Subcompartment Analysis
RWCU Line Break:
[Filter/Demineralizer Room]

1 Background

Subcompartment analysis review for the RWCU line break in the Filter/Demineralizer room of a Mark III containment is characterized by a need to assess and establish conservative modeling for phenomena associated with 1) the break up of subcooled and flashing liquid jets; 2) entrainment and de-entrainment rates for suspended liquid water; and, 3) two-phase pressure drop across vent pathways. Shown in Figure 1 are the thermodynamic boundary conditions for various coolant injections. In most scenarios involving primary system line ruptures the injection will begin with a flashing liquid release (a) and then transition from a flashing liquid (b) to a flashing two-phase (c) and finally to a vapor-vapor (d) release. In the case of the RWCU line break, a significant portion of the injection (first ~ 10 seconds) is from a subcooled liquid release followed by a flashing liquid release. For the flashing liquid release, the final condition is a vapor state in the containment, yet only a portion of the liquid flashes (pressure flash expansion option). Benchmarking and analysis of subcompartment events have typically been performed for only flashing liquid and higher energy releases. For some RWCU line breaks it is important to realize that 1) the injections are unique in that a large portion of the release is as subcooled liquid, and 2) the SRP [1] guidelines for review calculations are provided mainly for primary system line breaks and not the type of breaks that are characterized by large initial releases of subcooled liquid.

In this paper, phenomena associated with a particular RWCU line break which is discussed in light of a recent River Bend Station (RBS) request to utilize the GOTHIC code for subcompartment analysis using a drop/liquid conversion model. A number of CONTAIN subcompartment calculations are presented to demonstrate the range of break room peak pressures that may be encountered with this class of subcompartment analysis based on water entrainment, de-entrainment, and slip ratios in exit pathways. Additionally, the appropriate assumptions for a conservative assessment of the RBS RWCU line break in the Filter/Demineralizer room are summarized.

The recommendations for subcompartment analysis for highly subcooled injections, such as the RWCU line break, remain as stated in the CONTAIN qualification report[1] for subcompartment analysis, with the addition that water from liquid jets that does not flash should not be entrained into the break room atmosphere.

[1] CONTAIN Code Qualification Report/User Guide for Auditing Subcompartment Analysis Calculations, SMSAB-02-04, September 2002.

2 Phenomena

Shown in Table 1 is a list of phenomena that affect the break room pressure and also the pressure differential between the break room and the rest of containment. Note that this paper uses peak break room pressure as a safety criterion for the subcompartment analysis.[2] Because the time period for reaching peak pressure (and peak differential pressure) is short, and in lieu of a requirement for conservative analysis, the wall and pool components that would include phenomena associated with forced convection heat and mass transfer (condensation) is neglected. Entrainment of liquid however from wall and pool surfaces is included as part of the cell volume component.

The list includes phenomena or processes that occur throughout the injection period. The period however is realistically divided into to sub-periods that include 1) the subcooled liquid release phase (0-10 seconds) and 2) the flashing liquid release phase (10-60 seconds). These periods are indicated in the source injection, as shown in Figure 2. In this figure the horizontal line represents the saturated liquid water specific enthalpy at an initial pressure of ~ 1 atmosphere. Water enthalpy below this horizontal line represents subcooled liquid that will not flash; whereas, water enthalpy above the line corresponds to flashing liquid water.

Subcooled Liquid Release Phase

During the first ten seconds of the scenario, no vapor will be generated in the break room. The break room pressure will therefore remain essentially at atmospheric pressure. A small portion of the break room air will exit the room as liquid from the break partially displaces the air volume in the sump region.

The liquid entering the break room during the early period S_{sub} may be subject to partial atomization due to mechanical breakup of the liquid jet, Figure 3. However, since there is no vaporization that could generate significant gas flows within the break room, and due to the small size of the room, the jet core and any droplets formed may be assumed to impact surrounding structures (walls, tank, etc.) and drain and/or rainout rapidly onto the floor or sump of the room. It is noted that approximately 50% of the total water injected for the RWCU break scenario is from this subcooled liquid release. Therefore, the amount of water entrained into the break room atmosphere during the first 10 seconds of the RWCU injection would be considered minimal at the beginning of the flashing liquid release (t>10 seconds).

Flashing Liquid Release Phase

Following the subcooled liquid release, a portion of the *superheated* water will flash resulting in a vapor (steam) source S_{flash}^{vap} and an atomization of unflashed water S_{flash}^{liq} due

[2] The RWCU line break source is significant for raising the pressure in the break room but has an insignificant effect on containment pressure. Therefore the pressure differential between the break room and containment may be approximated simply as $\Delta P_{max} = P_{max}(breakroom) - P_{initial}$.

to flashing phenomena occurring within and on the surface of the liquid core of the injected jet, Figure 4. Shown in Figure 5 is an estimate of the partitioning of liquid and vapor for the injection based on a constant enthalpy expansion to the total pressure of the break room (pressure flash assumption in CONTAIN, i.e., safety relief valve injection option). As indicated, the portion of liquid that flashes goes from zero at ~ 10 seconds to x_{exit}~ 0.3 at about 30 seconds. For most cases involving flashing of liquid jets, the breakup of the unflashed liquid will be significant such that the Sauter mean droplet diameter (SMD) will be approximately < 100 μm. The vapor portion of the injection will generate gas circulation flows in the break room which may entrain a significant portion of the dispersed unflashed water droplets within the circulation flow. However, jet impaction on surrounding structures can significantly reduce this amount. And therefore jet impaction in the vicinity of the break, dependent on the break geometry and room obstructions, will significantly affect how much of the unflashed liquid will enter and remain in the cell free volume space.

Within the break room, droplets entrained in the flow may subsequently be deposited on wall or floor surfaces as a result of impaction and gravitation settling enhanced by coalescence. Additionally, liquid deposited on structures as a film and on the pool or sump water surface can be re-entrained into the gas flow provided that surface gas flows are relatively high (~ > 10 m/s) and directed along the surfaces. The characterization therefore of entrainment and de-entrainment by all the processes described is exceedingly complex for any arbitrary injection into a small room containing large amounts of equipment. Therefore, sensitivity analyses for the models involving these processes are required to ascertain the uncertainties in the safety criterion (peak pressure) in order to assure a conservative assessment.

The break room pressure will also be dependent on the rate of the gas mixture (air/steam) flow exiting the break room through the vent pathway(s). Due to the relatively high mass fluxes that are expected in subcompartment analyses (G > 1000 kg/s-m^2), and the small droplet sizes (normally characterized as a fog), the conservative practice has been to assume that the drag force on the particles due to the gas flow through the pathway is sufficiently large such that the flow is essentially homogeneous (i.e., with a slip ratio S = 1). Under such conditions the stagnant quality of the gas/steam/droplet mixture in the break room X_{st} is also the flow quality X in the vent pathway. The formula relating stagnant and flow quality is given as

$$\frac{1-X_{st}}{X_{st}} = \frac{1-X}{X} S \tag{1}$$

Shown in Figure 6 is the functional dependence of the flow quality with slip for various stagnation qualities. For a mass flux G_m through a vent pathway, the gas/steam mixture exit flow is X^*G_m; therefore, for a given mass flux, slip ratios much greater than S=1 (homogeneous flow) will result in significant increases in the gas/vapor flow rates with attendant reductions in break room pressure. Furthermore, as break room pressure increases during the injection, the potential for choking increases also such that at pressure ratios $P_{exit} / P_{upstream}$ of approximately 0.5 the exit flow is choked. The critical choked mass flux is dependent again on the slip ratio in the vent pathway. Accordingly for conservative analyses, a slip ratio S=1 (i.e., homogeneous flow) is utilized per SRP [1] recommendation.

3 Phenomena Modeling

Shown in Table 2 is the phenomena/process listing for the RWCU accident scenario with reference to the GOTHIC 7 models along with validation notes. A number of comments are in order to explain the GOTHIC model entries. First, entries in the table are restricted to the lumped-parameter calculation mode which necessarily eliminates momentum transport in cells and therefore a mechanistic determination of the gas velocity field within the free volume space. Further, the validation entries are based only on information provided in the GOTHIC qualification report [2].

Cell Internal Gas Velocity (Speed). The cell internal gas velocity appears as an independent variable in a number of correlations that determine droplet de-entrainment by wall impaction, entrainment rates for films and pool surfaces, jet mechanical breakup, and interfacial mass and heat transfer (droplet/gas). Due to the number of models dependent on internal gas flow, the method used to determine gas speed is considered important. Because 3-D nodalization of the cell volume is excluded (no momentum transport or shear) in the lumped-parameter mode, gas speed must be determined by an approximate formula. Cell gas speed (scalar parameter) is defined in the GOTHIC code as a volume averaging of vent pathway volume flows entering the cell free volume. Since the scalar velocity modeling method is of unknown accuracy, the method used to determine this quantity is of special concern. The entries in the validation columns of Table 2 for this process are "none." This characterization is made since there are no referenced measurements or discussions of the model equation for internal velocity (speed) in the qualification report for either SET or IET analysis.[3]

Additionally, for the break room, the implementation of the volume flow averaging equation for injections (which are not generally described using vent pathways), is unclear. In this regard, how the injection volume flow is characterized is not described in the GOTHIC technical manual. In this respect then, the entries for the cell volume component that are italicized indicate that the phenomenon entry is dependent on vent pathway input and modeling.

Entrainment. Models for entrainment of liquid water into the free volume space of a cell are based on empirical correlations. As empirical correlations, their usage may be limited by the data range used to develop the correlations. There are essentially no comments in the qualification report addressing issues involving limitations of the empirical correlations. As indicated under the validation columns, most of the correlations are not validated by the information provided in the GOTHIC qualification report; this apparently is either due to a lack of data on the primary quantity of interest (droplet size,

[3] Validation in this sense means that direct measurements of the parameter of interest (i.e., gas circulation speed) must be reported.

concentration, etc.) or a lack of information regarding key parameters on which the model is based (e.g., pool effective depth for entrainment, etc.).

De-entrainment. There are a number of phenomena associated with de-entrainment processes. The models for these processes are either empirical or analytical. The analytical models are simplified and therefore validation under accident type conditions is questionable. As with the entrainment models there is a minimum of SET/IET de-entrainment validation provided in the GOTHIC qualification report. One of the more important de-entrainment phenomena is direct jet impaction, as mentioned above. For this phenomenon there is only one IET set of data included; however, the data are limited to very low droplet concentrations corresponding to severe accident type of injection rates. Direct impaction modeling for lumped-parameter cells is parametric in that de-entrainment is not mechanistically calculated; rather, the de-entrainment depends on a tuning parameter "bend angle." Lack of data for impinging flashing jets in the qualification report for GOTHIC together with the limitation for the lumped-parameter representation of jets severely limits any validation of direct jet impaction modeling. Because it is believed that direct jet impaction significantly affects droplet size and concentration in the atmosphere, the lack of validation for jet impaction is a serious fault for the GOTHIC droplet/liquid conversion modeling in general.

Interfacial Drag. Separate field equations are solved in GOTHIC to determine phase mass fluxes in a vent pathway. The prediction of phase slip depends on the method used to determine interfacial drag between the phases. There are no SET data presented *in the qualification report* that validates the separate field modeling as implemented in the GOTHIC code. IET data from the HDR facility and the Battelle Model Containment (BMC) tests provide information on secondary quantities (pressures and pressure differentials), but no data are provided on the primary quantities of phase velocities in vent pathways. It should be noted however that instrumentation to obtain these velocities were included in the HDR test plan. Unfortunately, no reliable data were obtained from these instruments.

Critical Choked Flow. Essentially, all of the IET data involving two-phase flow between compartments during a simulated blowdown is for unchoked flows. As a result, the pressure differentials reported in the qualification report can not validate the critical flow models used in the GOTHIC code. Therefore, the analytical correlations (HEM) are validated only through verification that the correlations are implemented as described in the GOTHIC technical manual. Validation therefore relies on the acceptance of the HEM choked model, which appears to be an acceptable conservative method based on various test comparisons from a variety of sources not listed in the qualification report.

4 RWCU Line Break Accident

The discussion of the RWCU line break scenario focuses on four topical areas:

- Benchmarking
- Subcooled liquid entrainment
- Flashing liquid entrainment
- Vent pathway flow areas

(Except for the benchmarking exercise, the CONTAIN calculations reported below are for the SAR sources and vent pathways. The updated sources and new pathways referenced in the recent RBS submittal do not substantially affect the conclusions drawn from the results obtained using the SAR inputs.)

The CONTAIN input options that control simulations of jet entrainment (subcooled or flashing liquid) amounts and de-entrainment are listed in Table 3. In the cases involving partial entrainment of the liquid portion of the flashing jet (cases 6 and 7), the external atmospheric source is determined through a standalone analysis for constant enthalpy expansion to the break room pressure.

Benchmarking. Shown in Figures 7 and 8 are comparisons of the CONTAIN calculations for the RWCU line break in the Filter/Demineralizer room, with similar RBS code calculations performed with THREED (SAR) and GOTHIC 7 (new pathways and updated source), respectively. In the CONTAIN calculations, 100% entrainment of unflashed water is assumed, along with homogeneous flow through the pathways. Figure 7 shows that the CONTAIN and THREED code results are essentially identical. This confirms the original licensing basis and assumptions for entrainment and flow used in the RBS SAR. Figure 8 indicates that the CONTAIN results also compare favorably with GOTHIC calculations using updated break line sources and new vent pathways provided that the drop/liquid conversion model option is *not* used. Without the drop/liquid conversion model, the GOTHIC code appears to include models that force 1) 100% entrainment, and 2) homogeneous flow. Because the exit flows are choked in both the SAR and updated calculations (per CONTAIN result analysis), it would also appear that the critical choked modeling in all three codes, with S=1, are also similar. We note that the homogeneous frozen modeling (HFM) for critical choked flow in CONTAIN is scaled by input (recommended multiplier factor = 0.7) to approximate the homogeneous equilibrium model (HEM) used in both THREED and GOTHIC: the period of choking calculated by CONTAIN is shown in both Figure 7 and 8.

Subcooled liquid entrainment. The initial injection of subcooled liquid into the break room was assumed to have 100% water entrained into the free gas volume with no de-entrainment. Some breakup of the liquid jet could be expected due to mechanical or aerodynamic forces, but as noted above the assumption that 100% of the liquid is suspended would appear to be an overestimate, and nonconservative. Shown in Figure 9 are pressure profiles calculated assuming various entrainment amounts for the initial (10 second) injection of subcooled water. In these calculations, the liquid *flashing* jet, after

10 seconds, is assumed to be 100% entrained (as assumed in the benchmark exercise). These results from CONTAIN calculations show that peak pressure in the break room is very sensitive to the assumption of how much entrainment of the initial subcooled liquid water occurs.[4] From the discussion concerning subcooled liquid injections, it would be reasonable to select entrainment percentages significant below 100% for this early source of water. A conservative assumption would exclude subcooled liquid water as a possible entrainment source, locating this water into the sump of the break room.

Flashing liquid entrainment. Subsequent to the subcooled liquid injection, the enthalpy of the water is increased above the boiling point of water in the break room. Vaporization of water within the jet generates bubbles that aid in breaking up the jet, and forming small droplets (Sauter mean droplet diameters typically less than 100 μm). Since the vapor amounts are substantial, gas/steam mixture circulation flows within the break room will be relatively high such that some portion of the liquid droplets generated during the jet break up will be suspended. However, much of the unflashed liquid (as droplets and ligaments) will be removed from the atmosphere due to direct impaction of the jet with the surrounding structures. It seems reasonable that the net entrainment percentage for the unflashed liquid will be less than 100%. Shown in Figure10 are pressure profiles for various entrainment percentages for the unflashed liquid that is injected into the break room at times greater than 10 seconds. In the calculations, the subcooled liquid injected prior to 10 seconds is assumed to fall directly into the break room sump with no subsequent entrainment into the break room atmosphere. Clearly, as more unflashed liquid water is suspended, the peak pressure in the break room increases. This behavior of pressure increasing as a result of entrainment for flashing liquid jets is also confirmed for large scale liquid flashing tests such as the HDR tests V44 and T31.5.

In the above flashing liquid calculations, the unflashed liquid entrained into the atmosphere is assumed to remain suspended throughout the accident. Of course some liquid will be de-entrained by some of the processes listed in Table 1. Shown in Figure 11 is a sensitivity calculation assuming an initial 100% entrainment of unflashed liquid water with subsequent rapid dropout (removal of liquid water at end of timestep). The gas/vapor quality in the break room is shown in Figure 12. The increased quality for the case with essentially an infinite deposition rate effectively increases the gas/steam mass flux through the exit pathway according to $G_v = X_{st}*G_m$. The low quality for the ~ zero deposition rate significantly reduces the gas/steam flow and therefore increases the peak pressure calculated for the break room.

As we noted in the discussion on slip, if the slip ratio is increased the flow quality also increases. Therefore, at high slip ratios, the flow through the exit pathway is essentially all gas/steam. In CONTAIN, if the flashing liquid is injected into the break room atmosphere as an external water source along with liquid water aerosol generation, a simulation of near infinite slip ratio can be approximated. The infinite slip is effectively approximated since aerosol mass is not included in the homogeneous fluid density of gas/steam/aerosol mixture flowing through the pathway exit. By not including the

[4] Note that peak break room pressures above ~ 35.6 psia are above the design limit for the Filter/Demineralizer room (with the containment pressure remaining at initial pressure).

suspended liquid aerosol in the fluid density, an infinite slip ratio is simulated. Shown in Figure 13 is the pressure profile comparisons for 100% entrainment of unflashed liquid with liquid included in the fluid density ($G_v = X_{st}*G_m$), and the case with liquid excluded ($G_v = G_m$). The break room qualities, representing suspended water, are shown in Figure 14 (note: only for the case labeled "liquid suspension" is the quality factored into the calculation of gas/steam flow). Both methods have the suspended water in thermal equilibrium with the gas/steam mixture. It is interesting to note that the pressure profiles for aerosol suspension and the case with rapid dropout are essentially identical. These comparisons indicate that whether simulating rapid de-entrainment or ~ infinite slip ratio the cases result in similar break room pressures.[5]

Vent pathway flows. The exit pathway area for the Filter/Demineralizer room, referenced in the RBS SAR calculations, is 0.127 m^2 (1.4 ft^2). This vent area is quite small, and notably smaller than similar vents for Filter/Demineralizer rooms in some other Mark III containments (~ 1.4 m^2 or 15.1 ft^2). Shown in Figure15 is a comparison of pressure profiles for the 8 inch RWCU line break for various exit vent areas. As indicated in the figure, very modest peak pressures are shown for vent areas that approach the 1.4 m^2 vent exit area. Figure 16 shows the quality profiles in the break room calculated for these vent areas. Note that these calculations are performed with the subcooled liquid directed to the sump and 100% entrainment of unflashed liquid water with no de-entrainment in the break room. The vent flow is modeled as homogeneous flow.

5 Summary

Phenomena expected to occur in the Filter/Demineralizer room during a RWCU line break has been described. The list of phenomena has been related to GOTHIC models and the validation of those models, as indicated in the GOTHIC qualification report. In general, the validation of the complex phenomena and interaction of phenomena associated with droplet formation, entrainment, and de-entrainment in a break room has not been established for the conditions expected during RWCU line break events. Furthermore, the separate field modeling method used with the droplet/liquid conversion option in the GOTHIC code also does not appear to be validated for the highly subcooled injections that characterize the RWCU line breaks.

The CONTAIN code calculations for the RWCU line break, with equivalent assumptions regarding liquid water entrainment and flow modeling, have been benchmarked to the SAR THREED calculations and the more recent GOTHIC calculations for updated SAR sources and vent pathways.

[5] The aerosol sizes generated by nucleation are smaller than what may be generated by jet break up; therefore, we might expect a slight variation in the comparisons shown here if larges drops sizes had been used to simulate thermal non-equilibrium between drops and atmosphere. The effect however is believed to be insignificant for droplet diameters < 100 μm.

CONTAIN calculations using reasonable assumptions regarding entrainment of subcooled liquid jets, flashing jets, de-entrainment rates, and slip ratios for vent pathways have indicated that the conservative peak pressure (and also pressure differential) for the Filter/Demineralizer room is likely to be higher than the SAR values reported, and above design limits. It would appear that the RBS exit pathway area for the Filter/Demineralizer room at 0.127 m^2 is uncharacteristically too small. A more realistic pathway area for this relatively small room would likely result in peak and differential pressures that would be within the design limits of the break room. It is recommended that the original SAR peak pressure and differential pressure calculations for the RBS RWCU line break (and any subsequent calculations based on *full* entrainment of subcooled liquid releases) be re-evaluated in light of questionable assumptions regarding the early suspension of subcooled liquid water releases.

6 References

1. U.S. Nuclear Regulatory Commission Standard Review Plan, Section 6.2.1.2, NUREG-0800, Rev. 2, July 1981.
2. "GOTHIC Containment Analysis Package: Qualification Report," NAI8907-09 Rev 6, July 2001.
3. Witlox H. and Bowen P. J., "Flashing liquid jets and two-phase dispersion: A review," Health and Safety Executive Books (Contract Research Report 403/2002), Sudbury, Suffolk CO10 2WA, UK [HSE website: www.hse.gov.uk].
4. Park. B. S. and Lee S. Y., "An experimental investigation of the flash atomization mechanism," Atomization and Sprays, Volume 4, pp. 159-179, 1994.

Table 1. Phenomena Identification for RWCU Line Break in the Filter/Demineralizer Room	
Component	Description
Cell Volume [break room]	*Vapor/Gas circulation / velocity*, u_v
	Entrainment: γ_c
	Jet atomisation
	Mechanical breakup
	Flashing
	Film
	Pool
	De-entrainment: γ_d
	Gravity settling
	Impaction (walls)
	Impaction (jet)
	Coalescence, A_d
	Droplet Vaporization/Condensation, A_d
	Droplet Convection heat transfer
	Mist/drop formation, γ_m
	Nucleation
Vent pathway [from break room]	Interfacial drag, D_{uv}, D_{ud}
	Form/friction drag, K
	Critical flow, G_{choked}

Table 2. Identification of breakroom phenomena for lumped parameter modeling of sub-compartment accident events.

Component	Description	GOTHIC Model		
		Type	Validation Report	
			SET	IET
Cell Volume [breakroom]	*Vapor/Gas circulation / speed*, u_v	Approx. assumption	None	None
	Entrainment: γ_c	Empirical		
	Jet atomisation			
	Mechanical breakup		None	No data
	Flashing		Small jet	No data
	Film		Annular flow (small diameter tube)	No data
	Pool		None	No data
	De-entrainment: γ_d			
	Gravity settling	Analytical approx.	Correlation verification	None
	Impaction (walls)	Empirical	None	Limited range
	Impaction (jet)	Parametric	None	Parametric assessment
	Coalescence, A_d	Analytic approx.	None	None
	Droplet Vaporization/Condensation, A_d	HMTA	Free fall evaporation	Limited range
	Droplet Convection heat transfer	Analytic approx.	Free fall evaporation	None
	Mist/drop formation, γ_m	Parametric	None	None
	Nucleation	---	---	---
Vent pathway [from breakroom]	Interfacial drag, D_{uv}, D_{ud}	Empirical/single droplet	None	Limited range
	Form/friction drag, K	Input	---	---
	Critical flow, G_{choked}	Analytical (HEM)	Correlation verification	None

Table 3. Source and Entrainment/De-entrainment options for the CONTAIN calculations

Case No.	Simulation Type	Subcooled Jet (t<10 seconds) Source (Ext.)[a]	Subcooled Jet (t<10 seconds) Source (SRV)[b]	Subcooled Jet (t<10 seconds) De-entrainment[c]	Flashing Liquid Jet (t>10 seconds) Source (Ext.)	Flashing Liquid Jet (t>10 seconds) Source (SRV)	Flashing Liquid Jet (t>10 seconds) De-entrainment[c]
	Benchmark						
1	SAR (THREED)	S_{sub}	None	None	S_{flash}	None	None
2	Updated (GOTHIC)	S^{*}_{sub}	None	None	S^{*}_{flash}	None	None
	Subcooled						
3	0% entrainment	None	S_{sub}	None	S_{flash}	None	None
4	5%	$0.05S_{sub}$	$0.95S_{sub}$	None	S_{flash}	None	None
5	20%	$0.20S_{sub}$	$0.80S_{sub}$	None	S_{flash}	None	None
	Flashing Liquid						
6	5% entrainment	None	S_{sub}	None	$0.05S^{liq}_{flash}$	S_{flash}	None
7	30%	None	S_{sub}	None	$0.30S^{liq}_{flash}$	S_{flash}	None
8	100%	None	S_{sub}	None	S_{flash}	None	None
9	Rapid de-entrainment	None	S_{sub}	None	S_{flash}	None	dropout
10	Water aerosols	None	S_{sub}	None	S_{flash}	None	aerosol (NAC=1)
	Vent Pathways						
11		None	S_{sub}	None	S_{flash}	None	None

a External atmospheric source [thermal equilibrium; i.e., temperature flash]

b Safety Relief Valve source [pressure flash – with premixed dropout of liquid to sump]

c None is default [atmospheric liquid remains in atmosphere, with liquid added to atmospheric density]
dropout [removal to atmospheric liquid at end of timestep, after thermal equilibrium mixing (i.e., saturation)]
aerosol [water aerosols by homogeneous nucleation, water aerosol mass not included in atmospheric density]

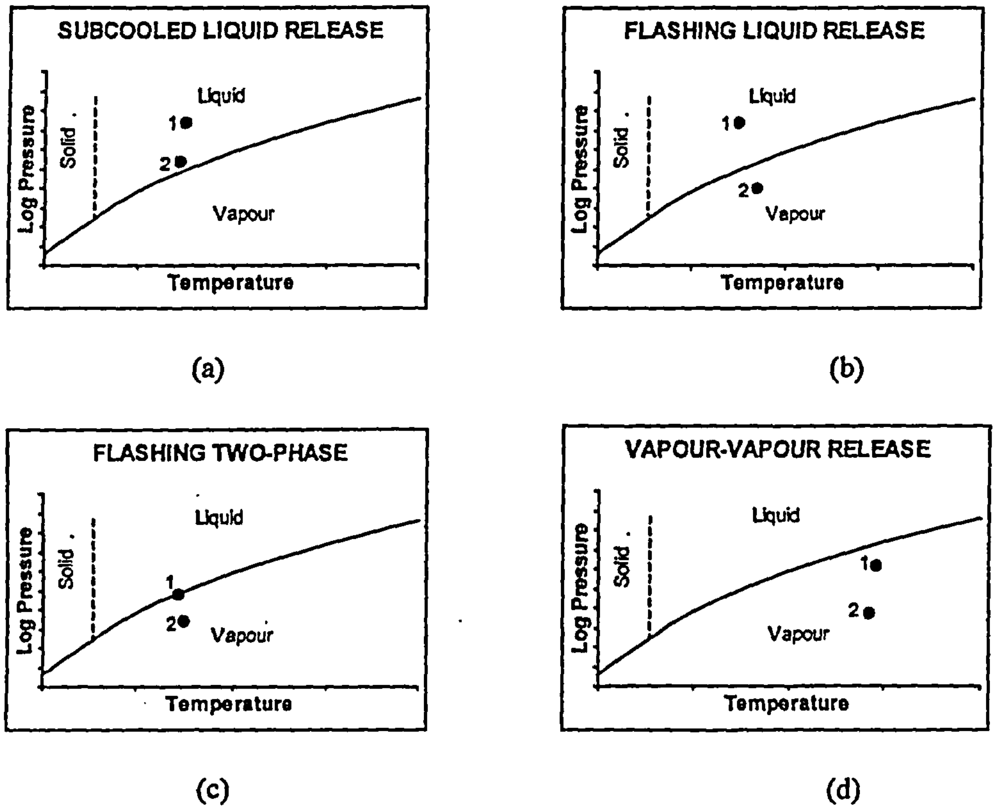

Figure 1 Thermodynamic boundary conditions in relation to saturated conditions [3]; point "1" refers to the initial liquid stagnation condition or far upstream condition, and point "2" refers to the atmospheric condition beyond the break exit.

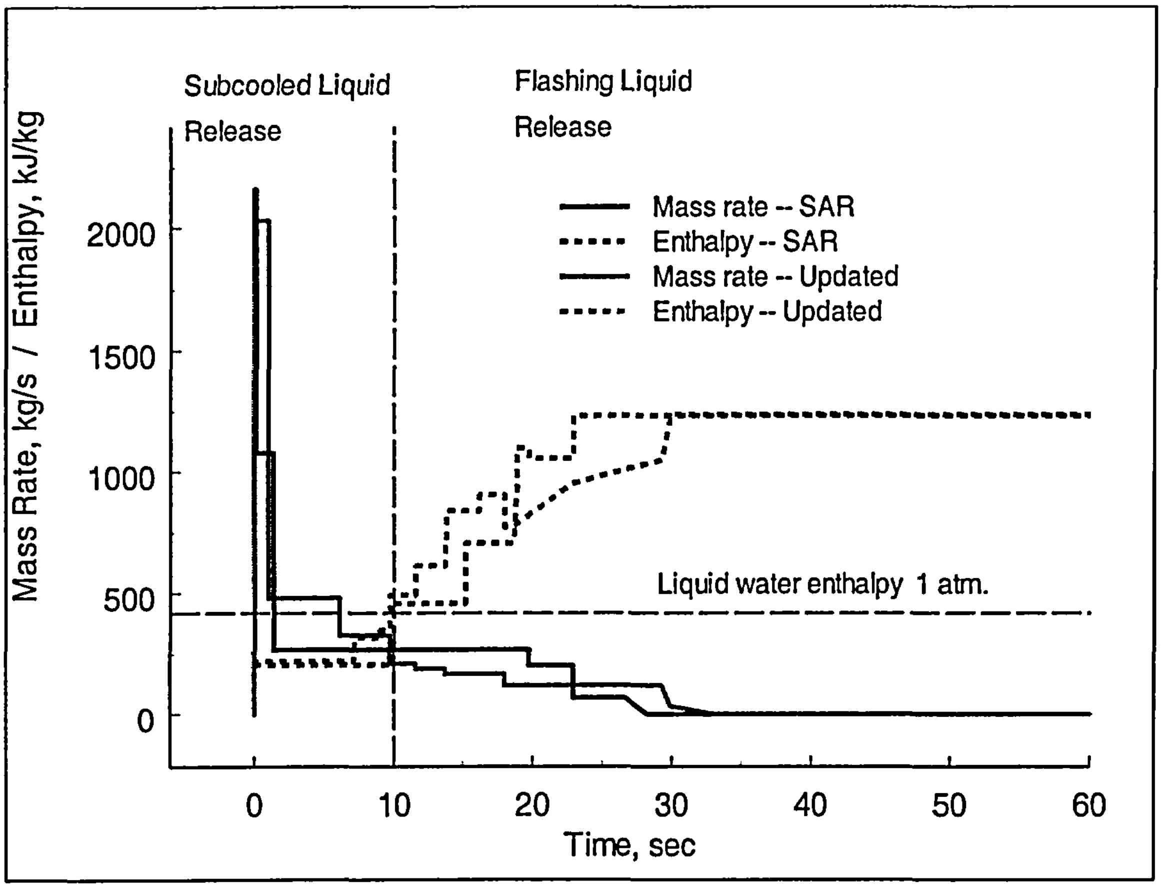

Figure 2 RWCU line break water source for the RBS filter/demineralizer room.

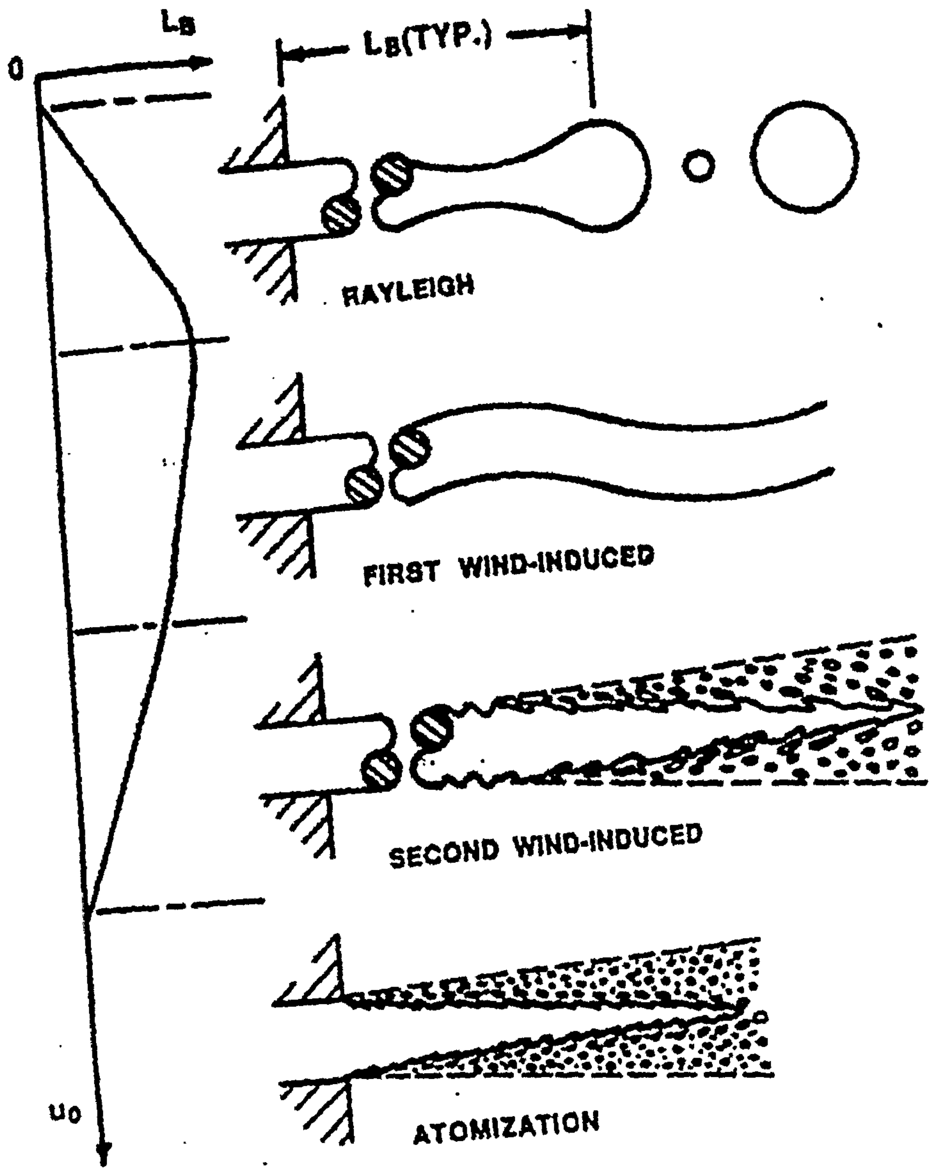

Figure 3 Mechanical jet-break-up regimes [3].

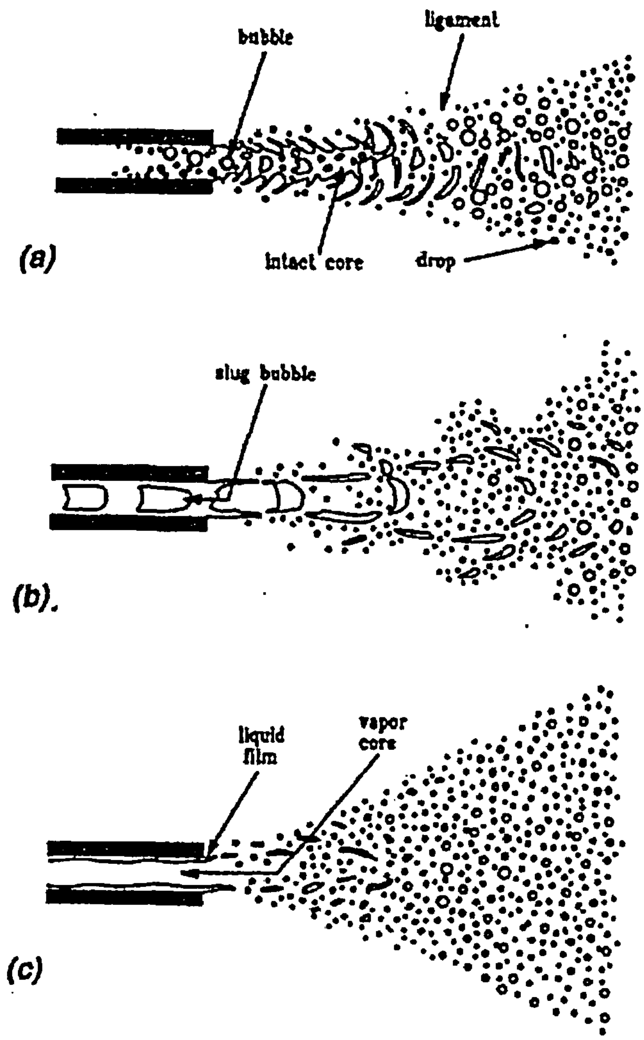

Figure 4 Dependence of spray characteristics on upstream flow conditions [4].

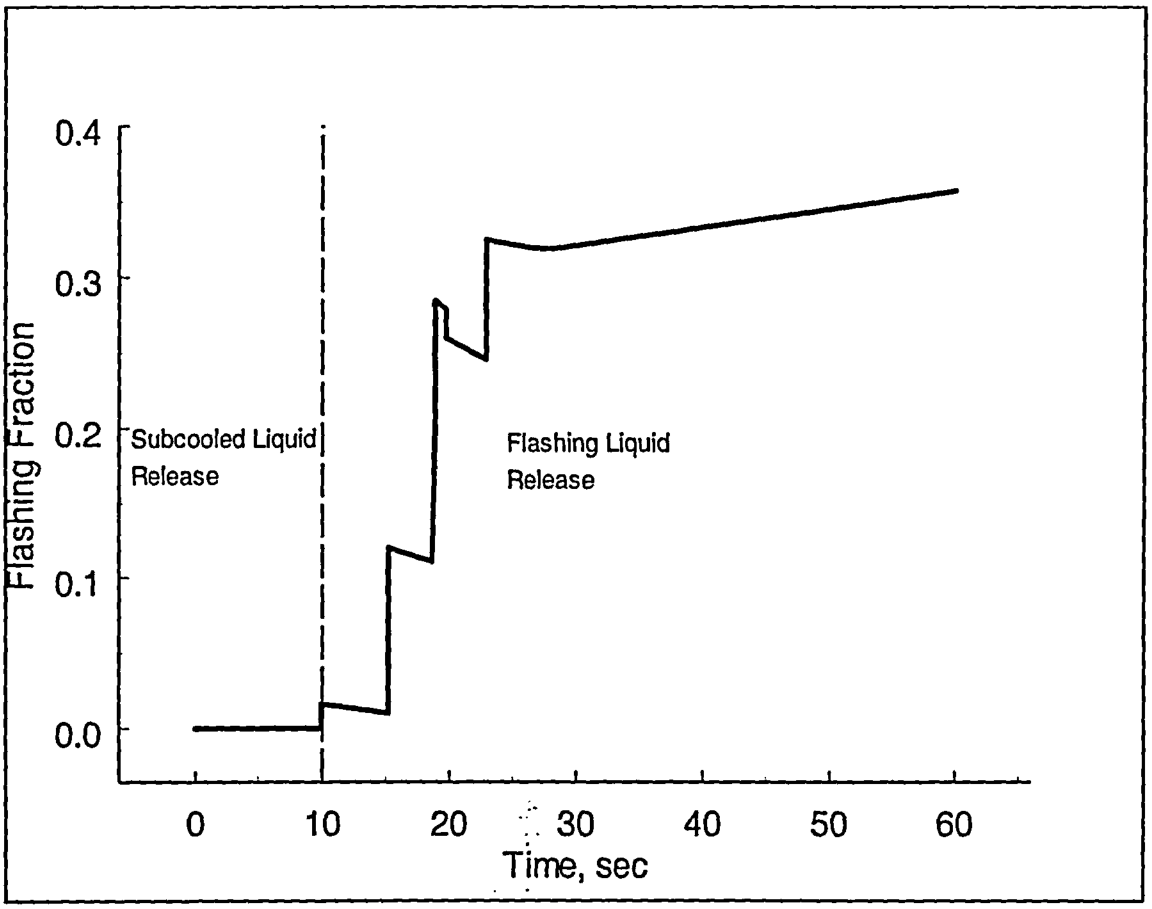

Figure 5 Flashing fraction (pressure flash) for RWCU break [RBS SAR].

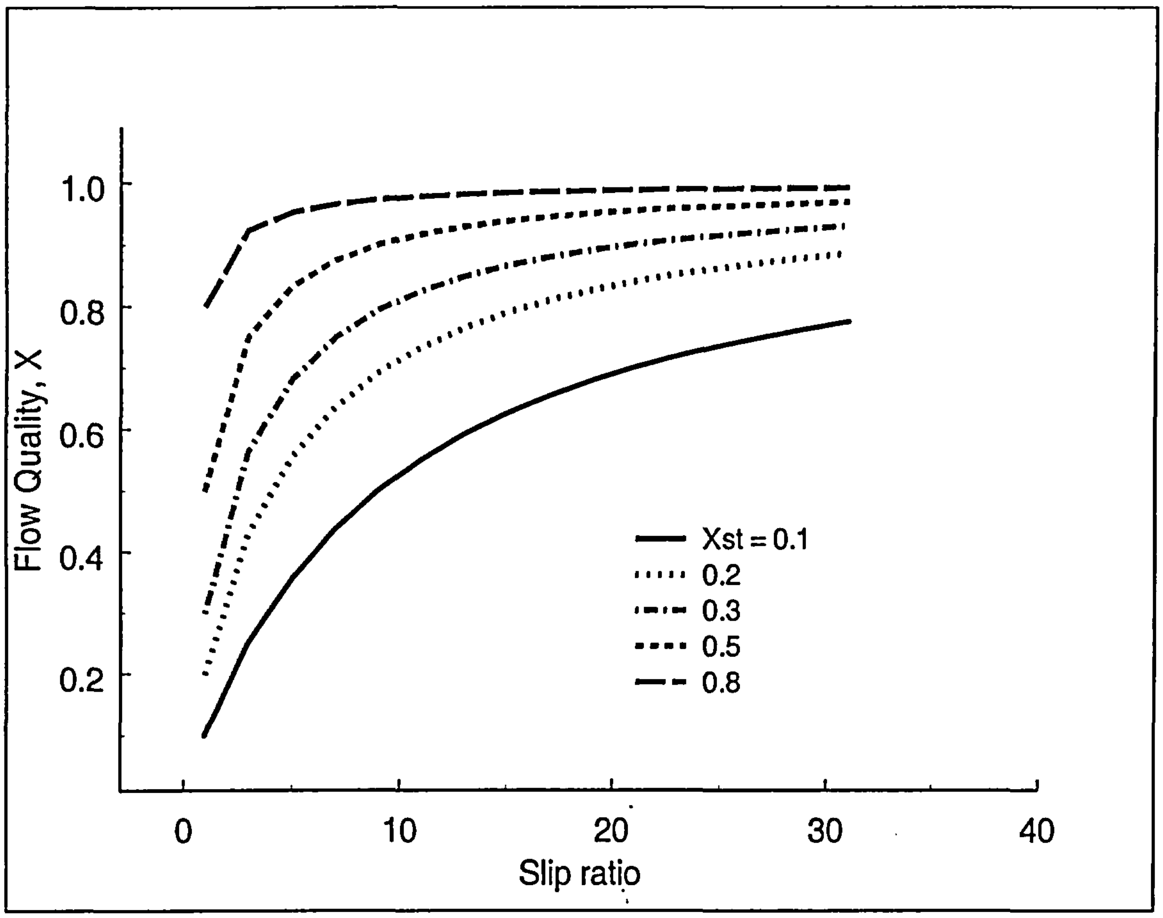

Figure 6 Relationship between flow qualities and slip ratio for various stagnation qualities.

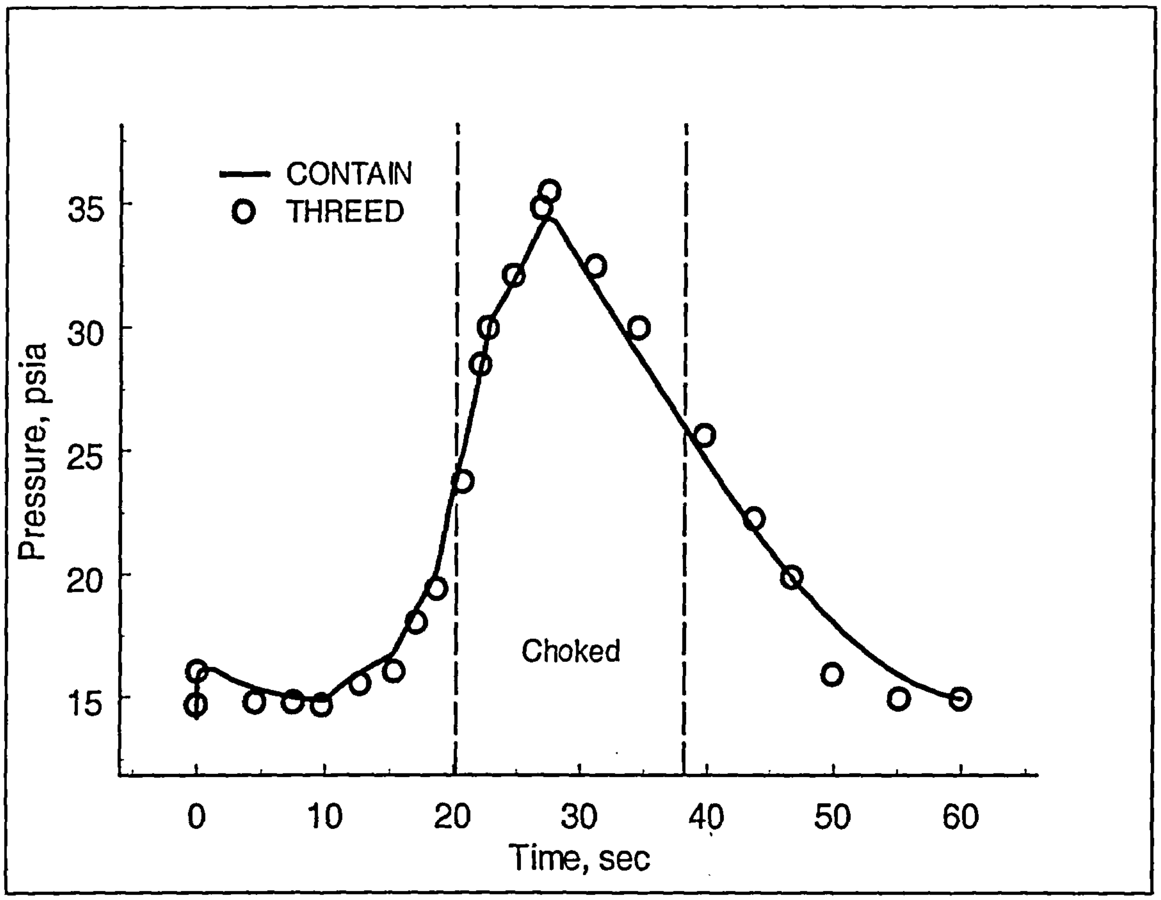

Figure 7 Pressure calculations in the filter/demineralizer room for the 8 inch RWCU line break [SAR injection sources and SAR vent pathways].

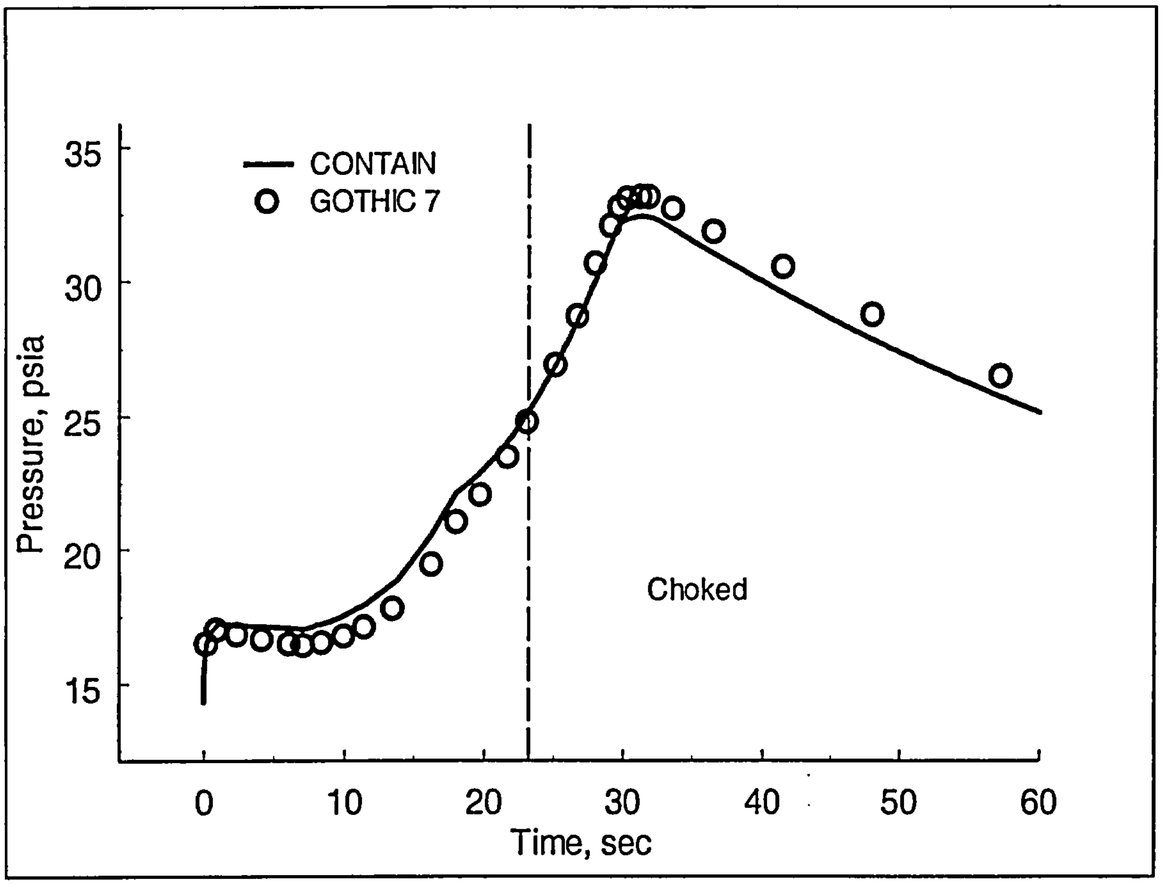

Figure 8 Pressure calculations in the filter/demineralizer room for the 8 inch RWCU line break – GOTHIC calculation without droplet/liquid conversion option [updated SAR injection sources and new vent pathways].

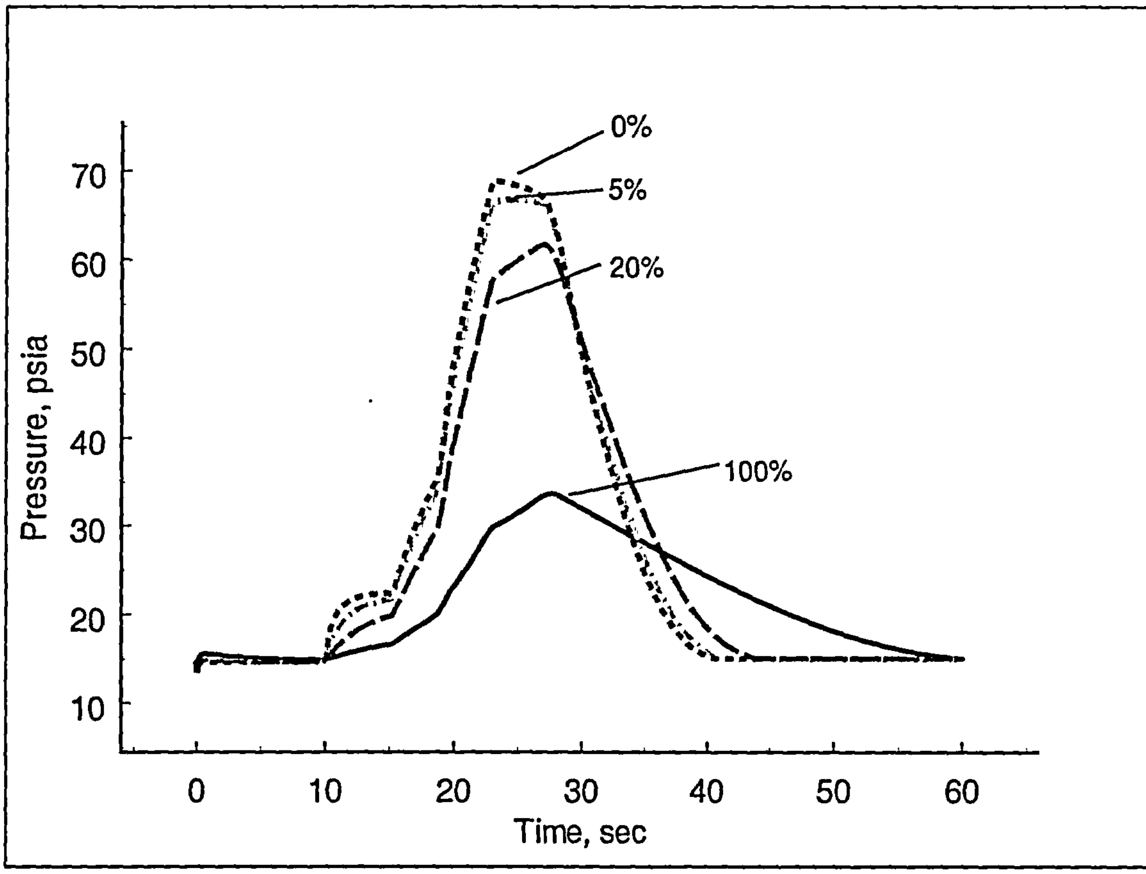

Figure 9 Break room pressure sensitivities for various subcooled liquid entrainment percentages for the 8 inch RWCU break in the filter/demineralizer room.

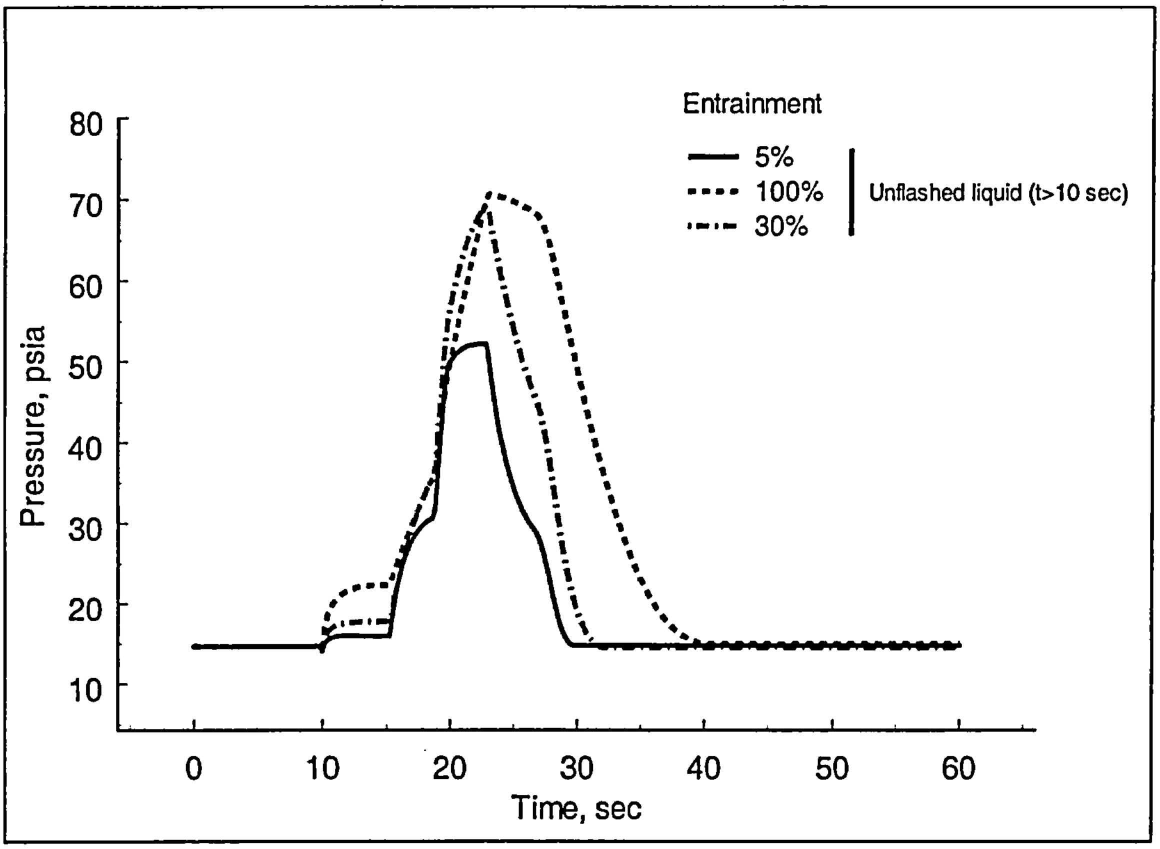

Figure 10 CONTAIN calculated filter/demineralizer room pressure for 8 inch RWCU line break using SAR water sources and pathways. Water injection prior to 10 seconds (subcooled liquid) is assumed to be transferred directly to the room sump.

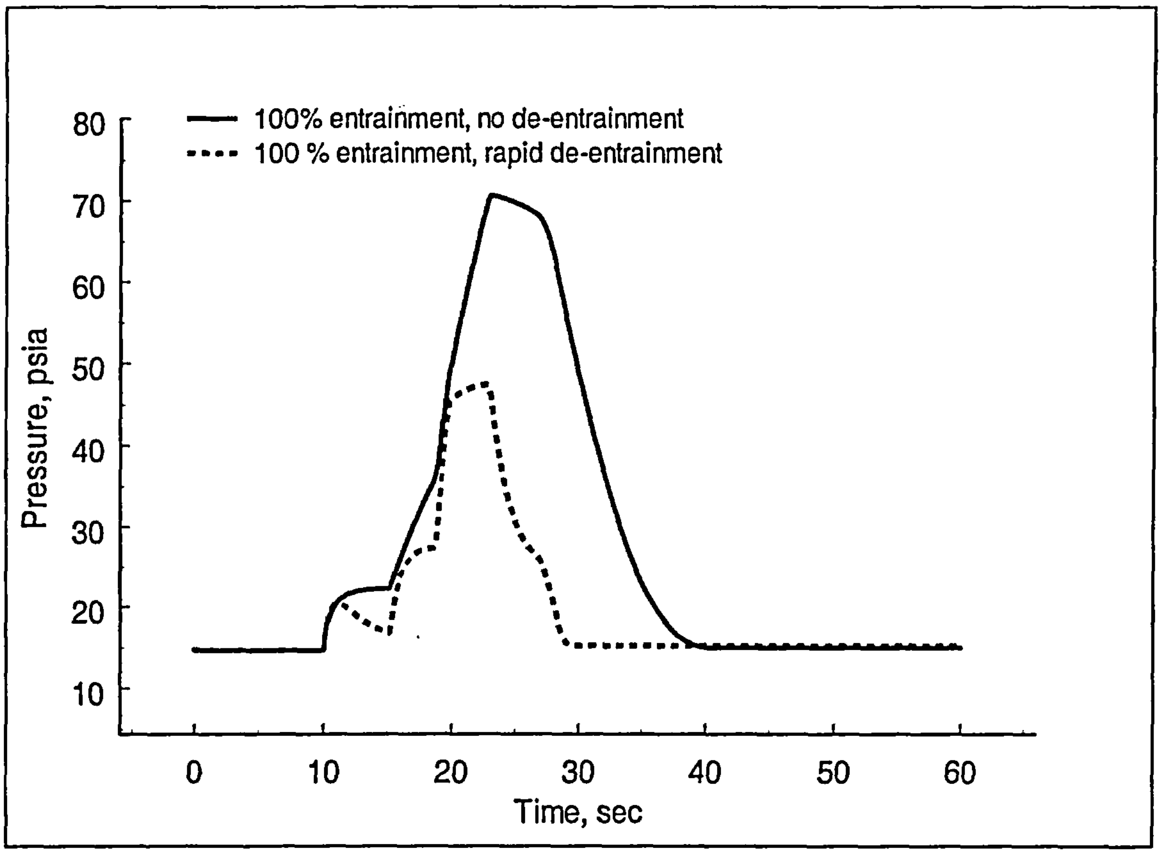

Figure 11 Sensitivity of break room pressure for 8 inch RWCU line break to de-entrainment of unflashed liquid water injected after 10 seconds.

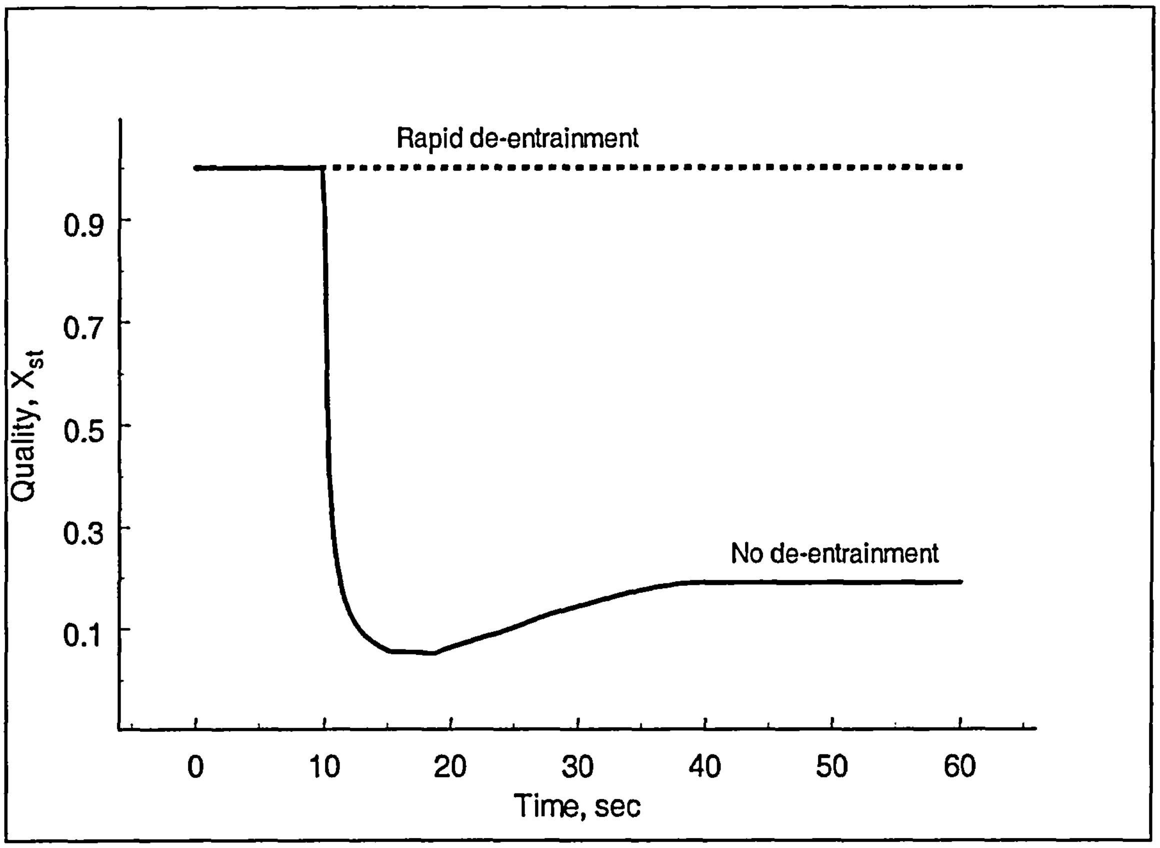

Figure 12 Break room qualities for 8 inch RWCU line break showing the effect of two de-entrainment extremes for unflashed liquid water injected after 10 seconds.

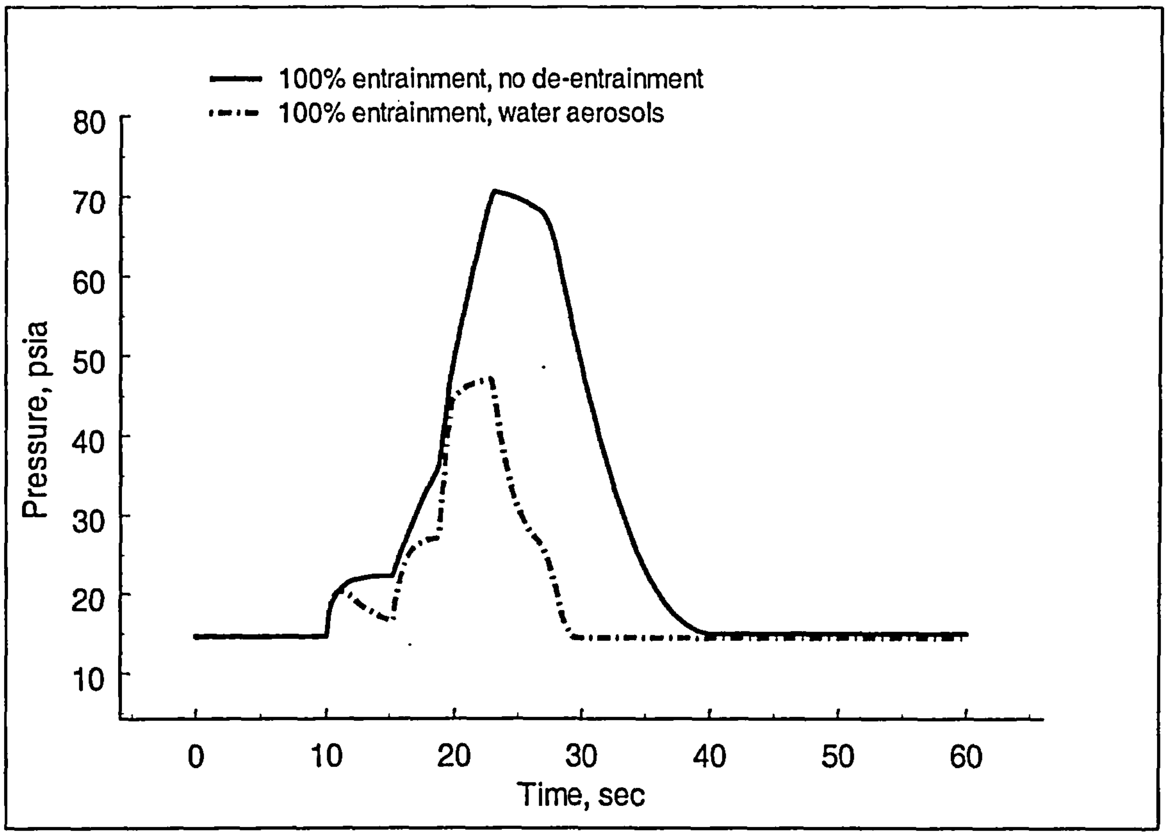

Figure 13 Sensitivity of break room pressure for 8 inch RWCU line break to slip ratios. The solid line represent the case with homogeneous flow, S=1. The dash-dot line corresponds to a simulation of near infinite slip ratio.

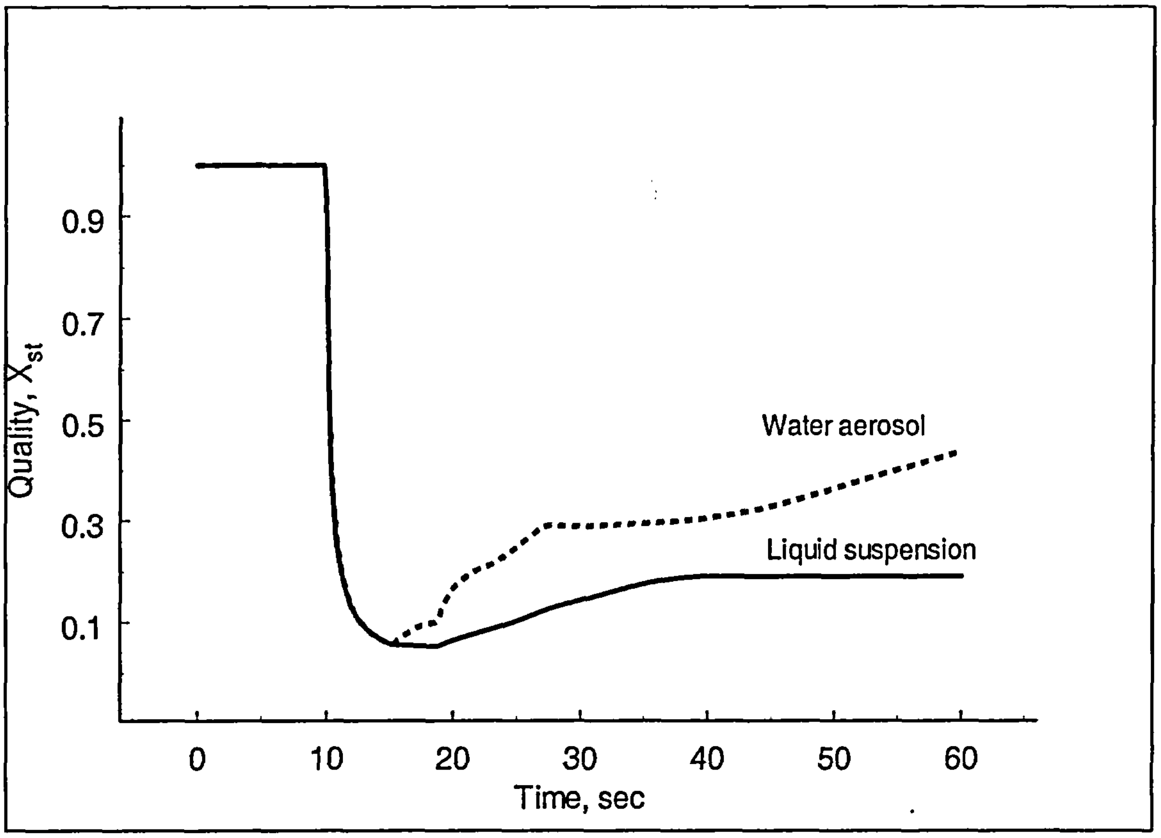

Figure 14 CONTAIN calculated qualities for 8 inch RWCU break for assumptions regarding the treatment of suspended water.

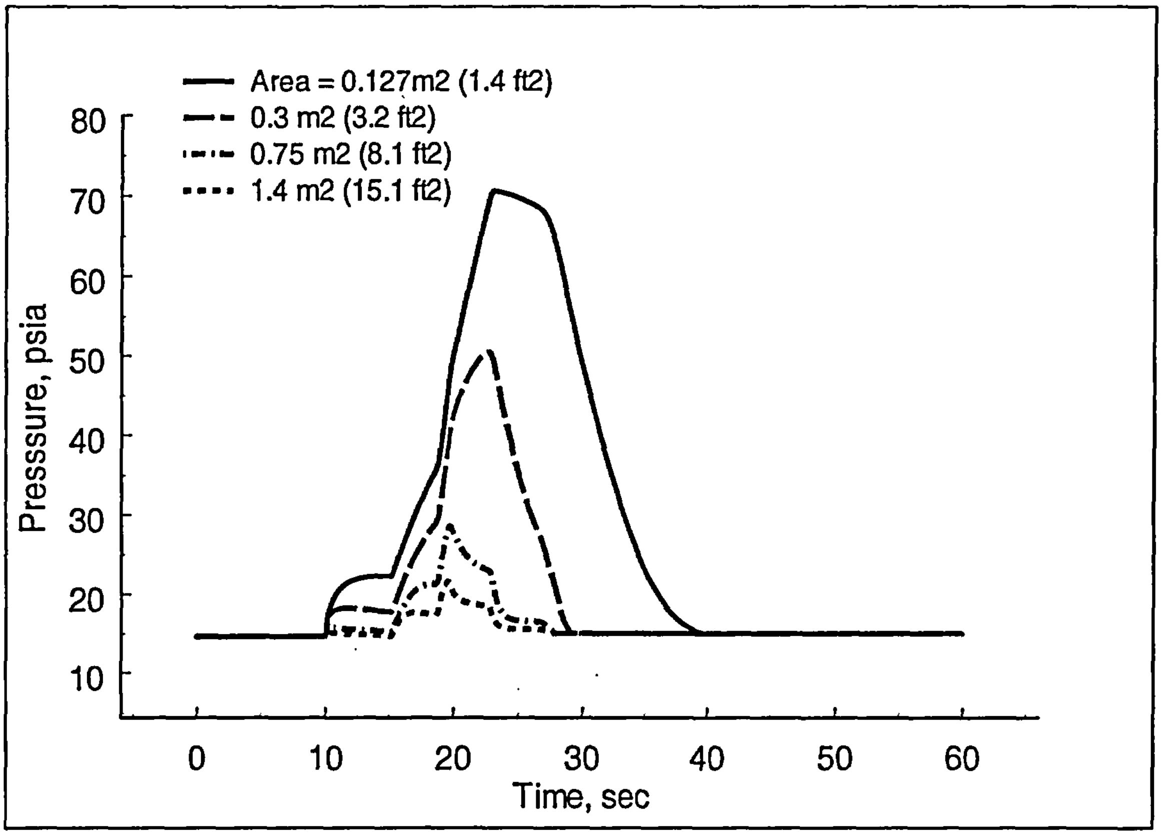

Figure 15 Sensitivity of pressure profiles to exit pathway area for the filter/demineralizer during an 8 inch RWCU line break (SAR sources and pathways).

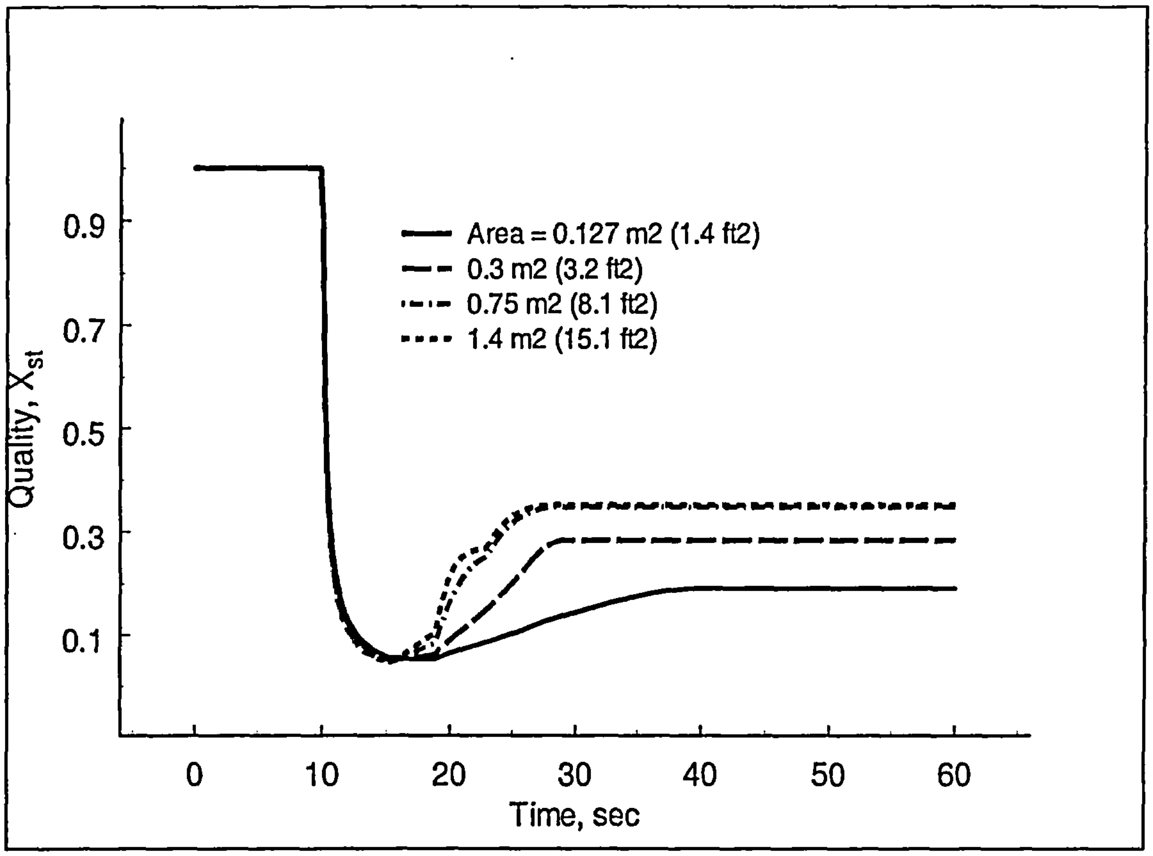

Figure 16 Sensitivity of quality profiles to exit pathway area for the filter/demineralizer during an 8 inch RWCU line break (SAR sources and pathways).