/m^3, specific heat capacity of 460 J/kg·K, and thermal conductivity of 1 W/m·K.

The following measurements (and associated accuracies) were made during each test

- pressure at HRZ outlet, point "C" of Figure 2.1 (±1.5 %);
- coolant mass flow rate (±2.08 kg/s·m^2 which translates to ±0.0018 kg/s);
- coolant temperature at HRZ inlet, point "B" of Figure 2.1 (±1 K but not in Ref. 5);
- electrical power (±947 W/m^2 which translates to ±2 kW);
- coolant density (±8 kg/m^3 at 10 axial levels);
- coolant density sensor location (±2 mm); and
- void fraction (±0.03; void is calculated rather than measured).

The location of the pressure and temperature measurements (among other things) allows the RELAP5 modeling to only include the HRZ, i.e., points "B" through "C" of Figure 2.1.

Coolant density was detected based on the coolant's attenuation of neutrons from a Pu-Be source as measured external to the HRZ. There was only one source/sensor combination. Readings were obtained at 10 axial locations (i.e., 0.385, 0.948, 1.573, 2.322, 2.947, 4.010, 4.823, 5.448, 6.135, and 6.760 m from bottom of heated length) by moving the equipment during a test. For some tests, the boundary conditions shifted somewhat during the time required to obtain measurements at all ten locations; these shifts were recorded. The direct measurement is counts/s. This was converted to a mixture density (ρ_m) based on attenuation rules, and the result was reported in Reference 5. The density was converted to a void fraction (ν) using

$$\nu = (\rho_l - \rho_m)/(\rho_l - \rho_v)$$

and the value was reported in Reference 5. In this expression, ρ_l is the liquid phase coolant density at the measured (i.e., outlet) pressure and local coolant temperature calculated based on heating the coolant over the non-boiling length. The quantity ρ_v is the steam phase density at saturation for the test's pressure. Void fraction is reported as "0" if the above procedure results in a negative value. Values were also reported for relative enthalpy (X_{re}); no formal definition was provided; however, the values are generally consistent with the mixture quality computed by RELAP5.

3. Description of Tests

Data were obtained from the facility at steady state for 25 combinations of outlet pressure (i.e., 3 and 7 MPa), coolant flow rate (i.e., 0.4 to 1.8 kg/s), inlet temperature (i.e., 329 to 540 K), and heater power (i.e., 290 to 630 kW). For each of these combinations, coolant density readings were made at each of the 10 axial levels (sequentially). Since the coolant density had to be measured at each of the locations sequentially rather than simultaneously, the four global boundary conditions (i.e., pressure, flow rate, temperature, and power) were recorded during each of the ten density measurements in order to report any changes within a test sequence.

The experiment conditions are shown along with the calculation results in Table 5.2.1. The first 4 columns (counting from the left) contain the four boundary conditions: pressure, mass flow rate, power, and inlet temperature, respectively. Columns 6, 9, and 12 (labeled with subscript "exp") show the experiment results for relative enthalpy, density, and void fraction, respectively. Within a test series, there is one row of entries for each of the ten axial levels shown in column 5. (The "cal" and "err" columns are the calculated results and the difference between calculated and experiment results; these will be discussed in Section 5.2.) The 11th row of information for each test series shows the average of the boundary conditions for the series of 10 measurements. The end of Table 5.2.1 has some notes by the current author about unusual experiment data items in the table.

4. Description of RELAP5/MOD3.2

The RELAP5/MOD3.2 computer program was used for the calculations reported in this report. A detailed description of RELAP5/MOD3.2 is given in Reference 6. The following summary description is adapted from References 4 and 6.

The RELAP5 computer program was developed by staff at the Idaho National Engineering and Environmental Laboratory (INEEL) under funding from the United States Nuclear Regulatory Commission (USNRC) for the analysis of transient behavior in light water reactors. This computer program continued the development which began in 1966 with the RELAPSE code, followed by RELAP2, RELAP3, and RELAP4. The principal new feature of the RELAP5 series is the use of a two-fluid, non-equilibrium, non-homogeneous, hydrodynamic model for transient simulation of two-phase system behavior. The hydrodynamic model is a one-dimensional, transient, two-fluid model for flow of a two-phase liquid-vapor mixture which can contain noncondensable components in the vapor phase and/or a soluble component in the liquid phase. Eight field equations are solved for eight primary independent variables: pressure, two phasic (i.e., one for liquid and one for vapor) specific internal energies, vapor volume (i.e., void) fraction, two phasic velocities, noncondensable quality, and soluble component (e.g., boron) density.

The RELAP5/MOD3.2 computer program was obtained from the INEEL, which, at that time, was the RELAP5 maintenance organization for the USNRC. The program has been installed in such a way as to be accessible to a network of Sun Microsystems workstation computers running under SunOS/5.6 (a version of UNIX) in the Reactor Analysis and Engineering Division at Argonne National Laboratory. No modifications have been made to the source code.

5. Application of RELAP5/MOD3.2 to Tests in Facility BM

5.1. Nodalization and Computation Method

Although Facility BM has a closed coolant flow loop, the tests were run in a mode such that the inlet temperature and exit pressure were constant (and known) during a data measurement sequence. Therefore, the analysis with RELAP5 modeled only the heat release zone (i.e., between points "B" and "C" in Figure 2.1). The nodalization used in the RELAP5 model is shown in Figure 5.1.1.

The heat release zone is represented by pipe component 160. This RELAP component is divided into 20 volumes. The lowest volume has a length of 0.38 m, the highest volume has a length of 0.32 m, and the other volumes have a length of 0.35 m each. This axial noding choice places the 19 interior junctions at locations of 19 of the spacer grids. The 20th spacer grid is physically located 0.03 m above the lower end of the heat release zone; in the RELAP model, it is located at the bottom of the heat release zone, being represented by a hydraulic loss in junction 158. The hydraulic loss factor was 0.4 for each spacer grid. The flow area (8.84×10^{-4} m^2) and hydraulic diameter (7.84 mm) for this region were as given in the Definition report.

Each of the seven heater rods is modeled as hollow cylinder heat structure 1601, having a 13.5 mm outer diameter and a 11 mm inner diameter. The axial noding was identical to that in fluid component 160. The steel annulus was divided into two intervals. The heat source was distributed uniformly, both within a rod radially and axially and from rod to rod. The total power from all rods (N) was input from the experiment conditions using general table 001; this was converted to a per rod power in control variable 001. Heat transfer from the outer surface of the rods to the coolant in component 160 was via convection using convection type 110 (vertical bundle without crossflow). The inner surface of the rods was adiabatic.

The outer wall of the test section was modeled as a two-region cylinder. The inner cylinder has an inner diameter of 49 mm, a thickness of 10.5 mm, and is composed of talcum chlorate; it was modeled using 3 intervals of equal thickness. The outer cylinder is steel and has a thickness of 5 mm; it was modeled using 2 intervals of equal thickness. The inner surface of the cylinder exchanges heat with the fluid in component 160 via convection of type 1. Rather than model the asbestos overcoat (of unknown thickness and material properties), the outer surface was treated adiabatic and the heat loss was modeled as a negative heat source in the outermost steel interval; the heat loss at axial node n is supplied from control variable 40+n, which uses the liquid temperature in volume n of component 160 in the heat-loss table defined by general table 002 (using the 4 points given in Section 2 plus assuming zero heat loss at 293 K) to obtain the total heat loss, multiplied by the fractional height of axial node n compared to the 7-m total length.

The 0.16-m region containing the copper tips supplying current to the bottom of the heater rods was modeled as single volume component 150, having the same flow area and hydraulic diameter as the heated zone. This region was modeled in order for there to be a single junction, 158, at the bottom of component 160 in which to model the loss associated with the lowest spacer grid.

The coolant source is represented by time-dependent volume 145, for which temperature and pressure are specified. The temperature comes directly from the experiment data (T_{in}). The inlet pressure was estimated to be somewhat larger than the exit pressure for input to initial calculation runs; later calculation runs used the value calculated from volume 150 in a previous run. The calculated results were not sensitive to the initial pressure specified in volume 145.

Volumes 145 and 150 are separated by time-dependent junction 148. The mass flow rate through this junction is specified to match the mass flow rate (G) in the experiment.

Time dependent volume 165 provides a pressure boundary condition on the system with the value (P_{ex}) coming from the experiment data. This volume connects to the outlet of component 160 through single junction 163.

As shown in Figure 5.1.1, the calculation model does not align perfectly with the 10 measurement locations for density. The noding was chosen so that the junctions between volumes align with the spacer grids, rather than aligning volume centers with the void sensor positions. In order to facilitate comparison of calculated results to measured results, a set of control variables were defined in RELAP to compute values at the sensor locations by linearly interpolating from the volume average values computed by RELAP. For example, the lowest density sensor is located 0.385 m above the bottom of the heated section; this is just above the junction separating the lowest two volumes in component 160; therefore, assuming that the RELAP values are associated with the volume centers, the density at the sensor location is computed using

$$\rho_{0.385} = [\rho_{0.19} \times (0.555\text{-}0.385) + \rho_{0.555} \times (0.385\text{-}0.19)] / (0.555\text{-}0.19) ,$$

where 0.19 and 0.555 m are the elevations of the centers of volumes 1 and 2 of component 160 and $\rho_{0.19}$ and $\rho_{0.555}$ are the mixture densities printed by RELAP for these two volumes. Control variables for void fraction (cntrlvar 020 – 029) and quality (100 – 109) at the sensor locations were defined in a manner similar to those for density (110 – 119).

A preliminary RELAP calculation was performed for each of the 25 experiments in order to obtain an estimate of the inlet pressure to be used in the subsequent calculations. Next, a base RELAP calculation was performed for each of the 25 experiments which used the average pressure, mass flow rate, power, and inlet temperature for the 10 experiment runs needed to obtain the measurements at the 10 axial positions. Two additional RELAP calculations were performed for each experiment using boundary conditions which (a) minimized and (b) maximized the voiding. The minimum void calculation used the maximum pressure, maximum mass flow rate, minimum inlet temperature, and minimum power of the 10 measurements. The maximum void calculation used the minimum pressure, minimum mass flow rate, maximum inlet temperature, and maximum power of the 10 measurements.

Each RELAP case was started in steady-state mode (i.e., entering “stdy-st” on Card 100). For most of the experiments, the RELAP code would declare steady state had been achieved after 30 to 40 s of case time. A review of the results at this time typically showed that the heat structures had not achieved thermal equilibrium. Therefore, the case was then continued in transient mode (i.e., entering “transnt” on Card 100) for another 50-60 s, by which time equilibrium had been achieved. This combination of steady-state and transient cases required less computer time than running the entire case in transient mode. Sample input files are shown in Appendix A.

5.2. Results

The results for relative enthalpy, density, and void fraction computed using RELAP5/MOD3.2 are shown in columns 7, 10, and 13 (using subscript “cal”), respectively, of Table 5.2.1. Columns 8, 11, and 14 (using subscript “err”) show the difference between calculated and experiment values. The results (labeled “calc 42”) are plotted as a function of axial position in Appendix B, where Figure B.n.1 shows density and void fraction for Test n and Figure B.n.2 shows relative enthalpy (or quality) for Test n.

The standard problem definition (Reference 5) states a preference for void fraction as the primary quantity to be compared between calculation and experiment. As shown in Table 5.2.1, the calculated results for void fraction follow the same trend with axial position as the experiment results. Most (i.e., 70%) of the calculated values are within the ±0.03 experiment error margin of the experiment results. This can be classed as "reasonable" agreement in the style of the qualitative standard in the Project 6 Guideline (Reference 2).

For the void fraction values outside of the ±0.03 accuracy limit, the void fraction calculated by RELAP is more likely (i.e., in approximately 75% of these measurements) to be lower than the experiment void than higher. The percentage of cases where the void fraction is low is higher for the high pressure cases than for the low pressure cases. Otherwise, there is no identifiable trend between level of error (i.e., between calculation and experiment) and the experiment boundary conditions.

Of the 10 points in each test, the one most likely to show a discrepancy between the calculation and the experiment is the lowest elevation point having a positive void fraction. This is a direct consequence of the somewhat coarse noding (i.e., 20 axial nodes covering 7 m) in the calculation model. There was no attempt to improve this by using smaller height nodes. One probably would not be able to use smaller nodes in a calculation for a power plant having multiple channels.

The results trends and errors for density and quality are similar to those seen for void fraction. The are a couple of interesting observations. Density is somewhat harder than void fraction to match at low elevations; the calculation and the experiment are more likely to agree within ±0.03 about a void fraction of 0.0 than to agree within ±8 kg/m^3 about a density of 800 kg/m^3.

The agreement between calculated quality and experiment relative enthalpy are generally quite good (e.g., for tests 4, 10, 12, 15, 17, 19, 21, 23, 25), although there are some notable exceptions (e.g., for tests 2, 3, 7, 9, 11). The agreement between these two is more likely to occur when quality is negative. No more time will be spent on this comparison, since there is not a precise definition of relative enthalpy for the experiment and evaluation of results for relative enthalpy was not required by the standard problem definition.

5.3. Sensitivity Analysis

One approach to investigating the experiment variations on results would be to perform RELAP calculations using the specific pressure, mass flow rate, power, and inlet temperature as measured in each of the 10 measurement sequences for each test. Instead, the present work has attempted to bound the result by performing only 2 extra RELAP calculations per test: one which minimized the void and one which maximized the void. The minimum void case used the maximum pressure, the maximum mass flow rate, the minimum inlet temperature, and the minimum power of the 10 measurement sequences for each tests (e.g., these values are 3.16 MPa, 0.4481 kg/s, 479 K, and 298.0 kW for Test 02); the changes needed in the base input file for Test 02 in order to run this variation are shown in Appendix A.3; the set of results for minimum void is shown as "calc 43" in the figures in Appendix B. The maximum void case used the minimum pressure, the minimum mass flow rate, the maximum inlet temperature, and

the maximum power of the 10 measurement sequences for each tests (e.g., these values are 3.06 MPa, 0.4361 kg/s, 483 K, and 305.7 kW for Test 02); the changes needed in the base input file for Test 02 in order to run this variation are shown in Appendix A.4; the set of results for maximum void is shown as "calc 44" in the figures in Appendix B. The calculation points which form "calc 43" and "calc 44" are connected with dashed lines in the figures in order to illustrate the bounding effect, although connection of the points with such a line is probably not appropriate due to the discreteness of the data. Note that the spread in boundary conditions from minimum void to maximum void may be larger than the stated experiment error. There are only 10% of experiment void fraction points for which the some part of the range of the experiment measurement for void fraction plus or minus its experiment error range is not within these minimum and maximum void calculations.

Four potential error sources are as follows. There was concern about using the exit pressure instead of the local pressure in the formula which converted measured density to void fraction; a sample calculation for the conditions of test 03 showed that the shift from exit to inlet pressure made no significant change (i.e., <0.001) in the calculated void fraction. The coarseness of the axial mesh limits the accuracy with which void fraction can be calculated; the cell-average value from RELAP5 is being compared with a point-wise measurement from the experiment; this will be most noticeable at the lowest axial location having a positive void fraction. Radial temperature variations could allow voiding to occur in a radially limited portion of the HRZ cross section in the experiment; this was probably not detectable with the density measuring device (and ,if measured, was not reported). Variation in electrical resistivity with temperature could result in heat generation being non-uniform axially instead of the assumed (and stated) uniformity. Neither of these last three error sources were investigated calculationally.

6. Conclusions

The RELAP5/MOD3.2 computer program has been used to analyze experiments performed in ENTEK Facility BM which investigated axial coolant void distribution in an RBMK flow channel at steady state. All 25 tests were analyzed. Most (70%) of the calculated results for void fraction are within the ±0.03 accuracy margin of the experiment results. This is considered "reasonable" agreement.

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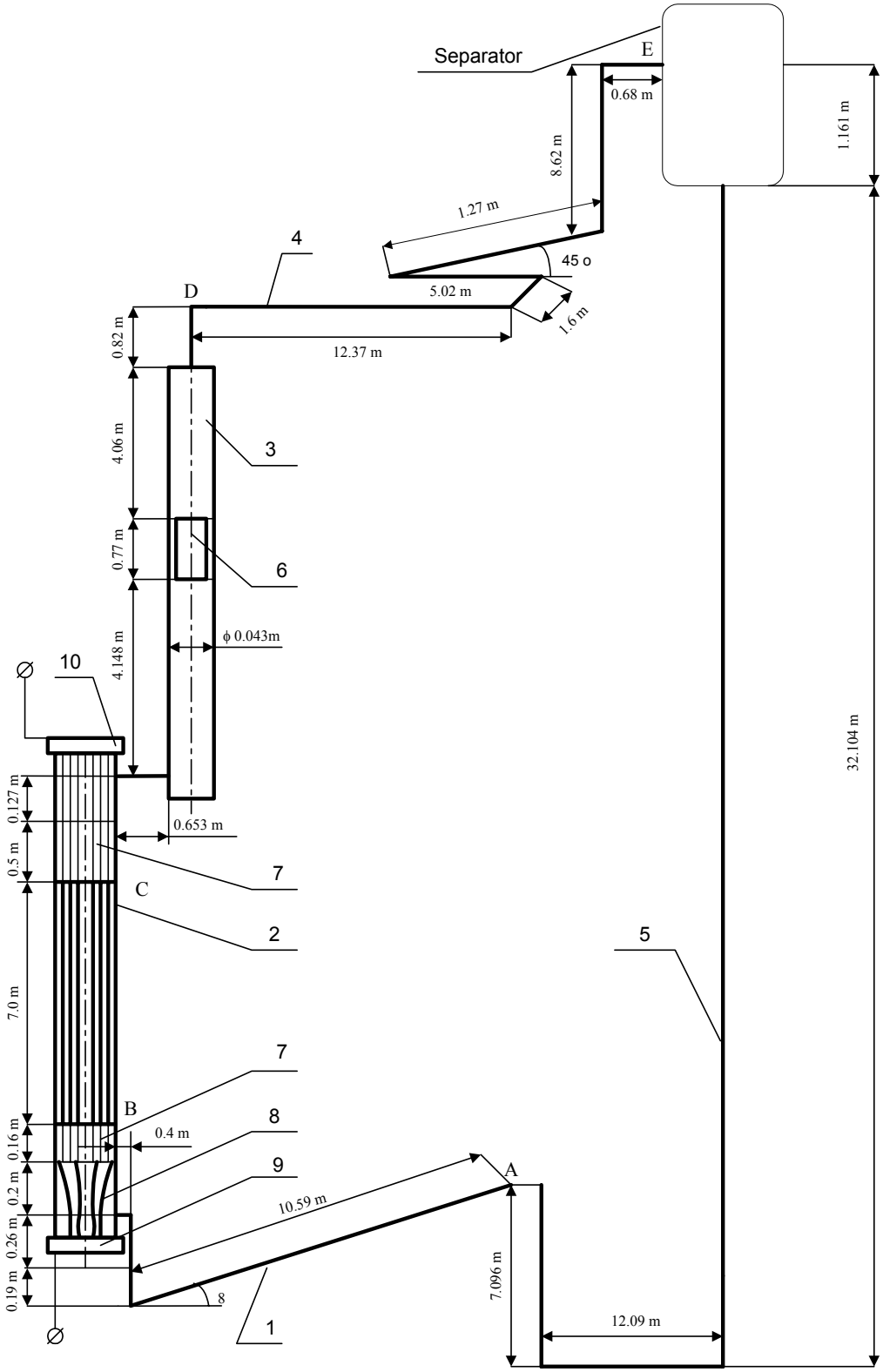

Figure 2.1 Overall Schematic of BM Facility at ENTEK

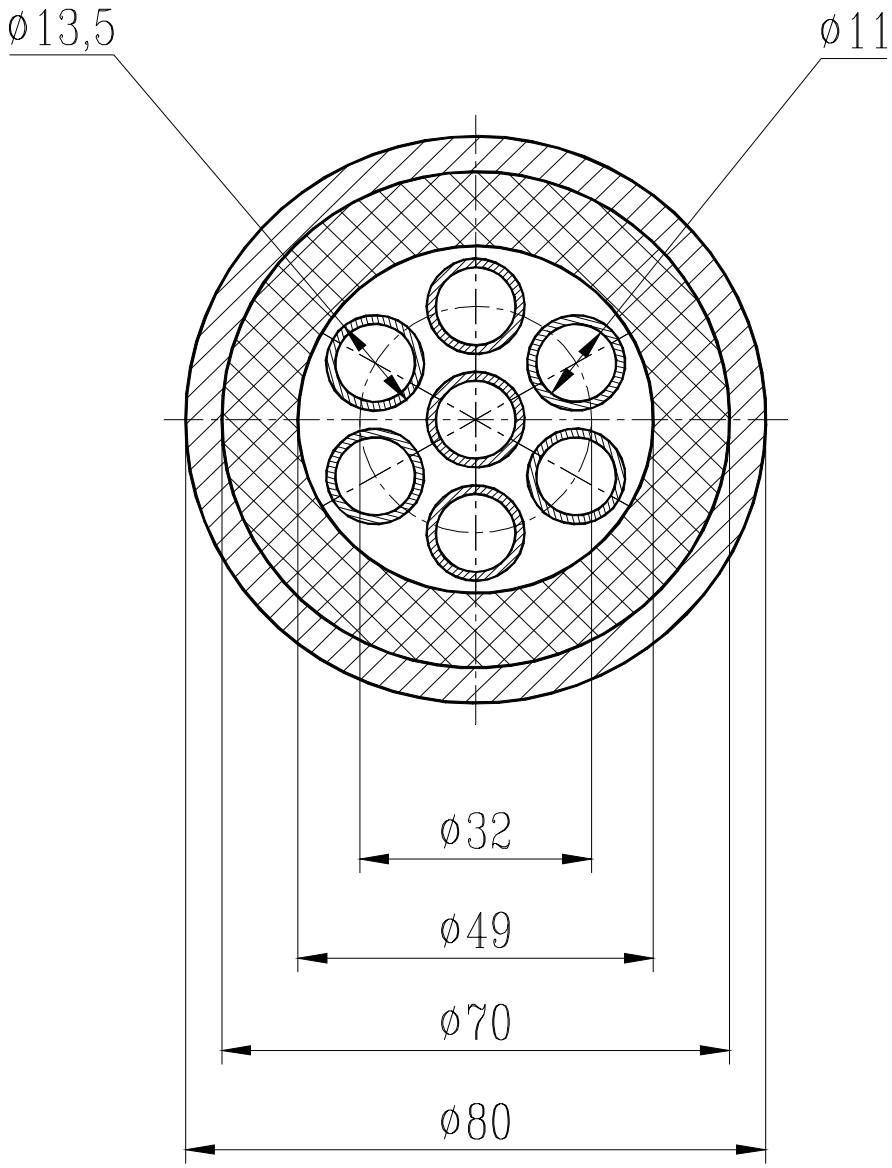

Figure 2.2 Cross Section of Heat Release Zone (ϕ is diameter in mm.)

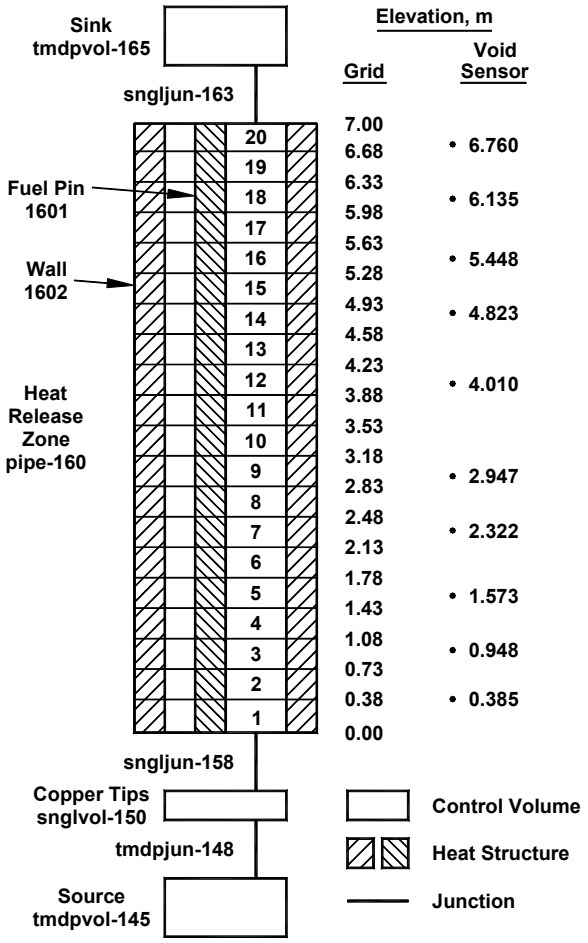

Figure 5.1.1 RELAP5 Nodalization for HRZ of Facility BM

Table 5.2.1 Experiment and Calculated Results

P_{ex} [MPa]	G [kg/s]	N [kW]	T_{in} [K]	Z [m]	$X_{re,exp}$ [-]	$X_{re,cal}$ [-]	$X_{re,err}$ [-]	ρ_{exp} [kg/m^3]	ρ_{cal} [kg/m^3]	ρ_{err} [kg/m^3]	ν_{exp} [-]	ν_{cal} [-]	ν_{err} [-]
Test 01													
3.13	0.4364	305.6	373	0.385	-0.313	-0.2748	0.0382	955.8	938.7	-17.1	0	0	0
3.16	0.4353	305.1	388	0.948	-0.249	-0.2441	0.0049	916.6	927.9	11.3	0	0	0
3.16	0.4344	305.1	388	1.573	-0.213	-0.2098	0.0032	902.3	915.0	12.7	0	0	0
3.11	0.4336	300.8	389	2.322	-0.168	-0.1687	-0.0007	912.6	898.5	-14.1	0	0	0
3.06	0.4481	302.3	389	2.947	-0.135	-0.1346	0.0004	894.6	884.0	-10.6	0	0	0
3.13	0.4403	296.7	389	4.01	-0.082	-0.0768	0.0052	870.8	857.7	-13.1	0	0	0
3.08	0.4339	296.8	388	4.823	-0.033	-0.0328	0.0002	815.2	836.1	20.9	0.027	0	-0.0270
3.11	0.4389	297.0	388	5.448	-0.003	-0.0021	0.0009	679.1	681.0	1.9	0.178	0.1752	-0.0028
3.13	0.4344	297.8	388	6.135	-0.037	0.0211	0.0581	423	410.3	-12.7	0.493	0.5088	0.0158
3.09	0.4350	296.0	388	6.76	0.072	0.0354	-0.0366	308.8	319.0	10.2	0.635	0.6225	-0.0125
3.12	0.4370	300.3	387	avg									
Test 02													
3.06	0.4369	298.3	479	0.385	-0.053	-0.0437	0.0093	846	840.4	-5.6	0.002	0	-0.0020
3.12	0.4361	298.0	481	0.948	-0.021	-0.0143	0.0067	730.8	806.9	76.1	0.122	0.0233	-0.0987
3.16	0.4356	298.7	482	1.573	0.014	0.0105	-0.0035	523.3	520.8	-2.5	0.368	0.3712	0.0032
3.08	0.4392	300.1	483	2.322	0.062	0.0326	-0.0294	343.7	331.7	-12.0	0.592	0.6062	0.0142
3.14	0.4433	298.7	482	2.947	0.088	0.042	-0.046	282.3	298.7	16.4	0.668	0.6473	-0.0207
3.12	0.4397	289.0	483	4.01	0.142	0.0722	-0.0698	229.6	212.4	-17.2	0.734	0.7550	0.0210
3.12	0.4392	298.7	482	4.823	0.193	0.0979	-0.0951	182.9	172.2	-10.7	0.792	0.8051	0.0131
3.10	0.4481	298.7	483	5.448	0.223	0.1194	-0.1036	172.9	148.9	-24.0	0.804	0.8341	0.0301
3.12	0.4439	305.7	482	6.135	0.269	0.1454	-0.1236	160.8	128.0	-32.8	0.819	0.8601	0.0411
3.11	0.4433	304.3	483	6.76	0.305	0.1796	-0.1254	136.4	105.8	-30.6	0.85	0.8878	0.0378
3.11	0.4405	299.0	482	avg									
Test 03													
3.08	0.4464	298.6	485	0.385	-0.04	-0.0304	0.0096	830.9	833.8	2.9	0	0	0
3.06	0.4439	298.6	487	0.948	-0.003	-0.0035	-0.0005	648	696.7	48.7	0.218	0.1554	-0.0626
3.09	0.4369	299.6	488	1.573	0.032	0.0182	-0.0138	466.6	439.0	-27.6	0.439	0.4726	0.0336
3.11	0.4383	299.7	487	2.322	0.07	0.0322	-0.0378	343.3	345.7	2.4	0.592	0.5888	-0.0032
3.08	0.4372	297.2	487	2.947	0.105	0.0486	-0.0564	277.1	273.6	-3.5	0.675	0.6788	0.0038

P_{ex} [MPa]	G [kg/s]	N [kW]	T_{in} [K]	Z [m]	$X_{re,exp}$ [-]	$X_{re,cal}$ [-]	$X_{re,err}$ [-]	ρ_{exp} [kg/m^3]	ρ_{cal} [kg/m^3]	ρ_{err} [kg/m^3]	ν_{exp} [-]	ν_{cal} [-]	ν_{err} [-]
3.11	0.4378	298.5	487	4.01	0.162	0.0797	-0.0823	227.1	198.5	-28.6	0.737	0.7723	0.0353
3.11	0.4356	298.5	487	4.823	0.208	0.1061	-0.1019	193.3	162.4	-30.9	0.779	0.8173	0.0383
3.13	0.4425	298.5	487	5.448	0.237	0.1283	-0.1087	174.1	140.9	-33.2	0.803	0.8441	0.0411
3.11	0.4431	298.5	488	6.135	0.277	0.1553	-0.1217	160.4	121.3	-39.1	0.82	0.8684	0.0484
3.10	0.4431	301.3	488	6.76	0.314	0.1907	-0.1233	140.1	100.3	-39.8	0.845	0.8945	0.0495
3.10	0.4405	298.9	487	avg									
Test 04													
3.11	0.8778	301.2	454	0.385	-0.13	-0.1364	-0.0064	894	884.1	-9.9	0	0	0
3.14	0.8786	297.0	454	0.948	-0.117	-0.1213	-0.0043	871.4	877.5	6.1	0.006	0	-0.0060
3.12	0.8778	297.0	454	1.573	-0.099	-0.1043	-0.0053	856	870.0	14.0	0.015	0	-0.0150
3.12	0.8764	297.0	453	2.322	-0.08	-0.0841	-0.0041	869.7	860.7	-9.0	0	0	0
3.12	0.8825	297.1	450	2.947	-0.07	-0.0672	0.0028	853.3	852.8	-0.5	0.002	0	-0.0020
3.12	0.8831	297.2	450	4.01	-0.043	-0.0386	0.0044	839.4	838.8	-0.6	0.002	0	-0.0020
3.12	0.8831	297.2	450	4.823	-0.021	-0.0167	0.0043	795.6	820.5	24.9	0.043	0.0090	-0.0340
3.06	0.8839	297.2	450	5.448	-0.001	-0.001	0	713.6	689.7	-23.9	0.136	0.1636	0.0276
3.08	0.8861	297.3	447	6.145	0.008	0.0137	0.0057	579.7	486.1	-93.6	0.299	0.4147	0.1157
3.08	0.8869	297.3	448	6.76	0.027	0.0232	-0.0038	440.3	397.7	-42.6	0.472	0.5246	0.0526
3.11	0.8816	297.6	451	avg									
Test 05													
n.a.	n.a.	n.a.	n.a.	0.385	n.a.	-0.0546	n.a	n.a.	845.4	n.a	n.a.	0	n.a
3.11	0.8764	295.4	482	0.948	-0.045	-0.0395	0.0055	839.9	837.9	-2.0	0.003	0	-0.0030
3.04	0.8767	293.2	483	1.573	-0.021	-0.0225	-0.0015	789	829.3	40.3	0.053	0	-0.0530
3.06	0.8847	297.0	484	2.322	0	-0.003	-0.003	681.9	720.1	38.2	0.174	0.1250	-0.0490
3.06	0.8903	296.7	484	2.947	0.017	0.0108	-0.0062	550.8	524.3	-26.5	0.335	0.3664	0.0314
3.09	0.7383	295.6	483	4.01	0.062	0.024	-0.038	378.5	408.0	29.5	0.549	0.5111	-0.0379
3.11	0.8836	293.1	483	4.823	0.061	0.0362	-0.0248	320.7	334.4	13.7	0.62	0.6029	-0.0171
3.13	0.8803	293.6	484	5.448	0.079	0.0463	-0.0327	282.8	291.3	8.5	0.667	0.6567	-0.0103
3.13	0.8947	295.3	485	6.135	0.098	0.058	-0.04	250.5	254.8	4.3	0.708	0.7023	-0.0057
3.13	0.8711	294.7	485	6.76	0.119	0.0746	-0.0444	208.4	210.2	1.8	0.76	0.7578	-0.0022
3.10	0.8662	295.0	484	avg									
Test 06													
3.14	1.3211	298.6	485	0.385	-0.056	-0.0557	0.0003	855	845.4	-9.6	0	0	0

P_{ex} [MPa]	G [kg/s]	N [kW]	T_{in} [K]	Z [m]	$X_{re,exp}$ [-]	$X_{re,cal}$ [-]	$X_{re,err}$ [-]	ρ_{exp} [kg/m^3]	ρ_{cal} [kg/m^3]	ρ_{err} [kg/m^3]	ν_{exp} [-]	ν_{cal} [-]	ν_{err} [-]
3.13	1.3278	298.6	486	0.948	-0.043	-0.0454	-0.0024	833.6	840.4	6.8	0.009	0	-0.0090
3.10	1.3403	298.6	486	1.573	-0.031	-0.0339	-0.0029	828	834.7	6.7	0.009	0	-0.0090
3.12	1.3478	297.7	486	2.322	-0.019	-0.02	-0.001	837.3	827.8	-9.5	0	0	0
3.07	1.3325	297.2	486	2.947	-0.005	-0.0084	-0.0034	745.6	806.9	61.3	0.097	0.0188	-0.0782
3.10	1.3292	297.7	486	4.01	0.013	0.0091	-0.0039	561.9	558.9	-3.0	0.32	0.3232	0.0032
3.10	1.0603	291.6	486	4.823	0.047	0.0197	-0.0273	450.6	431.2	-19.4	0.459	0.4823	0.0233
3.08	1.3303	294.4	486	5.448	0.039	0.0234	-0.0156	376.1	417.7	41.6	0.552	0.4993	-0.0527
3.10	1.3411	295.5	486	6.135	0.049	0.0311	-0.0179	333.6	367.5	33.9	0.604	0.562	-0.0420
3.08	1.3411	295.5	486	6.76	0.061	0.0427	-0.0183	283.6	299.7	16.1	0.667	0.6466	-0.0204
3.10	1.3071	296.5	486	avg									
Test 07													
3.01	1.7742	296.3	474	0.385	-0.081	-0.0576	0.0234	894	846.6	-47.4	0	0	0
3.06	1.7639	304.6	476	0.948	-0.07	-0.0495	0.0205	851.7	842.8	-8.9	0.006	0	-0.0060
3.06	1.7633	300.3	479	1.573	-0.054	-0.0404	0.0136	846.5	838.5	-8.0	0.003	0	-0.0030
3.06	1.7619	307.2	482	2.332	-0.035	-0.0295	0.0055	841.2	833.3	-7.9	0	0	0
3.06	1.7722	307.2	483	2.822	-0.025	-0.0204	0.0046	823.4	828.9	5.5	0.013	0	-0.0130
3.08	1.7511	306.9	490	4.01	0.008	-0.005	-0.013	634.2	793.2	159.0	0.231	0.0352	-0.1958
3.06	1.7556	306.7	494	4.823	0.031	0.0056	-0.0254	417.2	624.1	206.9	0.501	0.2431	-0.2579
3.08	1.7633	306.7	495	5.448	0.041	0.0133	-0.0277	364	501.3	137.3	0.567	0.3957	-0.1713
3.08	1.7642	303.8	495	6.135	0.05	0.0201	-0.0299	313.7	429.2	115.5	0.629	0.4857	-0.1433
3.06	1.7656	306.7	495	6.76	0.06	0.0271	-0.0329	276.6	373.3	96.7	0.676	0.5554	-0.1206
3.06	1.7635	304.6	486	avg									
Test 08													
3.08	0.4528	525.7	329	0.385	-0.399	-0.36	0.039	975.7	966.2	-9.5	0.003	0	-0.0030
3.11	0.4578	523.8	331	0.948	-0.346	-0.3079	0.0381	953.3	950.4	-2.9	0.01	0	-0.0100
3.08	0.4636	529.3	333	1.573	-0.282	-0.2494	0.0326	942.3	930.4	-11.9	0.001	0	-0.0010
3.11	0.4453	523.5	338	2.322	-0.198	-0.1795	0.0185	925.7	903.5	-22.2	0	0	0
3.08	0.4603	523.4	342	2.947	-0.137	-0.1214	0.0156	892.8	878.7	-14.1	0	0	0
3.10	0.4433	523.3	344	4.01	-0.023	-0.0238	-0.0008	664.9	785	120.1	0.206	0.0582	-0.1478
3.11	0.4433	523.3	344	4.823	0.053	0.0269	-0.0261	320.2	361.4	41.2	0.621	0.57	-0.0510
3.08	0.4428	519.7	344	5.448	0.111	0.0509	-0.0601	212	263.6	51.6	0.756	0.6914	-0.0646
3.08	0.4414	526.7	350	6.135	0.198	0.0867	-0.1113	152.4	186.4	34.0	0.83	0.7875	-0.0425
3.08	0.4414	523.1	350	6.76	0.253	0.1302	-0.1228	127.7	136.5	8.8	0.86	0.8495	-0.0105

P_{ex} [MPa]	G [kg/s]	N [kW]	T_{in} [K]	Z [m]	$X_{re,exp}$ [-]	$X_{re,cal}$ [-]	$X_{re,err}$ [-]	ρ_{exp} [kg/m^3]	ρ_{cal} [kg/m^3]	ρ_{err} [kg/m^3]	ν_{exp} [-]	ν_{cal} [-]	ν_{err} [-]
3.09	0.4492	524.2	341	avg									
Test 09													
3.08	0.4464	543.2	452	0.385	-0.105	-0.0893	0.0157	852.6	862	9.4	0.022	0	-0.0220
3.14	0.4267	524.9	455	0.948	-0.045	-0.0369	0.0081	742.1	821	78.9	0.121	0.0194	-0.1016
3.11	0.4297	522.6	457	1.573	0.022	0.0109	-0.0111	417.2	483.4	66.2	0.5	0.4186	-0.0814
3.06	0.4289	528.1	459	2.322	0.103	0.0428	-0.0602	263.4	296.2	32.8	0.692	0.6503	-0.0417
3.10	0.4308	522.6	459	2.947	0.159	0.0744	-0.0846	190.3	210.2	19.9	0.783	0.7576	-0.0254
3.08	0.4481	528.2	456	4.01	0.245	0.139	-0.106	151.2	133.9	-17.3	0.831	0.8528	0.0218
3.14	0.4461	504.6	455	4.823	0.298	0.2016	-0.0964	128.9	98.61	-30.3	0.859	0.8968	0.0378
3.13	0.4486	526.4	453	5.448	0.37	0.2612	-0.1088	105.1	77.19	-27.9	0.889	0.9234	0.0344
3.13	0.4500	522.7	454	6.135	0.429	0.3747	-0.0543	88.3	49.42	-38.9	0.91	0.958	0.0480
3.13	0.4500	522.7	454	6.76	0.488	0.4644	-0.0236	43.6	37.2	-6.4	0.965	0.9731	0.0081
3.11	0.4405	524.6	455	avg									
Test 10													
3.14	0.8833	505.6	427	0.385	-0.189	-0.186	0.003	915.6	904.4	-11.2	0	0	0
3.14	0.8850	505.6	427	1.198	-0.152	-0.1604	-0.0084	891.1	894	2.9	0.001	0	-0.0010
3.14	0.8839	505.6	427	1.573	-0.135	-0.1317	0.0033	879.8	881.7	1.9	0.006	0	-0.0060
3.15	0.8833	505.6	427	2.322	-0.101	-0.0973	0.0037	889.9	866.4	-23.5	0	0	0
3.11	0.8858	505.6	427	2.947	-0.071	-0.0688	0.0022	849.9	852.9	3.0	0.006	0	-0.0060
3.11	0.8864	505.6	427	4.01	-0.022	-0.0203	0.0017	696.9	804.2	107.3	0.165	0.0306	-0.1344
3.09	0.8856	505.7	427	4.823	0.016	0.0114	-0.0046	499.9	493.9	-6.0	0.398	0.4053	0.0073
3.10	0.8844	497.0	427	5.448	0.04	0.0247	-0.0153	384.4	402.3	17.9	0.541	0.5183	-0.0227
3.14	0.8856	505.6	427	6.135	0.074	0.0427	-0.0313	294.9	306	11.1	0.652	0.6385	-0.0135
3.12	0.8856	500.2	427	6.76	0.1	0.0654	-0.0346	224.9	230.7	5.8	0.74	0.7323	-0.0077
3.12	0.8849	504.2	427	avg									
Test 11													
3.12	0.8831	509.1	487	0.385	-0.04	-0.044	-0.004	838.4	837.6	-0.8	0.001	0	-0.0010
3.13	0.8847	510.6	484	0.948	-0.022	-0.0186	0.0034	744.4	800.8	56.4	0.106	0.03	-0.0760
3.13	0.8864	510.6	484	1.573	0.007	0.0067	-0.0003	566.2	546.7	-19.5	0.315	0.3378	0.0228
3.13	0.8850	471.5	484	2.322	0.034	0.0246	-0.0094	417.6	410.3	-7.3	0.5	0.5069	0.0069
3.14	0.8822	510.6	484	2.947	0.071	0.041	-0.03	304.5	319.4	14.9	0.64	0.6207	-0.0193
3.14	0.8806	490.8	486	4.01	0.118	0.0723	-0.0457	237.5	227.2	-10.3	0.724	0.7362	0.0122

P_{ex} [MPa]	G [kg/s]	N [kW]	T_{in} [K]	Z [m]	$X_{re,exp}$ [-]	$X_{re,cal}$ [-]	$X_{re,err}$ [-]	ρ_{exp} [kg/m^3]	ρ_{cal} [kg/m^3]	ρ_{err} [kg/m^3]	ν_{exp} [-]	ν_{cal} [-]	ν_{err} [-]
3.11	0.8864	510.6	485	4.823	0.159	0.1001	-0.0589	197.9	181.1	-16.8	0.773	0.7938	0.0208
3.13	0.8789	510.6	486	5.448	0.193	0.1249	-0.0681	174.2	151.8	-22.4	0.803	0.8306	0.0276
3.11	0.8844	510.5	488	6.135	0.229	0.1739	-0.0551	153.5	105	-48.5	0.828	0.8888	0.0608
3.11	0.8850	499.7	489	6.76	0.254	0.221	-0.033	129.6	77.3	-52.3	0.858	0.9233	0.0653
3.13	0.8837	503.5	486	avg									
Test 12													
3.14	1.3417	503.0	449	0.385	-0.142	-0.1416	0.0004	896.5	885.4	-11.1	0	0	0
3.14	1.3261	504.8	449	0.948	-0.125	-0.1243	0.0007	873.8	878	4.2	0.007	0	-0.0070
3.14	1.3242	504.8	449	1.573	-0.106	-0.105	0.001	867.7	869.5	1.8	0.004	0	-0.0040
3.10	1.3286	504.8	449	2.322	-0.081	-0.0819	-0.0009	881.3	858.9	-22.4	0	0	0
3.09	1.3294	503.0	449	2.947	-0.062	-0.0626	-0.0006	855	849.8	-5.2	0	0	0
3.10	1.3258	503.0	448	4.01	-0.032	-0.03	0.002	799.7	833.7	34.0	0.044	0	-0.0440
3.12	1.3317	504.8	448	4.823	-0.008	-0.0055	0.0025	619.3	727.3	108.0	0.254	0.1183	-0.1357
3.08	1.3347	504.9	447	5.448	0.01	0.0113	0.0013	512.8	506.3	-6.5	0.382	0.3895	0.0075
3.12	1.3306	504.8	448	6.135	0.03	0.0226	-0.0074	400.2	419.7	19.5	0.521	0.4969	-0.0241
3.11	1.3286	504.8	449	6.76	0.054	0.0371	-0.0169	300.5	325.4	24.9	0.645	0.6145	-0.0305
3.11	1.3301	504.3	449	avg									
Test 13													
3.14	1.3353	503.2	489	0.385	-0.043	-0.0496	-0.0066	836.4	839.5	3.1	0.005	0	-0.0050
3.12	1.3353	503.3	489	0.948	-0.025	-0.0326	-0.0076	814.2	830.9	16.7	0.022	0	-0.0220
3.08	1.3397	500.4	489	1.573	-0.004	-0.0133	-0.0093	657.9	800.7	142.8	0.206	0.0257	-0.1803
3.14	1.3361	500.4	487	2.322	0.011	0.0075	-0.0035	548.4	560.9	12.5	0.337	0.3187	-0.0183
3.13	1.3306	500.5	487	2.947	0.03	0.0209	-0.0091	428.2	430.6	2.4	0.486	0.4812	-0.0048
3.13	1.3300	500.4	487	4.01	0.063	0.0385	-0.0245	309.5	337.2	27.7	0.634	0.5984	-0.0356
3.14	1.3300	500.4	487	4.823	0.087	0.0562	-0.0308	260	272	12.0	0.696	0.6801	-0.0159
3.14	1.3278	500.4	487	5.448	0.106	0.0711	-0.0349	231.9	233	1.1	0.731	0.729	-0.0020
3.12	1.3244	500.4	487	6.135	0.128	0.0915	-0.0365	215	191	-24.0	0.752	0.7816	0.0296
3.14	1.3278	500.8	487	6.76	0.146	0.1252	-0.0208	188.5	133.4	-55.1	0.785	0.8534	0.0684
3.13	1.3317	501.0	488	avg									
Test 14													
3.12	1.7711	511.0	475	0.385	-0.079	-0.0822	-0.0032	857.3	856.4	-0.9	0.002	0	-0.0020
3.12	1.7711	511.0	475	0.948	-0.066	-0.0688	-0.0028	852.3	850.3	-2.0	0.001	0	-0.0010

P_{ex} [MPa]	G [kg/s]	N [kW]	T_{in} [K]	Z [m]	$X_{re,exp}$ [-]	$X_{re,cal}$ [-]	$X_{re,err}$ [-]	ρ_{exp} [kg/m^3]	ρ_{cal} [kg/m^3]	ρ_{err} [kg/m^3]	ν_{exp} [-]	ν_{cal} [-]	ν_{err} [-]
3.14	1.7739	511.1	472	1.573	-0.06	-0.0537	0.0063	852.6	843.2	-9.4	0	0	0
3.12	1.7756	511.1	472	2.322	-0.042	-0.0357	0.0063	859.7	834.4	-25.3	0	0	0
3.11	1.7786	511.9	472	2.947	-0.027	-0.0207	0.0063	833.9	826.9	-7.0	0	0	0
3.11	1.7706	512.1	475	4.01	0.006	0.0036	-0.0024	626.2	629.6	3.4	0.24	0.2349	-0.0051
3.08	1.7617	512.1	476	4.823	0.029	0.0195	-0.0095	430.6	436.1	5.5	0.484	0.4755	-0.0085
3.10	1.7542	511.9	481	5.448	0.054	0.0262	-0.0278	342.4	405.5	63.1	0.594	0.514	-0.0800
3.10	1.7494	511.9	479	6.135	0.067	0.0379	-0.0291	300.4	339.1	38.7	0.646	0.5971	-0.0489
3.10	1.7375	508.9	482	6.76	0.09	0.0544	-0.0356	242.6	261.3	18.7	0.718	0.6943	-0.0237
3.11	1.7644	511.3	476	avg									
Test 15													
7.16	0.4406	307.7	433	0.385	-0.375	-0.3476	0.0274	911.9	892.8	-19.1	0	0	0
7.14	0.4433	304.2	434	0.948	-0.333	-0.3116	0.0214	882.2	879.7	-2.5	0.008	0	-0.0080
7.20	0.4428	304.1	435	1.573	-0.292	-0.2713	0.0207	864.1	864.4	0.3	0.01	0	-0.0100
7.15	0.4464	304.1	438	2.322	-0.235	-0.2231	0.0119	856.5	845.1	-11.4	0	0	0
7.18	0.4414	302.6	439	2.947	-0.189	-0.1831	0.0059	827.8	828	0.2	0.003	0	-0.0030
7.15	0.4456	302.5	441	4.01	-0.117	-0.1153	0.0017	801.6	797.1	-4.5	0	0	0
7.14	0.4458	302.5	441	4.823	-0.062	-0.0639	-0.0019	756.7	771.6	14.9	0.017	0	-0.0170
7.08	0.4422	303.9	442	5.448	-0.012	-0.0245	-0.0125	686.7	750.9	64.2	0.087	0	-0.0870
7.17	0.4419	303.9	442	6.135	0.03	0.0113	-0.0187	560.3	574.5	14.2	0.253	0.2355	-0.0175
7.17	0.4467	303.9	442	6.76	0.066	0.0382	-0.0278	430.8	438.5	7.7	0.438	0.4273	-0.0107
7.15	0.4437	303.9	439	avg									
Test 16													
7.19	0.4425	303.9	512	0.385	-0.14	-0.1281	0.0119	815	802.6	-12.4	0	0	0
7.14	0.4369	304.0	510	0.948	-0.105	-0.0927	0.0123	782.3	785.6	3.3	0.003	0	-0.0030
7.14	0.4464	304.0	510	1.573	-0.066	-0.053	0.013	756	765.6	9.6	0.017	0	-0.0170
7.14	0.4428	304.0	510	2.322	-0.016	-0.0074	0.0086	632.1	673.7	41.6	0.164	0.0999	-0.0641
7.14	0.4447	303.9	512	2.947	0.031	0.0218	-0.0092	483.3	516.4	33.1	0.363	0.3167	-0.0463
7.14	0.4400	303.9	512	4.01	0.103	0.0589	-0.0441	333.4	368	34.6	0.577	0.5276	-0.0494
7.13	0.4447	303.9	512	4.823	0.153	0.0903	-0.0627	268.6	294	25.4	0.67	0.6333	-0.0367
7.14	0.4417	303.9	512	5.448	0.197	0.1166	-0.0804	231.3	251.6	20.3	0.723	0.694	-0.0290
7.15	0.4400	303.9	513	6.135	0.245	0.1468	-0.0982	188.9	216.3	27.4	0.783	0.7444	-0.0386
7.15	0.4422	303.9	513	6.76	0.258	0.184	-0.074	179.9	183	3.1	0.796	0.792	-0.0040
7.15	0.4422	303.9	512	avg									

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Test 17													
7.21	0.8956	308.0	496	0.385	-0.202	-0.1976	0.0044	848.5	833.3	-15.2	0	0	0
7.22	0.8794	303.1	498	0.948	-0.178	-0.1795	-0.0015	821.3	825.5	4.2	0.004	0	-0.0040
7.24	0.8797	302.4	501	1.573	-0.149	-0.1593	-0.0103	806.2	816.6	10.4	0.006	0	-0.0060
7.09	0.8722	303.3	494	2.322	-0.138	-0.1351	0.0029	815.6	805.6	-10.0	0	0	0
7.11	0.8825	301.6	494	2.947	-0.12	-0.115	0.005	793.6	796.2	2.6	0.009	0	-0.0090
7.18	0.8853	302.1	496	4.01	-0.084	-0.0809	0.0031	780	779.7	-0.3	0.002	0	-0.0020
7.20	0.8781	301.4	497	4.823	-0.052	-0.0549	-0.0029	752.1	766.6	14.5	0.017	0	-0.0170
7.17	0.8814	302.0	497	5.448	-0.031	-0.035	-0.004	730.2	756.1	25.9	0.033	0	-0.0330
7.16	0.8822	301.6	494	6.135	-0.018	-0.0127	0.0053	692.1	725.1	33.0	0.079	0.0278	-0.0512
7.16	0.8850	302.2	493	6.76	-0.001	0.0054	0.0064	604.9	625.7	20.8	0.194	0.1623	-0.0317
7.17	0.8821	302.8	496	avg									
Task 18													
7.14	0.8836	303.3	527	0.385	-0.101	-0.1052	-0.0042	792	791.4	-0.6	0	0	0
7.16	0.8817	303.3	526	0.948	-0.086	-0.0873	-0.0013	781.1	782.8	1.7	0.003	0	-0.0030
7.15	0.8769	303.4	525	1.573	-0.068	-0.0674	0.0006	774.6	772.8	-1.8	0	0	0
7.14	0.8817	303.4	526	2.322	-0.042	-0.0435	-0.0015	753.9	760.5	6.6	0.009	0	-0.0090
7.11	0.8781	303.4	524	2.947	-0.025	-0.0237	0.0013	688.7	749.9	61.2	0.089	0	-0.0890
7.15	0.8786	295.8	525	4.01	0.009	0.0083	-0.0007	546.4	606.6	60.2	0.275	0.1888	-0.0862
7.16	0.8850	300.5	524	4.823	0.032	0.0297	-0.0023	453.9	479.3	25.4	0.405	0.3686	-0.0364
7.11	0.8819	297.8	523	5.448	0.05	0.0453	-0.0047	398.6	408.6	10.0	0.485	0.4696	-0.0154
7.14	0.8847	306.4	523	6.135	0.076	0.0535	-0.0225	350.3	388.5	38.2	0.553	0.4984	-0.0546
7.14	0.8833	306.4	523	6.76	0.097	0.0712	-0.0258	308.8	335	26.2	0.612	0.5748	-0.0372
7.14	0.8816	302.4	525	avg									
Test 19													
7.16	1.7592	305.8	537	0.385	-0.075	-0.0712	0.0038	729.1	772.9	43.8	0	0	0
7.16	1.7575	308.6	538	0.948	-0.062	-0.0618	0.0002	765.4	768.3	2.9	0.007	0	-0.0070
7.16	1.7686	308.6	538	1.573	-0.052	-0.0513	0.0007	769.4	763.1	-6.3	0	0	0
7.16	1.7681	308.6	538	2.322	-0.039	-0.0387	0.0003	722.6	756.6	34.0	0.05	0	-0.0500
7.16	1.7689	308.6	538	2.947	-0.29	-0.0282	0.2618	741.4	751.2	9.8	0.017	0	-0.0170
7.16	1.7633	308.5	540	4.01	-0.004	-0.0103	-0.0063	654.5	741.8	87.3	0.124	0	-0.1240
7.16	1.7633	308.5	540	4.823	0.009	0.0033	-0.0057	573.7	665.2	91.5	0.235	0.1035	-0.1315

P_{ex} [MPa]	G [kg/s]	N [kW]	T_{in} [K]	Z [m]	$X_{re,exp}$ [-]	$X_{re,cal}$ [-]	$X_{re,err}$ [-]	ρ_{exp} [kg/m^3]	ρ_{cal} [kg/m^3]	ρ_{err} [kg/m^3]	ν_{exp} [-]	ν_{cal} [-]	ν_{err} [-]
7.16	1.7675	308.5	540	5.448	0.02	0.0123	-0.0077	520.2	597.9	77.7	0.31	0.1987	-0.1113
7.16	1.7667	308.5	540	6.135	0.031	0.0222	-0.0088	461.3	528.4	67.1	0.395	0.298	-0.0970
7.16	1.7664	308.5	540	6.76	0.042	0.032	-0.01	412.2	470.2	58.0	0.465	0.3814	-0.0836
7.16	1.7649	308.3	539	avg									
Test 20													
7.16	0.4339	524.0	461	0.385	-0.275	-0.2598	0.0152	877	859.4	-17.6	0	0	0
7.16	0.4444	524.0	461	0.948	-0.211	-0.1976	0.0134	841.5	833.7	-7.8	0	0	0
7.16	0.4472	524.0	461	1.573	-0.141	-0.1279	0.0131	807.4	802.5	-4.9	0	0	0
7.16	0.4433	524.0	461	2.322	-0.057	-0.045	0.012	710	756.6	46.6	0.077	0.0669	-0.0101
7.16	0.4414	524.0	459	2.947	0.011	0.0134	0.0024	503	534.4	31.4	0.34	0.2946	-0.0454
7.16	0.4519	524.1	458	4.01	0.118	0.0838	-0.0342	296	307.8	11.8	0.631	0.6136	-0.0174
7.16	0.4428	524.1	458	4.823	0.219	0.1452	-0.0738	218.6	218.9	0.3	0.841	0.7406	-0.1004
7.16	0.4414	524.0	459	5.448	0.295	0.1969	-0.0981	178	176.2	-1.8	0.799	0.8017	0.0027
7.16	0.4433	524.0	459	6.135	0.37	0.2603	-0.1097	145	142.3	-2.7	0.846	0.8501	0.0041
7.16	0.4403	524.0	459	6.76	0.446	0.3349	-0.1111	119.7	114.4	-5.3	0.882	0.89	0.0080
7.16	0.4430	524.0	460	avg									
Test 21													
7.17	0.8808	516.7	461	0.385	-0.296	-0.2902	0.0058	867.3	870.9	3.6	0.008	0	-0.0080
7.19	0.8803	516.7	461	0.948	-0.266	-0.2592	0.0068	860.4	858.9	-1.5	0.002	0	-0.0020
7.19	0.8794	504.4	461	1.573	-0.233	-0.2245	0.0085	847	844.9	-2.1	0	0	0
7.17	0.8856	522.2	461	2.322	-0.187	-0.1829	0.0041	839.4	827.3	-12.1	0	0	0
7.14	0.8869	516.3	461	2.947	-0.152	-0.1483	0.0037	816	811.8	-4.2	0	0	0
7.17	0.8828	514.9	461	4.01	-0.094	-0.0897	0.0043	789.7	784.1	-5.6	0	0	0
7.17	0.8814	516.7	461	4.823	-0.048	-0.0451	0.0029	728.5	761.3	32.8	0.046	0	-0.0460
7.18	0.8814	513.0	461	5.448	-0.015	-0.0108	0.0042	645.8	680.6	34.8	0.144	0.0921	-0.0519
7.17	0.8808	513.0	461	6.135	0.024	0.0218	-0.0022	537.3	508.5	-28.8	0.286	0.3284	0.0424
7.16	0.8819	513.1	461	6.76	0.059	0.0478	-0.0112	417	400.1	-16.9	0.458	0.4818	0.0238
7.17	0.8821	514.7	461	avg									
Test 22													
7.37	0.8817	519.5	514	0.385	-0.143	-0.1352	0.0078	805.7	802.3	-3.4	0.001	0	-0.0010
7.29	0.8800	517.4	514	0.948	-0.108	-0.1044	0.0036	777.5	787.7	10.2	0.018	0	-0.0180
7.29	0.8822	517.7	514	1.533	-0.073	-0.0698	0.0032	761.3	770.6	9.3	0.015	0	-0.0150

P_{ex} [MPa]	G [kg/s]	N [kW]	T_{in} [K]	Z [m]	$X_{re,exp}$ [-]	$X_{re,cal}$ [-]	$X_{re,err}$ [-]	ρ_{exp} [kg/m^3]	ρ_{cal} [kg/m^3]	ρ_{err} [kg/m^3]	ν_{exp} [-]	ν_{cal} [-]	ν_{err} [-]
7.29	0.8825	510.4	514	2.352	-0.032	-0.0286	0.0034	691.8	745.9	54.1	0.085	0.0046	-0.0804
7.29	0.8842	509.0	513	2.947	-0.001	0.004	0.005	586.4	604.3	17.9	0.22	0.1915	-0.0285
7.34	0.8858	513.9	511	4.01	0.051	0.0495	-0.0015	424.1	400.2	-23.9	0.446	0.4797	0.0337
7.29	0.8842	508.8	511	4.823	0.096	0.0748	-0.0212	331.5	336.5	5.0	0.579	0.5713	-0.0077
7.34	0.8864	511.3	511	5.448	0.13	0.0999	-0.0301	279.4	286.9	7.5	0.654	0.6427	-0.0113
7.34	0.8831	513.6	516	6.135	0.187	0.129	-0.058	224.6	245.4	20.8	0.733	0.7025	-0.0305
7.34	0.8747	511.9	523	6.76	0.247	0.167	-0.08	184.4	202.3	17.9	0.79	0.7646	-0.0254
7.32	0.8825	513.4	514	avg									
Test 23													
7.14	1.3225	515.6	485	0.385	-0.231	-0.2293	0.0017	838.7	846.4	7.7	0.012	0	-0.0120
7.17	1.3217	515.8	485	0.948	-0.211	-0.2085	0.0025	830.2	837.8	7.6	0.012	0	-0.0120
7.14	1.3231	515.8	485	1.573	-0.186	-0.1851	0.0009	825.2	827.9	2.7	0.006	0	-0.0060
7.16	1.3250	515.8	485	2.322	-0.159	-0.1572	0.0018	825.6	815.6	-10.0	0	0	0
7.11	1.3267	515.8	485	2.947	-0.134	-0.1339	0.0001	809.1	805.1	-4.0	0	0	0
7.10	1.3231	515.8	485	4.01	-0.094	-0.0944	-0.0004	796.1	786.4	-9.7	0	0	0
7.17	1.3244	515.8	485	4.823	-0.067	-0.0644	0.0026	742.4	771.5	29.1	0.041	0	-0.0410
7.14	1.3250	515.8	485	5.448	-0.042	-0.0413	0.0007	752	759.5	7.5	0.011	0	-0.0110
7.22	1.3253	515.9	485	6.135	-0.018	-0.0155	0.0025	705.3	729.9	24.6	0.059	0.0233	-0.0357
7.22	1.3267	515.9	485	6.76	-0.005	0.0059	0.0109	600.7	614.7	14.0	0.198	0.1786	-0.0194
7.16	1.3243	515.8	485	avg									
Test 24													
7.16	1.8050	518.4	527	0.385	-0.104	-0.1023	0.0017	775.3	788	12.7	0.021	0	-0.0210
7.16	1.7669	519.2	527	0.948	-0.088	-0.0866	0.0014	777.5	780.4	2.9	0.008	0	-0.0080
7.16	1.7639	518.8	527	1.573	-0.07	-0.0689	0.0011	772.2	771.7	-0.5	0.004	0	-0.0040
7.19	1.7606	518.7	528	2.322	-0.047	-0.0477	-0.0007	762.8	761	-1.8	0.002	0	-0.0020
7.16	1.7578	517.9	531	2.947	-0.02	-0.0301	-0.0101	702.4	751.8	49.4	0.066	0	-0.0660
7.16	1.7886	519.9	526	4.01	-0.006	-0.0002	0.0058	547	666.9	119.9	0.278	0.1027	-0.1753
7.16	1.7642	521.5	533	4.823	0.042	0.0198	-0.0222	432.9	539.8	106.9	0.435	0.2814	-0.1536
7.21	1.7908	517.4	533	5.448	0.054	0.0349	-0.0191	398.3	458.6	60.3	0.484	0.3973	-0.0867
7.20	1.7831	519.7	522	6.135	0.039	0.0501	0.0111	409.4	398.7	-10.7	0.468	0.4834	0.0154
7.16	1.7683	524.5	524	6.76	0.066	0.0665	0.0005	363.7	346.3	-17.4	0.534	0.5585	0.0245
7.17	1.7749	519.6	528	avg									

P_{ex} [MPa]	G [kg/s]	N [kW]	T_{in} [K]	Z [m]	$X_{re,exp}$ [-]	$X_{re,cal}$ [-]	$X_{re,err}$ [-]	ρ_{exp} [kg/m^3]	ρ_{cal} [kg/m^3]	ρ_{err} [kg/m^3]	ν_{exp} [-]	ν_{cal} [-]	ν_{err} [-]
Test 25													
7.16	0.8872	632.0	456	0.385	-0.307	-0.3034	0.0036	879.1	876	-3.1	0	0	0
7.16	0.8883	632.0	454	0.948	-0.274	-0.2654	0.0086	862.3	861.4	-0.9	0.004	0	-0.0040
7.16	0.8828	632.0	454	1.573	-0.231	-0.2228	0.0082	845.6	844.3	-1.3	0.003	0	-0.0030
7.16	0.8853	632.1	453	2.322	-0.183	-0.1719	0.0111	834.4	822.5	-11.9	0	0	0
7.16	0.8847	632.1	453	2.947	-0.14	-0.1296	0.0104	810.6	803.2	-7.4	0	0	0
7.16	0.8833	632.1	453	4.01	-0.067	-0.0578	0.0092	722.8	768	45.2	0.065	0	-0.0650
7.16	0.8842	632.1	453	4.823	-0.011	-0.0042	0.0068	607.7	635.2	27.5	0.197	0.1548	-0.0422
7.16	0.8836	632.1	453	5.448	0.031	0.0317	0.0007	505.2	456.6	-48.6	0.332	0.4021	0.0701
7.19	0.8836	632.0	463	6.145	0.078	0.0582	-0.0198	379.4	374.8	-4.6	0.511	0.5178	0.0068
7.16	0.8861	632.1	452	6.76	0.117	0.0937	-0.0233	282.6	289.5	6.9	0.65	0.6398	-0.0102
7.16	0.8849	632.1	454	avg									

1. Note that the Z value is nonstandard in several instances: Test 04: 9th elevation from bottom; Test 07: 4th and 5th elevations; Test 10: 2nd elevation,; Test 22: 3rd elevation; and Test 25: 4th and 9th elevations.
2. Test 01: $X_{re,exp}$ is more logical result if value is +0.037 instead of –0.037 for Z=6.135.
3. Test 05: G is quite low at Z=4.01.
4. Test 06: G is quite low at Z=4.823.
5. Test 19: $X_{re,exp}$ is more logical result if value is -0.029 instead of –0.290 for Z=2.947.

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Appendix A

RELAP Input Files

The following sections show representative RELAP input files used to begin a calculation in steady-state mode (A.1), continue the calculation in transient mode (A.2), and what changes in the steady-state input file are needed to minimize the void (A.3), to maximize the void (A.4), and to run a totally different case (A.5). The "what changes" files are the result of the UNIX command `diff file1 file2`, which shows the lines in file1 must be changed to obtain file2.

A.1 Begin Calculation for Test 02 in Steady-State Mode

```
=INSC-SP-R7: ETEK BM Test Facility: Axial Void Fraction: X02
* ------------------------------------------------------------
*  RELAP5/MOD3.2 Input for
*  INSC-SP-R7: ENTEK BM Test Facility: Axial Void Fraction
*  All tests: steady-state, uniform Q, other?
*  Test X02:
*    P = 3.11 MPa (3.06-3.16), G = 0.4405 kg/s (0.4361-0.4481),
*    T-in = 482. K (479.-483.), N = 0.2990 MW (0.2890-0.3057).
*    P-in = 3.192 MPa based on prior run.
*  Flow Losses:
*    K-grid = 0.4 (per spacer), spacer#1 moved to inlet,
*    Bundle Friction (b=1 in tlpvbfe),
*    Wall Roughness = 5.0e-5 m (guess),
*    VolOpt: Wall friction has been turned on (f=0 in tlpvbfe).
*  JunOpt: Choking is off (c=1 in efvcahs).
*  CHF params input for rods.
*  Input properties for steel and talcum chlorate.
*  Noding is based on grid spacer locations; alternate: use
*  void detector locations (and fewer nodes - combine spacers).
*  Relative to deck 05:
*    Area=1 in in/out tmdpvol instead of 8.84e-4;
*    Pin ht xfer coef #110 not #1;
*    Omit CHF at wall;
*    Use control variables to interpolate results @ measure locs.
*  Relative to deck 35:
*    Add Dh=7.84e-3 for comp 158 and 163.
*  Pat Garner (PLGarner@anl.gov, 630-252-4872)  June 2001
* ------------------------------------------------------------
*
* ------------------------------------------------------------
*  Miscellaneous
* ------------------------------------------------------------
*
*100  new  transnt
*  Try steady-state mode, although this is generally discouraged.
100  new  stdy-st
102  si  si
120  160010000  0.19  h2o  bm
*100  restart  transnt
*103  4252 * restart#
*  Need card 200 only if switching stdy-st to transnt or vice versa.
*200  42.52 * case_time
*
201 50.  1.0e-6  0.01  00003  100  1000  1000
*201  10.  1.0e-6  0.01  00003  100  1000  1000
*++ May want to change '00003' to '00015'.
*
* ------------------------------------------------------------
*  Minor Edit Requests
* ------------------------------------------------------------
*
320  cntrlvar  020
321  cntrlvar  021
322  cntrlvar  022
323  cntrlvar  023
324  cntrlvar  024
325  cntrlvar  025
326  cntrlvar  026
327  cntrlvar  027
328  cntrlvar  028
329  cntrlvar  029
330  cntrlvar  100
331  cntrlvar  101
332  cntrlvar  102
333  cntrlvar  103
334  cntrlvar  104
335  cntrlvar  105
336  cntrlvar  106
337  cntrlvar  107
338  cntrlvar  108
339  cntrlvar  109
340  cntrlvar  110
341  cntrlvar  111
342  cntrlvar  112
343  cntrlvar  113
344  cntrlvar  114
345  cntrlvar  115
346  cntrlvar  116
347  cntrlvar  117
348  cntrlvar  118
349  cntrlvar  119
*++ Add more minor edit requests.
*++ Add "4xx" or "206xxxxx" trip input.
*
* ------------------------------------------------------------
*  Hydrodynamic Components
* ------------------------------------------------------------
*
*  145:  Source of Flow (not a real component)
*  Use because not modeling the complete flow loop.
1450000  nltsorc  tmdpvol
* x101:  Area  Len  Vol  Azimth  Incline  ElevCh  Rough  D-h  Opt
1450101  1.  0.  1.0e6  0.  0.  0.  5.0e-5 7.84e-3 0000010
1450200  003  * BC-type
1450201  0.   3.192e+6  482.  * t  P  T
*
*  148:  Junction Inlet_BC to HRZ
1480000  jnltcu  tmdpjun
1480101  145010002  150010001  0.  * in out A
1480200  1  * bc: opt
1480201  0. 0.4405  0.  0.0  * bc: t m-l m-v 0.
*
*  150:  Copper Tips Below Heat Release Zone (Item 5 in Tbl 1.2)
1500000  cu_in  snglvol
*        area     len   vol azi incl elev  rough   d_h      v_flags
1500101  8.84e-4  0.16  0.  0.  90.  0.16  5.0e-5  7.84e-3  0000100
1500200  001  482.  0.  * vol ic
*
*  158:  Junction Inlet_BC to HRZ
1580000  jcuinhrz  sngljun
1580101  150010002  160010001  0.  0.4 0.4  0001000  * in out A K-f K-r opt
*  Above card contains loss associated with lowest bundle grid spacer;
* this location is 0.03 m too low.
1580110  7.84e-3  1.  1.  1.  * Dh  3*unused
1580201  1  0.4405  0.  0.0  * ic: opt m-l m-v 0.
*
*  160:  Heat Release Zone (Item 6 in Tbl 1.2)
1600000  hrz  pipe
1600001  20  * # of volumes
1600101  8.84e-4 20  * vol flow area
1600201  8.84e-4 19  * jun flow area
1600301  0.38 1  0.35 19  0.32 20  * vol len
1600401  0.  20  * vol: compute from area and length.
1600501  0.  20  * azimuth angle: omit
1600601  90. 20  * vertical angle
1600801  5.0e-5 7.84e-3 20  * vol rough, hyd dia
1600901  0.4 0.4 19  * loss-f loss-r jun#
```

```
*  The lowest grid spacer loss is currently on preceeding sngljun.
1601001  0000100 20  * vol options
1601101  0001000 19  * jun options
1601201  001  482.  0.  0.  0.  0.  20  * vol ic
1601300  1  * jun ic type (1=flow)
1601301  0.4405  0.  0.  19  * jun ic
1601401  7.84e-3 0. 1. 1. 19  * jun: hyd_dia, CCFL: frm intrcpt slope
*
*  163:  Junction HRZ to Exit_BC
1630000  jhrzxit  sngljun
1630101  160200002  165010001  0.  0.  0.  0001000  * in out A K-f K-r opt
1630110  7.84e-3  1.  1.  1.  * Dh  3*unused
1630201  1  0.4405  0.  0.0  * ic: opt m-l m-v 0.
*
*  165:  Exit_BC (not a real component)
*  Use because not modeling the complete flow loop.
1650000  xitsink  tmdpvol
* x101:  Area  Len  Vol  Azimth  Incline  ElevCh  Rough  D-h  Opt
1650101  1.  0.  1.0e6  0.  0.  0.  5.0e-5  7.84e-3 0000010
1650200  002  * BC-type
1650201  0.   3.11e+6  0.0  * t  P  x
*++ Boundary conditions need to be checked.
*
* ------------------------------------------------------------
*  Heat Structures
* ------------------------------------------------------------
*
*  1601:  Heated Rods (heat source)
11601000  20  3  2  1  0.0055  0  * #ax #rad geom ss pos-left ic reflood
11601100  0  1  * mesh-loc mesh-format
11601101  2  0.00675  * #-of_intervals  pos-right
11601201  1  2  * matl# int#
11601301  1. 2  * q-rel(r) int#
11601400  0  * ic-opt
11601401  482. 3  * ic: T rnode#
*  BC cards: cell (or Tsink) incr type A-fact A-fact #ax
*  Area factor is 7 time fluid mesh height to account for 7 rods.
11601501          0      0     0  1  2.66   1  * left: adiabatic
11601502          0      0     0  1  2.45  19  * left: adiabatic
11601503          0      0     0  1  2.24  20  * left: adiabatic
11601601  160010000  10000  110  1  2.66   1  * right:  hook-to-fluid
11601602  160020000  10000  110  1  2.45  19  * right:  hook-to-fluid
11601603  160200000  10000  110  1  2.24  20  * right:  hook-to-fluid
11601701  10002  0.0543  0.  0.   1  * source-ctl#1 ax-fac mod. mod. int#
11601702  10002  0.05    0.  0.  19  * source-ctl#1 ax-fac mod. mod. int#
11601703  10002  0.0457  0.  0.  20  * source-ctl#1 ax-fac mod. mod. int#
11601900   1  * 12-word format for Cards 9xx.
*         d_ht    ht_len_F/R  sp_len_F/R  los_F/R bf nc p/d  foul int#
11601901  0.01191 0.190 6.810 0.19  0.19  0.4 0.4 1. 7. 1.185 1.  1
11601902  0.01191 0.555 6.445 0.175 0.175 0.4 0.4 1. 7. 1.185 1.  2
11601903  0.01191 0.905 6.095 0.175 0.175 0.4 0.4 1. 7. 1.185 1.  3
11601904  0.01191 1.255 5.745 0.175 0.175 0.4 0.4 1. 7. 1.185 1.  4
11601905  0.01191 1.605 5.395 0.175 0.175 0.4 0.4 1. 7. 1.185 1.  5
11601906  0.01191 1.955 5.045 0.175 0.175 0.4 0.4 1. 7. 1.185 1.  6
11601907  0.01191 2.305 4.695 0.175 0.175 0.4 0.4 1. 7. 1.185 1.  7
11601908  0.01191 2.655 4.345 0.175 0.175 0.4 0.4 1. 7. 1.185 1.  8
11601909  0.01191 3.005 3.995 0.175 0.175 0.4 0.4 1. 7. 1.185 1.  9
11601910  0.01191 3.355 3.645 0.175 0.175 0.4 0.4 1. 7. 1.185 1. 10
11601911  0.01191 3.705 3.295 0.175 0.175 0.4 0.4 1. 7. 1.185 1. 11
11601912  0.01191 4.055 2.945 0.175 0.175 0.4 0.4 1. 7. 1.185 1. 12
11601913  0.01191 4.405 2.595 0.175 0.175 0.4 0.4 1. 7. 1.185 1. 13
11601914  0.01191 4.755 2.245 0.175 0.175 0.4 0.4 1. 7. 1.185 1. 14
11601915  0.01191 5.105 1.895 0.175 0.175 0.4 0.4 1. 7. 1.185 1. 15
11601916  0.01191 5.455 1.545 0.175 0.175 0.4 0.4 1. 7. 1.185 1. 16
11601917  0.01191 5.805 1.195 0.175 0.175 0.4 0.4 1. 7. 1.185 1. 17
11601918  0.01191 6.155 0.845 0.175 0.175 0.4 0.4 1. 7. 1.185 1. 18
11601919  0.01191 6.505 0.495 0.175 0.175 0.4 0.4 1. 7. 1.185 1. 19
11601920  0.01191 6.840 0.160 0.16  0.16  0.4 0.4 1. 7. 1.185 1. 20
*++ What should "local boiling factor" on Card3801 be instead of "1."?
*
*  1602:  Wall adjacent to Heated Rods (heat sink)
*         2-layer cylinder: talcum chlorate and steel.
11602000  20  6  2  1  0.0245  0  * #ax #rad geom ss pos-left ic reflood
11602100  0  1  * mesh-loc mesh-format
11602101  3  0.035  2  0.040  * #-of_intervals  pos-right
11602201  2  3  1  5  * matl# int#
11602301  0. 4  1. 5  * q-rel(r) int#
11602400  0  * ic-opt
11602401  482. 6  * ic: T rnode#
*  BC cards: cell (or Tsink) incr type A-fact A-fact #ax
*  Heat loss at right (outer) surface is simulated using negative
*  heat source in radial interval 5.
11602501  160010000  10000     1  1  0.38   1  * left: hook-to-fluid
11602502  160020000  10000     1  1  0.35  19  * left: hook-to-fluid
11602503  160200000  10000     1  1  0.32  20  * left: hook-to-fluid
11602601          0      0     0  1  0.38   1  * right: adiabatic
11602602          0      0     0  1  0.35  19  * right: adiabatic
11602603          0      0     0  1  0.32  20  * right: adiabatic
11602701  10041  0.0543  0.  0.   1  * source-ctl#41 ax-fac mod. mod. int#
11602702  10042  0.05    0.  0.   2  * source-ctl#42 ax-fac mod. mod. int#
11602703  10043  0.05    0.  0.   3  * source-ctl#43 ax-fac mod. mod. int#
11602704  10044  0.05    0.  0.   4  * source-ctl#44 ax-fac mod. mod. int#
11602705  10045  0.05    0.  0.   5  * source-ctl#45 ax-fac mod. mod. int#
11602706  10046  0.05    0.  0.   6  * source-ctl#46 ax-fac mod. mod. int#
11602707  10047  0.05    0.  0.   7  * source-ctl#47 ax-fac mod. mod. int#
11602708  10048  0.05    0.  0.   8  * source-ctl#48 ax-fac mod. mod. int#
11602709  10049  0.05    0.  0.   9  * source-ctl#49 ax-fac mod. mod. int#
11602710  10050  0.05    0.  0.  10  * source-ctl#50 ax-fac mod. mod. int#
11602711  10051  0.05    0.  0.  11  * source-ctl#51 ax-fac mod. mod. int#
11602712  10052  0.05    0.  0.  12  * source-ctl#52 ax-fac mod. mod. int#
11602713  10053  0.05    0.  0.  13  * source-ctl#53 ax-fac mod. mod. int#
11602714  10054  0.05    0.  0.  14  * source-ctl#54 ax-fac mod. mod. int#
11602715  10055  0.05    0.  0.  15  * source-ctl#55 ax-fac mod. mod. int#
11602716  10056  0.05    0.  0.  16  * source-ctl#56 ax-fac mod. mod. int#
11602717  10057  0.05    0.  0.  17  * source-ctl#57 ax-fac mod. mod. int#
11602718  10058  0.05    0.  0.  18  * source-ctl#58 ax-fac mod. mod. int#
11602719  10059  0.05    0.  0.  19  * source-ctl#59 ax-fac mod. mod. int#
11602720  10060  0.0457  0.  0.  20  * source-ctl#60 ax-fac mod. mod. int#
11602800   1  * 12-word format for Cards 9xx.
*         d_ht    ht_len_F/R  sp_len_F/R  los_F/R bf nc p/d  foul int#
11602801  0.023   10. 10.     0. 0.       0. 0.   1. 7. 1.185 1. 20
*  CHF has been ignored at the wall.
*++ What should "local boiling factor" on Card3801 be instead of "1."?
*
*
* ------------------------------------------------------------
*  Heat Structure Material Properties
* ------------------------------------------------------------
*
*   001:  X18H10T Steel: properties from p. 14 of Data Rept.
20100100  tbl/fctn  1  1  * type k:tabular rho*Cp:tabular.
*  k: tabular vs. temperature
20100101   300. 15.0
20100102   400. 17.0
20100103   600. 19.8
20100104  1000. 26.6
20100105  1500. 27.8
20100106  2000. 29.4
* rho*Cp:  6400*490  (constant)
20100151  3.136e+6
*
*   002:  Talcum Chlorate: properties from p. 10 of Data Rept.
```

```
20100200  tbl/fctn  1  1  * type k:tabular rho*Cp:tabular.
*  k: constant
20100201   1.
* rho*Cp:  2790*460  (constant)
20100251  1.283e+6
*
* ------------------------------------------------------------
*  General Tables
* ------------------------------------------------------------
*
*   001:  Power source total for 7 rods [W]
20200100  power  * Type: power vs. time.
20200101   0.   0.2990e+6
*
*   002:  Qeat Loss [W] for HRZ
20200200  reac-t  * Type: chosen so no units conversion.
*  Data are Q [W] versus avg coolant temperature [K].
*  The value of 0 at 293 K is artificial but needed.
*  (RELAP: the end-point values are used outside of table limits.)
20200201   293.   0.
20200202   436.  -4.5e+3
20200203   475.  -6.9e+3
20200204   515.  -9.0e+3
20200205   535. -11.2e+3
*
*   003:  Sink Temperature [K] vs. Time [s] for HRZ
20200300  temp  * Type
*  Input value is assumed 293 K and constant in time; used in
*  conjunction with GenTbl002 for heat loss from HtSt1602.
*  (RELAP: the end-point values are used outside of table limits.)
20200301     0. 293.
*
* ------------------------------------------------------------
*  Control Variables
* ------------------------------------------------------------
*
20500000  999  * Type#1 numbering; allows up to 999 control variables.
*
*   001:  Rod Power [W]
*         Multiple total heat table 001 by 1/7 rods.
20500100  pow_rod  function  0.142857  1.  1 0  * name type mult value init
20500101  time 0 001
*
*   002:  Total Power [W]
*         Multiple power of 1 rod by 7 rods.
20500200  pow_tot  mult  7.0  1.  1 0  * name type mult value init
20500201  cntrlvar 001
*
*   003:  Rod-to-Coolant Heat Transfer Rate [W] in HRZ
*         Node length weighting; 0.296881 is circum=7*pi*.0135.
20500300  Qhrz1r  sum  0.296881  1.  1 0
20500301  0. .38 htrnr 160100101 .35 htrnr 160100201
20500302     .35 htrnr 160100301 .35 htrnr 160100401
20500303     .35 htrnr 160100501 .35 htrnr 160100601
20500304     .35 htrnr 160100701 .35 htrnr 160100801
20500305     .35 htrnr 160100901 .35 htrnr 160101001
20500306     .35 htrnr 160101101 .35 htrnr 160101201
20500307     .35 htrnr 160101301 .35 htrnr 160101401
20500308     .35 htrnr 160101501 .35 htrnr 160101601
20500309     .35 htrnr 160101701 .35 htrnr 160101801
20500310     .35 htrnr 160101901 .32 htrnr 160102001
*
*  Interpolation: A = (A1*(Z2-Z)+A2*(Z-Z1))/(Z2-Z1).
*   020:  Void Fraction @ Z=0.385
*  Between center of cells 1 (0.190) and 2 (0.555).
20502000  vf_0.385  sum  2.7397  1.  1 0
20502001  0.  0.170 voidg 160010000  0.195 voidg 160020000
*
*   021:  Void Fraction @ Z=0.948
*  Between center of cells 3 (0.905) and 4 (1.255).
20502100  vf_0.948  sum  2.8571  1.  1 0
20502101  0.  0.307 voidg 160030000  0.043 voidg 160040000
*
*   022:  Void Fraction @ Z=1.573
*  Between center of cells 4 (1.255) and 5 (1.605).
20502200  vf_1.573  sum  2.8571  1.  1 0
20502201  0.  0.032 voidg 160040000  0.318 voidg 160050000
*
*   023:  Void Fraction @ Z=2.322
*  Between center of cells 7 (2.305) and 8 (2.655).
20502300  vf_2.322  sum  2.8571  1.  1 0
20502301  0.  0.333 voidg 160070000  0.017 voidg 160080000
*
*   024:  Void Fraction @ Z=2.947
*  Between center of cells 8 (2.655) and 9 (3.005).
20502400  vf_2.947  sum  2.8571  1.  1 0
20502401  0.  0.058 voidg 160080000  0.292 voidg 160090000
*
*   025:  Void Fraction @ Z=4.010
*  Between center of cells 11 (3.705) and 12 (4.055).
20502500  vf_4.010  sum  2.8571  1.  1 0
20502501  0.  0.045 voidg 160110000  0.305 voidg 160120000
*
*   026:  Void Fraction @ Z=4.823
*  Between center of cells 14 (4.755) and 15 (5.105).
20502600  vf_4.823  sum  2.8571  1.  1 0
20502601  0.  0.282 voidg 160140000  0.068 voidg 160150000
*
*   027:  Void Fraction @ Z=5.448
*  Between center of cells 15 (5.105) and 16 (5.455).
20502700  vf_5.448  sum  2.8571  1.  1 0
20502701  0.  0.007 voidg 160150000  0.343 voidg 160160000
*
*   028:  Void Fraction @ Z=6.135
*  Between center of cells 17 (5.805) and 18 (6.155).
20502800  vf_6.135  sum  2.8571  1.  1 0
20502801  0.  0.020 voidg 160170000  0.330 voidg 160180000
*
*   029:  Void Fraction @ Z=6.760
*  Between center of cells 19 (6.505) and 20 (6.840).
20502900  vf_6.760  sum  2.9851  1.  1 0
20502901  0.  0.080 voidg 160190000  0.255 voidg 160200000
*
*   031:  Avg Coolant Temperature [K] in HRZ
*         Node length weighting; 0.142857 is 1/(sum(DZ)).
20503100  Tavghrz  sum  0.142857  1.  1 0
20503101  0. .38 tempf 160010000 .35 tempf 160020000
20503102     .35 tempf 160030000 .35 tempf 160040000
20503103     .35 tempf 160050000 .35 tempf 160060000
20503104     .35 tempf 160070000 .35 tempf 160080000
20503105     .35 tempf 160090000 .35 tempf 160100000
20503106     .35 tempf 160110000 .35 tempf 160120000
20503107     .35 tempf 160130000 .35 tempf 160140000
20503108     .35 tempf 160150000 .35 tempf 160160000
20503109     .35 tempf 160170000 .35 tempf 160180000
20503110     .35 tempf 160190000 .32 tempf 160200000
*
*   032:  Q-loss [W] in HRZ
*         Lookup from Table-2 as function of T-avg-coolant.
*         Only used for printout.
20503200  Qloshrz  function  1.  1.  1 0
20503201  cntrlvar 031 002
```

```
*
*   041-60:  Q-loss [W] in HRZ by axial node
*         Lookup from Table-2 as function of T-local-coolant.
20504100  Qlhrz01  function  1.  1.  1 0
20504101  tempf 160010000 002
20504200  Qlhrz02  function  1.  1.  1 0
20504201  tempf 160020000 002
20504300  Qlhrz03  function  1.  1.  1 0
20504301  tempf 160030000 002
20504400  Qlhrz04  function  1.  1.  1 0
20504401  tempf 160040000 002
20504500  Qlhrz05  function  1.  1.  1 0
20504501  tempf 160050000 002
20504600  Qlhrz06  function  1.  1.  1 0
20504601  tempf 160060000 002
20504700  Qlhrz07  function  1.  1.  1 0
20504701  tempf 160070000 002
20504800  Qlhrz08  function  1.  1.  1 0
20504801  tempf 160080000 002
20504900  Qlhrz09  function  1.  1.  1 0
20504901  tempf 160090000 002
20505000  Qlhrz10  function  1.  1.  1 0
20505001  tempf 160100000 002
20505100  Qlhrz11  function  1.  1.  1 0
20505101  tempf 160110000 002
20505200  Qlhrz12  function  1.  1.  1 0
20505201  tempf 160120000 002
20505300  Qlhrz13  function  1.  1.  1 0
20505301  tempf 160130000 002
20505400  Qlhrz14  function  1.  1.  1 0
20505401  tempf 160140000 002
20505500  Qlhrz15  function  1.  1.  1 0
20505501  tempf 160150000 002
20505600  Qlhrz16  function  1.  1.  1 0
20505601  tempf 160160000 002
20505700  Qlhrz17  function  1.  1.  1 0
20505701  tempf 160170000 002
20505800  Qlhrz18  function  1.  1.  1 0
20505801  tempf 160180000 002
20505900  Qlhrz19  function  1.  1.  1 0
20505901  tempf 160190000 002
20506000  Qlhrz20  function  1.  1.  1 0
20506001  tempf 160200000 002
*
*   061:  Coolant-to-Wall Heat Transfer Rate [W] in HRZ
*         Node length weighting; 0.153938 is circum=pi*.049.
20506100  Qhrz2l  sum  0.153938  1.  1 0
20506101  0. .38 htrnr 160200100 .35 htrnr 160200200
20506102     .35 htrnr 160200300 .35 htrnr 160200400
20506103     .35 htrnr 160200500 .35 htrnr 160200600
20506104     .35 htrnr 160200700 .35 htrnr 160200800
20506105     .35 htrnr 160200900 .35 htrnr 160201000
20506106     .35 htrnr 160201100 .35 htrnr 160201200
20506107     .35 htrnr 160201300 .35 htrnr 160201400
20506108     .35 htrnr 160201500 .35 htrnr 160201600
20506109     .35 htrnr 160201700 .35 htrnr 160201800
20506110     .35 htrnr 160201900 .32 htrnr 160202000
*
*  Interpolation: A = (A1*(Z2-Z)+A2*(Z-Z1))/(Z2-Z1).
*   100:  Quality @ Z=0.385
*  Between center of cells 1 (0.190) and 2 (0.555).
20510000  x_0.385  sum  2.7397  1.  1 0
20510001  0.  0.170 quale 160010000  0.195 quale 160020000
*
*   101:  Quality @ Z=0.948
*  Between center of cells 3 (0.905) and 4 (1.255).
20510100  x_0.948  sum  2.8571  1.  1 0
20510101  0.  0.307 quale 160030000  0.043 quale 160040000
*
*   102:  Quality @ Z=1.573
*  Between center of cells 4 (1.255) and 5 (1.605).
20510200  x_1.573  sum  2.8571  1.  1 0
20510201  0.  0.032 quale 160040000  0.318 quale 160050000
*
*   103:  Quality @ Z=2.322
*  Between center of cells 7 (2.305) and 8 (2.655).
20510300  x_2.322  sum  2.8571  1.  1 0
20510301  0.  0.333 quale 160070000  0.017 quale 160080000
*
*   104:  Quality @ Z=2.947
*  Between center of cells 8 (2.655) and 9 (3.005).
20510400  x_2.947  sum  2.8571  1.  1 0
20510401  0.  0.058 quale 160080000  0.292 quale 160090000
*
*   105:  Quality @ Z=4.010
*  Between center of cells 11 (3.705) and 12 (4.055).
20510500  x_4.010  sum  2.8571  1.  1 0
20510501  0.  0.045 quale 160110000  0.305 quale 160120000
*
*   106:  Quality @ Z=4.823
*  Between center of cells 14 (4.755) and 15 (5.105).
20510600  x_4.823  sum  2.8571  1.  1 0
20510601  0.  0.282 quale 160140000  0.068 quale 160150000
*
*   107:  Quality @ Z=5.448
*  Between center of cells 15 (5.105) and 16 (5.455).
20510700  x_5.448  sum  2.8571  1.  1 0
20510701  0.  0.007 quale 160150000  0.343 quale 160160000
*
*   108:  Quality @ Z=6.135
*  Between center of cells 17 (5.805) and 18 (6.155).
20510800  x_6.135  sum  2.8571  1.  1 0
20510801  0.  0.020 quale 160170000  0.330 quale 160180000
*
*   109:  Quality @ Z=6.760
*  Between center of cells 19 (6.505) and 20 (6.840).
20510900  x_6.760  sum  2.9851  1.  1 0
20510901  0.  0.080 quale 160190000  0.255 quale 160200000
*
*  Interpolation: A = (A1*(Z2-Z)+A2*(Z-Z1))/(Z2-Z1).
*   110:  Density @ Z=0.385
*  Between center of cells 1 (0.190) and 2 (0.555).
20511000  ro_0.385  sum  2.7397  1.  1 0
20511001  0.  0.170 rho 160010000  0.195 rho 160020000
*
*   111:  Density @ Z=0.948
*  Between center of cells 3 (0.905) and 4 (1.255).
20511100  ro_0.948  sum  2.8571  1.  1 0
20511101  0.  0.307 rho 160030000  0.043 rho 160040000
*
*   112:  Density @ Z=1.573
*  Between center of cells 4 (1.255) and 5 (1.605).
20511200  ro_1.573  sum  2.8571  1.  1 0
20511201  0.  0.032 rho 160040000  0.318 rho 160050000
*
*   113:  Density @ Z=2.322
*  Between center of cells 7 (2.305) and 8 (2.655).
20511300  ro_2.322  sum  2.8571  1.  1 0
20511301  0.  0.333 rho 160070000  0.017 rho 160080000
*
*   114:  Density @ Z=2.947
*  Between center of cells 8 (2.655) and 9 (3.005).
```

```
20511400  ro_2.947  sum  2.8571  1.  1 0
20511401  0.  0.058 rho 160080000  0.292 rho 160090000
*
*   115:  Density @ Z=4.010
*  Between center of cells 11 (3.705) and 12 (4.055).
20511500  ro_4.010  sum  2.8571  1.  1 0
20511501  0.  0.045 rho 160110000  0.305 rho 160120000
*
*   116:  Density @ Z=4.823
*  Between center of cells 14 (4.755) and 15 (5.105).
20511600  ro_4.823  sum  2.8571  1.  1 0
20511601  0.  0.282 rho 160140000  0.068 rho 160150000
*
*   117:  Density @ Z=5.448
*  Between center of cells 15 (5.105) and 16 (5.455).
20511700  ro_5.448  sum  2.8571  1.  1 0
20511701  0.  0.007 rho 160150000  0.343 rho 160160000
*
*   118:  Density @ Z=6.135
*  Between center of cells 17 (5.805) and 18 (6.155).
20511800  ro_6.135  sum  2.8571  1.  1 0
20511801  0.  0.020 rho 160170000  0.330 rho 160180000
*
*   119:  Density @ Z=6.760
*  Between center of cells 19 (6.505) and 20 (6.840).
20511900  ro_6.760  sum  2.9851  1.  1 0
20511901  0.  0.080 rho 160190000  0.255 rho 160200000
*
.  * -----  End of Input File  -----
```

A.2 Continue Calculation for Test 02 in Transient Mode

```
=INSC-SP-R7: ETEK BM Test Facility: Axial Void Fraction: X02
*
*100  new  transnt
*  Try steady-state mode, although this is generally discouraged.
*100  new  stdy-st
*102  si  si
*120  160010000  0.19  h2o  bm
100  restart  transnt
103  2496 * restart#
*  Need card 200 only if switching stdy-st to transnt or vice versa.
200  24.96 * case_time
*
201 100.  1.0e-6  0.01  00003  100  1000  1000
*201  10.  1.0e-6  0.01  00003  100  1000  1000
*++ May want to change '00003' to '00015'.
*
.  * -----  End of Input File  -----
```

A.3 Changes to Beginning Input to Minimize Void in Test 02

```
9a10,11
> *    Use extreme BCs for low void: P = 3.16 (hi),
> *    G = 0.4481 (hi), T-in = 479. (lo), N = 0.2890 (lo).
95c97
< 1450201  0.   3.192e+6  482.  * t  P  T
---
> 1450201  0.   3.192e+6  479.  * t  P  T
101c103
< 1480201  0. 0.4405  0.  0.0  * bc: t m-l m-v 0.
---
> 1480201  0. 0.4481  0.  0.0  * bc: t m-l m-v 0.
107c109
< 1500200  001  482.  0.  * vol ic
---
> 1500200  001  479.  0.  * vol ic
115c117
< 1580201  1  0.4405  0.  0.0  * ic: opt m-l m-v 0.
---
> 1580201  1  0.4481  0.  0.0  * ic: opt m-l m-v 0.
131c133
< 1601201  001  482.  0.  0.  0.  0.  20  * vol ic
---
> 1601201  001  479.  0.  0.  0.  0.  20  * vol ic
133c135
< 1601301  0.4405  0.  0.  19  * jun ic
---
> 1601301  0.4481  0.  0.  19  * jun ic
140c142
< 1630201  1  0.4405  0.  0.0  * ic: opt m-l m-v 0.
---
> 1630201  1  0.4481  0.  0.0  * ic: opt m-l m-v 0.
148c150
< 1650201  0.   3.11e+6  0.0  * t  P  x
---
> 1650201  0.   3.16e+6  0.0  * t  P  x
162c164
< 11601401  482. 3  * ic: T rnode#
---
> 11601401  479. 3  * ic: T rnode#
206c208
< 11602401  482. 6  * ic: T rnode#
---
> 11602401  479. 6  * ic: T rnode#
272c274
< 20200101   0.   0.2990e+6
---
> 20200101   0.   0.2890e+6
```

A.4 Changes to Beginning Input to Maximize Void for Test 02

```
9a10,11
> *    Use extreme BCs for hi void: P = 3.06 (lo),
> *    G = 0.4361 (lo), T-in = 483. (hi), N = 0.3057 (hi).
95c97
< 1450201  0.   3.192e+6  482.  * t  P  T
---
> 1450201  0.   3.192e+6  483.  * t  P  T
101c103
< 1480201  0. 0.4405  0.  0.0  * bc: t m-l m-v 0.
---
> 1480201  0. 0.4361  0.  0.0  * bc: t m-l m-v 0.
107c109
```

```
< 1500200  001  482.  0.  * vol ic
---
> 1500200  001  483.  0.  * vol ic
115c117
< 1580201  1  0.4405  0.  0.0  * ic: opt m-l m-v 0.
---
> 1580201  1  0.4361  0.  0.0  * ic: opt m-l m-v 0.
131c133
< 1601201  001  482.  0.  0.  0.  0.  20  * vol ic
---
> 1601201  001  483.  0.  0.  0.  0.  20  * vol ic
133c135
< 1601301  0.4405  0.  0.  19  * jun ic
---
> 1601301  0.4361  0.  0.  19  * jun ic
140c142
< 1630201  1  0.4405  0.  0.0  * ic: opt m-l m-v 0.
---
> 1630201  1  0.4361  0.  0.0  * ic: opt m-l m-v 0.
148c150
< 1650201  0.   3.11e+6  0.0  * t  P  x
---
> 1650201  0.   3.06e+6  0.0  * t  P  x
162c164
< 11601401  482. 3  * ic: T rnode#
---
> 11601401  483. 3  * ic: T rnode#
206c208
< 11602401  482. 6  * ic: T rnode#
---
> 11602401  483. 6  * ic: T rnode#
272c274
< 20200101   0.   0.2990e+6
---
> 20200101   0.   0.3057e+6
```

A.5 Change to Beginning Input for Test 02 to Begin Test 03

```
1c1
< =INSC-SP-R7: ETEK BM Test Facility: Axial Void Fraction: X02
---
> =INSC-SP-R7: ETEK BM Test Facility: Axial Void Fraction: X03
6,9c6,9
< *  Test X02:
< *    P = 3.11 MPa (3.06-3.16), G = 0.4405 kg/s (0.4361-0.4481),
< *    T-in = 482. K (479.-483.), N = 0.2990 MW (0.2890-0.3057).
< *    P-in = 3.192 MPa based on prior run.
---
> *  Test X03:
> *    P = 3.10 MPa (3.06-3.13), G = 0.4405 kg/s (0.4356-0.4464),
> *    T-in = 487. K (485.-488.), N = 0.2989 MW (0.2972-0.3013).
> *    P-in = 3.185 MPa based on prior run.
95c95
< 1450201  0.   3.192e+6  482.  * t  P  T
---
> 1450201  0.   3.185e+6  487.  * t  P  T
107c107
< 1500200  001  482.  0.  * vol ic
---
> 1500200  001  487.  0.  * vol ic
131c131
< 1601201  001  482.  0.  0.  0.  0.  20  * vol ic
---
> 1601201  001  487.  0.  0.  0.  0.  20  * vol ic
148c148
< 1650201  0.   3.11e+6  0.0  * t  P  x
---
> 1650201  0.   3.10e+6  0.0  * t  P  x
162c162
< 11601401  482. 3  * ic: T rnode#
---
> 11601401  487. 3  * ic: T rnode#
206c206
< 11602401  482. 6  * ic: T rnode#
---
> 11602401  487. 6  * ic: T rnode#
272c272
< 20200101   0.   0.2990e+6
---
> 20200101   0.   0.2989e+6
```

Appendix B

Plots of Results Calculated Using RELAP

Results are shown on the following pages for the experiment and as calculated using RELAP5/MOD3.2. In the plot legends, "expt" denotes an experiment result, "calc 42" denotes results of the base calculation using average boundary conditions, "calc 43" denotes results from the calculation using boundary conditions which minimized the void, and "calc 44" denotes results from the calculation using boundary conditions which maximized the void. Additional details and discussion are in Sections 5.2 and 5.3 of the main text.

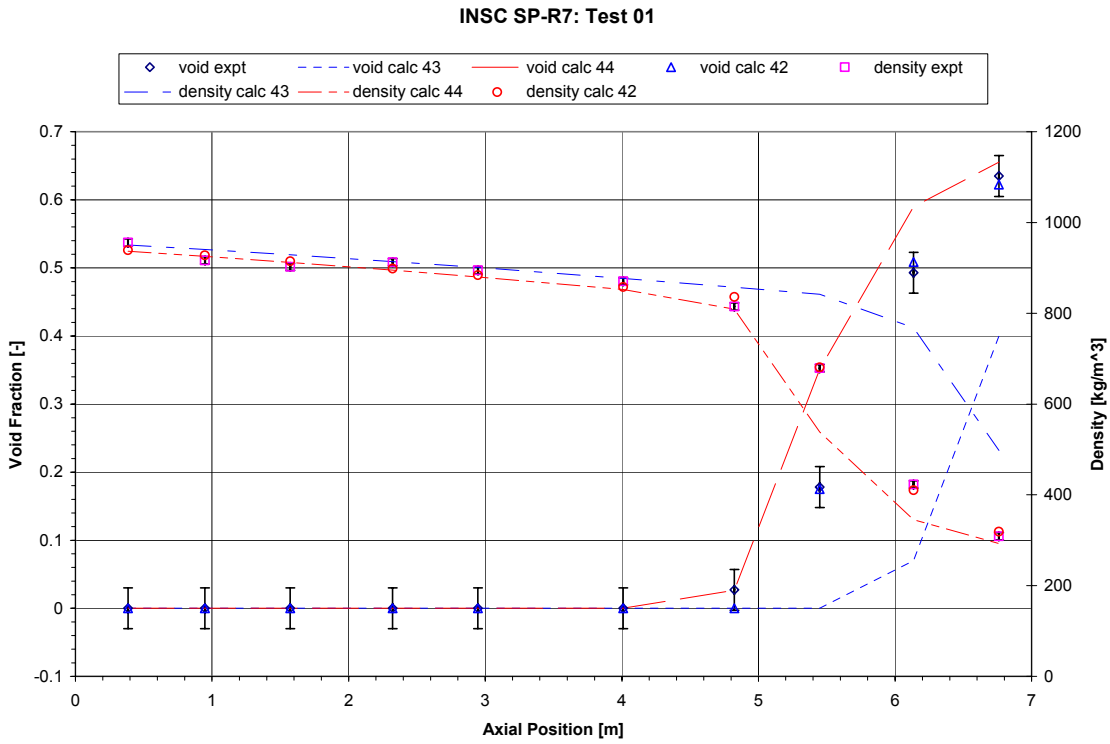

Figure B.1.1 Density and Void Fraction for Test 01

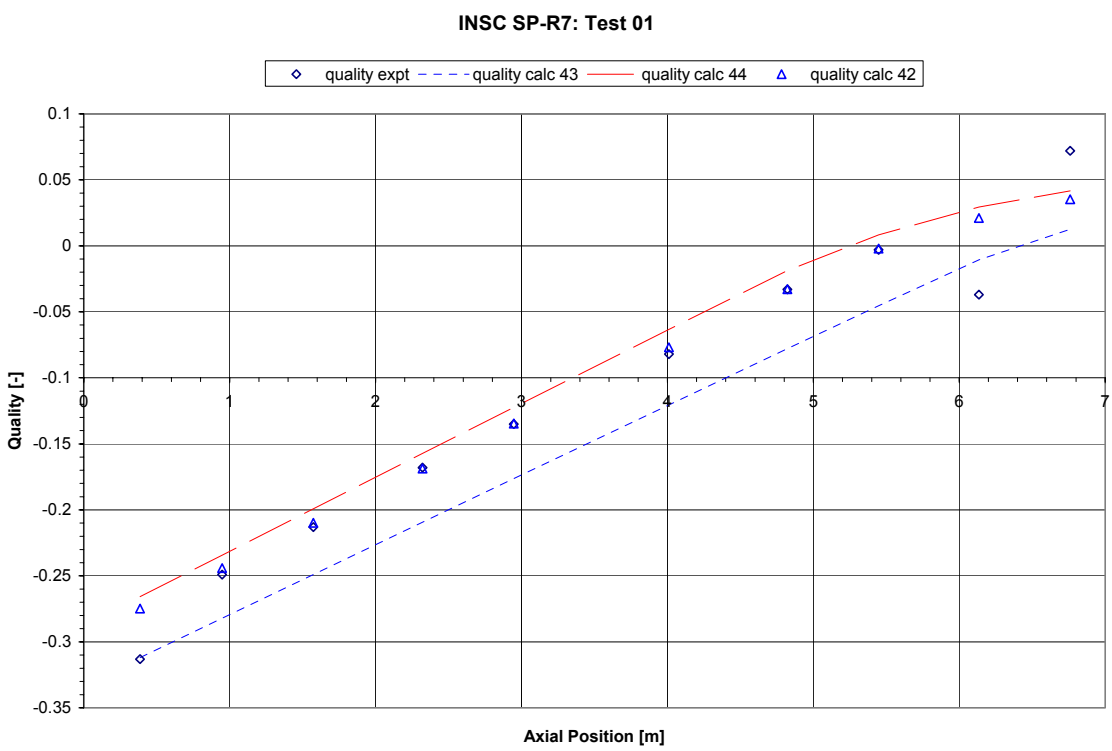

Figure B.1.2 Quality for Test 01

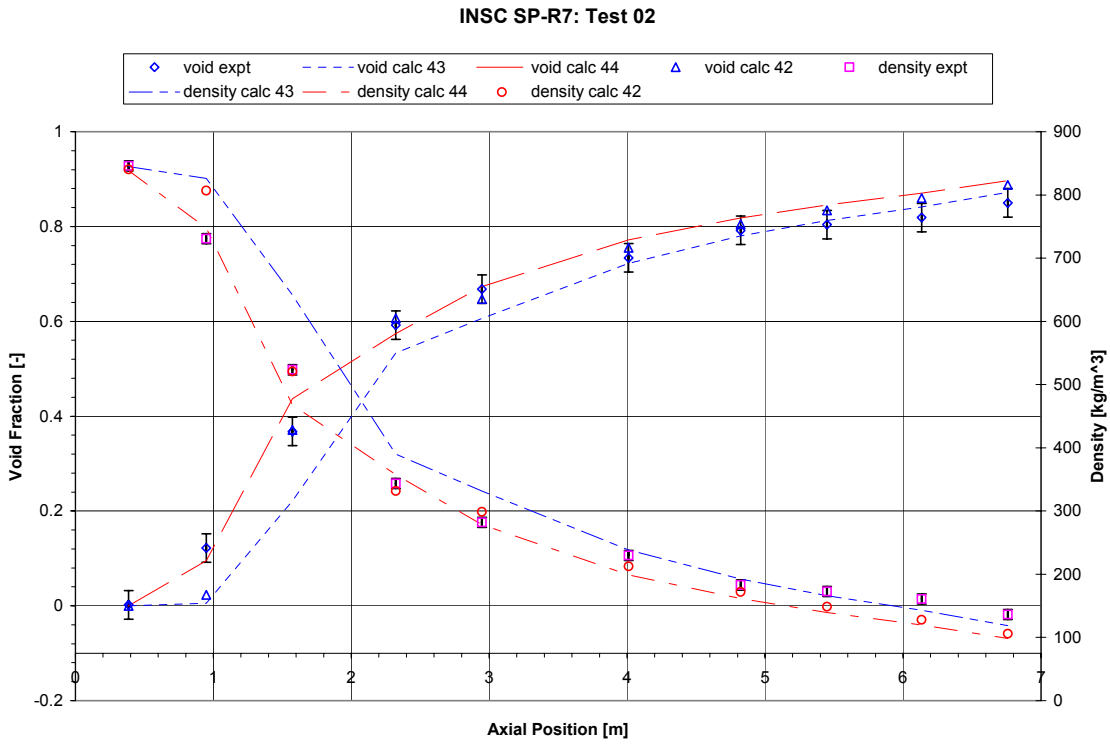

Figure B.2.1 Density and Void Fraction for Test 02

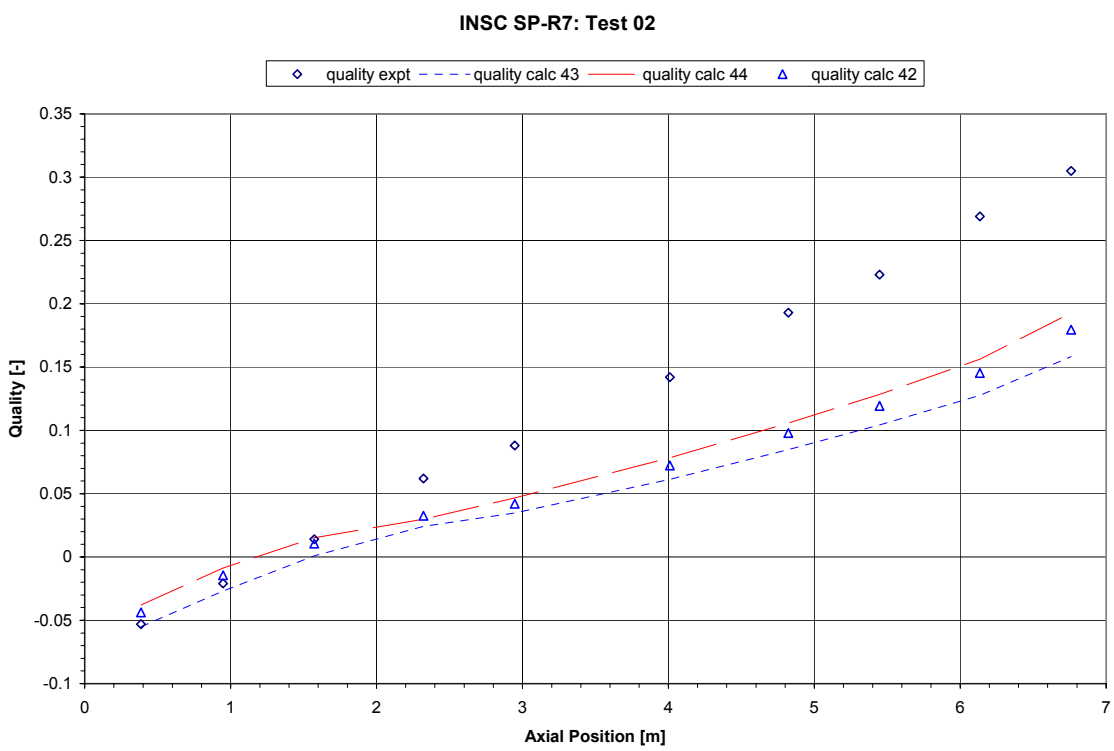

Figure B.2.2 Quality for Test 02

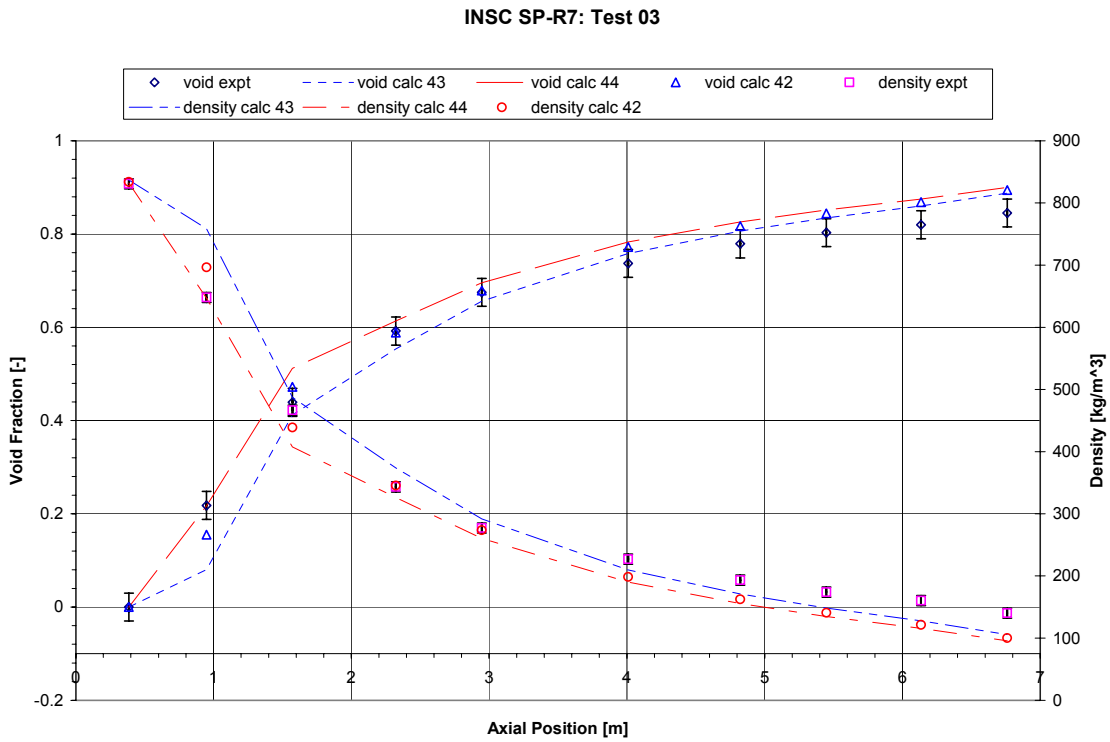

Figure B.3.1 Density and Void Fraction for Test 03

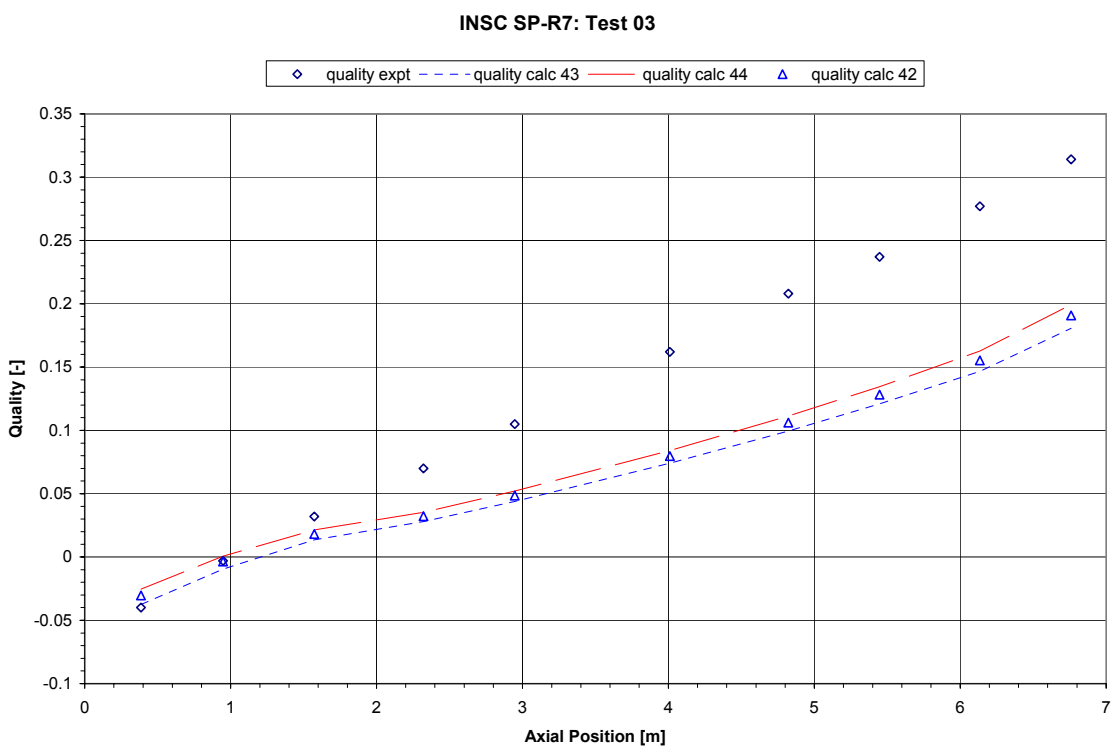

Figure B.3.2 Quality for Test 03

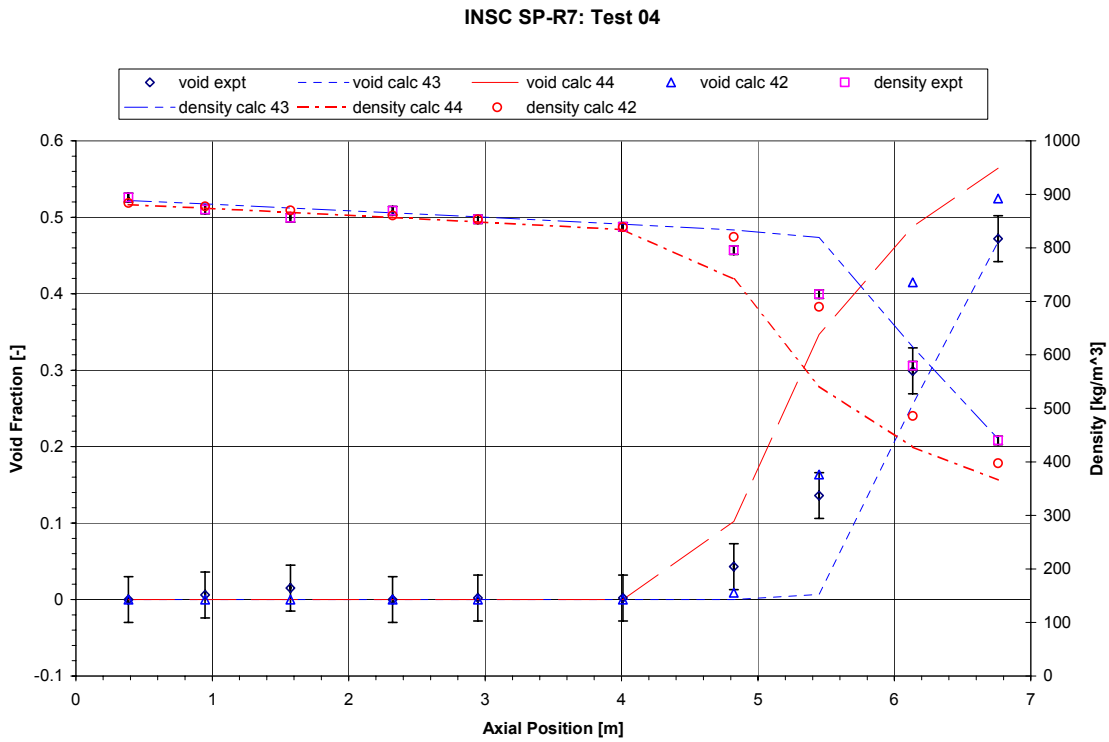

Figure B.4.1 Density and Void Fraction for Test 04

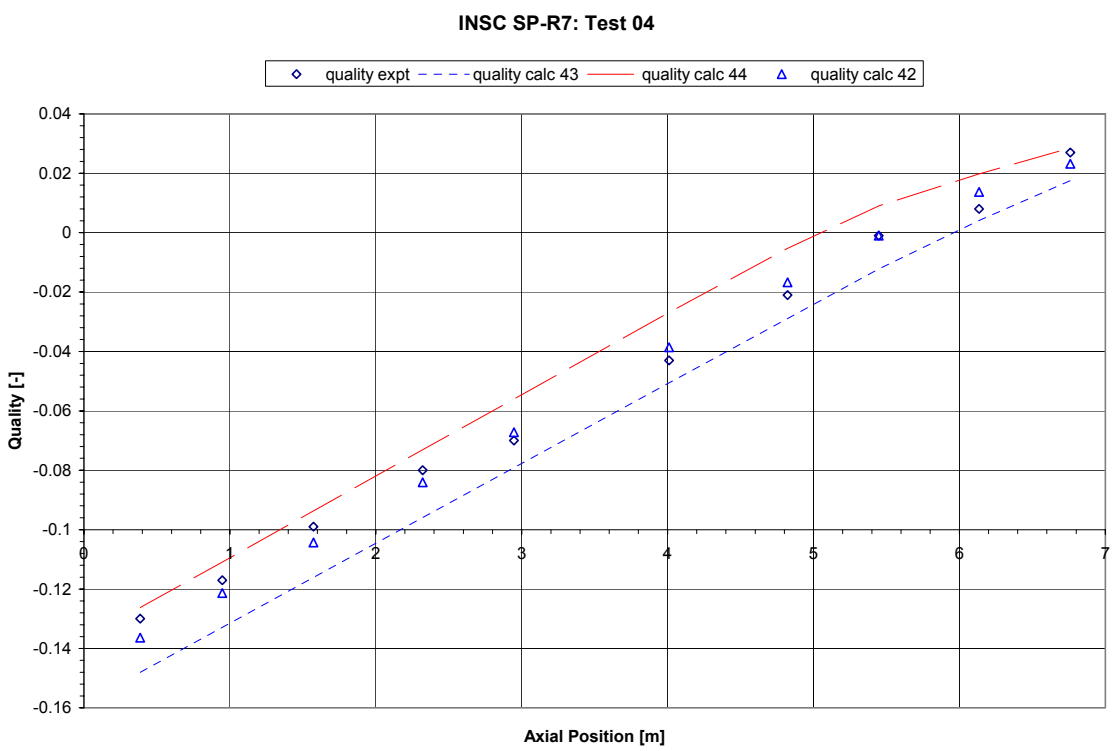

Figure B.4.2 Quality for Test 04

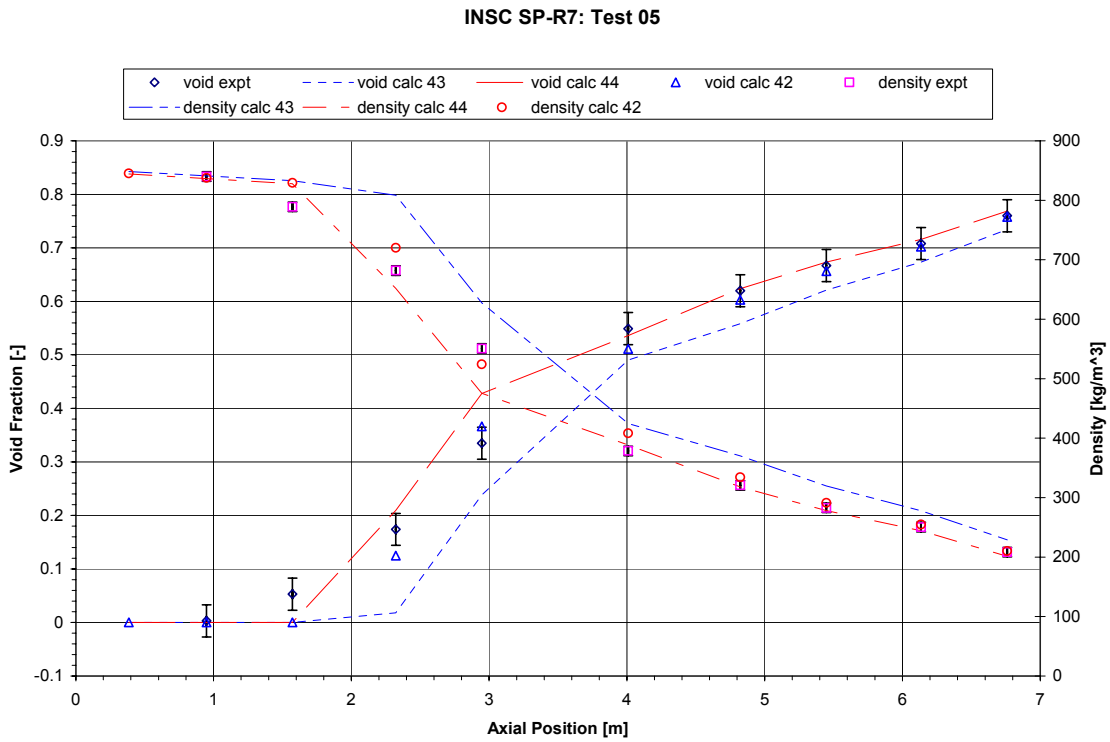

Figure B.5.1 Density and Void Fraction for Test 05

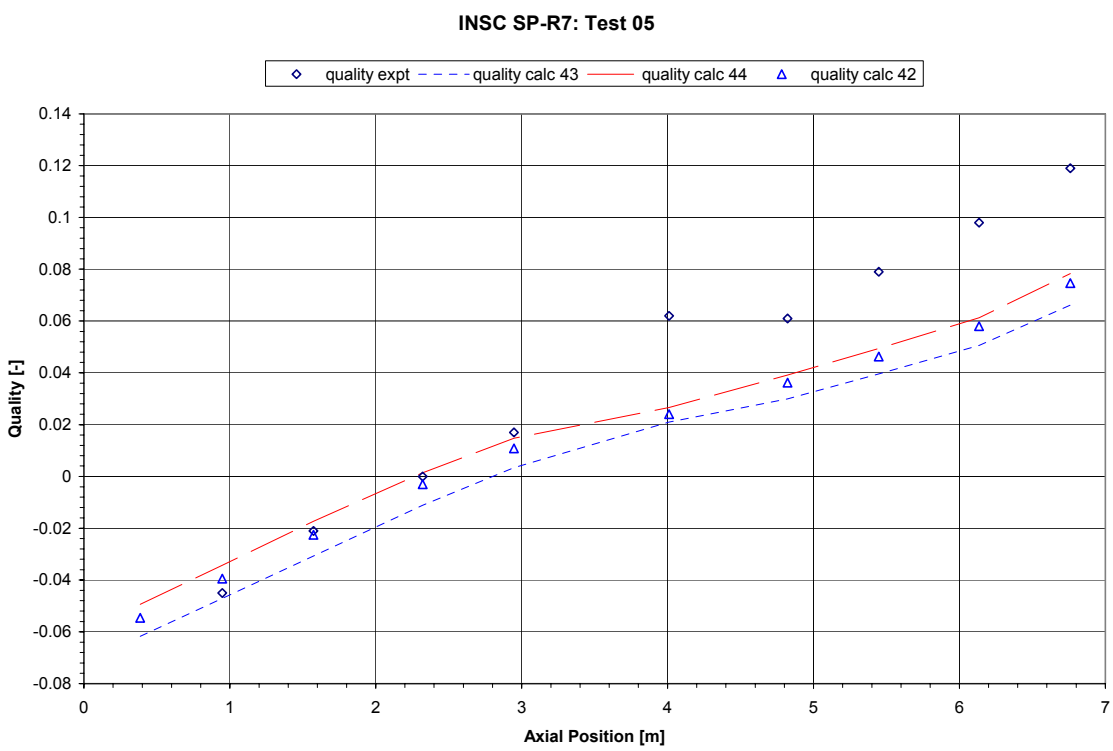

Figure B.5.2 Quality for Test 05

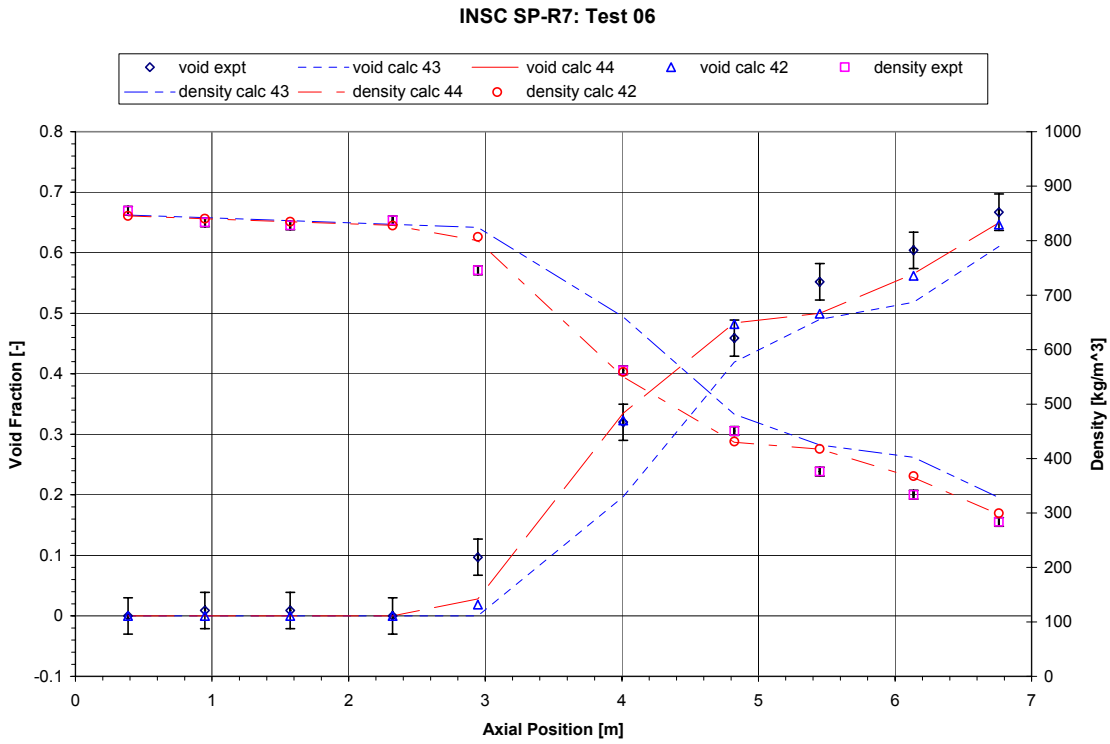

Figure B.6.1 Density and Void Fraction for Test 06

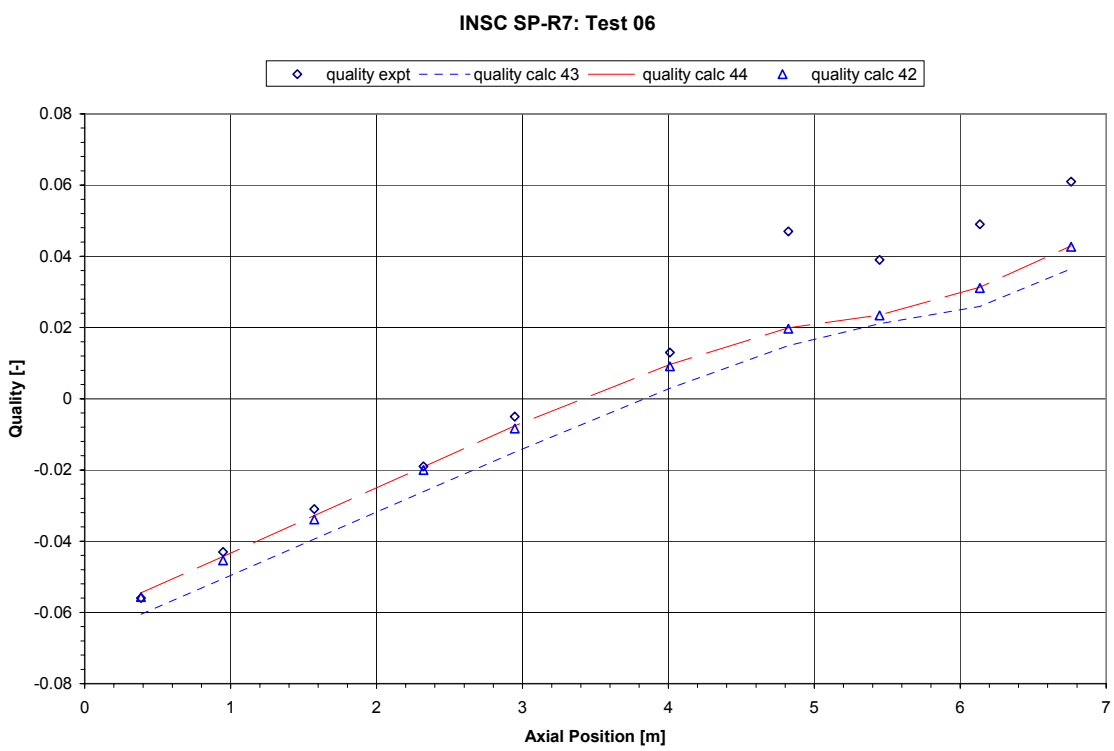

Figure B.6.2 Quality for Test 06

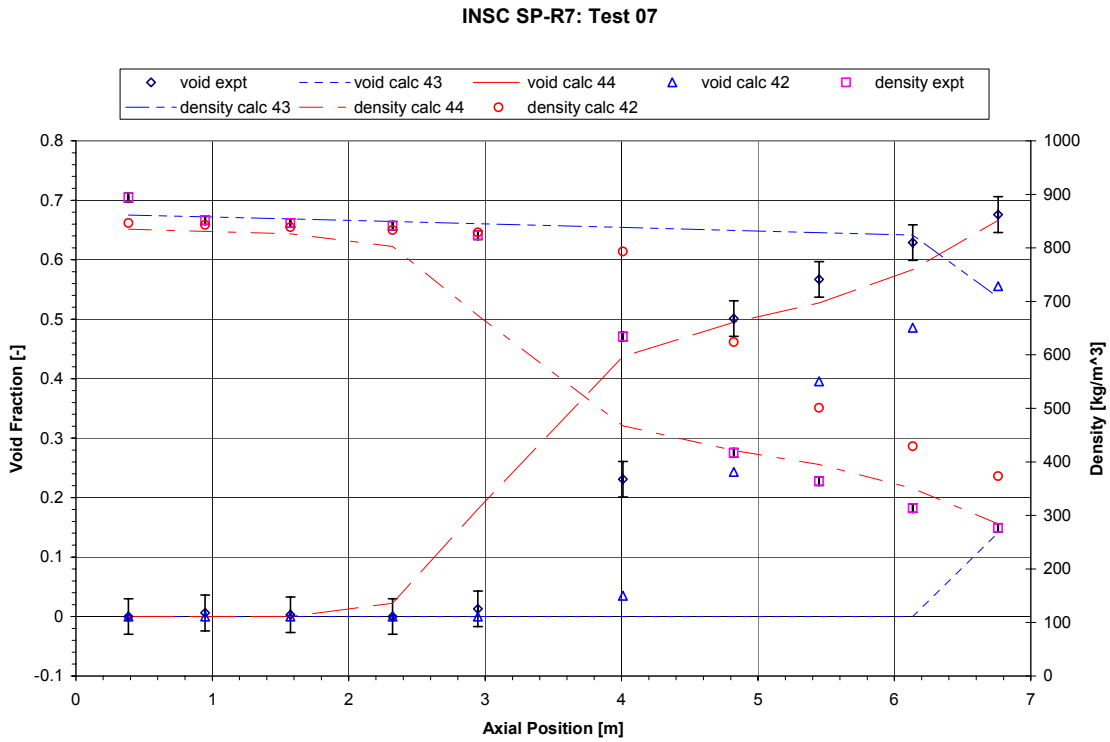

Figure B.7.1 Density and Void Fraction for Test 07

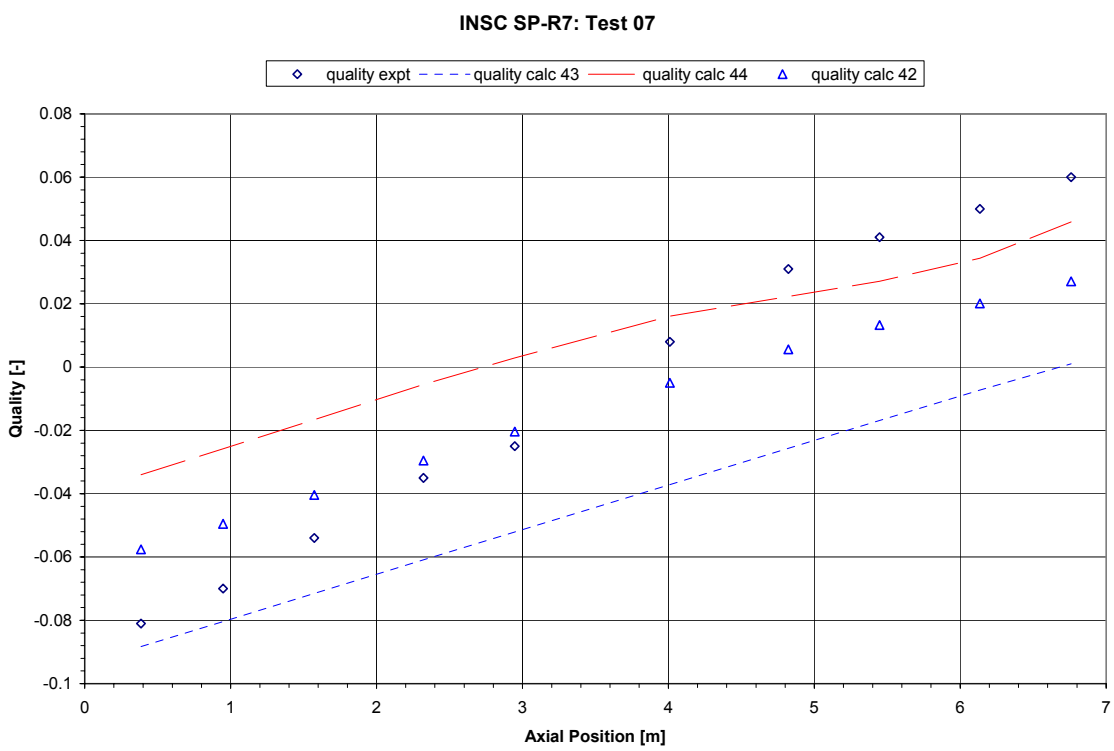

Figure B.7.2 Quality for Test 07

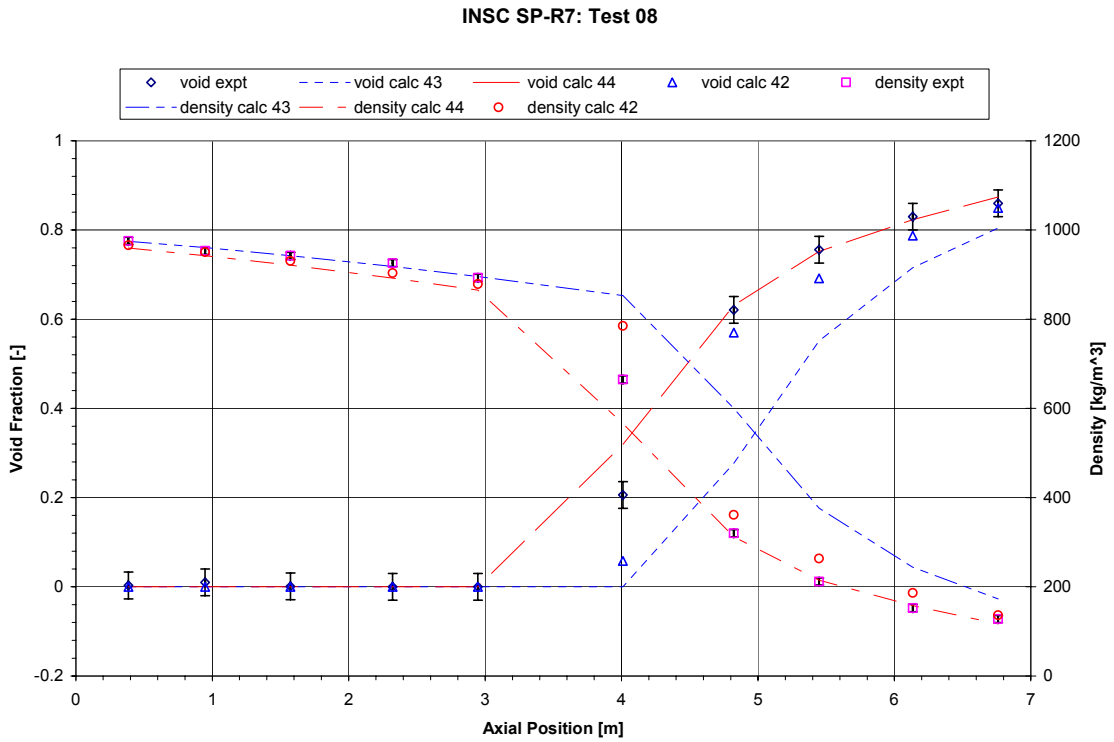

Figure B.8.1 Density and Void Fraction for Test 08

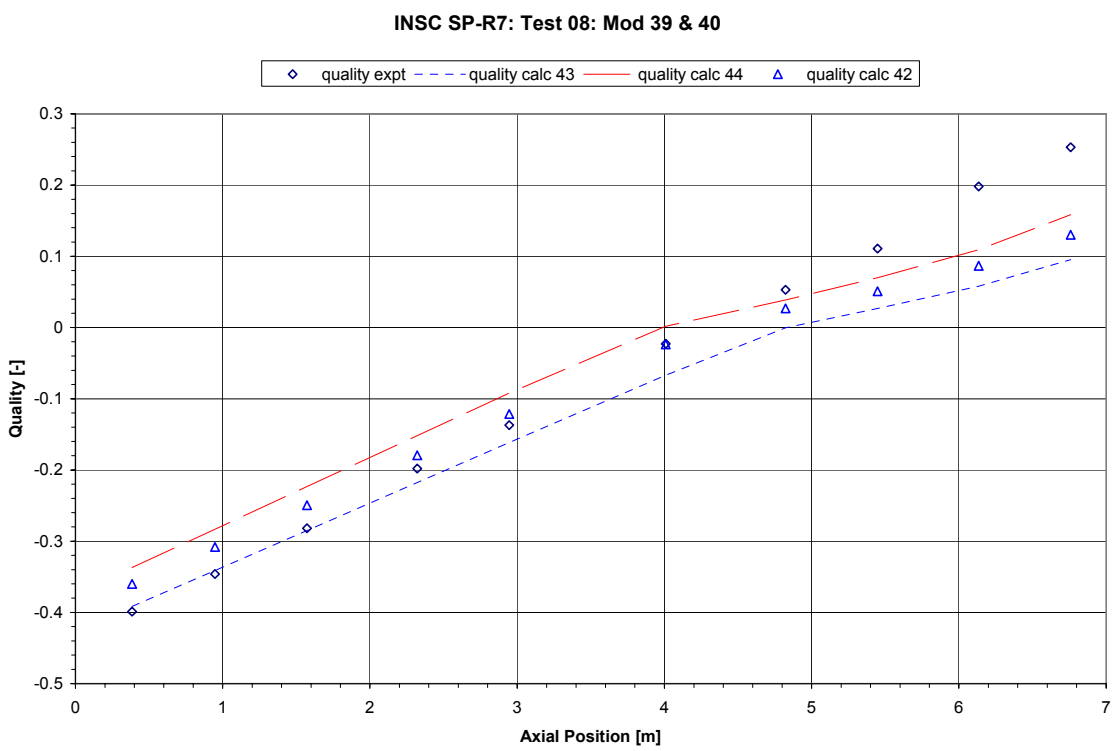

Figure B.8.2 Quality for Test 08

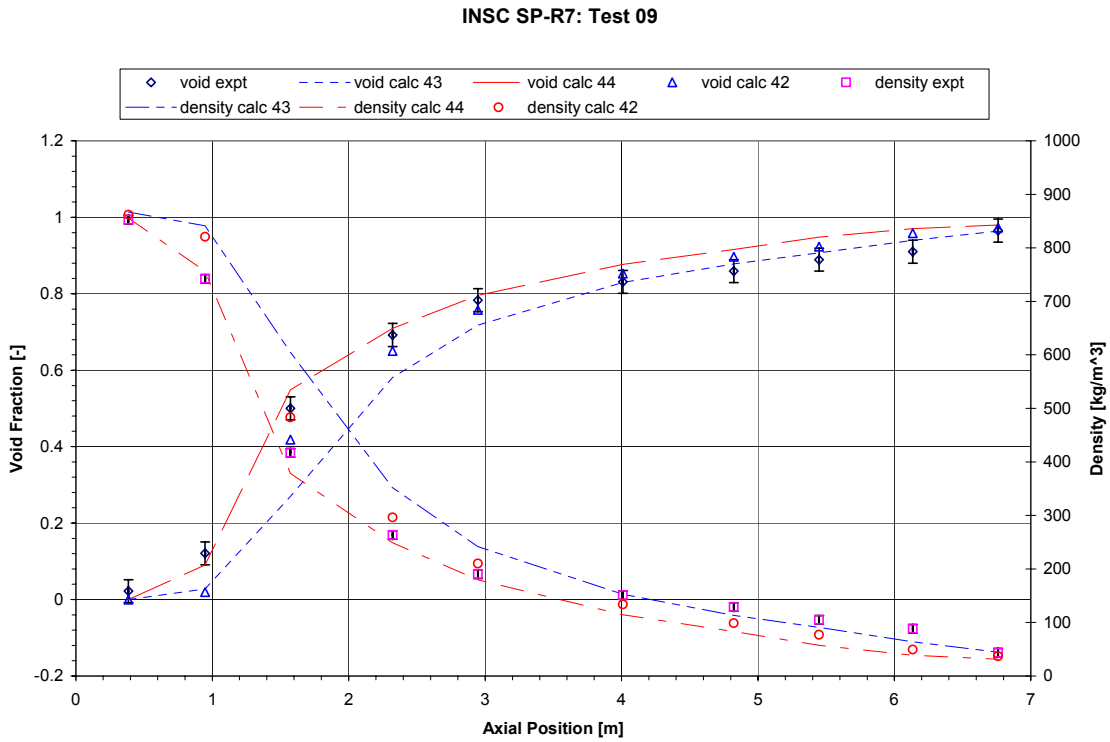

Figure B.9.1 Density and Void Fraction for Test 09

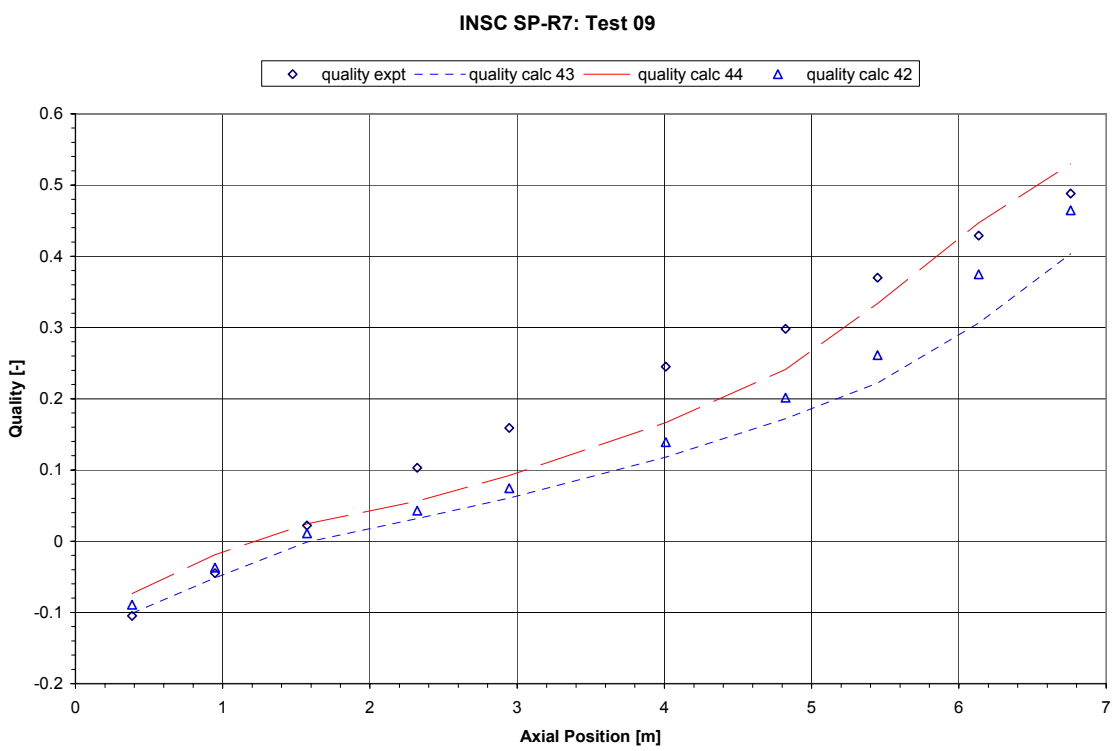

Figure B.9.2 Quality for Test 09

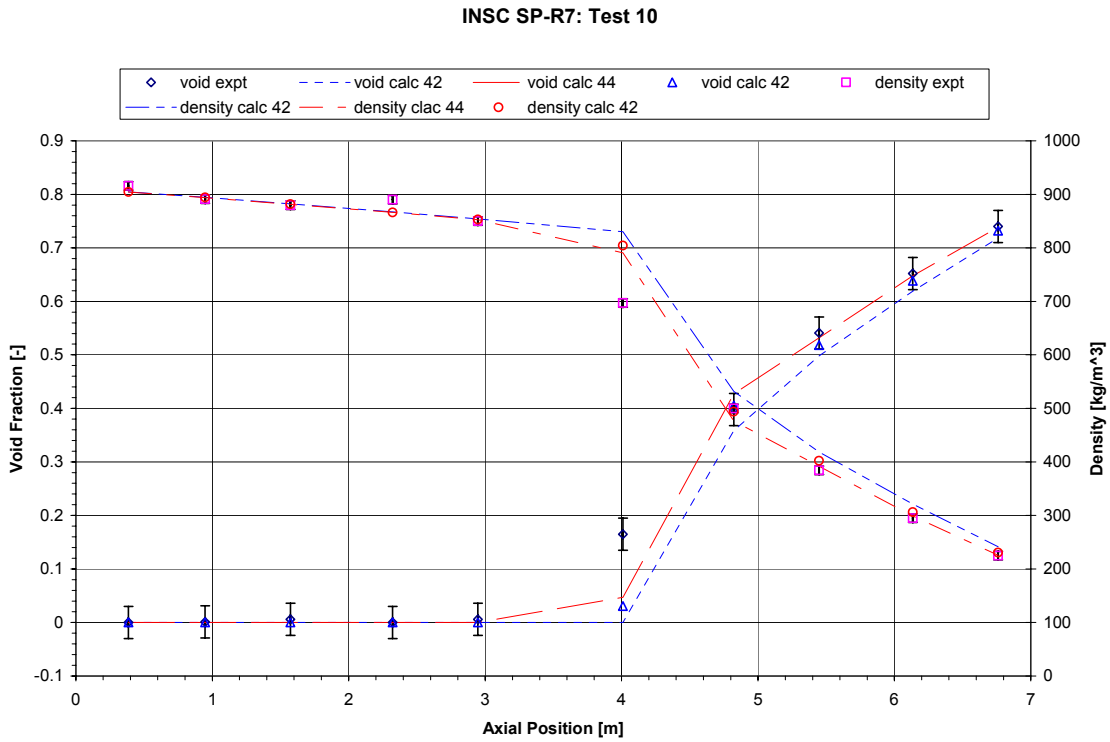

Figure B.10.1 Density and Void Fraction for Test 10

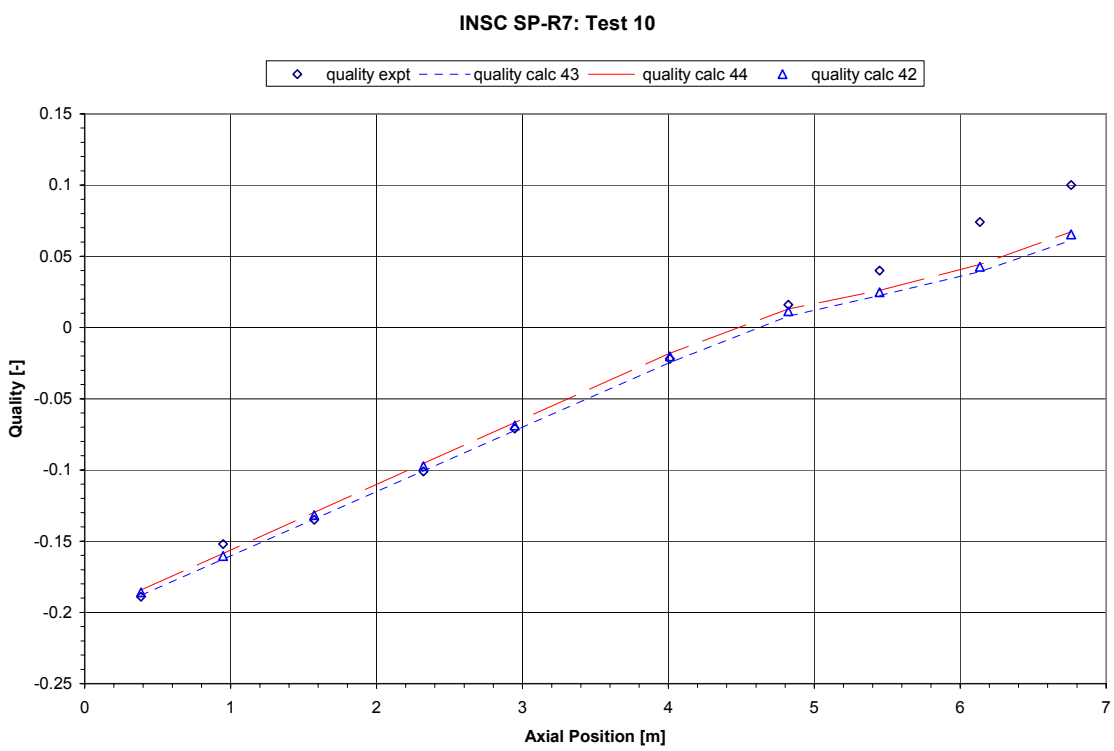

Figure B.10.2 Quality for Test 10

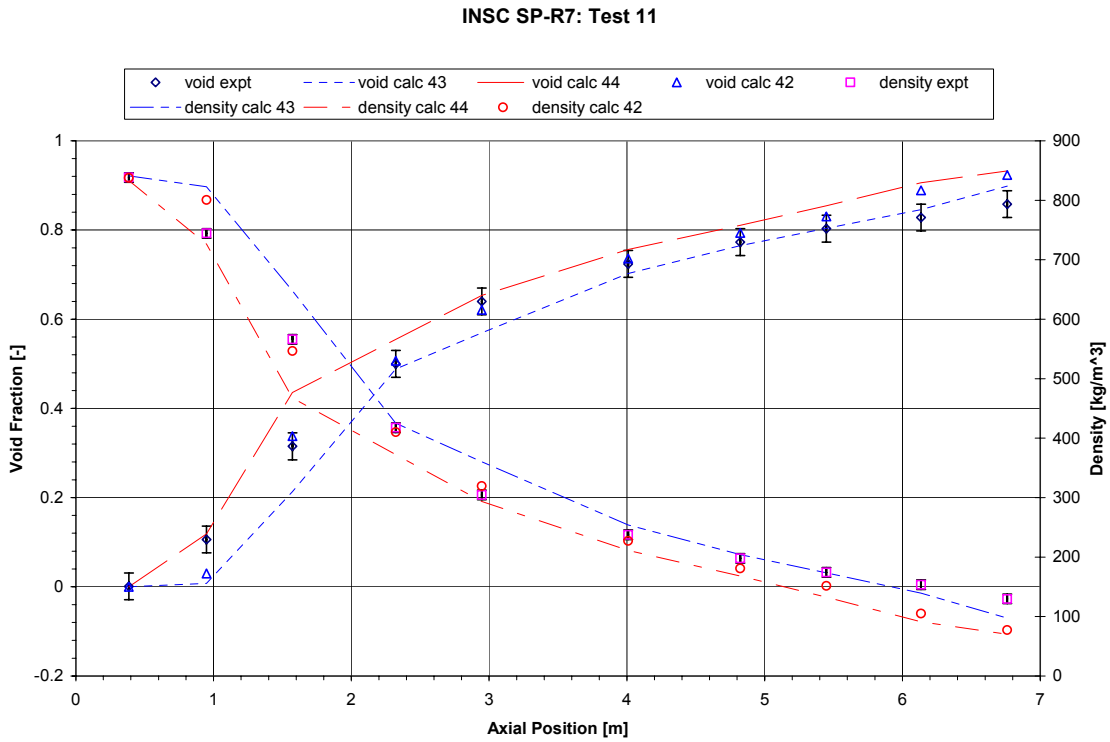

Figure B.11.1 Density and Void Fraction for Test 11

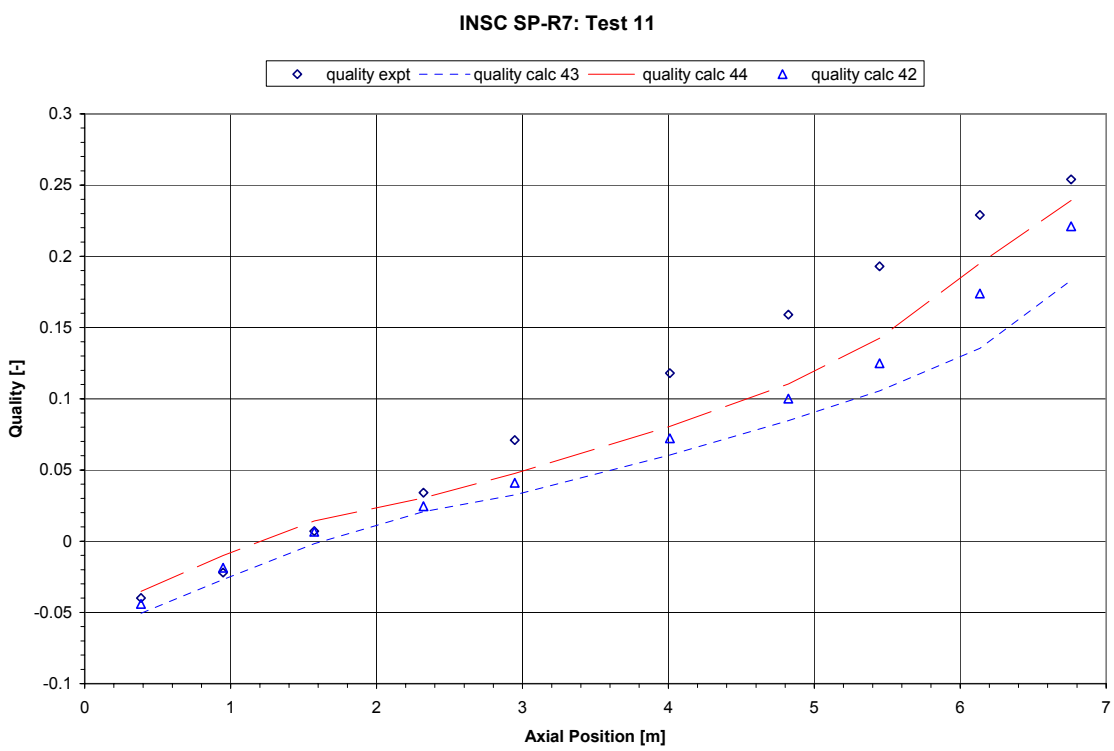

Figure B.11.2 Quality for Test 11

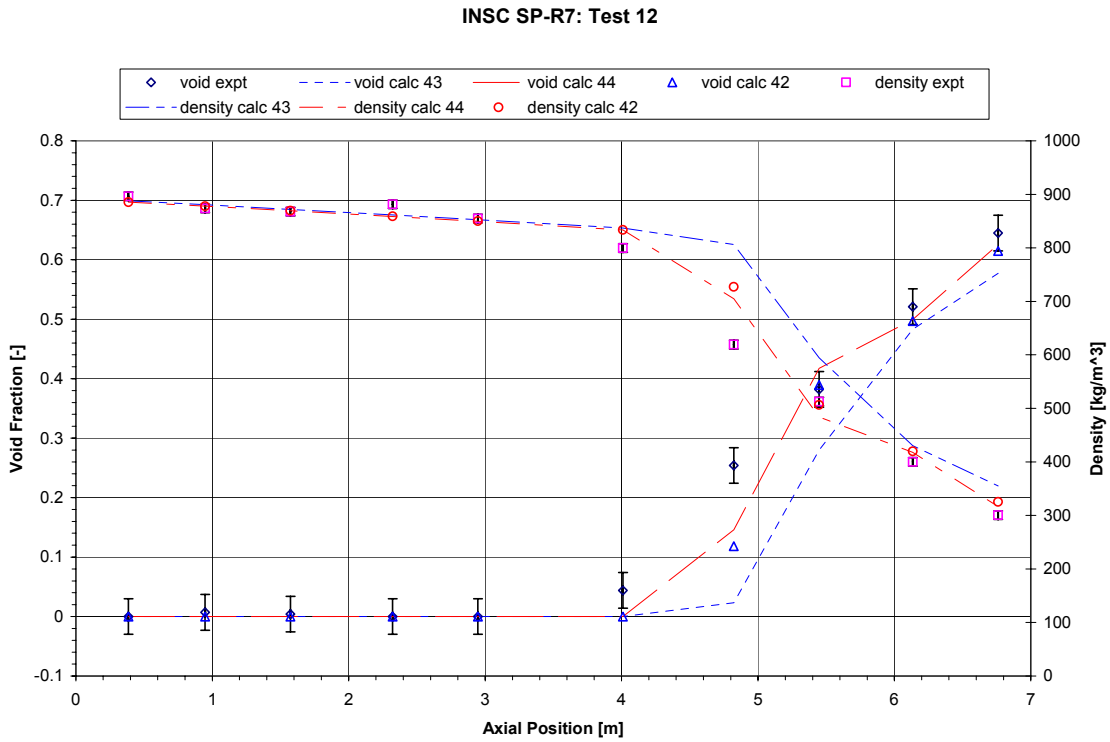

Figure B.12.1 Density and Void Fraction for Test 12

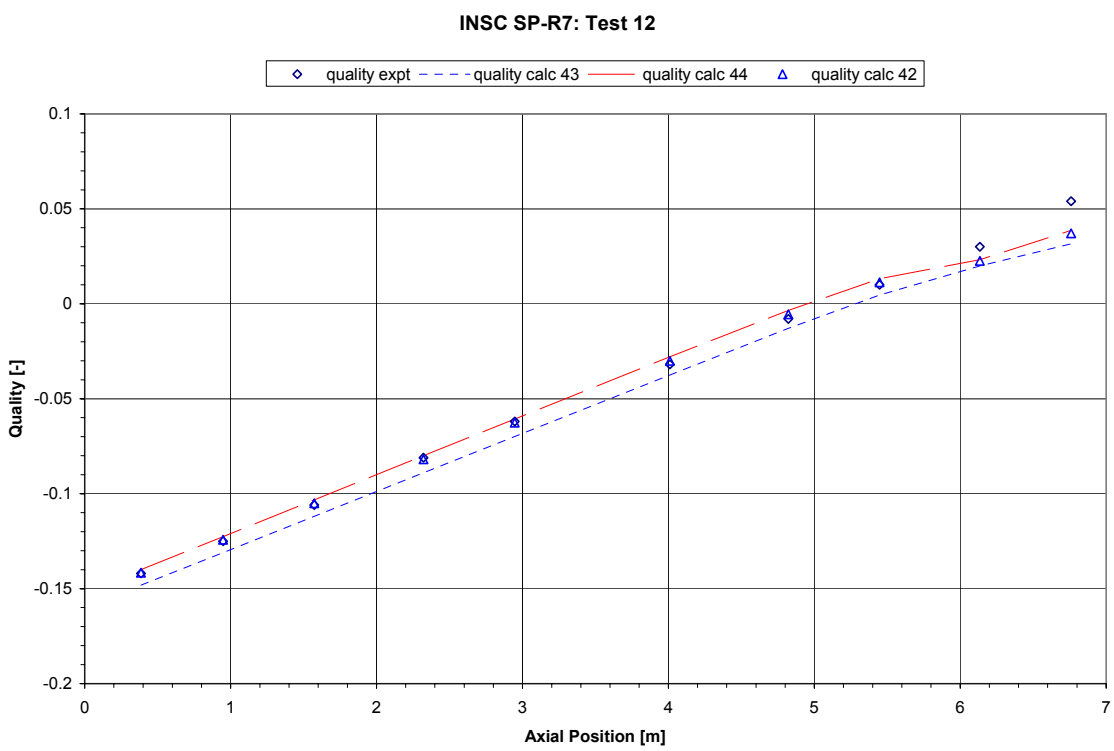

Figure B.12.2 Quality for Test 12

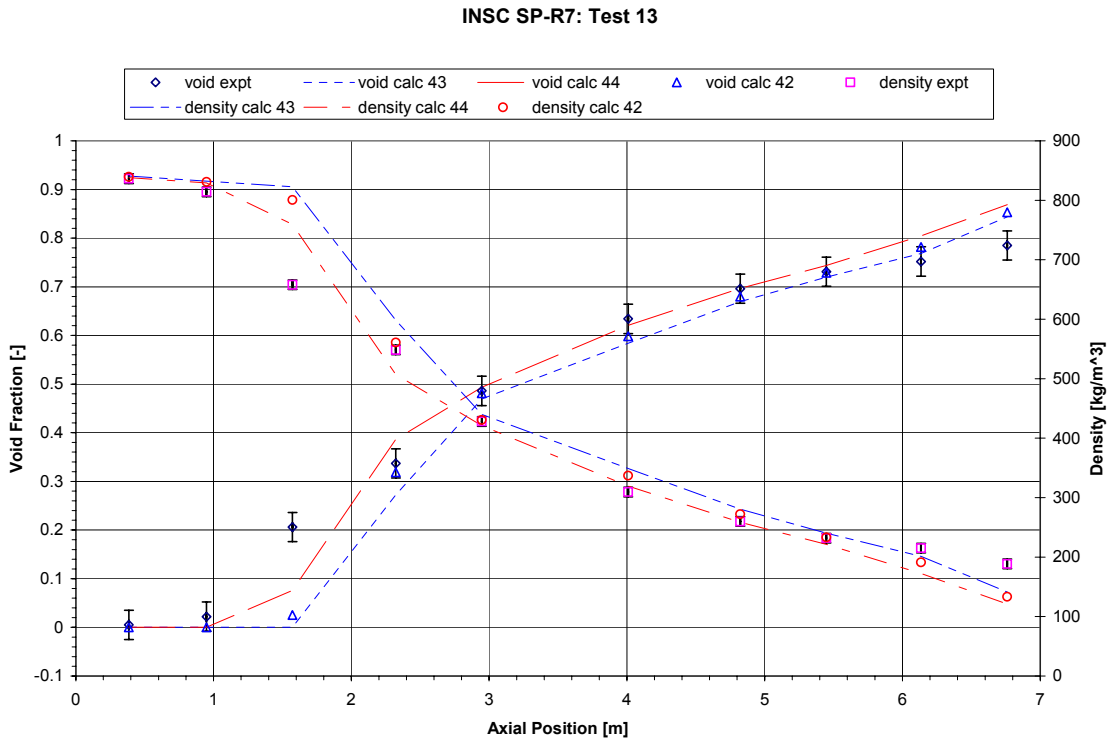

Figure B.13.1 Density and Void Fraction for Test 13

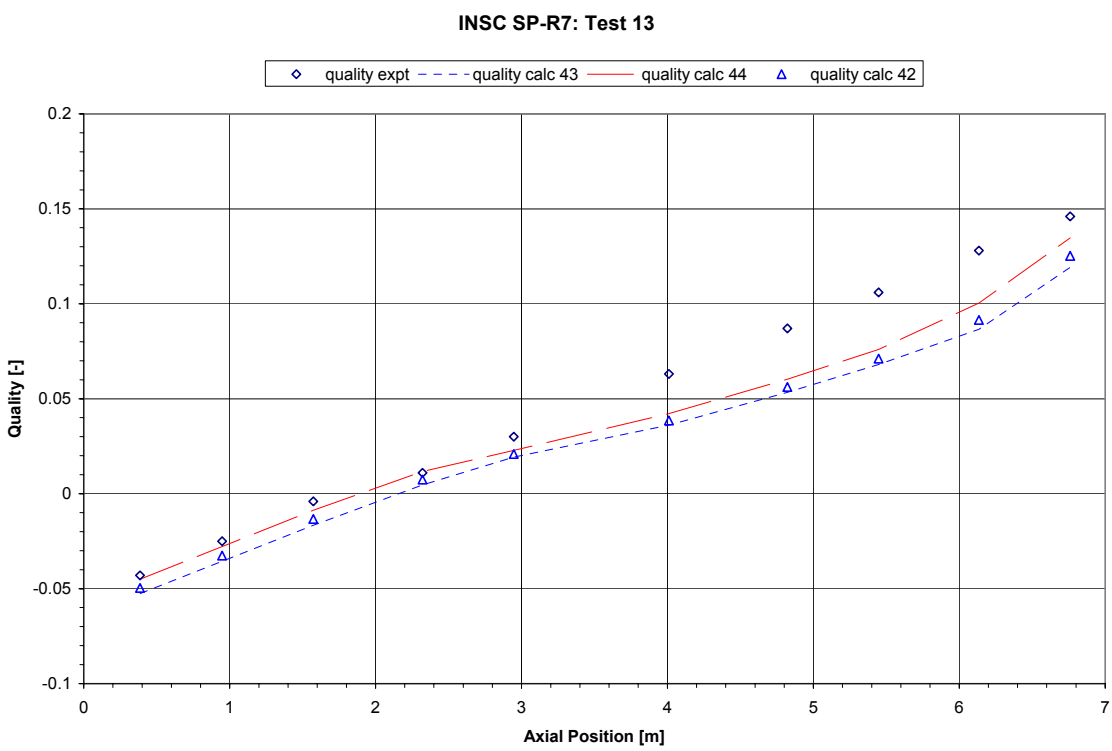

Figure B.13.2 Quality for Test 13

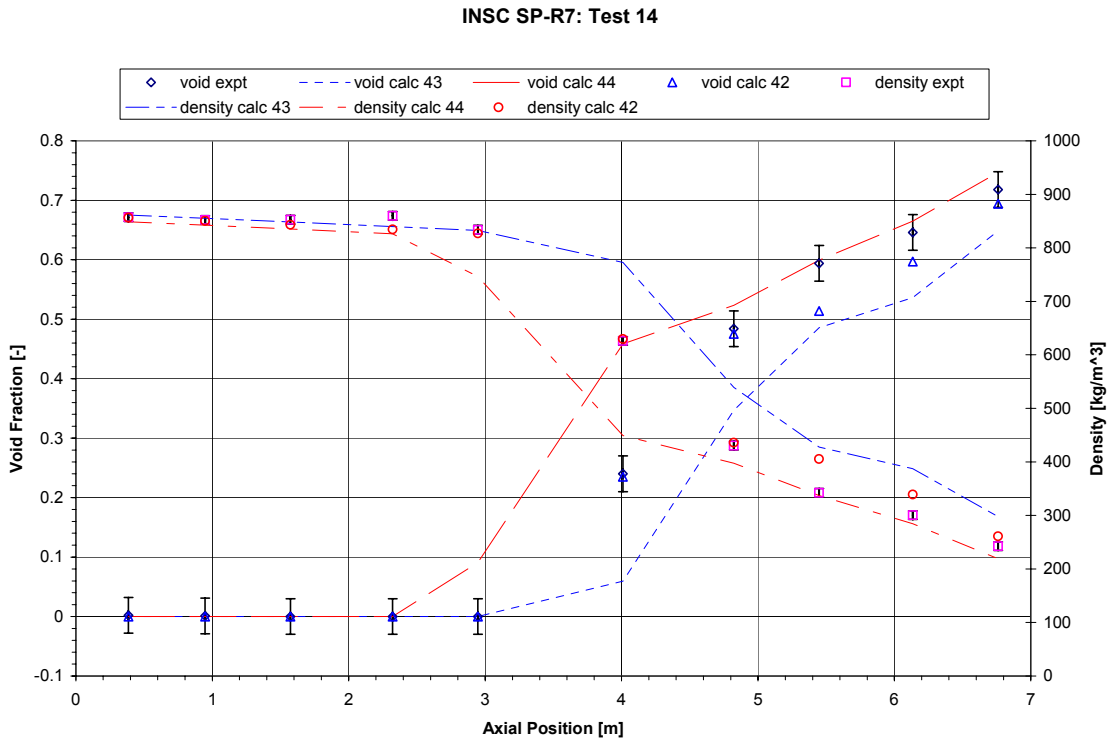

Figure B.14.1 Density and Void Fraction for Test 14

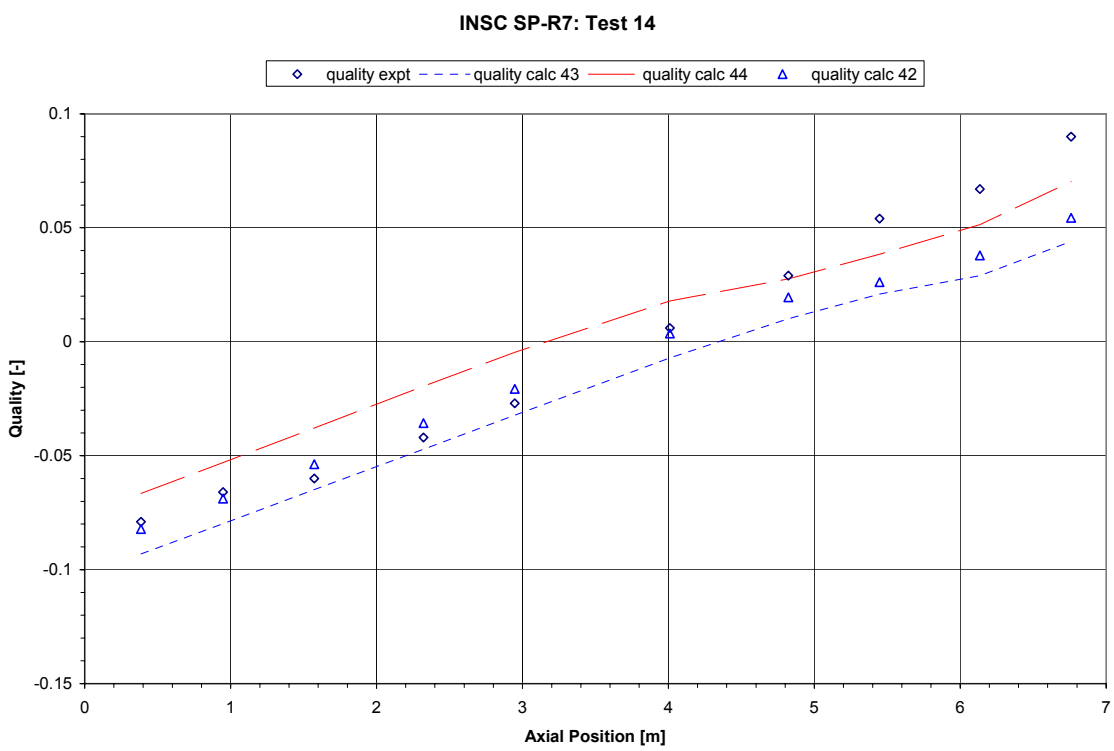

Figure B.14.2 Quality for Test 14

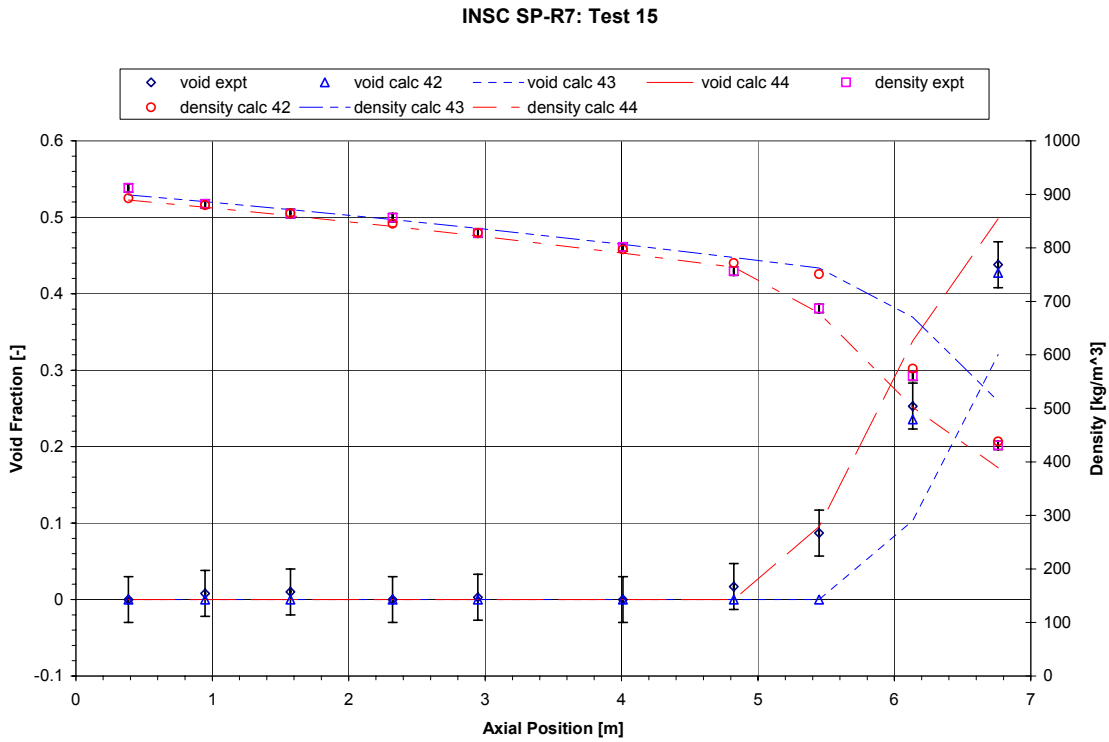

Figure B.15.1 Density and Void Fraction for Test 15

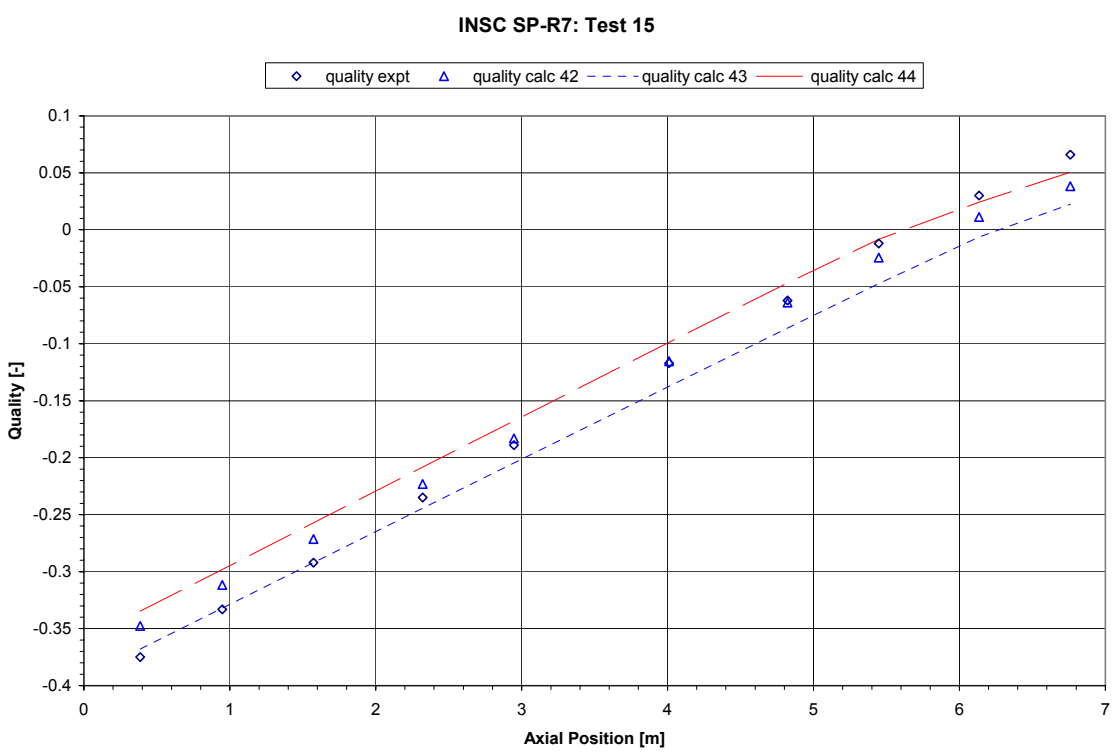

Figure B.15.2 Quality for Test 15

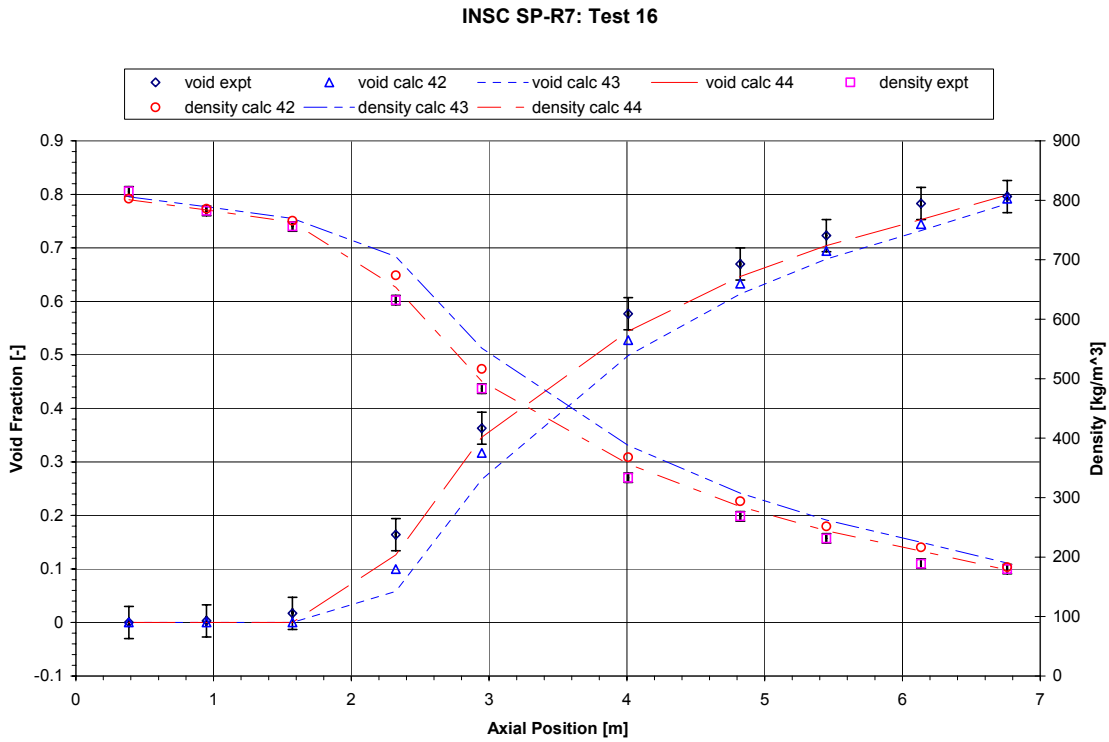

Figure B.16.1 Density and Void Fraction for Test 16

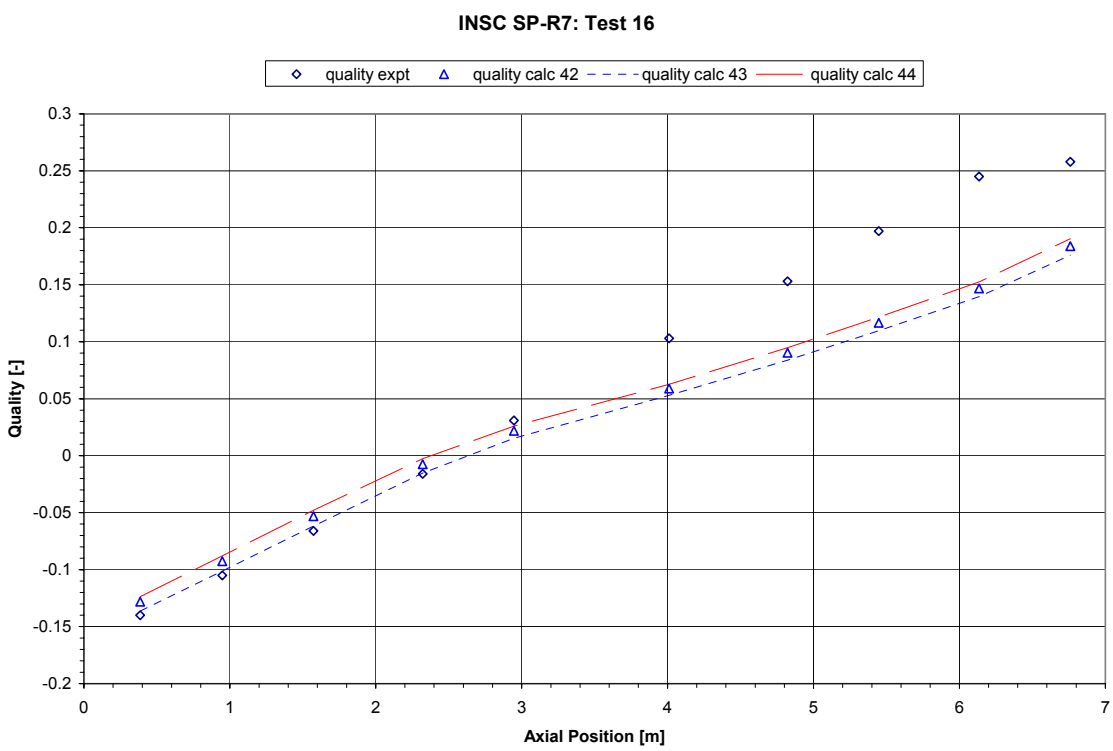

Figure B.16.2 Quality for Test 16

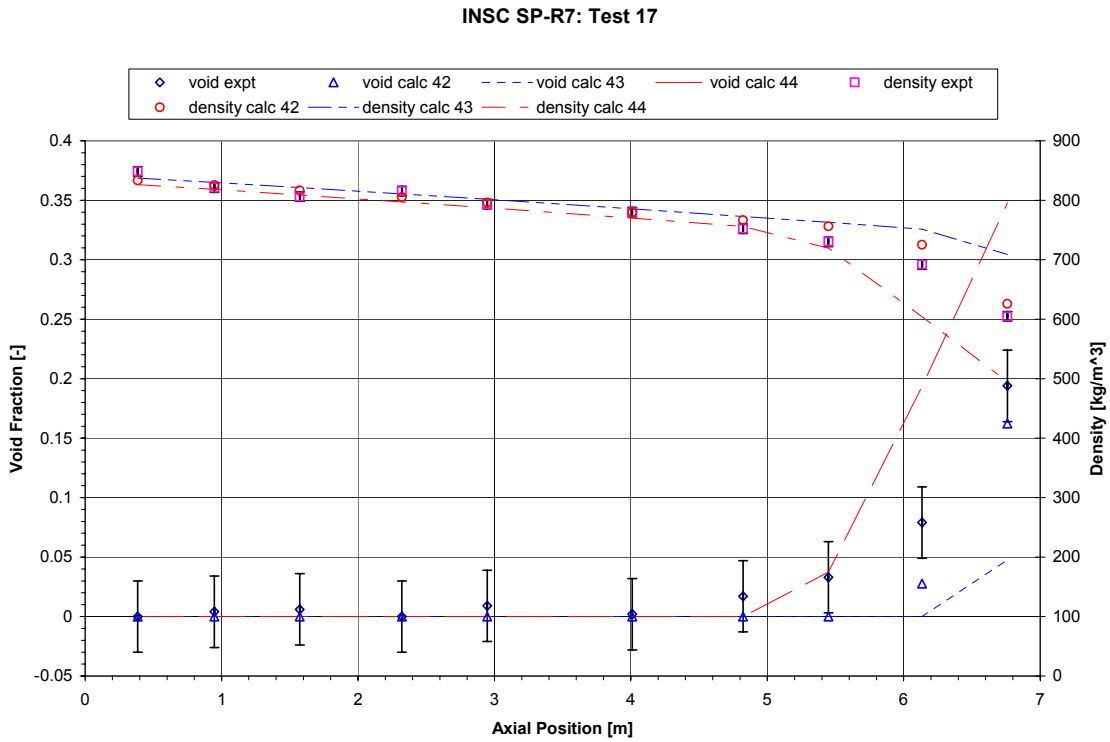

Figure B.17.1 Density and Void Fraction for Test 17

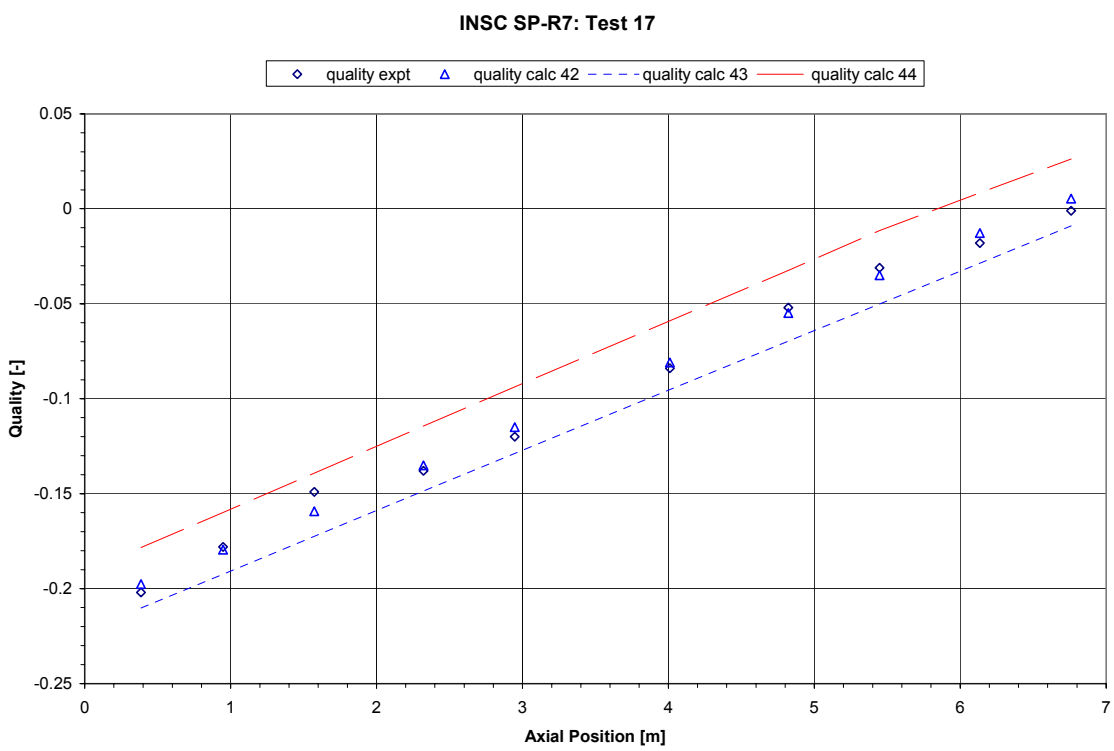

Figure B.17.2 Quality for Test 17

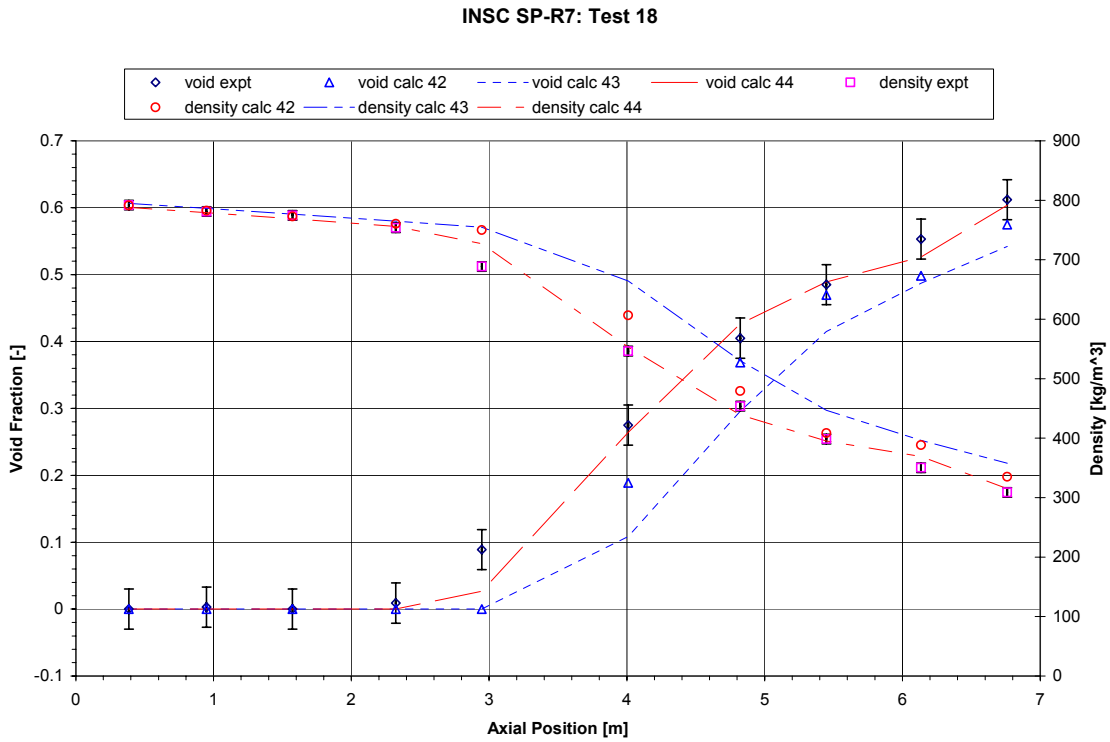

Figure B.18.1 Density and Void Fraction for Test 18

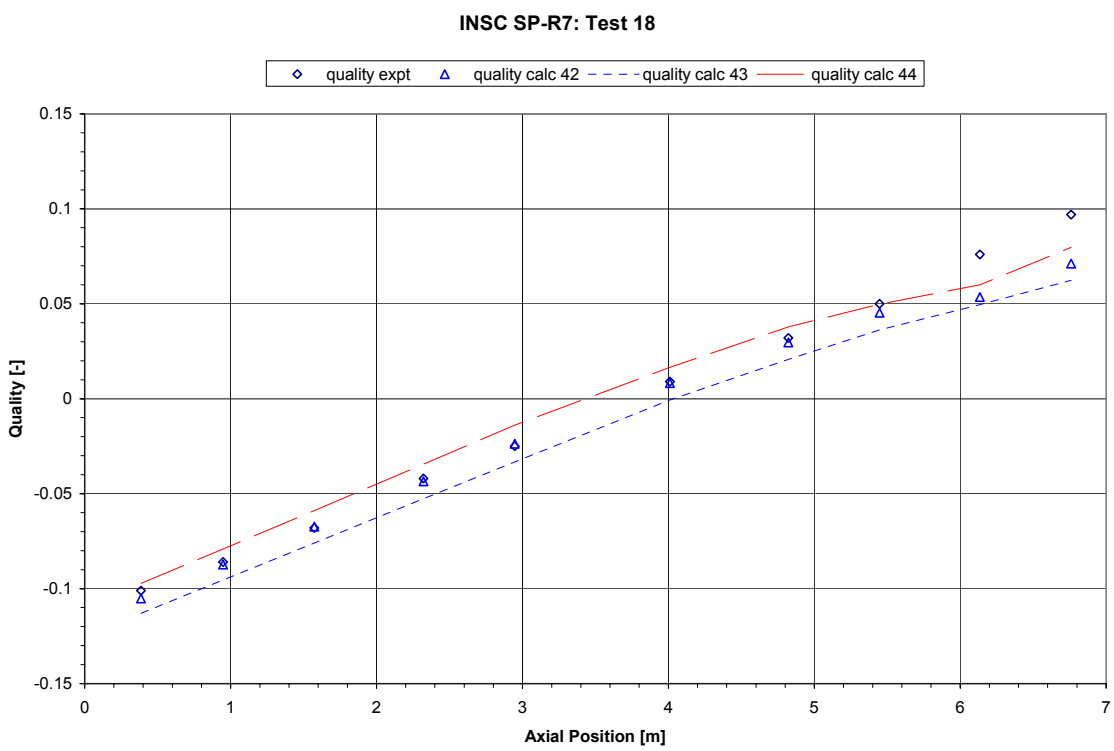

Figure B.18.2 Quality for Test 18

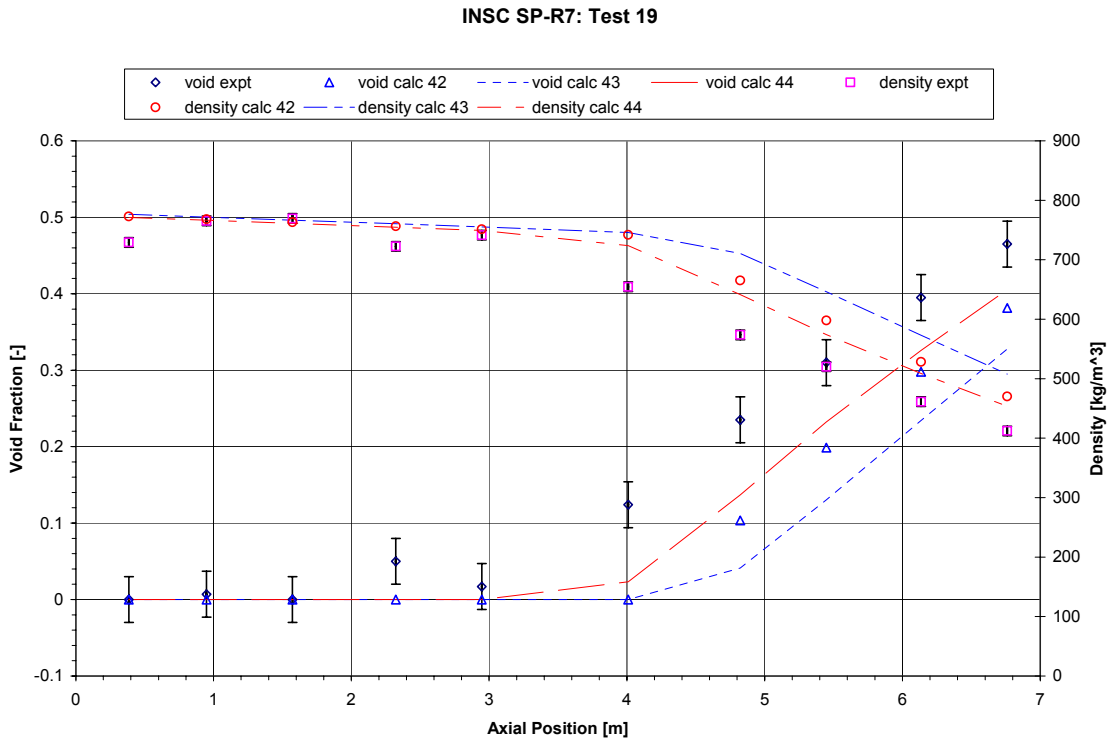

Figure B.19.1 Density and Quality for Test 19

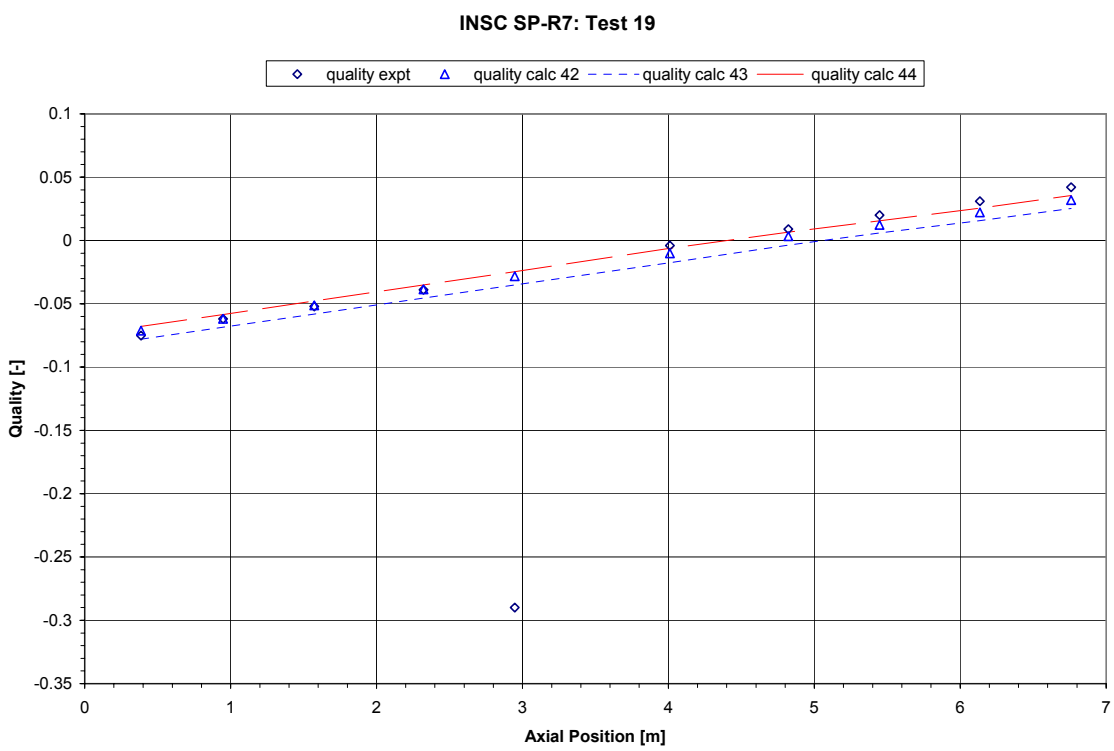

Figure B.19.2 Quality for Test 19

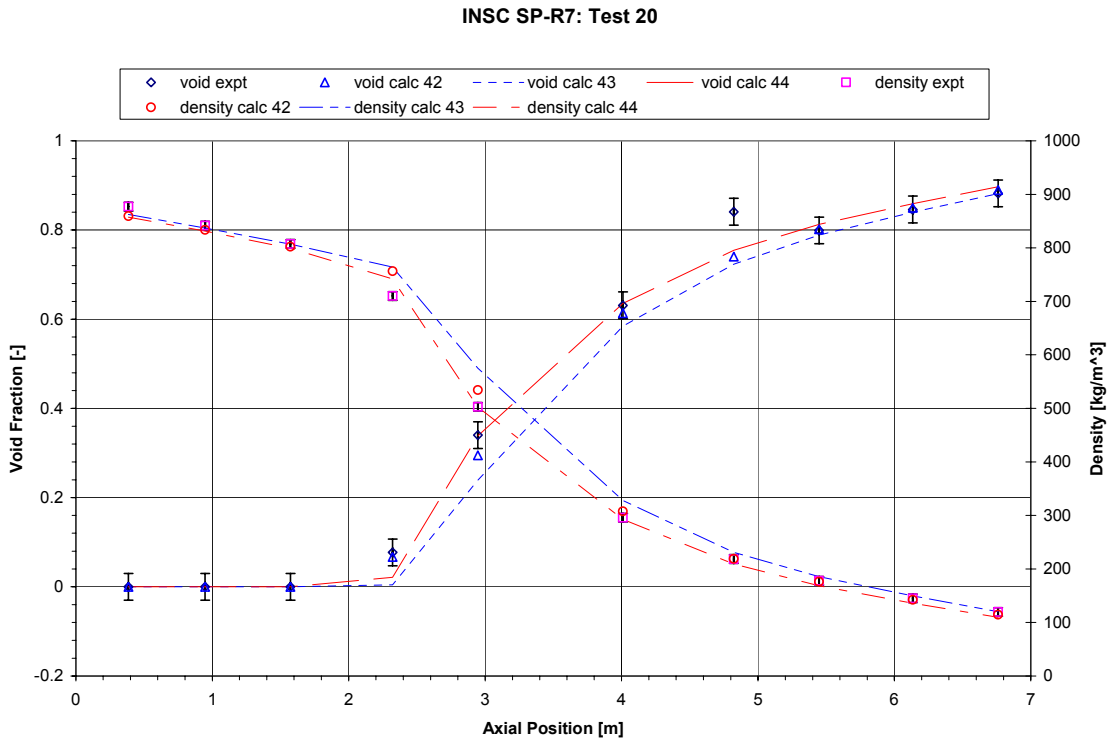

Figure B.20.1 Density and Void Fraction for Test 20

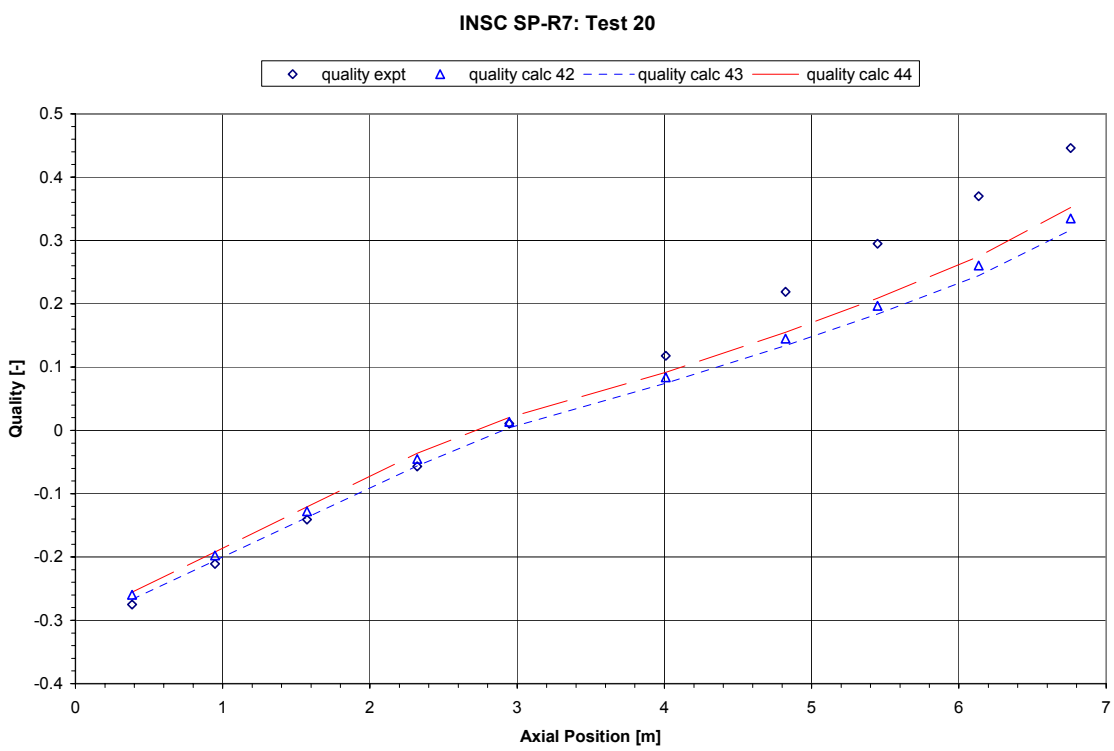

Figure B.20.2 Quality for Test 20

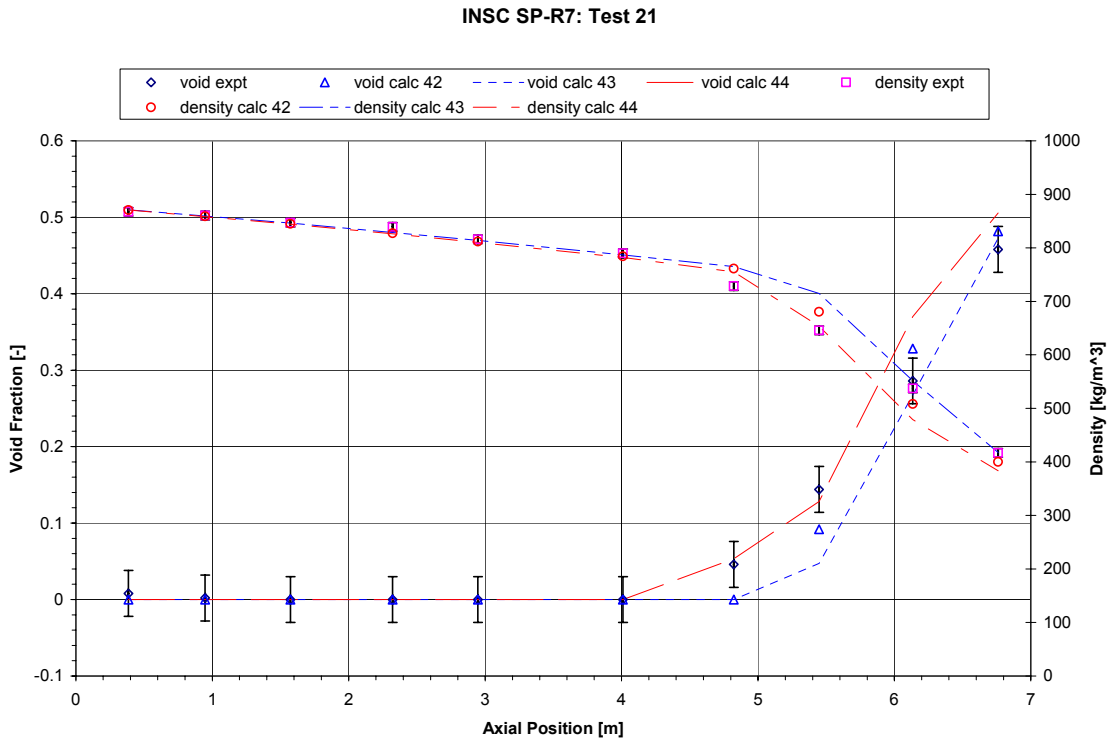

Figure B.21.1 Density and Void Fraction for Test 21

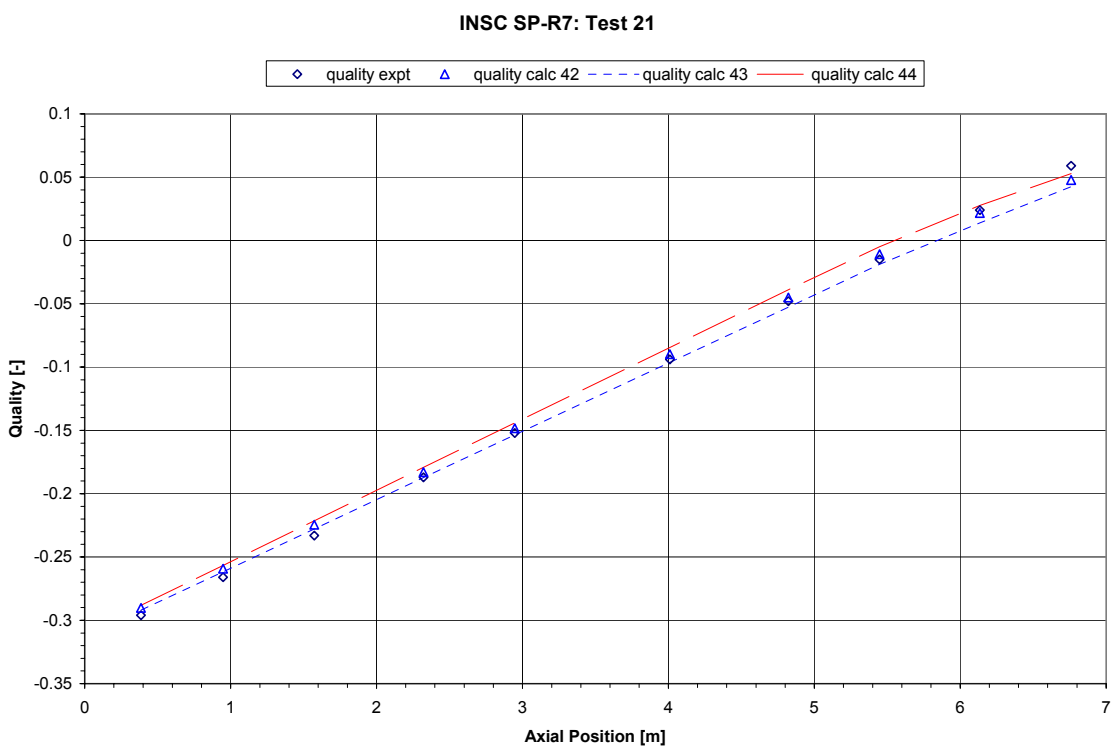

Figure B.21.2 Quality for Test 21

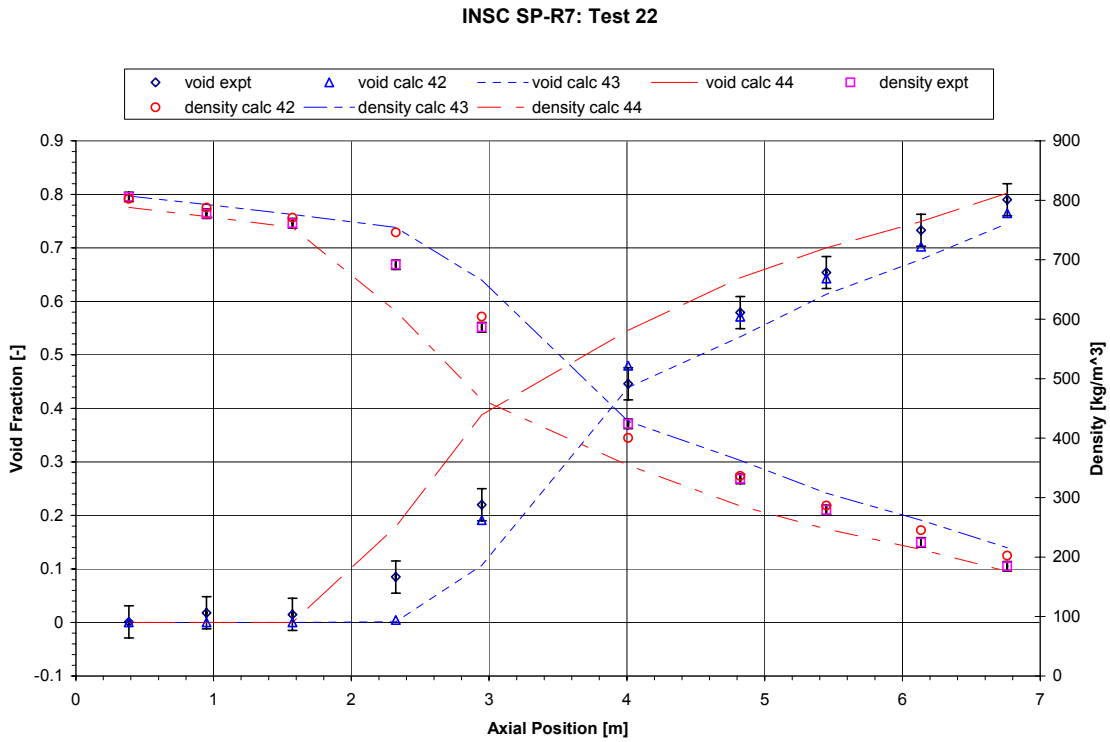

Figure B.22.1 Density and Void Fraction for Test 22

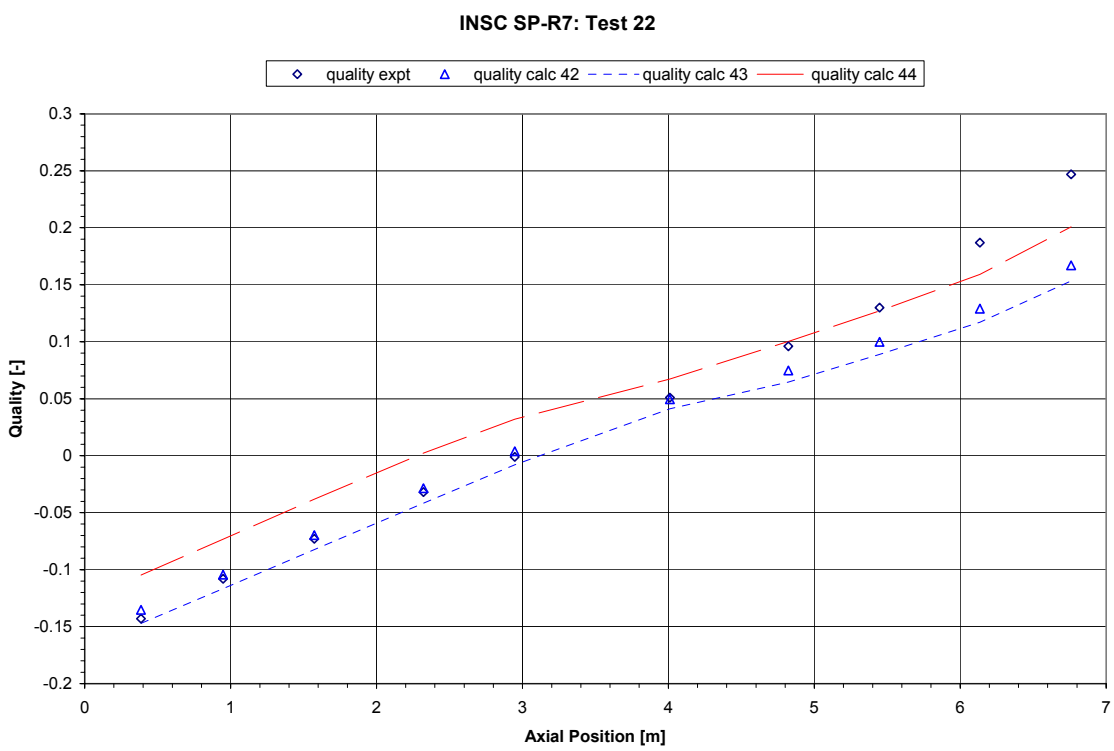

Figure B.22.2 Quality for Test 22

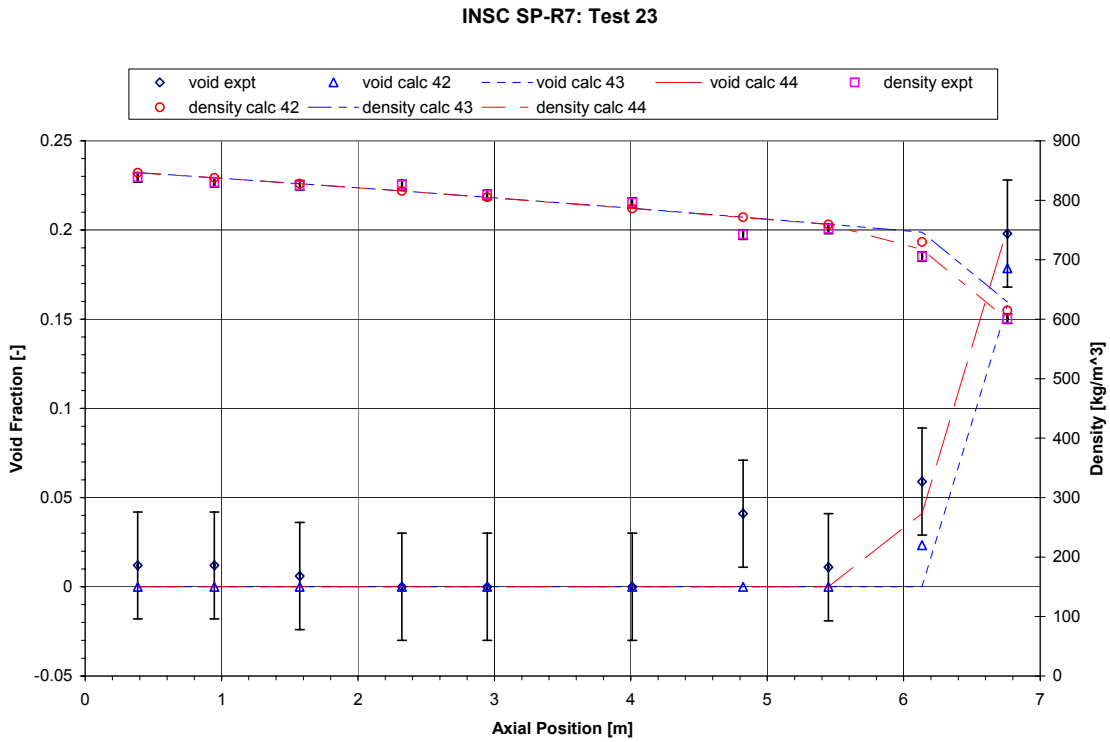

Figure B.23.1 Density and Void Fraction for Test 23

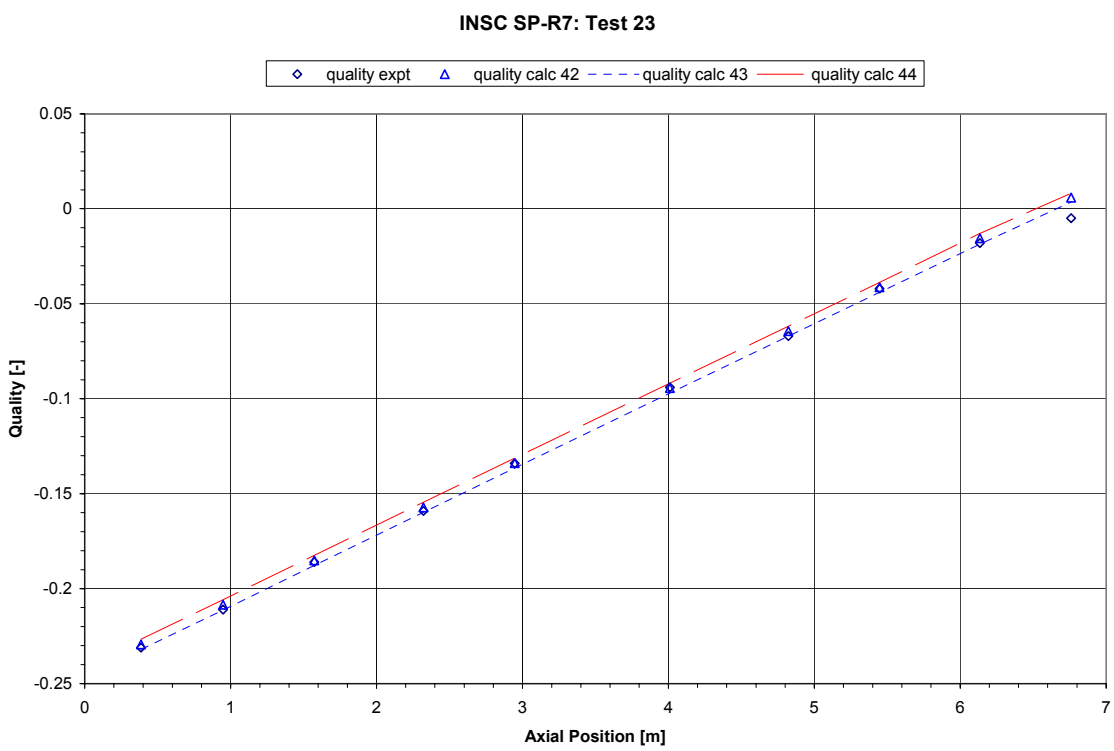

Figure B.23.2 Quality for Test 23

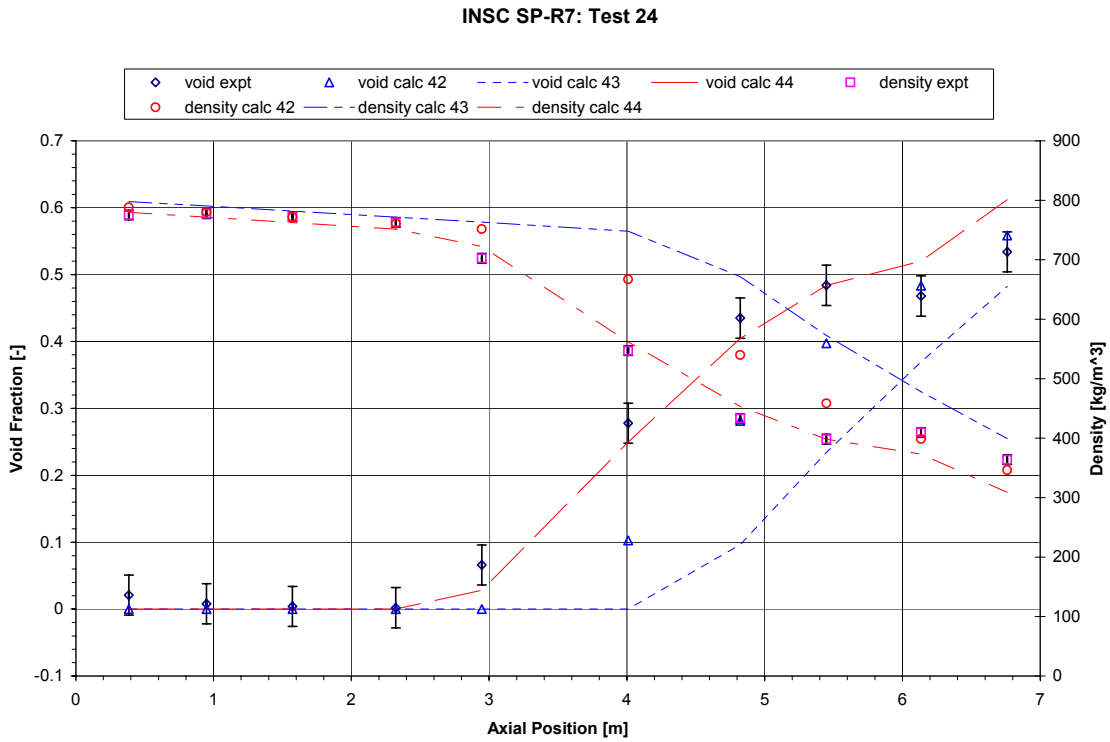

Figure B.24.1 Density and Void Fraction for Test 24

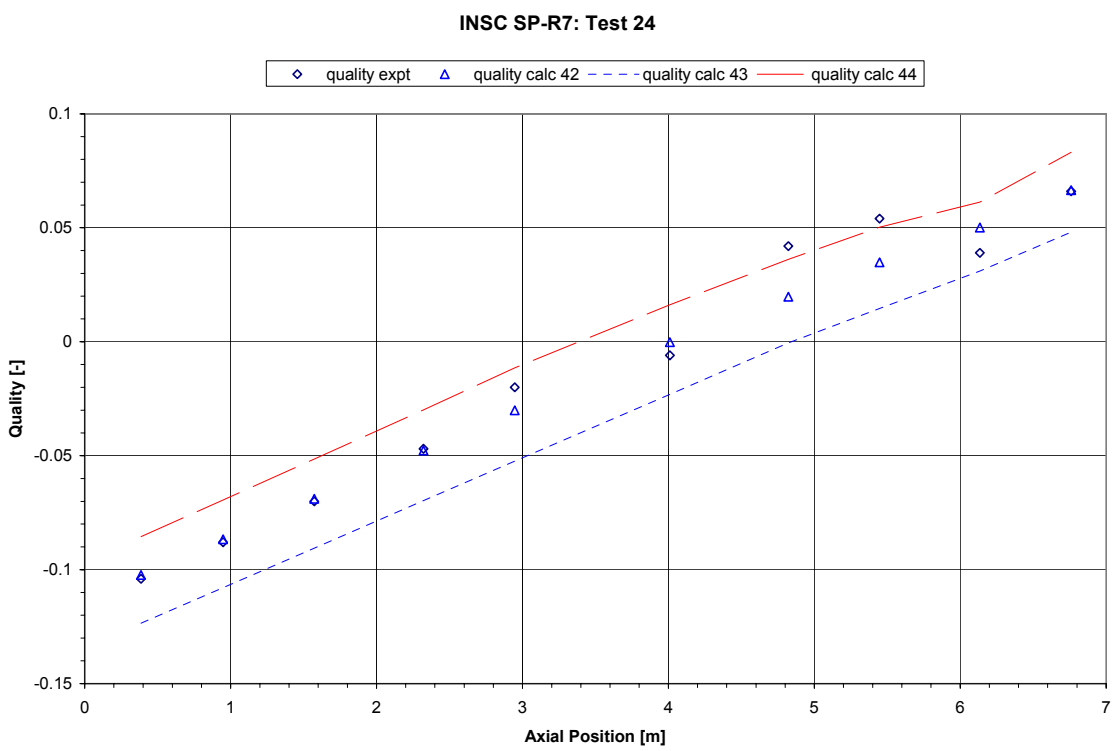

Figure B.24.2 Quality for Test 24

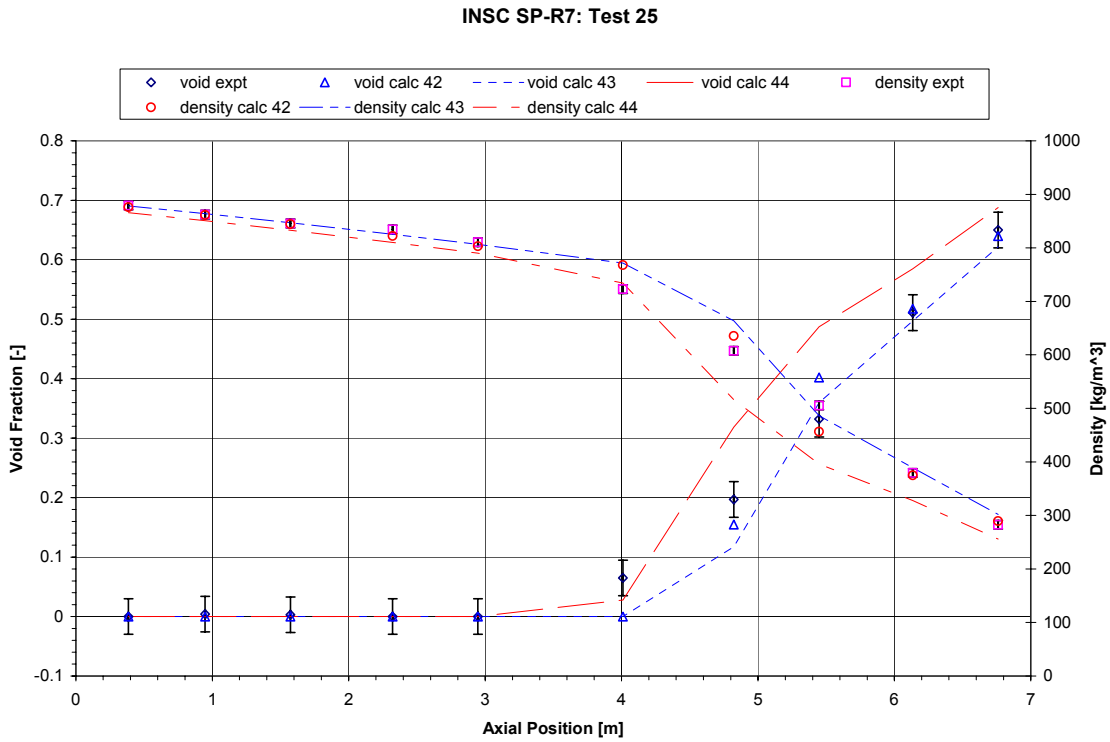

Figure B.25.1 Density and Void Fraction for Test 25

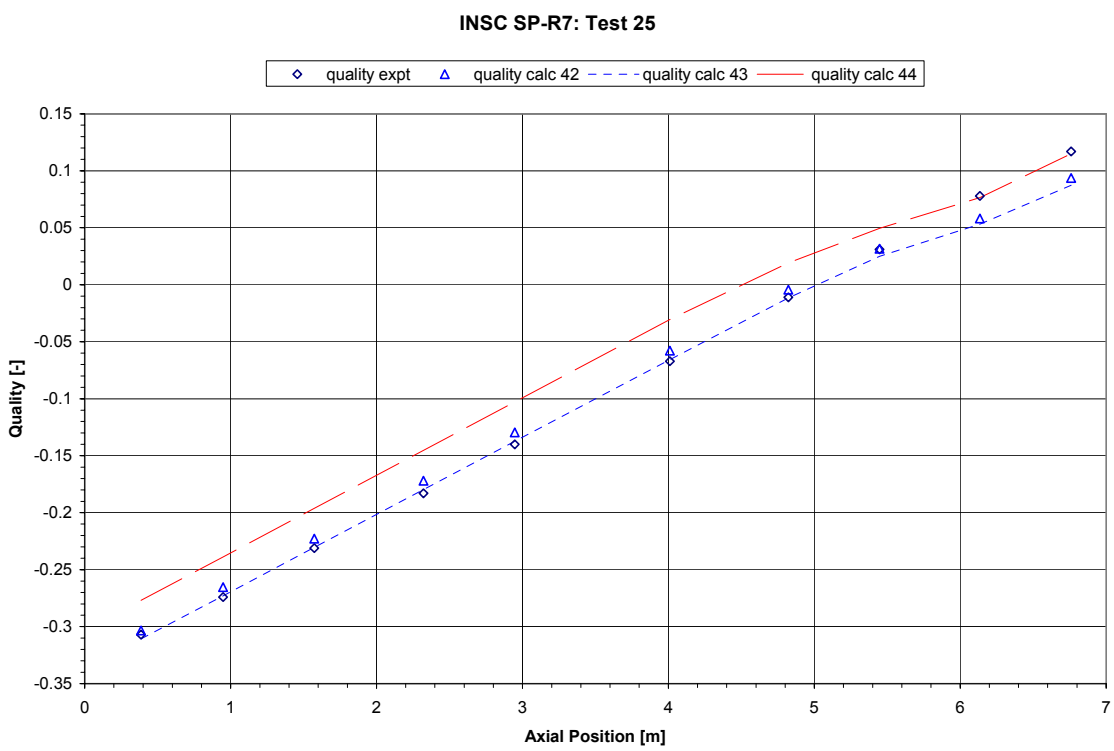

Figure B.25.2 Quality for Test 25

Appendix C

Input File Review

The following sections show comments on the input file and analysis and the author's response.

C.1. Review Comments

The following comments were provided by A. M. Tentner (ANL) .

1. Comments about the results.

Although most of the calculated void fraction values (70%) are within the 0.03 error margins of the experimental results, some comments should be included about the possible causes for the larger deviations between calculations and experiments observed in the remaining 30% of the results. These include:

- Coolant temperature radial non-uniformity effects, which were not considered in the RELAP analysis. The coolant associated with the central heating element is likely to have somewhat higher temperatures than the outer channel coolant, and than the average coolant modeled by RELAP. Therefore, it is possible that the higher voids observed, usually at lower void fractions, in the experiments are due to the early void formation in the central channel. The calculated void values, based on the average coolant channel, would generally result in lower void fraction values.

- The use of a relatively coarse axial mesh grid is likely to distort the computational results, leading to lower computed void fractions in the lowest void segments.

Other error sources, estimated to have a small effect on results, include:

- Possible heat generation axial non-uniformity, due to tube resistivity changes with temperature. Axial temperature changes occur primarily between the coolant inlet into the HRZ and the point where the coolant bulk boiling begins. The RELAP calculations assumed axially uniform heat generation.

- The liquid and vapor densities used in the calculation of the experiment void fraction were based on the outlet pressure, rather than the higher pressure at the density sensor location.

2. Input deck review.

The input deck included in the R7 report has been reviewed and found to be in agreement with the RELAP experiment analysis described in the report.

C.2. Author's Response

The reviewer's points about sources of error are all accepted as possible. All have now been noted in summary fashion in Section 5.3. Only the last item was investigated numerically; there was found to be no noticeable difference (i.e., less than 0.001) in void fraction as computed from density between using the exit pressure versus the inlet pressure for Test 03.