NUREG/IA-0096
AEA-TRS-1050
AEEW-R2501

International Agreement Report

Numerics and Implementation of the UK Horizontal Stratification Entrainment Off-Take Model Into RELAP5/MOD3

Prepared by
W. M. Bryce

Physics and Thermal Hydraulics Division
AEA Thermal Reactor Services
Winfrith Technology Centre
Dorchester, Dorset
DT2 8DH, United Kingdom

Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

June 1993

Prepared as part of
The Agreement on Research Participation and Technical Exchange
under the International Thermal-Hydraulic Code Assessment
and Application Program (ICAP)

Published by
U.S. Nuclear Regulatory Commission

Available from

Superintendent of Documents
U.S. Government Printing Office
P.O. Box 37082
Washington, D.C. 20013-7082

and

National Technical Information Service
Springfield, VA 22161

NUREG/IA-0096
AEA-TRS-1050
AEEW-R2501

International Agreement Report

Numerics and Implementation of the UK Horizontal Stratification Entrainment Off-Take Model Into RELAP5/MOD3

Prepared by
W. M. Bryce

Physics and Thermal Hydraulics Division
AEA Thermal Reactor Services
Winfrith Technology Centre
Dorchester, Dorset
DT2 8DH, United Kingdom

Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

June 1993

Prepared as part of
The Agreement on Research Participation and Technical Exchange
under the International Thermal-Hydraulic Code Assessment
and Application Program (ICAP)

Published by
U.S. Nuclear Regulatory Commission

NOTICE

Numerics and Implementation of the UK Horizontal Stratification Entrainment Off-take Model Into RELAP5/MOD3

W M Bryce

SUMMARY

RELAP5/MOD3 is a computer code for the the analysis of fault transients in light water reactor systems. It has been subject to an international development exercise.

Among the fault transients which can be analysed using RELAP5/MOD3 is a loss-of-coolant accident (LOCA) in a Pressurised Water Reactor (PWR), in which a small break occurs in one of the large diameter horizontal pipes forming the reactor inlet or outlet legs. In this situation the steam and water in the pipe may separate to form a liquid level. The quality of fluid discharged from the break (proportion of the mass flow which is steam) then depends on whether the break is above or below the liquid level. RELAP5/MOD3 contains a special model to calculate discharge from an off-take connected to a large diameter horizontal pipe in which there is stratified flow, referred to as the horizontal stratification entrainment (HSE) model. Apart from small break LOCAs, such a model is also needed for analysing other abnormal conditions in PWRs.

Early in its development, the RELAP5/MOD3 HSE model was the same as that of the RELAP5/MOD2 code. This was assessed by Ardron and Bryce [1] who found that the model tended to under-predict significantly the discharge quality in many cases. They selected improved correlations for the off-take quality and implemented them in a modified version of RELAP5/MOD2 Cycle 36.04. The modified code was shown to give much improved agreement with separate effects test data.

This report describes the numerics and implementation details for the modification of RELAP5/MOD3 to use the same improved correlations. These details include the areas where the use of the HSE correlation set are extended outside of its range. The modifications, which were incorporated into pre-release code version 411, have been retained in the first "frozen" release of the code (version 5m5). Areas where changes have been made by EG&G in producing the release version which might affect the modelling are noted in the section on programming details. Particularly noteworthy is the restriction which apparently excludes the full control of the HSE model at the internal junctions of PIPE components.

A simple test problem is used to verify the RELAP5/MOD3 coding of the correlations, making use of the control system logic. This problem, run using the release code version, also

demonstrates that this version seems to be more prone to instability than the pre-release version 411. The problem is not believed to be associated with the HSE model.

Physics and Thermal Hydraulics Division
Winfrith Technology Centre

March 1991

Contents

List of Figures

Notation

A area (m^2)
C constant in Equation (5)
d diameter of off-take pipe (m)
D diameter of main pipe (m)
g acceleration due to gravity (m/s^2)
G mass flux ($kg/m^2/s$)
h "height" of liquid level in main pipe with respect to centre of the off-take pipe entrance (m)

For a top off-take this is the distance of the liquid level from the top of the pipe cross-section

For a side off-take this is the distance of the liquid level above the off-take centre, it is negative if the liquid level is below the centre

For a bottom off-take this is the distance of the liquid level above the bottom of the pipe cross-section

h_b critical value of h at which entrainment or pull-through commences (m)
K empirical constant in Equation (1)
p pressure (MPa)
R non-dimensional height ($= h/h_b$)
S slip ratio ($= v_g / v_f$)
S^* modified slip ratio
v velocity (m/s)
w width of stratified liquid surface in pipe (m)
W mass flow-rate (kg/s)
x quality ($= W_g / W$)
$\bar{X}$ static quality ($= \alpha_g \rho_g / \rho$)
x_0 reference quality defined after Equation (4)
α volumetric concentration or area fraction
ϕ angle used in Equation (12)
ρ density (kg/m^3)
$\Delta\rho$ density difference ($= \rho_f - \rho_g$)

Subscripts

c associated with choked flow
f property of liquid phase
g property of gas phase
j property of junction between main pipe and off-take pipe
k property of continuous phase
K property of donor volume

Superscripts

n an old timestep value
P an intermediate value
(1) an intermediate value
* an intermediate or modified value

1. INTRODUCTION

When a gas-liquid mixture discharges from a large diameter horizontal pipe into a small diameter off-take branch, the discharge flow quality depends on the liquid level in the main pipe. If the entrance to the off-take branch is submerged, the discharge flow is mainly liquid which may contain an entrained gas component. If the entrance is above the liquid level, the discharge is predominantly gas, which may contain an entrained liquid component.

The necessity for modelling this situation has been discussed previously [1]. Also, the RELAP5/MOD2 model to compute the quality discharged into a small off-take pipe when there is stratified flow in the main pipe (so called 'horizontal stratification entrainment (HSE) model') was assessed. The model was found to have a tendency to under-predict significantly the discharge quality over a wide range of conditions. An alternative set of discharge quality correlations were included in a modified version of RELAP5/MOD2 and shown to give considerably improved agreement with separate effects data.

This Report presents the numerics and implementation details to add the same improved discharge quality correlations into RELAP5/MOD3. In the light of experience with the modified RELAP5/MOD2 code, some of the numerics has been slightly changed for RELAP5/MOD3. The description is quite detailed in order to facilitate change by some future code developer. A simple test calculation was performed to confirm the coding of the correlations implemented in RELAP5/MOD3.

2. OFF-TAKE DISCHARGE QUALITY CORRELATION SET

To aid clarity, the correlation set used is repeated below. The reasons for its choice and the references to the originators are given in [1]. First there are correlations for the critical depth for entrainment and then correlations for the off-take discharge quality.

2.1. Critical Depth for Entrainment

The critical liquid height or depth h_b is a function of the off-take conditions. Its correlation has the same form for all orientations:

$$h_b = KW_k^{0.4}/(g\rho_k\Delta\rho)^{0.2} \tag{1}$$

where k refers to the 'continuous' phase, which is the gas phase for an upward branch, the liquid phase for a downward branch. For a horizontal side-branch, k is the gas phase when the liquid level is below the nozzle centre, and the gas phase otherwise. The values of K chosen are:

VERTICAL UPWARD BRANCH	K = 1.67	(2)
VERTICAL DOWNWARD BRANCH	K = 1.50	
HORIZONTAL SIDE BRANCH	K = 0.75: gas entrainment	
	K = 0.69: liquid entrainment	

2.2. Discharge Flow Quality

The correlations for discharge quality are given below according to off-take orientation. In these expressions R is the non-dimensional height of liquid level in the main pipe with respect to the centre of the off-take pipe entrance and is defined in the Notation:

2.2.1. Vertical Upward Branch

$$x = R^{3.25(1-R)^2} \tag{3}$$

2.2.2. Vertical Downward Branch

$$x = x_0^{2.5R}\left[1-0.5\,R(1+R)x_0^{(1-R)}\right]^{0.5} \tag{4}$$

where

$$x_0 = 1.15/(1+\sqrt{\rho_f/\rho_g})$$

2.2.3. Horizontal Side Branch

$$x = x_0^{(1+CR)}\left[\ 1-0.5\ R(1+R)x_0^{(1-R)}\ \right]^{0.5} \tag{5}$$

where

$$x_0 = 1.15/(1+\sqrt{\rho_f/\rho_g})$$

and

$$C = \begin{cases} 1.09 \text{ for gas entrainment} \\ 1.00 \text{ for liquid entrainment} \end{cases}$$

For this case R is negative if the liquid level is below the main pipe centre.

3. EXTENSIONS OF THE CORRELATIONS

The correlations for off-take discharge quality are based on simple experimental situations whereas RELAP5 is a general purpose code and may have flow conditions different to the experiments. For example the main pipe flow may not be low or the off-take may have counter-current flow. All such aspects have to be allowed for in the implementation and are considered below.

3.1. High Flow-rate Limit

In the current RELAP5/MOD3 HSE model, homogeneous discharge conditions (that is normal donoring) are assumed in flow regimes other than stratified flow. This assumption fails to recognise that partial separation of the phases occurs in the slug, plug and annular flow regimes, in horizontal flow. As stated in [1], this is allowed for by applying the HSE model to all horizontal flow regimes except dispersed flow, which is assumed to be entered when $G > 3000$ kg $m^{-2}s^{-1}$. A linear interpolation zone is defined between $G = 2500$ kg $m^{-2}s^{-1}$ and $G = 3000$ kg $m^{-2}s^{-1}$ in which the void fraction transitions from the value calculated from the quality given by the HSE correlations, to the donored value. The expression used for the mass flux G in this case is given below:

$$G = \mathrm{Max}\left[\alpha_{gK}\rho_{gK}|v_{gK}| + \alpha_{fK}\rho_{fK}|v_{fK}| \;,\; (\alpha_{gj}{}^{n}\rho_{gj}v_{gj}+\alpha_{fj}{}^{n}\rho_{fj}v_{fj})\,A_j\,/A_K \right] \tag{6}$$

This choice should suppress the HSE off-take model if there is high flow anywhere in the upstream volume.

3.2. Extreme Voids

The interpolation factor introduced in the previous section is reduced towards zero (such that the donor value for the off-take conditions is used) linearly if either of the phase area fractions (gas and liquid) of the donor volume approach zero. The boundaries of the two transition regions are

$$\left.\begin{aligned} &\alpha_{gK} = 10^{-5} \\ &\text{and} \\ &\alpha_{fK} = \mathrm{Max}\left[2*10^{-7} \,,\, \mathrm{Max}\left[2*10^{-4} \,,\, 2*10^{-3}\rho_{gK}/\rho_{fK} \right] \right] \end{aligned}\right\} \tag{7}$$

In the above equation, the subscript K denotes the upstream volume according to the phase flowing from the horizontal volume. These particular void limits are based on those used in the code flow regime package. These limits imply, for example, that if the donor volume gas fraction α_{gK} has the value $5*10^{-6}$ then the interpolation factor is halved.

3.3. Allowing for Slip at the Take-off Junction

The correlations given above specify the flow quality in the off-take branch. RELAP5 requires the void fraction of the flow in the off-take. A desired flow quality can be obtained indirectly by converting the quality to a void fraction using a modified slip ratio as below:

$$S^*_j = \mathrm{Max}\left[\, 1.0\ ,\ \mathrm{Min}\left[\, \mathrm{Max}\left[\, \rho_{fj}/\rho_{gj}\ ,\ 10^{-7}\right]^{0.5},\ \frac{|v_{gj}|}{|v_{fj}|}\right]\right] \qquad (8)$$

The modifications in this expression restrict the range of slip ratio and use absolute velocities to maintain a finite positive result even when the flow becomes counter-current (this state is discussed further below) and to avoid discontinuities. The limits are arbitrary but are expected to be reasonable in most situations. In most cases S^*_j will be the actual junction flow slip ratio. (The release version 5m5 of RELAP5/MOD3 now has a junction flow quality defined but this extension has not been altered).

3.4. Allowing for Counter-Current Flow at the Off-Take Junction

For co-current off-take flow either α_g or α_f is calculated from the correlations as described above and manipulated into a junction value α_{gj} or α_{fj}. The other phase junction area fraction is obtained by requiring that the phase area fractions sum to unity.

For counter-current off-take flow the correlations are definitely outside their range of validity. However the code can enter this state. It was decided to use an ad hoc extension of the HSE model with the objective of minimising discontinuities in phase flow rates when the other phase off-take flow reverses. The junction phase area fractions calculated by RELAP5 in the absence of an HSE model do not normally sum to unity for counter-current off-take flow. Thus summing to unity was not taken as an objective. The ad hoc extension model is outlined below.

In this HSE extension model for counter-current flow, the gas area fraction is calculated on the basis of gas upwind conditions and the liquid area fraction is based on liquid upwind conditions, in line with the normal code practice. If the upwind volume for a phase is horizontal then the HSE correlations will be used for that phase. However four abnormal states may arise due to the flow being counter-current:

(a) A gas flow from above the liquid level which could entrain liquid except that the liquid flows the opposite way.

(b) A liquid flow from below the liquid level which could pullthrough gas except that the gas flows the opposite way.

(c) A gas flow from below the liquid level which would normally be pulled through by a liquid flow except that the liquid flows the opposite way.

(d) A liquid flow from above the liquid level which would normally be entrained by a gas flow except that the gas flows the opposite way.

For case (a)/(b) the reverse flow is ignored (the flowrate of the non-continuous phase does not appear in the correlations) and the gas/liquid area fraction calculated from the correlations. Cases (c) and (d) would not be expected to occur frequently. A fixup is required that will not introduce large discontinuities at phase flow reversals or when the level crosses a side off-take. For case (c)/(d) the gas/liquid area fraction is calculated from the correlations as if the liquid/gas flowrate was outwards but at the limit of zero. Thus there should be no discontinuity at phase flow reversals. For side off-take, at a void fraction of 0.5 in the horizontal volume Equation (5) gives a quality that is independent of flowrates so there is no discontinuity as the level passes the off-take for counter-current flow.

The RELAP5/MOD2 model has a partial implementation of this procedure. It fails to deal with two cases both involving two horizontally stratified volumes connected by a small orifice with counter-current flow. The two cases are where the orifice junction has been marked as an upward oriented off-take junction or a downward junction. In the first case the liquid is just given a donor calculated area fraction. Similarly in the second case the gas is given a donor value.

3.5. Treatment of Side Off-Take of Non-Negligible Area

The horizontal stratification entrainment model in RELAP5/MOD2 contains coding for treating the case where the liquid level in the main pipe is between the elevations of the top and bottom of the side branch entrance. The procedure used ensures that the junction void fraction tends to the void fraction in the main pipe when the side branch area tends to the area of the main pipe. Essentially there is an interpolation between the HSE model value and the donor value of void fraction. Virtually the same procedure is used in the implementation of the HSE model of [1] into RELAP5/MOD3.

To illustrate the procedure, consider the case where the liquid level is **above** the centre of the off-take branch ($\alpha_{gK} < 0.5$). Let α^*_g be the void fraction at which the liquid level would be at the elevation of the top of the side branch and let α^c_g be the void fraction calculated from the pull-through correlation. Then the liquid area fraction resulting from the procedure is calculated from the equations

$$\left.\begin{array}{ll} \alpha_f = 1-\alpha^c_g & \alpha^*_g \geq \alpha_{gK} \\ \alpha_f = 1-\left[\left\{\dfrac{\alpha^*_g}{\alpha_{gK}}\right\}\alpha^c_g+\left\{1-\dfrac{\alpha^*_g}{\alpha_{gK}}\right\}\alpha_{gK}\right] & \alpha^*_g < \alpha_{gK} \end{array}\right\} \quad (9)$$

where α_{gK} is the void fraction in the (gas) donor volume.

In fact, there is one additional complication. In the HSE model coding of RELAP5/MOD2 the void fraction is modified. Within the context of this new model, before α^*_g is used in Equation (9) it would be modified as follows:

$$\alpha^*_g \rightarrow \text{Min}\left[\ \alpha^*_g\ , 0.49\right] * 0.85 \qquad (10)$$

Documentation of the reason for this modification has not been seen by this author. It appears to extend the range of gas void fractions within which interpolation of the HSE and donor models may take place to a range of at least 0.4165 to 0.5835. It has been partially implemented in this new model with the factor 0.85 being omitted in Equation (10).

An analogous equation to (9) is used for $\alpha_{gK} > 0.5$ (entrainment). For the purposes of these calculations, the off-take orifice is assumed to have the diameter d^c_K given below:

$$d^c_K = D_K \sqrt{A_j / A_K} \qquad (11)$$

In this implementation another modification is made. The critical depth h_b is given a minimum value of half of the estimated off-take diameter d^c_K. This helps avoid rapid changes as the level crosses the off-take for low off-take flow.

3.6. Treatment of Top and Bottom Off-Take of Non-Negligible Area

In the RELAP5/MOD2 coding, a procedure based on Equation (9) is also used for top and bottom off-takes. As noted in [1], this seems unreasonable since the liquid does not intersect the off-take entrance for these cases. However, some form of smoothing may be necessary when the liquid level approaches the level of the off-take. The correlations have not been demonstrated to be valid with large off-take area but the the implementation described here gives code users the option of using them or not.

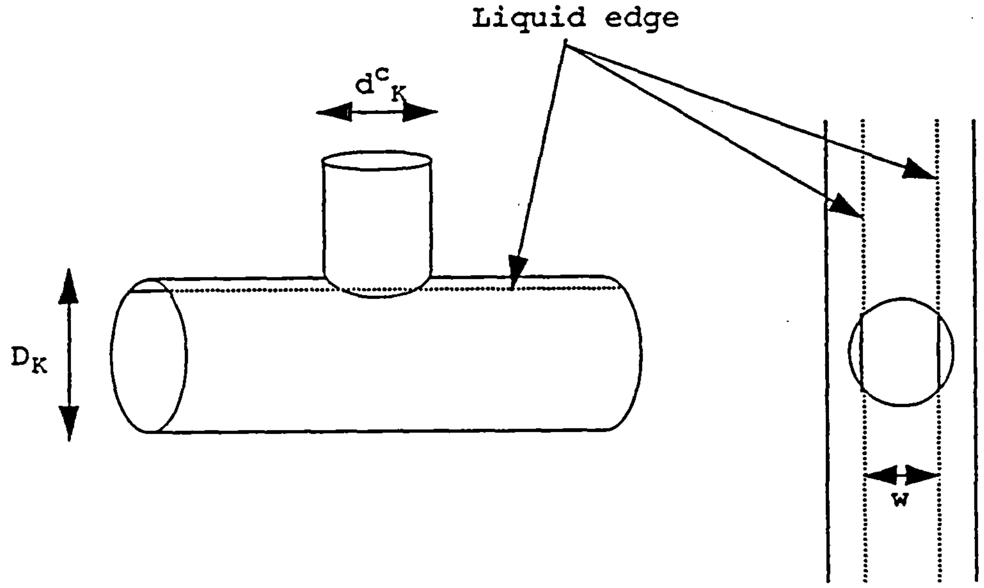
The smoothing used is based on a physical picture (see the next page). Looking at the main pipe through the off-take, if the liquid level is near the off-take and the edges of the liquid are in the field of view then the smoothing is applied. The smoothing is by interpolating to the donor void value according to the area of the field of view not occupied by liquid for a bottom off-take and according to that occupied by the liquid for a top off-take. The algorithm used is illustrated by the example of a bottom take-off:

$$\left.\begin{array}{ll} \alpha_f = 1-\alpha^c_g & \alpha_{gK} \geq 0.5 \text{ or } \sin\phi > 1 \\ \alpha_f = 1-\dfrac{2}{\pi}\left[\ \sin\phi\ \cos\phi + \phi\right] & \text{otherwise} \end{array}\right\} \qquad (12)$$

where

$$\sin\phi = \frac{w}{\mathrm{Min}\left[D_K , d^c_K \right]}$$

and w is the width of the liquid surface. This algorithm is slightly changed from that used in the RELAP5/MOD2 code version mentioned in Reference [1].



Schematic of View of Liquid Edge Through Top Off-take

3.7. Treatment of Large Critical Depths

It is conceivable that the critical entrainment depth h_b could imply a depth which is not contained within the main pipe. In this case the correlations (1)-(5) would predict gas pullthrough when the main pipe contains only liquid, or liquid entrainment when the pipe contains only gas. Such extreme values of h_b must take the correlations outside their range of validity. In this RELAP5/MOD3 model therefore it is assumed that the range of h_b is limited to the span of the main pipe diameter. This will imply less entrainment when the limit is in effect. This algorithm is different to that used in the RELAP5/MOD2 code version mentioned in Reference [1].

4. NUMERICS OF THE IMPLEMENTATION

A straightforward implementation of the correlations and extensions described above using old timestep values for all required properties is a recipe for disaster. Instead several improvements on this approach are used. These are described in the following Sections.

4.1. Time Level of Properties

The current values of almost all the property variables are used. (Current means the values at the time the HSE subroutine HZFLOW is called). The exceptions are the junction phase area fractions α_{fj} and α_{gj} used to evaluate the continuous phase flowrate W_k of Equation (1). For these the old timestep values $\alpha_{fj}{}^n$ and $\alpha_{gj}{}^n$ are used for two reasons. Firstly, the old timestep values will have been calculated with the HSE model (unless there has been a velocity reversal) and will be a better starting point than donor values from any intermediate calculation. Secondly, there is no change in values with this choice if a timestep is rejected and the calculation retried with half the timestep.

There is a special case however. If the flowrate W_k calculated from the old timestep junction phase area fraction would result in no entrainment then the flowrate W_k is recalculated using assuming the continuous phase area fraction $\alpha_{kj}{}^n$ was 1.0 corresponding to no entrainment. This helps to avoid large perturbations as entrainment starts and stops.

4.2. Condition the Correlations

Equations (4) and (5) for flow quality contain terms of the form

$$\left[1-0.5\ R(1+R)x_0{}^{(1-R)} \right]^{0.5}$$

This term changes rapidly in the region of R = 1. To avoid numerical instabilities due to this behaviour the correlations are conditioned by replacing the term by a linear variation between its values at R = 0.9 and R = 1.0.

The non-dimensional height (or depth) R involves a division by h_b. To avoid problems when $h_b \rightarrow 0$ at zero off-take continuous phase flow W_k it is given a minimum magnitude of 10^{-6} m. The value of W_k is altered to the value $W_k{}^{(1)}$ which maintains the relationship Equation (1). (Such an alteration is also done if the minimum magnitude of h_b given for side off-takes, described just after Equation (11), is used).

To avoid other singularities, the density difference $\Delta\rho$ is given a minimum value of 10^{-7} kg/m^3.

4.3. Improve Numerical Stability for Unchoked Flow

The explicit formulation described above is an invitation to instability. To try to overcome this a special procedure is applied. This is illustrated below for the calculation of liquid entrainment in co-current unchoked flow. Basically the procedure uses linear approximations of the non-linear functions. The resulting linear system is solved to give a better, more stable, calculation of the junction phase area fractions.

The entrainment is caused by the steam flow W_g (W_k is W_g in this case) from which a critical height h_b is calculated using Equation (1). This height may be modified if it is small as described above in which case it is associated with a modified gas flow $W_g^{(1)}$. Without the modification, $W_g^{(1)}$ is equal to W_g.

The appropriate entrainment correlation gives a flow quality which is converted into an off-take junction gas area fraction using the slip ratio S^*_j defined in Equation (8). Again this may be modified, by the finite area off-take modification or the high flow-rate modification for example, to give a gas area fraction which is denoted using the superscript P. This gas area fraction α_{gj}^P is unlikely to be the same value as that (α_{gj}^n) used to calculate W_g and this is the source of instability. The gas flow W_g may be considered as a function of the initial gas area fraction α_{gj}^n and the gas area fraction α_{gj}^P may be considered as a function of the gas flow. Then working to first order accuracy, the junction gas area fraction α_{gj} is set to the value which gives a gas flow which produces an entrainment giving rise to a self consistent gas area fraction.

This definition is represented by the following equations:

$$\alpha_{gj} = \alpha_{gj}^P + \frac{\partial \alpha_{gj}^P}{\partial W_g}\left[W_g^* - W_g^{(1)} \right] \tag{13}$$

$$W_g^* = W_g + \frac{\partial W_g}{\partial \alpha_{gj}^n}\left[\alpha_{gj} - \alpha_{gj}^n \right] \tag{14}$$

where in this case

$$\frac{\partial W_g}{\partial \alpha_{gj}^n} = A_j v_{gj} \rho_{gj} \tag{15}$$

and $\partial \alpha_{gj}^P / \partial W_g$ is non-positive. This partial derivative is evaluated assuming the slip ratio S^*_j and the degree of mixing of pure donor derived α_g are constant. The intermediate gas flow W_g^* is eliminated leaving the following expression for α_{gj}.

$$\alpha_{gj} = \frac{\alpha_{gj}^P + \frac{\partial \alpha_{gj}^P}{\partial W_g}\left[W_g - W_g^{(1)} - \alpha_{gj}^n \frac{\partial W_g}{\partial \alpha_{gj}^n} \right]}{1 - \frac{\partial W_g}{\partial \alpha_{gj}^n}\frac{\partial \alpha_{gj}^P}{\partial W_g}} \tag{16}$$

Under some circumstances the partial derivative $\frac{\partial \alpha_{gj}{}^{P}}{\partial W_g}$ is explicitly set zero:

i. If the large critical depth modification was invoked.

ii. If the flow was in counter-current cases (c) or (d).

iii. If $\alpha_{gj}{}^{P}$ is 1.0 and $\alpha_{gj}{}^{n}$ is 1.0. (If $\alpha_{gj}{}^{n}$ is not 1.0 and the modified correlations give a non-zero derivative this is used to reduce perturbations as entrainment stops and starts.)

iv. If $\alpha_{gj}{}^{P}$ is 0.0.

If the process is not calculated to be a negative feedback process, then the gas junction area fraction α_{gj} is left at the value $\alpha_{gj}{}^{P}$.

Exactly the same form of procedure can be followed for counter-current flow for each phase flowing from a horizontal volume. For gas pullthrough the roles of gas and liquid are exchanged and the junction liquid area fraction is calculated by an expression like Equation (16):

$$\alpha_{fj} = \frac{\alpha_{fj}{}^{P} + \frac{\partial \alpha_{fj}{}^{P}}{\partial W_f}\left[W_f - W_f{}^{(1)} - \alpha_{fj}{}^{n}\frac{\partial W_f}{\partial \alpha_{fj}{}^{n}} \right]}{1 - \frac{\partial W_f}{\partial \alpha_{fj}{}^{n}}\frac{\partial \alpha_{fj}{}^{P}}{\partial W_f}} \tag{17}$$

Again under some circumstances the partial derivative $\frac{\partial \alpha_{fj}{}^{P}}{\partial W_f}$ is explicitly set zero:

i. If the large critical depth modification was invoked.

ii. If the flow was in counter-current cases (c) or (d).

iii. If $\alpha_{fj}{}^{P}$ is 1.0 and $\alpha_{fj}{}^{n}$ is 1.0. (If $\alpha_{fj}{}^{n}$ is not 1.0 and the modified correlations give a non-zero derivative this is used to reduce perturbations as entrainment stops and starts.)

iv. If $\alpha_{fj}{}^{P}$ is 0.0 and $\alpha_{fj}{}^{n}$ is 0.0. (If $\alpha_{fj}{}^{n}$ is not 0.0 and the modified correlations give a non-zero derivative this is used to reduce perturbations as liquid first appears.)

4.4. Improve Numerical Stability for Choked Flow

When the off-take flow is choked and co-current the assumption that only the dependence of the gas flow on the gas area fraction (Equation (14)) need be accounted for to obtain stability has been seen in practice to break down for liquid entrainment. Gas pullthrough with choked flow has also been seen to have problems. Procedures to improve stability for these two cases are described in the following two Subsections.

4.4.1. Liquid Entrainment

As stated above, the stability obtained by using the assumption of Equation (14) is not always satisfactory. Account has to be taken of the change in choked flow gas velocity v_g associated with a change in junction void fraction α_{gj}. Over a wide range of void fractions, an increase in junction gas area fraction results in an increase of choked gas velocity. This then would cause more entrainment of liquid in the next timestep reducing the junction gas area fraction. This is a negative feedback process which can cause oscillations.

The approximation used to take account of the change in choked flow gas velocity is to assume that $v_c\rho_j$ is a constant G_c and that the slip ratio S is also constant where

$$v_c = \frac{\alpha_{gj}\rho_{fj}v_g + (1-\alpha_{gj})\rho_{gj}v_f}{\alpha_{gj}\rho_{fj} + (1-\alpha_{gj})\rho_{gj}} \tag{18}$$

and

$$\rho_j = \alpha_{gj}\rho_{gj} + (1-\alpha_{gj})\rho_{fj} \tag{19}$$

Velocity v_c is used in the code's choked flow model. The assumed constant product G_c is evaluated with the old gas area fraction α_{gj}^n and current velocities. The assumptions then imply a relationship between v_g and α_{gj} and hence between W_g and α_{gj}. This latter relationship is linearised about α_{gj}^n and used to replace Equation (14). The derivative is constrained to be non-negative. The equations involved are Equations (20)-(25) below.

$$v_c = \frac{G_c}{\alpha_{gj}^n\rho_{gj} + \alpha_{fj}^n\rho_{fj}} \tag{20}$$

$$v_g = \frac{v_c(\alpha_{gj}^n\rho_{fj} + \alpha_{fj}^n\rho_{gj})S}{\alpha_{gj}^n\rho_{fj}S + \alpha_{fj}^n\rho_{gj}} \tag{21}$$

$$W_g = Av_g\rho_{gj}\alpha_{gj}^n \tag{22}$$

where, because choked flow will be co-current, when calculating derivatives it is assumed that

$$\alpha_{fj}^n = 1-\alpha_{gj}^n \tag{23}$$

The replacements for Equations (14) and (16) are

$$W_g^* = W_g + \frac{\partial W_g}{\partial \alpha_{gj}^n}\left[\alpha_{gj} - \alpha_{gj}^n\right] \tag{24}$$

and

$$\alpha_{gj} = \frac{\alpha_{gj}^P + \dfrac{\partial \alpha_{gj}^P}{\partial W_g}\left[W_g - W_g^{(1)} - \alpha_{gj}^n \dfrac{\partial W_g}{\partial \alpha_{gj}^n}\right]}{1 - \dfrac{\partial W_g}{\partial \alpha_{gj}^n}\dfrac{\partial \alpha_{gj}^P}{\partial W_g}} \tag{25}$$

where W_g and $\partial W_g / \partial \alpha_{gj}^n$ are evaluated from Equations (20), (21) and (22).

4.4.2. Gas Pullthrough

The situation is different for gas pullthrough. The negative feedback process described for liquid entrainment becomes a positive feedback. An increase in junction liquid area fraction results, for a wide range of void fractions, in a decrease in junction choked flow liquid velocity. The next timestep would then have less gas pullthrough (ignoring the countering effect of the increased liquid area fraction on the liquid mass flowrate) and hence there would be an increase in junction liquid area fraction. This may or may not give rise to instability. Using a procedure like that described above for liquid entrainment is likely to exacerbate any potential positive feedback instability because it could result in a reduced or negative denominator in the replacement expression for Equation (16) due to a small or negative value of $\partial W_f / \partial \alpha_{fj}^P$. This potential problem was not realised when the RELAP5/MOD2 code version of Reference [1] was developed.

Another problem observed in the RELAP5/MOD2 code version of Reference [1] is associated with the choked flow model transition between the subcooled and two-phase regimes. It is illustrated by considering a horizontal volume containing stratified gas and liquid with the liquid being subcooled. Consider a side off-take below the liquid level with the choked outflow liquid causing gas pullthrough. As the liquid level falls the equilibrium quality of the flow from a side off-take can change from subcooled to two-phase (the actual quality being two-phase throughout). As this happens the choked flowrate drops. This causes a drop in pullthrough resulting in a drop in off-take equilibrium quality to a subcooled value. If the choked flow routine is correctly coded (that is it uses junction equilibrium quality rather than upstream volume equilibrium quality) the next timestep will use the subcooled choked flow model giving an increase in off-take flow. This cycle can continue causing oscillations with period linked to the timestep size. This potential problem was not realised when the RELAP5/MOD2 code version of Reference [1] was developed. At the time of this development, it was expected that the released version of RELAP5/MOD3 would be based on the junction static quality and that this might also suffer from a similar instability.

In order to reduce such oscillations, a kind of damping is introduced by replacing the gas pullthrough version of Equation (14)

$$W_f^* = W_f + \frac{\partial W_f}{\partial \alpha_{fj}^n} \left[\alpha_{fj} - \alpha_{fj}^n \right] \tag{26}$$

by expressions involving an artificially large negative dependence of the choked liquid flowrate upon the junction gas area fraction.

Let $\overline{X}^n$ be the static quality corresponding to α_{fj}^n and let $\overline{X}^P$ be that corresponding α_{fj}^P (calculated from the extended correlations as used in previous Sections). The damping is applied if $\overline{X}^n < 2.5\ 10^{-3}$ or $\overline{X}^P < 2.5\ 10^{-3}$. In this case the junction liquid flowrate W_f^P is assumed to depend on $\overline{X}^P$ according to

$$W_f^P = C\,(5\ 10^{-3} - \overline{X}^P) \tag{27}$$

The "constant" C is chosen such that at the static quality $\overline{X}^D$ the liquid flowrate calculated using the current liquid velocity v_f matches that given by Equation (27). The static quality $\overline{X}^D$ is the minimum of $2.5\ 10^{-3}$ and $\overline{X}^n$.

A partial derivative $\partial W_f^P / \partial \alpha_{fj}^P$ is evaluated from Equation (27) assuming that the only dependence is due to the $\overline{X}^P$ term. This derivative is then used in Equation (26) in place of $\partial W_f / \partial \alpha_{fj}^n$.

5. PROGRAMMING DETAILS

5.1. New Variables

Six new global array variables have been added to the junction block:

VODFJO
This is the old junction liquid area fraction α_{fj}^{n}. The existing variable VOIDFJ cannot be used because it is overwritten before the HSE calculation is performed.

VODGJO
This is the old junction gas area fraction α_{gj}^{n}. The existing variable VOIDGJ cannot be used because it is overwritten before the HSE calculation is performed.

VDFJOO
This is the old junction liquid area fraction from the previous timestep. It is necessary because when a timestep is restarted the junction properties routine JPROP is called to recalculate the old junction variables from saved old volume variables.

VDGJOO
This is the old junction gas area fraction from the previous timestep.

VELFO
This is the old volume average liquid velocity.

VELGO
This is the old volume average gas velocity.

The number of junction variables in a parameter statement in the junction block is incremented by six.

5.2. Input Routines

No change. It should be noted that the release 5m5 has been changed compared to the pre-release version 411 for which this section applies. In particular it appears that pipe internal junctions are forced to have a value zero for the junction control flag "v" which denotes the junction orientation. The input data description does not state whether this means that the HSE model cannot be invoked (which is unduly restrictive) or whether it is invoked but as a central off-take orientation only.

5.3. Output Routines

No change.

5.4. Initialisation Routines

The changes described in this section were all made to the pre-release version 411. The release version 5m5 has changes to the input junction control flag "v" which denotes the junction orientation. The associated coding changes made by EG&G have not been studied by the author.

ICMPN1

For the original RELAP5/MOD2 HSE model, all junction geometries involving no significant area reduction between the horizontal volume and the off-take volume revert to the donor model for junction phase area fractions. For efficiency this is hardwired into subroutine ICMPN1. However for the new model described in this paper, upward and downward off-takes do not revert to the donor model in these geometries. Thus ICMPN1 was altered to allow these two types of off-take to use the new HSE model.

IJPROP

The new variables VDFJOO and VODFJO are initialised at the end of this routine to the initial junction value VOIDFJ (normally a donor value) calculated in the routine. Similarly VDGJOO and VODGJO are initialised to VOIDGJ. Currently RELAP5/MOD3 does not use any HSE model in the initialisation of junction conditions.

5.5. Transient Routines

MOVER

This routine is called when a timestep is accepted or rejected. If a timestep is rejected then the two junction variables VODFJO and VODGJO are reset to VDFJOO and VDGJOO respectively. Also the two volume variables VELF and VELG are reset to VELFO and VELGO respectively. If a timestep is accepted then VDFJOO and VDGJOO are updated to VODFJO and VODGJO, VODFJO and VODGJO are updated to VOIDFJ (α_{fj} at this stage) and VOIDGJ (α_{gj}) respectively. Also the two volume variables VELFO and VELGO are updated to VELF and VELG respectively.

HZFLOW

This is the routine that calculates the phase area fractions given by the HSE model for the junction phase flows that satisfy the model conditions. The new HSE model described in this report cannot be incorporated simply by following the existing routine logic because the new model can be in effect in flow conditions and geometries for which the old RELAP5/MOD2 model is not. The following pseudo-coding shows the essential part of the overall routine logic. The block IF levels have been numbered to aid in matching this logic to comments in the code source.

```
***This is a comment
***Enter routine with $\alpha_{fj}$ and $\alpha_{gj}$ set to donor volume values
IF ( HSE_model_not_allowed ) EXIT
***consider liquid entrainment
IF ( not_zero_gas_velocity ) THEN    *** 0
 IF ( counter_current OR not_downward_off-take ) THEN    *** 1
  LET off-take_volume = gas_downstream_volume
  LET upstream_volume = gas_upstream_volume
  IF ( upstream_volume_two-phase[$\alpha_{gK}$>0 AND $\alpha_{fK}$>0] ) THEN    *** 2
   IF ( upstream_volume_horizontal ) THEN    *** 3
    IF ( off-take_area_smaller OR not_side_off-take ) THEN    *** 4
     IF ( counter_current OR upward_off-take OR
     ( side_off-take AND upstream_volume>half_empty ) ) THEN    *** 5
      ***liquid entrainment section
      IF ( allowed_upstream_void_range ) THEN    *** 6
       IF ( allowed_upstream_volume_mass_flux ) THEN    *** 7
        { Calculate $\alpha_{gj}$ using new model }
        IF ( co_current ) THEN    *** 8
         LET $\alpha_{fj}$ = 1 - $\alpha_{gj}$
         EXIT
        ENDIF    *** 8
       ENDIF    *** 7
      ENDIF    *** 6
     ENDIF    *** 5
    ENDIF    *** 4
   ENDIF    *** 3
  ENDIF    *** 2
 ENDIF    *** 1
 IF ( co_current AND (upward_off-take OR
 ( side_off-take AND upstream_volume>half_empty ) ) ) EXIT
ENDIF    *** 0
***consider gas pullthrough
IF ( not_zero_liquid_velocity ) THEN    *** 1
 LET off-take_volume = liquid_downstream_volume
 LET upstream_volume = liquid_upstream_volume
 IF ( upstream_volume_two-phase[$\alpha_{fK}$>0 AND $\alpha_{gK}$>0] ) THEN
  IF ( upstream_volume_horizontal ) THEN    *** 2
   IF ( off-take_area_smaller OR not_side_off-take ) THEN    *** 3
    ***gas pullthrough section
    IF ( allowed_upstream_void_range ) THEN    *** 4
     IF ( allowed_upstream_volume_mass_flux ) THEN    *** 5
      { Calculate $\alpha_{fj}$ using new model }
      IF ( co_current ) THEN    *** 6
       LET $\alpha_{gj}$ = 1 - $\alpha_{fj}$
      ENDIF    *** 6
     ENDIF    *** 5
    ENDIF    *** 4
```

```
      ENDIF    *** 3
    ENDIF    *** 2
  ENDIF    *** 1
ENDIF    *** 0
```

6. PROGRAM TESTING

A simple test problem was used to verify the coding (in pre-release version 411) of the correlations. A time dependent volume was connected by a 1 sq cm test junction to a 206mm diameter horizontal volume. This volume discharged into a time-dependent volume at a fixed pressure of 0.1 MPa. The supplying volume fluid was kept at a fixed pressure of 0.7 MPa but its quality was swept from zero to unity in a sequence of ramps. The flow rate was determined by choking in the test junction. This simple three volume system was repeated three times to cover the three different possible orientations of the test junction: upwards, sideways and downwards. Thus the coded HSE correlations were swept over the complete range of liquid levels for co-current flow.

To automate the verification process, the RELAP5 control logic was used to calculate the code's values of the off-take flow qualities (flow quality was not an output variable for pre-release version 411 of the code for which the test input was developed) obtained with the HSE model enabled. The RELAP5 control logic was also used to calculate the off-take qualities directly by simulating the HSE correlations. This simulation took account of the modifications to the correlations to handle large critical depths and the critical depth modification for side off-takes given just after Equation (11). As such it will not give the off-take flow quality arising from the correlations alone. The modifications were included to minimise the differences to be expected in the comparison. The data is given in Appendix A. It has been modified to run on the release version 5m5 of the code. (The data needed changing because of a change in definition of the junction flags).

The two independent calculations, from the junction properties (determined by the HSE model) and from control system HSE simulation, of the off-take flow quality are compared graphically in Figures 1-6. These figures were produced by running the released code, version 5m5, on a Sun SPARCstation 1. Figures 1 and 2 show the up case, ie with upward oriented junction. Figure 1 shows the flow quality calculated from the junction properties, the control system simulated flow quality and the height ratio R (distance h of liquid level from off-take divided by the critical height h_b) plotted against time. Figure 2 shows the two flow qualities plotted against the height ratio R. The two qualities are indistinguishable despite transient effects. The plotting utility used to generate these figures was also used to calculate and plot the flow quality from the junction and volume properties assuming there was no HSE effect. During the period of interest, this quality was virtually zero.

Figures 3 and 4 show the side case, ie with side or central oriented junction. Figure 3 shows the flow quality calculated from the junction properties, the control system simulated flow quality and the height ratio R (height h of liquid level above the off-take divided by the critical height h_b) plotted against time. Figure 4 shows the two flow qualities plotted against the height ratio R. The two qualities are barely distinguishable except around the zero height ratio area. The difference here is due to the finite off-take area modification. Also plotted is the off-take flow quality calculated assuming there was no HSE effect. During the period of interest, this quality was virtually zero.

Figures 5 and 6 show the down case, ie with downward oriented junction. Figure 6 shows the flow quality calculated from the junction properties, the control system simulated flow quality and the height ratio R (distance h of liquid level from off-take divided by the critical height h_b) plotted against time. Figure 6 shows the two flow qualities plotted against the height ratio R. The two qualities were more distinguishable in this case than the up case. This is thought to be due to transient effects. The flow quality is changing significantly over a short time period. Also plotted is the off-take flow quality calculated assuming there was no HSE effect. In this case, during the period of interest, this quality was greater than that of the HSE model.

This test verified the coding of the correlations.

During this testing, a run was performed in which the flow area of the discharge junctions (downstream of the test junctions) was set to $5.0\,10^{-5}$. This showed numerical oscillations in the test junctions at high qualities. These oscillations persisted even when the test junction flow was single phase steam. It was also noticed that the slip was oscillating. This suggests that the problem is associated with a model other than the HSE model.

7. CONCLUSION

This report has described the numerics and implementation details for the modification of RELAP5/MOD3 to use the HSE correlation set described in Reference [1]. These details include the areas where the use of the HSE correlation set has been extended outside of its range. The modifications, which were incorporated into pre-release code version 411, remain in the first "frozen" release of the code (version 5m5). Areas where changes have been made by EG&G in producing the release version which might affect the modelling have been noted in the section on programming details. Particularly noteworthy is the restriction which apparently excludes the full control of the HSE model at the internal junctions of PIPE components.

A simple test problem was used to verify the RELAP5/MOD3 coding of the correlations, making use of the control system logic. This problem was run using the release code version. It was noted that this version seemed to be more prone to instability than the pre-release version 411. The problem is not believed to be associated with the HSE model.

REFERENCES

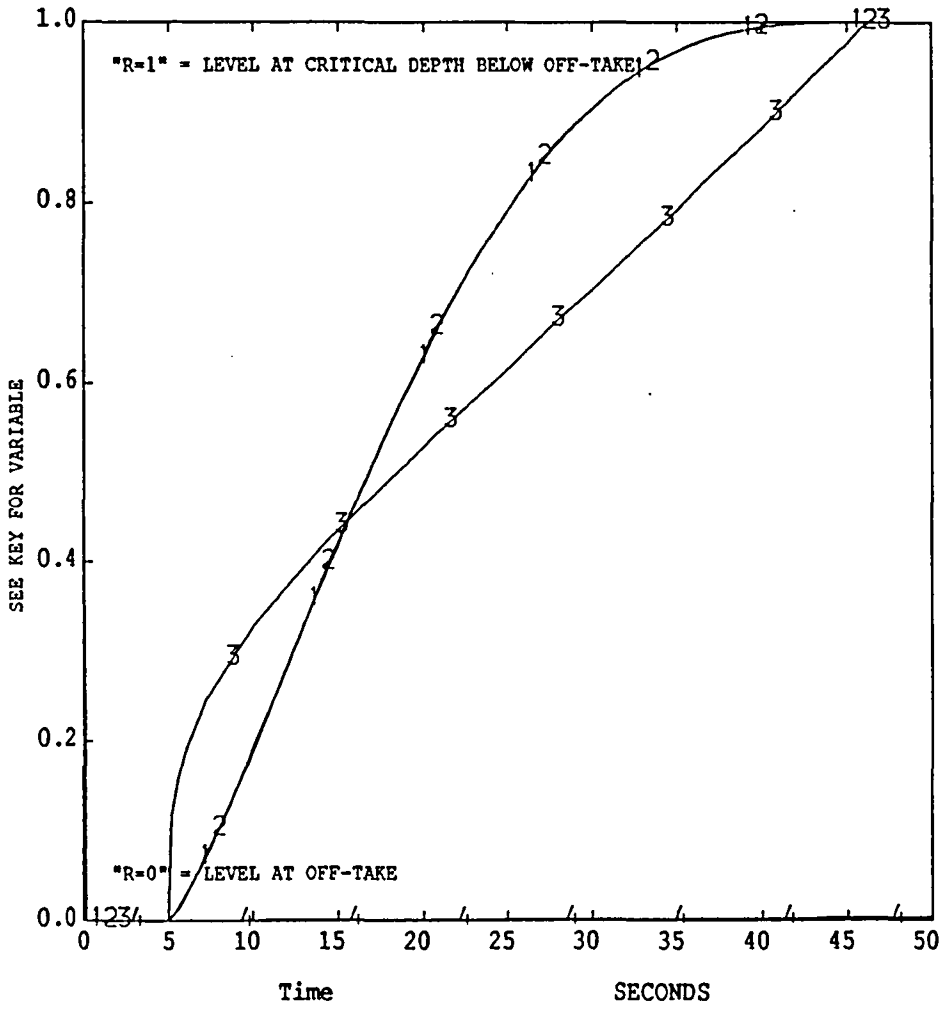
1. Ardron, K H, Bryce, W M. Assessment of Horizontal Stratification Entrainment Model in RELAP5/MOD2. AEEW-R 2345. April 1988.

Winfrith

THE FOLLOWING ARE PLOTTED AGAINST Time

Control Component No,FROM VOL/JN PROPS

KEY		
SYM BOL	NAME	UNITS
—1—	Control Component No, FLOW X FROM JN. PROPS. LOC= 204/ 0/ 0 MNEM=CCNO INF=1	
—2—	Control Component No, FLOW X CONTROL SYS. HSE CALC. LOC= 255/ 0/ 0 MNEM=CCNO INF=1	
—3—	Control Component No, R ("HEIGHT" RATIO) LOC= 243/ 0/ 0 MNEM=CCNO INF=1	
—4—	FROM VOL/JN PROPS FLOW X WITH NO HSE MOD.	



SIMPLE HSE TEST CASES RELAP5/MOD3 5M5 SUN SPARC 1

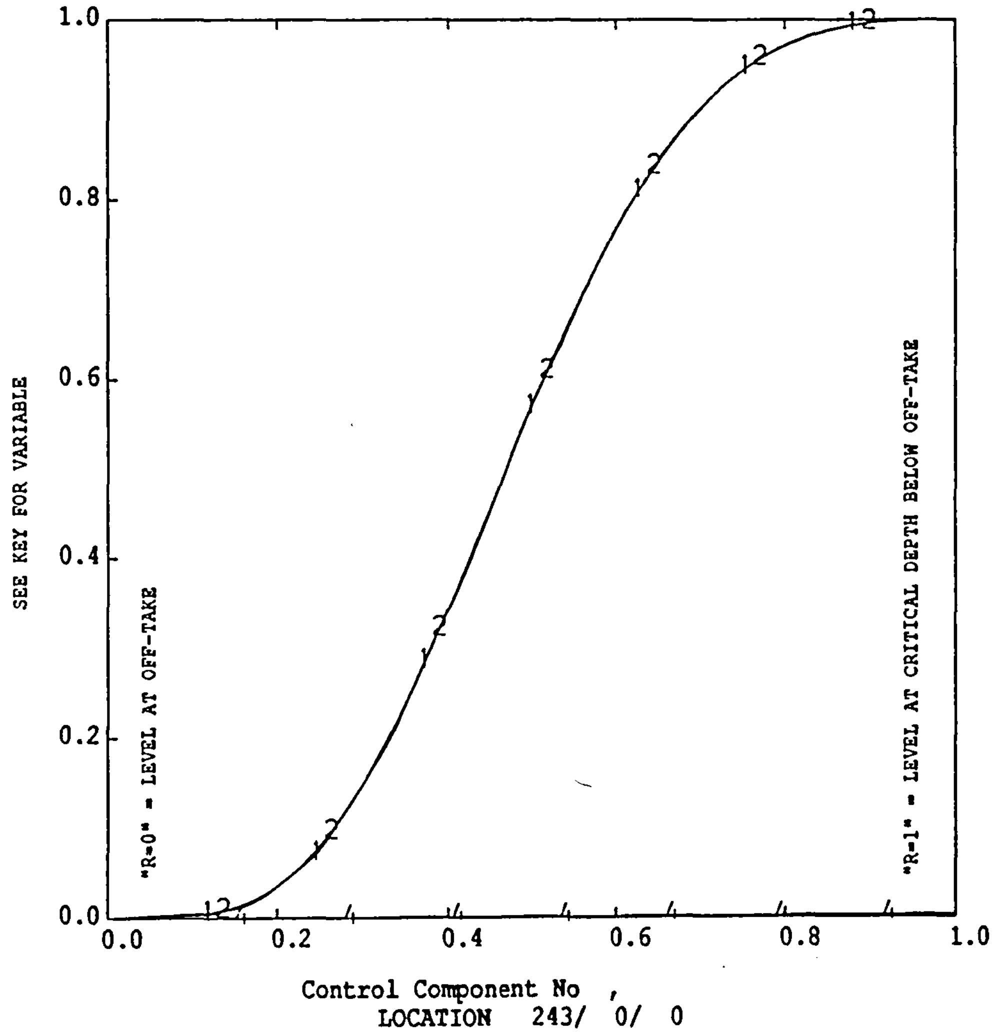
FIGURE 1 TEST ENTRALLC - UP CASE FLOW QUALITY

THE FOLLOWING ARE PLOTTED AGAINST Control Component No

Control Component No,FROM VOL/JN PROPS

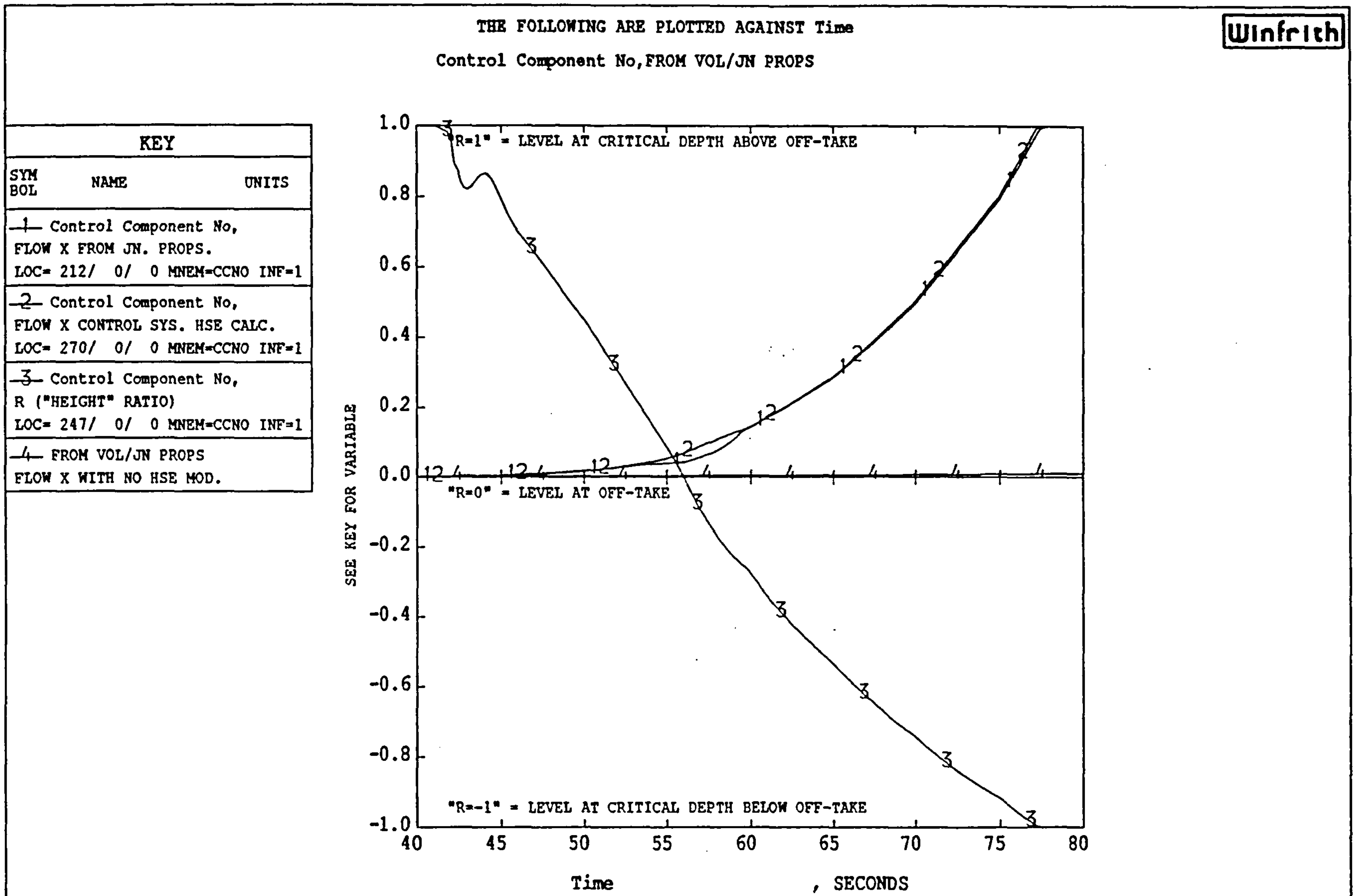
Winfrith

KEY		
SYM BOL	NAME	UNITS
—1— Control Component No, FLOW X FROM JN. PROPS. LOC= 204/ 0/ 0 MNEM=CCNO INF=1		
—2— Control Component No, FLOW X CONTROL SYS. HSE CALC. LOC= 255/ 0/ 0 MNEM=CCNO INF=1		
—4— FROM VOL/JN PROPS FLOW X WITH NO HSE MOD.		



SIMPLE HSE TEST CASES RELAP5/MOD3 5M5 SUN SPARC 1

FIGURE 2 TEST ENTRALLC - UP CASE FLOW QUALITY



SIMPLE HSE TEST CASES RELAP5/MOD3 5M5 SUN SPARC 1

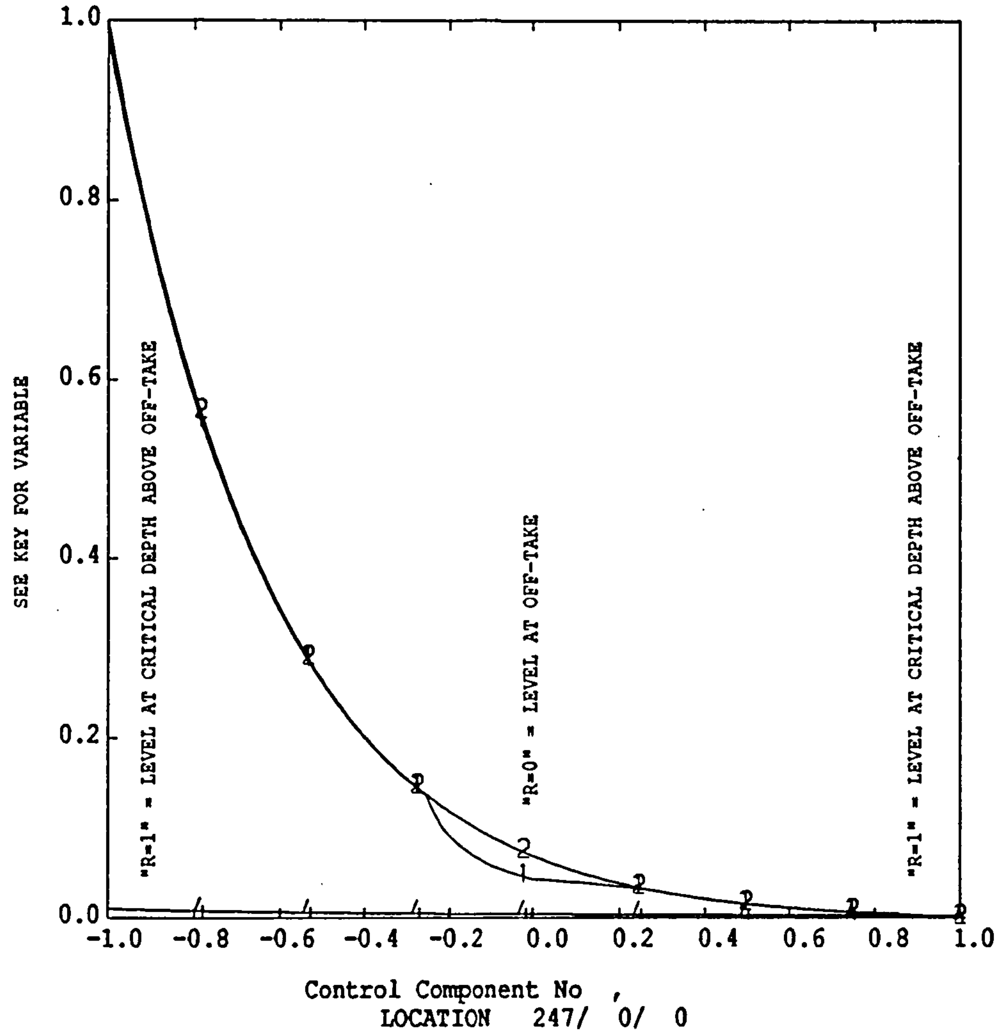
FIGURE 3 TEST ENTRALLC - SIDE CASE FLOW QUALITY

Winfrith

THE FOLLOWING ARE PLOTTED AGAINST Control Component No

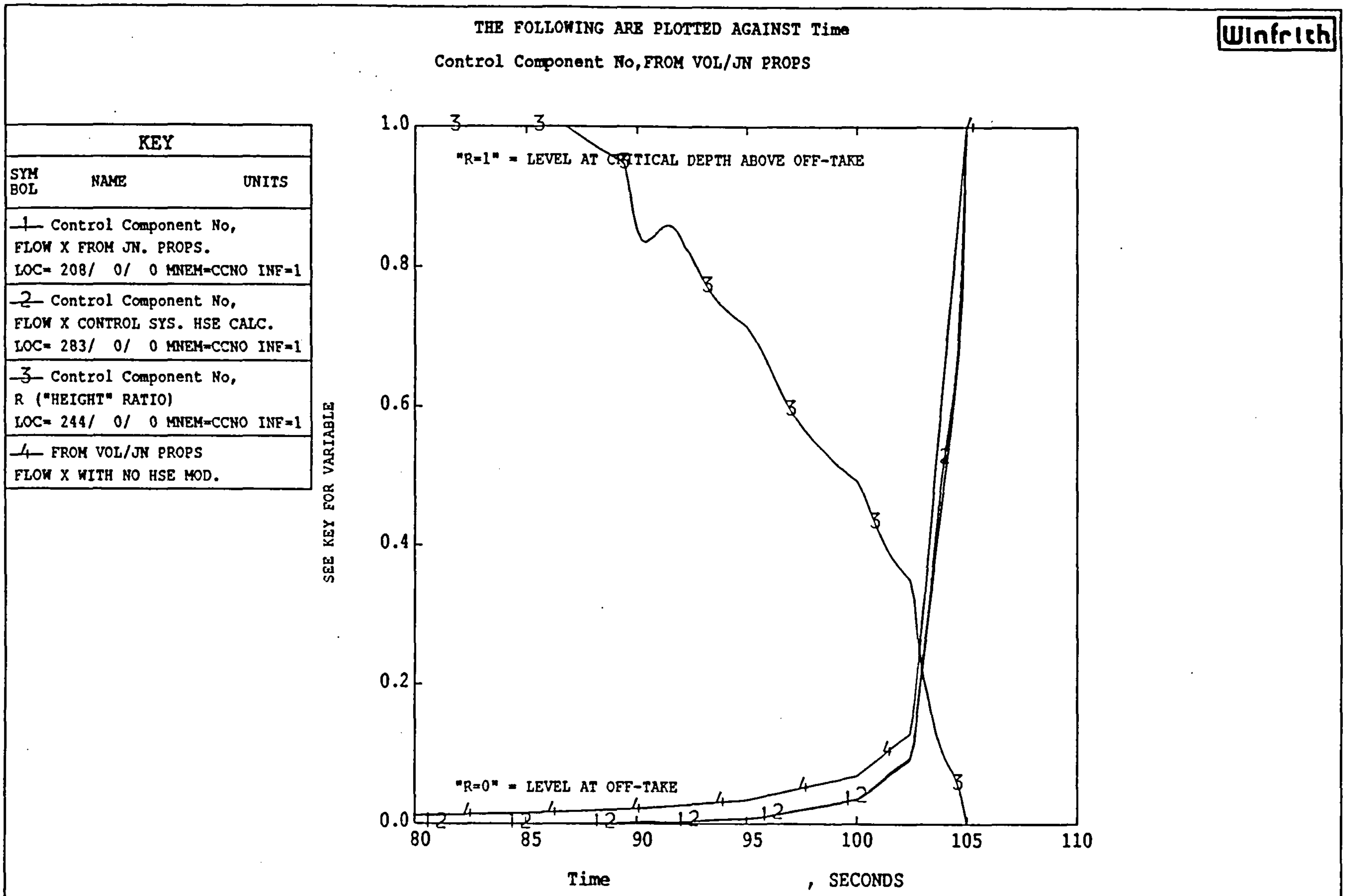
Control Component No,FROM VOL/JN PROPS

KEY		
SYM BOL	NAME	UNITS
1	Control Component No, FLOW X FROM JN. PROPS. LOC= 212/ 0/ 0 MNEM=CCNO INF=1	
2	Control Component No, FLOW X CONTROL SYS. HSE CALC. LOC= 270/ 0/ 0 MNEM=CCNO INF=1	
4	FROM VOL/JN PROPS FLOW X WITH NO HSE MOD.	



SIMPLE HSE TEST CASES RELAP5/MOD3 5M5 SUN SPARC 1

FIGURE 4 TEST ENTRALLC - SIDE CASE FLOW QUALITY



SIMPLE HSE TEST CASES RELAP5/MOD3 5M5 SUN SPARC 1

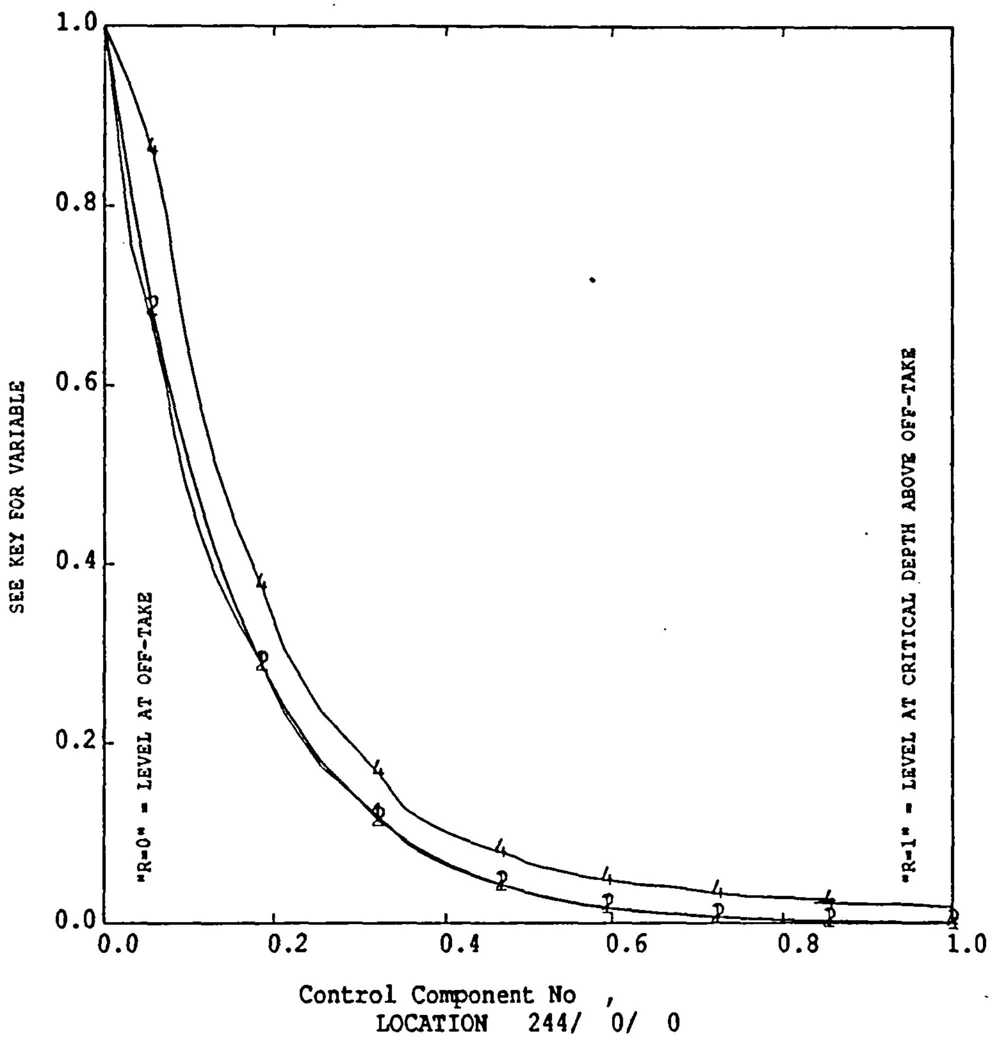
FIGURE 5 TEST ENTRALLC - DOWN CASE FLOW QUALITY

Winfrith

THE FOLLOWING ARE PLOTTED AGAINST Control Component No

Control Component No, FROM VOL/JN PROPS

KEY		
SYM BOL	NAME	UNITS
1	Control Component No, FLOW X FROM JN. PROPS. LOC= 208/ 0/ 0 MNEM=CCNO INF=1	
2	Control Component No, FLOW X CONTROL SYS. HSE CALC. LOC= 283/ 0/ 0 MNEM=CCNO INF=1	
4	FROM VOL/JN PROPS FLOW X WITH NO HSE MOD.	



SIMPLE HSE TEST CASES RELAP5/MOD3 5M5 SUN SPARC 1

FIGURE 6 TEST ENTRALLC - DOWN CASE FLOW QUALITY

Appendix A. Test Data Listing

The following is a listing of the test data for RELAP5/MOD3 release version 5m5:

```
=entrailc entrainment model test   all voids and orientations (choking)
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
* switch on hse option for mod2
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
0000100  new        transnt
0000105  1.0        2.0
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*        time step control cards
*        end_time  min_dt  max_dt  optn   mnr  mjr  rst
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
0000201  110.0    1.0e-7  0.10    1603   3    100  1000
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*        minor edit variables
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
0000301  p         104010000     * pipe pressure
0000302  p         108010000     * upward branch pressure
0000303  quals     104010000     * pipe static quality
0000304  quals     108010000     * upward branch static quality
0000305  voidgj    107000000     * upward branch jun void fractn
0000306  voidg     104010000     * pipe void fraction
0000307  voidg     108010000     * upward branch void fraction
0000308  mflowj    107000000     * upward branch junction flow
0000309  velfj     107000000     * upward branch liquid velocity
0000310  velgj     107000000     * upward branch steam velocity
0000311  cntrlvar  201           * upward branch steam flow
0000312  cntrlvar  202           * upward branch liquid flow
0000313  cntrlvar  232           * upward branch crn distance
0000314  cntrlvar  240           * upward branch liq distance
0000315  cntrlvar  243           * upward branch distance ratio
0000316  cntrlvar  255           * upward branch check quality
0000317  cntrlvar  204           * upward branch flow quality
0000318  cntrlvar  255           * upward branch check quality
318      quale     108010000
*
0000321  p         114010000     * pipe pressure
0000322  p         118010000     * downward branch pressure
0000323  quals     114010000     * pipe static quality
0000324  quals     118010000     * downward branch static quality
0000325  voidgj    117000000     * downward branch jun void fractn
0000326  voidg     114010000     * pipe void fraction
0000327  voidg     118010000     * downward branch void fraction
0000328  mflowj    117000000     * downward branch junction flow
0000329  velfj     117000000     * downward branch liquid velocity
0000330  velgj     117000000     * downward branch steam velocity
0000331  cntrlvar  205           * downward branch steam flow
0000332  cntrlvar  206           * downward branch liquid flow
0000333  cntrlvar  233           * downward branch crn depth
0000334  cntrlvar  241           * downward branch liq depth
0000335  cntrlvar  244           * downward branch depth ratio
0000336  cntrlvar  283           * downward branch check quality
0000337  cntrlvar  208           * downward branch flow quality
0000338  cntrlvar  283           * downward branch check quality
*
0000341  p         124010000     * pipe pressure
0000342  p         128010000     * side branch pressure
0000343  quals     124010000     * pipe static quality
0000344  quals     128010000     * side branch static quality
0000345  voidgj    127000000     * side branch jun void fractn
0000346  voidg     124010000     * pipe void fraction
0000347  voidg     128010000     * side branch void fraction
0000348  mflowj    127000000     * side branch junction flow
0000349  velfj     127000000     * side branch liquid velocity
0000350  velgj     127000000     * side branch steam velocity
0000351  cntrlvar  209           * side branch steam flow
0000352  cntrlvar  210           * side branch liquid flow
0000353  cntrlvar  234           * side branch crn_low height
0000354  cntrlvar  235           * side branch crn_high height
0000355  cntrlvar  242           * side branch liq height
0000356  cntrlvar  247           * side branch height ratio
0000357  cntrlvar  212           * side branch flow quality
0000358  cntrlvar  270           * side branch check quality
*
* extras
*
20800001 dt 0
20800002 dtcrnt 0
20800003 xej 107000000
20800004 xej 117000000
20800005 xej 127000000
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*    hydraulic data
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*        main pipe for upward connection
1040000  supup    tmdpvol
*        varea    vlen    vvol    h-ang    v-ang    v-ht
1040101  0.0333   1.0     0.0     0.0      0.0      0.0
*        rough    hy-diam  vflags
1040102  0.0      0.0      10
*        ic-ind
1040200  006
*        search   press    uliq       ugas        voidg   quale
1040201  0.0      0.70e6   6.8852e5   2.56951e6   1.0e-8  0.0
1040202  5.0      0.70e6   6.8852e5   2.56951e6   1.0e-8  0.0
1040203  55.0     0.70e6   6.8852e5   2.56951e6   1.0     0.0
1040204  60.0     0.70e6   6.8852e5   2.56951e6   1.0     0.0
*        ic-ind
1040200  002
*        search   press    qual
1040201  0.0      0.70e6   0.0
1040202  5.0      0.70e6   0.0
1040203  7.5      0.70e6   9.9790e-5
1040204  10.0     0.70e6   2.0481e-4
1040205  15.0     0.70e6   4.3228e-4
1040206  20.0     0.70e6   6.8638e-4
1040207  25.0     0.70e6   9.7210e-4
1040208  30.0     0.70e6   1.2957e-3
1040209  35.0     0.70e6   1.6653e-3
1040210  40.0     0.70e6   2.0914e-3
1040211  45.0     0.70e6   2.5881e-3
```

```
1040212 50.0    0.70e6   3.1744e-3
1040213 55.0    0.70e6   3.8771e-3
1040214 60.0    0.70e6   4.7346e-3
1040215 65.0    0.70e6   5.8044e-3
1040216 70.0    0.70e6   7.1765e-3
1040217 75.0    0.70e6   9.0000e-3
1040218 80.0    0.70e6   1.1542e-2
1040219 85.0    0.70e6   1.5330e-2
1040220 90.0    0.70e6   2.1580e-2
1040221 95.0    0.70e6   3.3844e-2
1040222 100.0   0.70e6   6.8859e-2
1040223 102.5   0.70e6   1.3179e-1
1040224 105.0   0.70e6   1.0
1040225 110.0   0.70e6   1.0
1040226 112.5   0.70e6   1.3179e-1
1040227 115.0   0.70e6   6.8859e-2
1040228 120.0   0.70e6   3.3844e-2
1040229 125.0   0.70e6   2.1580e-2
1040230 130.0   0.70e6   1.5330e-2
1040231 135.0   0.70e6   1.1542e-2
1040232 140.0   0.70e6   9.0000e-3
1040233 145.0   0.70e6   7.1765e-3
1040234 150.0   0.70e6   5.8044e-3
1040235 155.0   0.70e6   4.7346e-3
1040236 160.0   0.70e6   3.8771e-3
1040237 165.0   0.70e6   3.1744e-3
1040238 170.0   0.70e6   2.5881e-3
1040239 175.0   0.70e6   2.0914e-3
1040240 180.0   0.70e6   1.6653e-3
1040241 185.0   0.70e6   1.2957e-3
1040242 190.0   0.70e6   9.7210e-4
1040243 195.0   0.70e6   6.8638e-4
1040244 200.0   0.70e6   4.3228e-4
1040245 205.0   0.70e6   2.0481e-4
1040246 210.0   0.70e6   9.9790e-5
1040247 215.0   0.70e6   0.0
1040248 220.0   0.70e6   0.0
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*       upward test junction
1070000 testu     sngljun
*     from      to       area     loss-f   loss-r   fvcahs
1070101 104000000 108000000 1.0e-4   0.0      0.0       10100
*     ic-ind   l-flow   g-flow   int
1070201 1       0.0      0.0      0.0
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*       upward branch pipe
1080000 off-pu   snglvol
*     varea    vlen     vvol     h-ang    v-ang    v-ht
1080101 3.1416e-2 10.0   0.0      0.0      0.0      0.0
*     rough    hy-diam  vflags
1080102 5.0e-5   0.0     00
*     ic-ind   press    qual
1080200 002      0.11e6   0.01
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*       upward throttle valve
1090000 throttlu sngljun
*     from      to       area     loss-f   loss-r   fvcahs
$$$$ vcahs v flag changed on next card
1090101 108010000 110000000 0.0 0.0 0.0 00100
*%%% vcahs flag w6 now fvcahs & v has changed
*     ic-ind   l-flow   g-flow   int
1090201 1       0.0      0.0      0.0
```

```
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*       upward sink time dependent volume
1100000 sink     tmdpvol
*     varea    vlen     vvol     h-ang    v-ang    v-ht
1100101 1.0e5    1.0      0.0      0.0      0.0      0.0
*     rough    hy-diam  vflags
1100102 0.0      0.0      10
*     ic-ind
1100200 004
1100200 002
*     search   press    temp     quala
1100201 0.0      0.10e6   293.0    1.0e-2
*     search   press    quale
1100201 0.0      0.10e6   0.9
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*       main pipe for downward connection
1140000 supdown  tmdpvol
*     varea    vlen     vvol     h-ang    v-ang    v-ht
1140101 0.0333   1.0      0.0      0.0      0.0      0.0
*     rough    hy-diam  vflags
1140102 0.0      0.0      10
*     ic-ind
1140200 006
*     search   press    uliq     ugas     voidg    quala
1140201 0.0      0.70e6   6.8852e5 2.56951e6 1.0e-8   0.0
1140202 5.0      0.70e6   6.8852e5 2.56951e6 1.0e-8   0.0
1140203 55.0     0.70e6   6.8852e5 2.56951e6 1.0      0.0
1140204 60.0     0.70e6   6.8852e5 2.56951e6 1.0      0.0
*     ic-ind
1140200 002
*     search   press    qual
1140201 0.0      0.70e6   0.0
1140202 5.0      0.70e6   0.0
1140203 7.5      0.70e6   9.9790e-5
1140204 10.0     0.70e6   2.0481e-4
1140205 15.0     0.70e6   4.3228e-4
1140206 20.0     0.70e6   6.8638e-4
1140207 25.0     0.70e6   9.7210e-4
1140208 30.0     0.70e6   1.2957e-3
1140209 35.0     0.70e6   1.6653e-3
1140210 40.0     0.70e6   2.0914e-3
1140211 45.0     0.70e6   2.5881e-3
1140212 50.0     0.70e6   3.1744e-3
1140213 55.0     0.70e6   3.8771e-3
1140214 60.0     0.70e6   4.7346e-3
1140215 65.0     0.70e6   5.8044e-3
1140216 70.0     0.70e6   7.1765e-3
1140217 75.0     0.70e6   9.0000e-3
1140218 80.0     0.70e6   1.1542e-2
1140219 85.0     0.70e6   1.5330e-2
1140220 90.0     0.70e6   2.1580e-2
1140221 95.0     0.70e6   3.3844e-2
1140222 100.0    0.70e6   6.8859e-2
1140223 102.5    0.70e6   1.3179e-1
1140224 105.0    0.70e6   1.0
1140225 110.0    0.70e6   1.0
1140226 112.5    0.70e6   1.3179e-1
1140227 115.0    0.70e6   6.8859e-2
1140228 120.0    0.70e6   3.3844e-2
1140229 125.0    0.70e6   2.1580e-2
```

```
1140230 130.0   0.70e6   1.5330e-2
1140231 135.0   0.70e6   1.1542e-2
1140232 140.0   0.70e6   9.0000e-3
1140233 145.0   0.70e6   7.1765e-3
1140234 150.0   0.70e6   5.8044e-3
1140235 155.0   0.70e6   4.7346e-3
1140236 160.0   0.70e6   3.8771e-3
1140237 165.0   0.70e6   3.1744e-3
1140238 170.0   0.70e6   2.5881e-3
1140239 175.0   0.70e6   2.0914e-3
1140240 180.0   0.70e6   1.6653e-3
1140241 185.0   0.70e6   1.2957e-3
1140242 190.0   0.70e6   9.7210e-4
1140243 195.0   0.70e6   6.8638e-4
1140244 200.0   0.70e6   4.3228e-4
1140245 205.0   0.70e6   2.0481e-4
1140246 210.0   0.70e6   9.9790e-5
1140247 215.0   0.70e6   0.0
1140248 220.0   0.70e6   0.0
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*       downward test junction
1170000 testd    sngljun
*       from     to        area    loss-f   loss-r   fvcahs
1170101 114000000 118000000 1.0e-4  0.0      0.0      20100
*       ic-ind   l-flow    g-flow   int
1170201 1        0.0       0.0      0.0
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*       downward branch pipe
1180000 off-pd   snglvol
*       varea    vlen      vvol     h-ang    v-ang    v-ht
1180101 3.1416e-2 10.0     0.0      0.0      0.0      0.0
*       rough    hy-diam   vflags
1180102 5.0e-5   0.0       00
*       ic-ind   press     qual
1180200 002      0.11e6    0.01
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*       downward throttle valve
1190000 throttld sngljun
*       from     to        area    loss-f   loss-r   fvcahs
$$$$ vcahs v flag changed on next card
1190101 118010000 120000000 0.0 0.0 0.0 00100
*%%% vcahs flag w6 now fvcahs & v has changed; new w9
*       ic-ind   l-flow    g-flow   int
1190201 1        0.0       0.0      0.0
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*       downward sink time dependent volume
1200000 sink     tmdpvol
*       varea    vlen      vvol     h-ang    v-ang    v-ht
1200101 1.0e5    1.0       0.0      0.0      0.0      0.0
*       rough    hy-diam   vflags
1200102 0.0      0.0       10
*       ic-ind
1200200 004
1200200 002
*       search   press     temp     quala
1200201 0.0      0.10e6    293.0    1.0e-2
*       search   press     quale
1200201 0.0      0.10e6    0.9
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*       main pipe for side connection
1240000 supside  tmdpvol
*       varea    vlen      vvol     h-ang    v-ang    v-ht
1240101 0.0333   1.0       0.0      0.0      0.0      0.0
*       rough    hy-diam   vflags
1240102 0.0      0.0       10
*       ic-ind
1240200 006
*       search   press     uliq     ugas     voidg    quala
1240201 0.0      0.70e6    6.8852e5 2.56951e6 1.0e-8  0.0
1240202 5.0      0.70e6    6.8852e5 2.56951e6 1.0e-8  0.0
1240203 55.0     0.70e6    6.8852e5 2.56951e6 1.0     0.0
1240204 60.0     0.70e6    6.8852e5 2.56951e6 1.0     0.0
*       ic-ind
1240200 002
*       search   press     qual
1240201 0.0      0.70e6    0.0
1240202 5.0      0.70e6    0.0
1240203 7.5      0.70e6    9.9790e-5
1240204 10.0     0.70e6    2.0481e-4
1240205 15.0     0.70e6    4.3228e-4
1240206 20.0     0.70e6    6.8638e-4
1240207 25.0     0.70e6    9.7210e-4
1240208 30.0     0.70e6    1.2957e-3
1240209 35.0     0.70e6    1.6653e-3
1240210 40.0     0.70e6    2.0914e-3
1240211 45.0     0.70e6    2.5881e-3
1240212 50.0     0.70e6    3.1744e-3
1240213 55.0     0.70e6    3.8771e-3
1240214 60.0     0.70e6    4.7346e-3
1240215 65.0     0.70e6    5.8044e-3
1240216 70.0     0.70e6    7.1765e-3
1240217 75.0     0.70e6    9.0000e-3
1240218 80.0     0.70e6    1.1542e-2
1240219 85.0     0.70e6    1.5330e-2
1240220 90.0     0.70e6    2.1580e-2
1240221 95.0     0.70e6    3.3844e-2
1240222 100.0    0.70e6    6.8859e-2
1240223 102.5    0.70e6    1.3179e-1
1240224 105.0    0.70e6    1.0
1240225 110.0    0.70e6    1.0
1240226 112.5    0.70e6    1.3179e-1
1240227 115.0    0.70e6    6.8859e-2
1240228 120.0    0.70e6    3.3844e-2
1240229 125.0    0.70e6    2.1580e-2
1240230 130.0    0.70e6    1.5330e-2
1240231 135.0    0.70e6    1.1542e-2
1240232 140.0    0.70e6    9.0000e-3
1240233 145.0    0.70e6    7.1765e-3
1240234 150.0    0.70e6    5.8044e-3
1240235 155.0    0.70e6    4.7346e-3
1240236 160.0    0.70e6    3.8771e-3
1240237 165.0    0.70e6    3.1744e-3
1240238 170.0    0.70e6    2.5881e-3
1240239 175.0    0.70e6    2.0914e-3
1240240 180.0    0.70e6    1.6653e-3
1240241 185.0    0.70e6    1.2957e-3
1240242 190.0    0.70e6    9.7210e-4
1240243 195.0    0.70e6    6.8638e-4
1240244 200.0    0.70e6    4.3228e-4
1240245 205.0    0.70e6    2.0481e-4
```

```
1240246  210.0    0.70e6    9.9790e-5
1240247  215.0    0.70e6    0.0
1240248  220.0    0.70e6    0.0
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*        side test junction
1270000  tests    sngljun
*        from     to       area     loss-f    loss-r    fvcahs
* for mod2 (uk e03)
1270101  124000000 128000000 1.0e-4    0.0       0.0       100100
* for mod3 (uk)
$$$$ vcahs v flag changed on next card
1270101 124000000 128000000 1.0e-4 0.0 0.0 30100
*%%% vcahs flag w6 now fvcahs & v has changed; new w9
*        ic-ind    l-flow    g-flow    int
1270201  1         0.0       0.0       0.0
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*        side branch pipe
1280000  off-ps   snglvol
*        varea    vlen     vvol     h-ang    v-ang    v-ht
1280101  3.1416e-2 10.0    0.0      0.0      0.0      0.0
*        rough    hy-diam  vflags
1280102  5.0e-5   0.0      00
*        ic-ind   press    qual
1280200  002      0.11e6   0.01
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*        side throttle valve
1290000  throttls sngljun
*        from     to       area     loss-f    loss-r    fvcahs
$$$$ vcahs v flag changed on next card
1290101 128010000 130000000 0.0 0.0 0.0 00100
*%%% vcahs flag w6 now fvcahs & v has changed; new w9
*        ic-ind    l-flow    g-flow    int
1290201  1         0.0       0.0       0.0
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*        side sink time dependent volume
1300000  sink     tmdpvol
*        varea    vlen     vvol     h-ang    v-ang    v-ht
1300101  1.0e5    1.0      0.0      0.0      0.0      0.0
*        rough    hy-diam  vflags
1300102  0.0      0.0      10
*        ic-ind
1300200  004
1300200  002
*        search   press    temp     quala
1300201  0.0      0.10e6   293.0    1.0e-2
*        search   press    quale
1300201  0.0      0.10e6   0.9
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*        tables
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*        table to relate liquid height to void fraction
20200100 reac-t   0
*               void fraction  height from centre
20200101  0.000000000000e+00  5.000000000000e-01
20200102  8.184178458320e-04  4.938441702975e-01
20200103  6.451071621177e-03  4.755282581474e-01
20200104  2.124094630001e-02  4.455032620938e-01
20200105  4.863465427216e-02  4.045084971869e-01
20200106  9.084505690862e-02  3.535533905924e-01
20200107  1.486346542727e-01  2.938926261450e-01
20200108  2.212409463010e-01  2.269952498682e-01
20200109  3.064510716225e-01  1.545084971855e-01
20200110  4.008184178474e-01  7.821723251785e-02
20200111  5.000000000000e-01  0.000000000000e+00
20200112  5.991815821557e-01 -7.821723252289e-02
20200113  6.935489283801e-01 -1.545084971904e-01
20200114  7.787590537009e-01 -2.269952498727e-01
20200115  8.513653457283e-01 -2.938926261491e-01
20200116  9.091549430914e-01 -3.535533905960e-01
20200117  9.513653457268e-01 -4.045084971899e-01
20200118  9.787590536981e-01 -4.455032620962e-01
20200119  9.935489283762e-01 -4.755282581490e-01
20200120  9.991815821511e-01 -4.938441702983e-01
20200121  1.000000000000e+00 -5.000000000000e-01
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*    calculators for liquid and vapour mass flows
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*        upward branch
20520100 vap-uflw  mult    3.1416e-2 1.0e-20  1  1   1.0e-20
20520101 voidgj    107000000
20520102 rhogj     107000000
20520103 velgj     107000000
*
20520200 liq-uflw  mult    3.1416e-2 1.0e-20  1  1   1.0e-20
20520201 voidfj    107000000
20520202 rhofj     107000000
20520203 velfj     107000000
*
20520300 tot-uflw  sum      1.0      0.01     1
20520301 0.0       1.0      cntrlvar  201
20520302           1.0      cntrlvar  202
*
20520400 x-junu    div      1.0      0.0      1  3   0.0  1.0
20520401 cntrlvar  203
20520402 cntrlvar  201
*
*        downward branch
20520500 vap-dflw  mult    3.1416e-2 1.0e-20  1  1   1.0e-20
20520501 voidgj    117000000
20520502 rhogj     117000000
20520503 velgj     117000000
*
20520600 liq-dflw  mult    3.1416e-2 1.0e-20  1  1   1.0e-20
20520601 voidfj    117000000
20520602 rhofj     117000000
20520603 velfj     117000000
*
20520700 tot-dflw  sum      1.0      0.01     1
20520701 0.0       1.0      cntrlvar  205
20520702           1.0      cntrlvar  206
*
20520800 x-jund    div      1.0      0.0      1  3   0.0  1.0
20520801 cntrlvar  207
20520802 cntrlvar  205
*
*        side branch
20520900 vap-sflw  mult    3.1416e-2 1.0e-20  1  1   1.0e-20
20520901 voidgj    127000000
20520902 rhogj     127000000
20520903 velgj     127000000
*
```

```
20521000 liq-sflw  mult     3.1416e-2 1.0e-20  1  1   1.0e-20
20521001 voidfj    127000000
20521002 rhofj     127000000
20521003 velfj     127000000
*
20521100 tot-sflw  sum      1.0    0.01     1
20521101 0.0       1.0      cntrlvar 209
20521102           1.0      cntrlvar 210
*
20521200 x-juns    div      1.0    0.0      1  3   0.0 1.0
20521201 cntrlvar 211
20521202 cntrlvar 209
*
*     summed phase flows
20521400 vap-flow  sum      1.0    0.0      1
20521401 0.0       1.0      cntrlvar 201
20521402           1.0      cntrlvar 205
20521403           1.0      cntrlvar 209
*
20521600 liq-flow  sum      1.0    0.0      1
20521601 0.0       1.0      cntrlvar 202
20521602           1.0      cntrlvar 206
20521603           1.0      cntrlvar 210
*
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*     calculators for htc correlations
*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$*$
*     calculators for critical height/depth hb
20521700 gdrho     sum      9.81   1.0      1
20521701 0.0       1.0      rhof   104010000
20521702           -1.0     rhog   104010000
*
20521800 wgwgu     mult     1.0    1.0e-20  1  1   1.0e-20
20521801 cntrlvar 201       cntrlvar 201
*
20521900 wgwgs     mult     1.0    1.0e-20  1  1   1.0e-20
20521901 cntrlvar 209       cntrlvar 209
*
20522000 wfwfd     mult     1.0    1.0e-20  1  1   1.0e-20
20522001 cntrlvar 206       cntrlvar 206
*
20522100 wfwfs     mult     1.0    1.0e-20  1  1   1.0e-20
20522101 cntrlvar 210       cntrlvar 210
*
20522200 rggdrho   mult     1.0    1.0e-20  1  1   1.0e-20
20522201 cntrlvar 217       rhog   104010000
*
20522300 rfgdrho   mult     1.0    1.0e-20  1  1   1.0e-20
20522301 cntrlvar 217       rhof   104010000
*
20522400 wgwgund   div      1.0    1.0e-20  1  1   1.0e-20
20522401 cntrlvar 222       cntrlvar 218
*
20522500 wgwgsnd   div      1.0    1.0e-20  1  1   1.0e-20
20522501 cntrlvar 222       cntrlvar 219
*
20522600 wfwfdnd   div      1.0    1.0e-20  1  1   1.0e-20
20522601 cntrlvar 223       cntrlvar 220
*
20522700 wfwfsnd   div      1.0    1.0e-20  1  1   1.0e-20
20522701 cntrlvar 223       cntrlvar 221
*
20522800 wgwgup2   powerr   1.0    1.0e-20  1  1   1.0e-20
20522801 cntrlvar 224       0.2
*
20522900 wgwgsp2   powerr   1.0    1.0e-20  1  1   1.0e-20
20522901 cntrlvar 225       0.2
*
20523000 wfwfdp2   powerr   1.0    1.0e-20  1  1   1.0e-20
20523001 cntrlvar 226       0.2
*
20523100 wfwfsp2   powerr   1.0    1.0e-20  1  1   1.0e-20
20523101 cntrlvar 227       0.2
*
20523200 hbup      sum      1.67   1.0e-6   1  3   1.0e-6 0.206
20523201 0.0       1.0      cntrlvar 228
*
20523300 hbdown    sum      1.50   1.0e-6   1  3   1.0e-6 0.206
20523301 0.0       1.0      cntrlvar 230
*
20523400 hbsi_low  sum      0.69   5.64e-3  1  3   5.64e-3 0.103
20523401 0.0       1.0      cntrlvar 229
*
20523500 hbsi_hgh  sum      0.75   5.64e-3  1  3   5.64e-3 0.103
20523501 0.0       1.0      cntrlvar 231
*
*     calculators for level height
* liquid level above main pipe centre as fraction of pipe diameter
20523900 llc/d     function 1.0    0.0      1  3   -0.5  0.5
20523901 voidg     104010000 001
*
20524000 hup       sum      0.206  1.0e-20  1  1   1.0e-20
20524001 0.5       -1.0     cntrlvar 239
*
20524100 hdown     sum      0.206  1.0e-20  1  1   1.0e-20
20524101 0.5       1.0      cntrlvar 239
*
20524200 hside     sum      0.206  0.0      1
20524201 0.0       1.0      cntrlvar 239
*
*     calculators for non-dimensional height r
20524300 rup       div      1.0    1.0e-20  1  3   1.0e-20 1.0
20524301 cntrlvar 232       cntrlvar 240
*
20524400 rdown     div      1.0    1.0e-20  1  3   0.0    1.0
20524401 cntrlvar 233       cntrlvar 241
*
20524500 rside1    div      1.0    0.0      1  3   -1.0  0.0
20524501 cntrlvar 234       cntrlvar 242
*
20524600 rside2    div      1.0    0.0      1  3   0.0   1.0
20524601 cntrlvar 235       cntrlvar 242
*
20524700 rside     sum      1.0    0.0      1
20524701 0.0       1.0      cntrlvar 245
20524702           1.0      cntrlvar 246
*
*     calculators for std quality x0
20524900 rf/rg     div      1.0    1.0      1
20524901 rhog      104010000 rhof  104010000
*
20525000 rf/rgp5   stdfnctn 1.0    1.0      1
20525001 sqrt      cntrlvar 249
*
```

```
20525100 "1+sqrt" sum      1.0     1.0     1
20525101 1.0      1.0      cntrlvar 250
*
20525200 x0       div      1.15    1.0     1
20525201 cntrlvar 251
*
*       calculators for upward quality x
20525300 xu1      sum      1.0     0.0     1  3  0.0  1.0
20525301 1.0      -1.0     cntrlvar 243
*
20525400 xu2      mult     3.25    0.0     1
20525401 cntrlvar 253      cntrlvar 253
*
20525500 xup      powerx   1.0     0.0     1  3  0.0  1.0
20525501 cntrlvar 243      cntrlvar 254
*
*       calculators for side quality x
*
*       calculators for x0 exponents
20525600 x0s1     sum      1.00    0.0     1  2  0.0
20525601 0.0      1.0      cntrlvar 245
*
20525700 x0s2     sum      1.09    0.0     1  1  0.0
20525701 0.0      1.0      cntrlvar 246
*
20525800 x0s      sum      1.00    0.0     1
20525801 1.0      1.0      cntrlvar 256
20525802          1.0      cntrlvar 257
*
20526200 "1-rs"   sum      1.0     0.0     1
20526201 1.0      -1.0     cntrlvar 247
*
20526300 x0p1-rs  powerx   1.0     0.0     1
20526301 cntrlvar 252      cntrlvar 262
*
20526400 "1+rs"   sum      1.0     0.0     1
20526401 1.0      1.0      cntrlvar 247
*
20526500 x0tm1s   mult     -0.5    0.0     1
20526501 cntrlvar 247      cntrlvar 264
20526502 cntrlvar 263
*
20526600 x0tm2s   sum      1.0     0.0     1  1  0.0
20526601 1.0      1.0      cntrlvar 265
*
20526700 x0tm3s   stdfnctn 1.0     0.0     1
20526701 sqrt     cntrlvar 266
*
20526800 x0tm4s   powerx   1.0     0.0     1
20526801 cntrlvar 252      cntrlvar 258
*
20527000 xside    mult     1.0     0.0     1  3  0.0  1.0
20527001 cntrlvar 267      cntrlvar 268
*
*       calculators for downward quality x
*
*       calculators for x0 exponent
20527500 x0d      sum      2.5     0.0     1  3  0.0  2.5
20527501 0.0      1.0      cntrlvar 244
*
20527600 "1-rd"   sum      1.0     0.0     1
20527601 1.0      -1.0     cntrlvar 244
*
20527700 x0p1-rd  powerx   1.0     0.0     1
20527701 cntrlvar 252      cntrlvar 276
*
20527800 "1+rd"   sum      1.0     0.0     1
20527801 1.0      1.0      cntrlvar 244
*
20527900 x0tm1d   mult     -0.5    0.0     1
20527901 cntrlvar 244      cntrlvar 278
20527902 cntrlvar 277
*
20528000 x0tm2d   sum      1.0     0.0     1  1  0.0
20528001 1.0      1.0      cntrlvar 279
*
20528100 x0tm3d   stdfnctn 1.0     0.0     1
20528101 sqrt     cntrlvar 280
*
20528200 x0tm4d   powerx   1.0     0.0     1
20528201 cntrlvar 252      cntrlvar 275
*
20528300 xdown    mult     1.0     0.0     1  3  0.0  1.0
20528301 cntrlvar 281      cntrlvar
```

NRC FORM 335 (2-89) NRCM 1102, 3201, 3202 — U.S. NUCLEAR REGULATORY COMMISSION	1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)
BIBLIOGRAPHIC DATA SHEET *(See instructions on the reverse)*	NUREG/IA-0096
2. TITLE AND SUBTITLE Numerics and Implementation of the UK Horizontal Stratification Entrainment Off-Take Model into RELAP5/MOD3	3. DATE REPORT PUBLISHED MONTH: June — YEAR: 1993 4. FIN OR GRANT NUMBER L2245
5. AUTHOR(S) W. M. Bryce	6. TYPE OF REPORT Technical 7. PERIOD COVERED *(Inclusive Dates)*

8. PERFORMING ORGANIZATION — NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

Physics and Thermal Hydraulics Division
AEA Thermal Reactor Services
Winfrith Technology Centre
Dorchester, Dorset
DT2 8DH, UK

9. SPONSORING ORGANIZATION — NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

This report presents the numerics and implementation details to add the same improved discharge quality correlations into RELAP5/MOD3. In the light of experience with the modified RELAP5/MOD2 code, some of the numerics has been slightly changed for RELAP5/MOD3. The description is quite detailed in order to facilitate change by some future code developer. A simple test calculation was performed to confirm the coding of the correlations implemented in RELAP5/MOD3.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*	13. AVAILABILITY STATEMENT Unlimited
ICAP Program RELAP5/MOD3 UK Numerics and Implementation	14. SECURITY CLASSIFICATION *(This Page)* Unclassified *(This Report)* Unclassified
	15. NUMBER OF PAGES
	16. PRICE

Printed on recycled paper

Federal Recycling Program

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

FIRST CLASS MAIL
POSTAGE AND FEES PAID
USNRC
PERMIT NO. G-67

(4 copies)

Gene Rhee, RES
NL/N-353