NUREG/IA-0238

International Agreement Report

RELAP5/MOD3 Horizontal Off-Take Model for Application to Reactor Headers of CANDU Type Reactors

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ABSTRACT

The RELAP5 liquid entrainment and vapor pull-through models of horizontal pipe have been extended for the better prediction of thermal hydraulics in reactor header of CANDU plant. The model of RELAP5 accounts for the phase separation phenomena and computes the flux of mass and energy through an off-take attached to a horizontal pipe when stratified conditions occur in the horizontal pipe. This model is sometimes referred to as the off-take model. The importance of predicting the fluid conditions through an off-take in a small-break LOCA has been well known. In CANDU reactor, off-take model becomes so important that it controls the coolant flow of 95 feeders connected to the reactor header component where the horizontal stratification occurs. The current RELAP5 model is able to treat the only 3 directions junctions; vertical upward, downward, and side oriented junctions, thus improvements for the off-take model is needed for modeling the exact angles. The RELAP5 off-take model has been modified and generalized by considering the geometric effect of branching angles. Verification calculations have been performed for a conceptual blowdown problem in a pipe with different connected angles of branch. The calculated void fraction and mass flow rate of different location of branches shows the validity of implemented model. Experimental works have been also suggested for the further verification and improvement of models.

FOREWORD

RELAP5 is one of the best-estimate thermal-hydraulic system codes to date. It was developed by United States Nuclear Regulatory Commission (USNRC) and its latest version, RELAP5/MOD3.3 (patch 03) was released in 2006. Though USNRC has been moving most of their developmental efforts from RELAP5 to TRACE, the RELAP5 code is still widely applied to analyses of various transients in Light Water Reactors (LWRs), including the postulated large break loss-of-coolant accident (LBLOCA).
In Korea, four CANDU (CANada Deuterium Uranium)-type heavy water reactors are in operation, which have design peculiarities, especially the reactor core composed of many small separated horizontal fuel channels and the moderator separated from the coolant. For purpose of a regulatory auditing calculation, the RELAP5 code has been adapted to the CANDU reactor design by model modifications and developments. This report, as part of such an effort, describes how the current RELAP5 model capable of treating the only 3 directions junctions; vertical upward, downward, and side oriented junctions, have been modified and generalized to consider the geometric effect of branching angles.

The authors acknowledge the financial support of the National Research Foundation under the national mid- and long-term nuclear research and development program of the Ministry of Educ ation, Science and Technology of the Republic of Korea.

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The variables related to the correlations and conditions in Subprogram "hzflow" were modified by using the relations derived from the geometry of header configuration and elevation of connected branch. Subprogram "rbrnch", "rsngj", "rvalve" were also modified for users to input the connection angle of branch pipes to a header, and users can apply the extended model to single junction, branch, and valve.

Verification calculations have been performed for a conceptual blowdown problem with different connection angles of branch in a horizontal pipe. The calculated void fraction and mass flow rate of different location of branches shows the validity of implemented model. Since the model was developed by extending the existing RELAP5 side off-take model without any experimental validation, careful consideration should be taken into account in the amount of liquid entrainment and vapor pull-through. It is recommended that the branch where the connection angle is more than ±60° should be modeled with the existing upward or downward off-take option. Experimental works have been also recommended for the further verification and improvement of models.

1. INTRODUCTION

The CANDU-type Pressurized Heavy Water Reactors (PHWR) have been developed by AECL in Canada and constructed in many countries including Korea during the past decades. At present time, four 600 MWe CANDU reactors [1] are operating in the Wolsung site of Korea, and the guarantee of safety for CANDU type reactor become more and more important.

The efforts have been done for many years to develop a thermal hydraulic auditing code for CANDU-type plant by extending the model of RELAP5/MOD3 code [2]. Major thermal hydraulic phenomena for the key CANDU events and modeling limitation of RELAP5/MOD3 for CANDU applications has been identified and code improvement has been attempted [3] by extending existing RELAP5 models. Although many models for CANDU applications have been successfully implemented into the current RELAP5/MOD3.3 code [4], there are still many remained items related to LOCA event. One of these items is a stratification off-take model for CANDU reactor headers. The unique features of CANDU design are that the 190 fuel channels are horizontal and connected through 95 feeders to headers that distribute coolant to each channel. Figure 1 shows the schematic drawing of feeder connections in primary heat transport system of CANDU. Feeder pipes are connected with 5 orientation angles, i.e. 0-degree (horizontal), 36-degree, 72-degree, 108-degree, and 144 degree downward. The details are shown in Figure 2.

During the hypothetical events, such as SBLOCA, the phase separation usually occurs by gravitational force in the reactor header which is the one of the largest horizontal pipe in CANDU heat transport system. One consequence of stratification in a large horizontal header pipe is that the properties of the fluid convected through a small flow path in the pipe wall depend on the location of stratified liquid level in the large pipe relative to the location of the branch in the header pipe wall. Since the emergency core cooling system has been designed to inject water into the header volume, the connected angle of feeder is important to the coolant flow into the fuel channel.

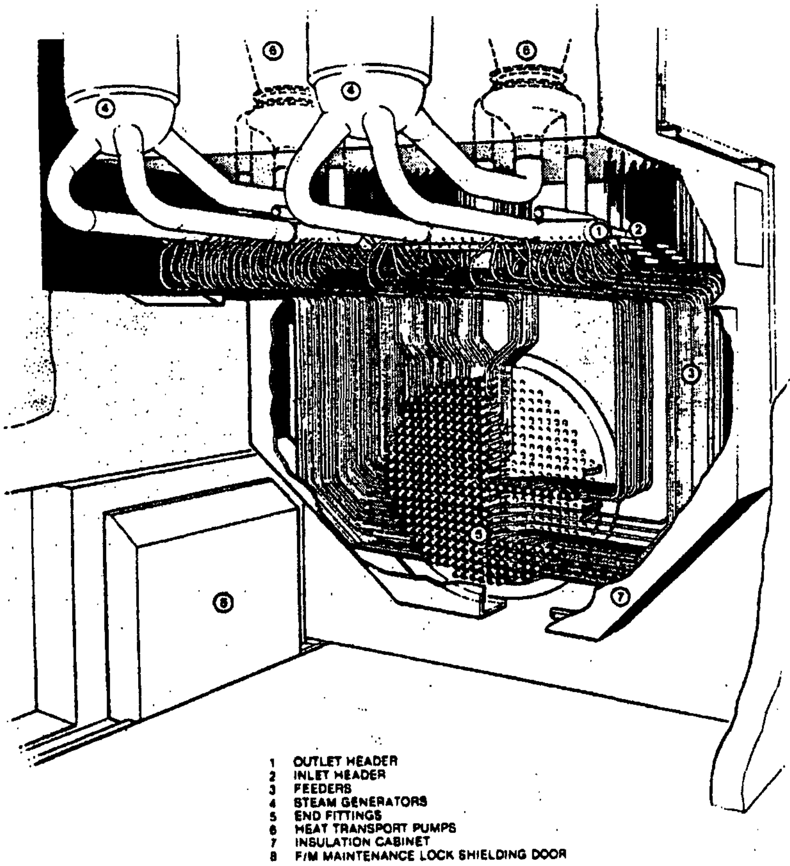


Figure 1 Schematic Diagram of CANDU Feeder and Header Arrangement

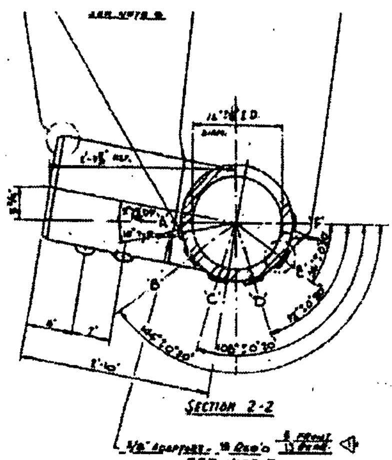


Figure 2 Connection angles of Feeders in Horizontal Header Pipe
(Location F- 0, E-36, D-72, C-108, B-144 degree)

2. MODEL REVIEW

RELAP5/MOD3 horizontal stratification entrainment/pull-through model [5] accounts for phase separation phenomena and computes the flux of mass and energy through an off-take attached to a horizontal pipe. The importance of predicting the fluid conditions through an off-take in a small-break LOCA has been discussed in detail by Zuber [6]. When stratification occurs in a large horizontal pipe, the quality of a branch line can be calculated by "upward off-take", "downward off-take," and "horizontal off-take" models according to connection angle between a large horizontal and branch pipes (Fig. 3). These models were developed from experimental studies where the inception height on liquid entrainment and vapor pull-through were measured.

The inception height, h_b, associated with the onset of liquid entrainment or vapor pull-through is represented as follows [7].

$$h_b = \frac{C W_k^{0.4}}{\left[g\rho_k\left(\rho_f - \rho_g\right)\right]^{0.2}} \qquad (1)$$

where, k represents the phase properties of a continuum flowing in a branch pipe before the onset of liquid entrainment or vapor pull-through. For example, k represents liquid properties for downward oriented off-take. W is the flow rate of a continuum. C is a coefficient determined by experiment.

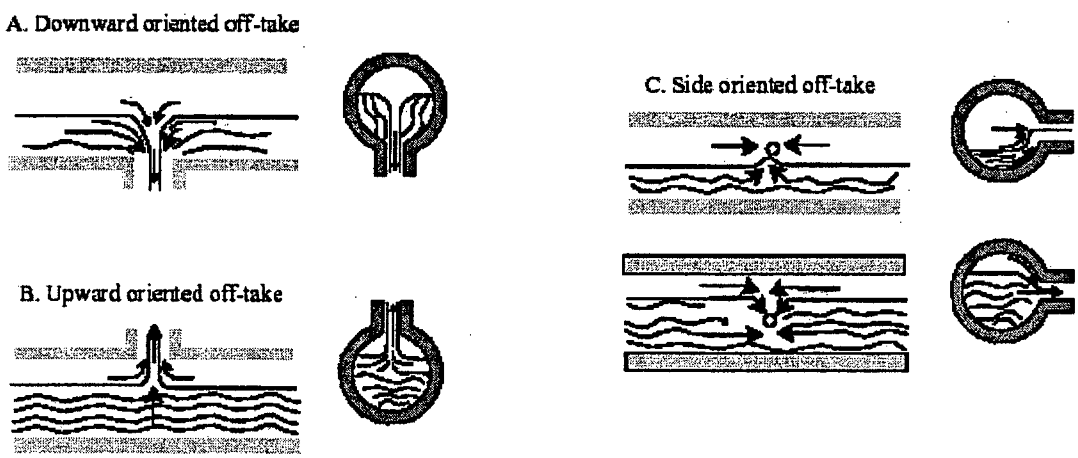


Figure 3 Off-Take Phenomena between a Large Horizontal and Branch Pipes

$$C = \begin{cases} 1.67 & \text{for upward off-take liquid entrianment} \\ 1.50 & \text{for downward off-take gas pull-through} \\ 0.75 & \text{for horizontal off-take gas pull-through} \\ 0.75 & \text{for horizontal off-take liquid entrianment} \end{cases} \quad (2)$$

Experiment The correlations used for calculation of flow quality, X, at the branch entrance with off-take are dependent on the connection angle between a large horizontal and branch pipes, and represented as follows;

$$X = \begin{cases} R^{3.25(1-R)} & \text{for an upward off-take branch} \\ X_o^{2.5R}\left[1-0.5R(1+R)X_o^{(1-R)}\right]^{0.5} & \text{for a downward off-take branch} \\ X_o^{(1+CR)}\left[1-0.5R(1+R)X_o^{(1-R)}\right]^{0.5} & \text{for a horizontal off-take branch} \end{cases}, \quad (3)$$

where,

$$R = \frac{h}{h_b}, \quad (4)$$

$$X_o = \frac{1.15}{1+\left(\rho_f/\rho_g\right)^{0.5}},$$

h = distance from the stratified liquid level to junction

$$C = \begin{cases} 1.09 & \text{for gas pull-through} \\ 1.00 & \text{for liquid-entrainment} \end{cases}.$$

Figures 4, 5, and 6 show the experimental results of discharge flow quality as a function of liquid depth for an upward, downward, and horizontal off-take branches respectively.

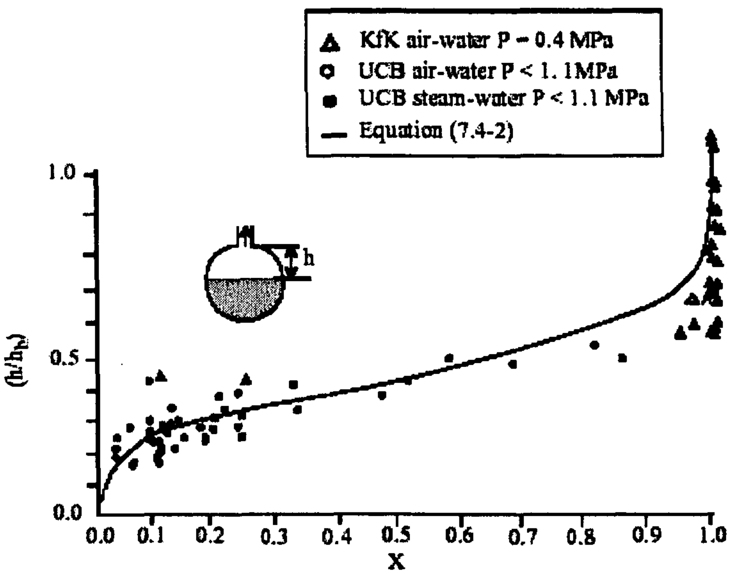


Figure 4 Discharge Flow Quality versus Liquid Depth for an Upward Off-Take Branch

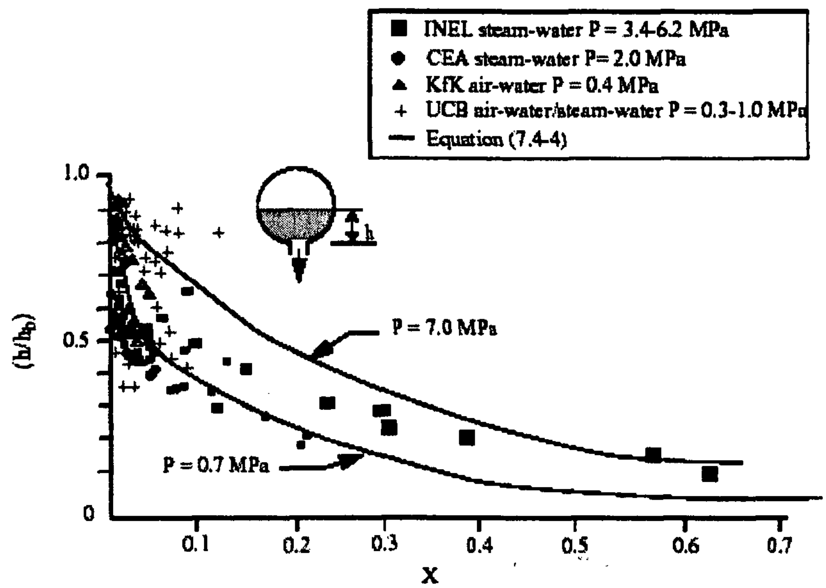


Figure 5 Discharge Flow Quality versus Liquid Depth for a Downward Off-Take Branch

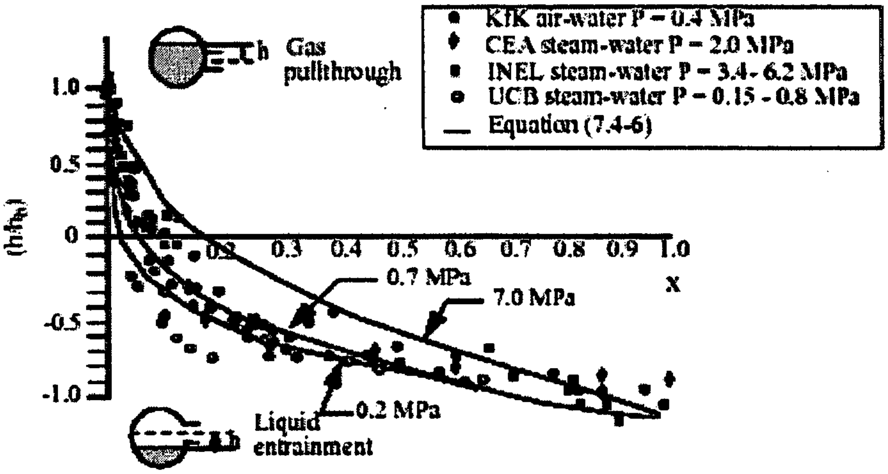


Figure 6 Discharge Flow Quality versus Liquid Depth for a Horizontal Off-Take Branch

3. MODEL EXTENSION

Among the three RELAP5 off-take model, the side oriented off-take model was considered to be suitable to extend for CANDU header application. In Figure 6, the side off-take model has the both vapor pull-through and liquid entrainment model, and it has a correlation of relative location between branch and water level. The side off-take model can be easily extended for the case of general connection angle in Figure 7. In order to formulate the generalized off-take model, the followings are needed.

1) The geometric formulation of relations between stratified water level and branch

2) Experimental correlation of inception height, h_b, associated with the onset of liquid entrainment or vapor pull-through at angled branch

3) Experimental correlations used for calculation of flow quality at angled branch

In this study, off-take model was modified to consider only the geometric configuration between a header and branches with any connection angles. It should be noted that original top and bottom off-take models in RELAP5 code was not modified. A side off-take model was extended to the branch with general connection angles [8].

Figure 7 shows the conceptual diagrams of vapor pull-through and liquid entrainment for the branch with angle of □ to the horizon. From the Fig. 7, the void fraction, α_g*, at which the liquid level is at the middle of the branch with the connection angle of □ can be represented by the following equation.

$$\alpha_g * = \frac{(\pi/2 - \vartheta) - \sin(\pi/2 - \vartheta)\cos(\pi/2 - \vartheta)}{\pi} \quad (5)$$

For the horizontal off-take case, that is, $\vartheta = 0$, then the above equation provides $\alpha_g^* = 0.5$. For the upward ($\vartheta = \pi/2$) and downward ($\vartheta = -\pi/2$) cases, $\alpha_g^* = 0.0$ and $\alpha_g^* = 1.0$ are obtained respectively.

The liquid level from the branch, h_c, can be obtained by the geometry.

$$h_c = \frac{D}{2}(\sin\phi - \sin\vartheta) \tag{6}$$

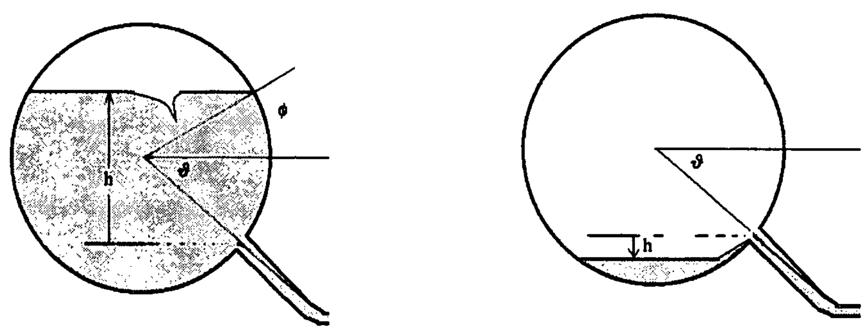
Where D is diameter of pipe and ϕ is horizontal angle to water level on the pipe wall. The angle can be determined implicitly from the void fraction of header volume.

Since there is no experimental data of angled branch, the inception height, h_b was taken from the side off-take model. Thus nondimensional depth R, i.e. h_c/h_b, can be determined from Eq. (6) and Eq. (1). The correlation of branch flow quality is usually represented as a function of nondimensional depth R, as Eq. (3). Without any experimental data, the side off-take correlation was taken as an angled branch correlation.

$$X = X_o^{(1+CR)}\left[1 - 0.5R(1+R)X_o^{(1-R)}\right]^{0.5} \quad \text{for a horizontal angled branch} \tag{7}$$

$$X_o = \frac{1.15}{1+\left(\rho_f / \rho_g\right)^{0.5}}$$

$$C = \begin{cases} 1.09 & \textit{for gas pull-through} \\ 1.00 & \textit{for liquid-entrainment} \end{cases}$$



(a) Vapor Pull-through (b) Liquid Entrainment

Figure 7 Conceptual Diagram for Off-Take with Connection Angle, ϑ

4. CODE AND INPUT CARD CHANGE

4.1 Code Change

The variables related to conditions in Subprogram "hzflow" were modified to implement the model derived from the geometrical relationship between water level and branch location, with the absence of experimental correlations. Since side off-take correlation was used for coding, extended model is not applicable to the upward and downward off-take branches. Subprogram "rbrnch", "rsngj", "rvalve" were also modified for user's input of the connection angle of branch pipes. Thus users can utilize the extended model by user's option in the component of "single junction", "branch", and valve". Modified parts of each Subprogram are listed in Appendix A.

4.2 Input Card Change

In order to use the extended off-take model, single-junction geometry cards, ccc0101 through ccc0109, should be modified as follows. The junction data for branch and valve component should be also modified as similar ways.

W6(I) Junction control flags. This word has the packed format jefvcahs . It is not necessary to input leading zeros.
The digit v specifies horizontal stratification entrainment/ pull-through options. This model is for junctions connected to a horizontal volume. v =0 means the model is not applied; v =1 means an upward-oriented junction; v =2 means a downward-oriented junction; and v =3 means a centrally (side) located junction. **v=4 means extended angled side located junction**

W7(R) Discharge coeff.

W8(R) Non Eq. Factor for H-F (default = 0.14)

W9(R) Not used in default H-F model. If W6(I) is 4, this word is the horizontal angle (degr ee) between from-volume and to-volume

5. MODEL VERIFICATION

A conceptual problem, as shown in figure 8, has been set for model installation verification. Total 8 branches are connected to a header with different connection angles (from 0 to 90 degree). Inner diameter and horizontal length of the header are 1 m, and 3 m respectively. Each branch pipe has same inner diameter of 0.01 m.

The header is modeled as 3 nodes. All branch junctions are connected to the middle node (100-2) of the header. Initially, a header pipe is full of saturated heavy water at 10 MPa pressure. The valves are fully open to atmosphere, and blowdown occurs at time zero. The input deck for the verification problem is listed in Appendix B.

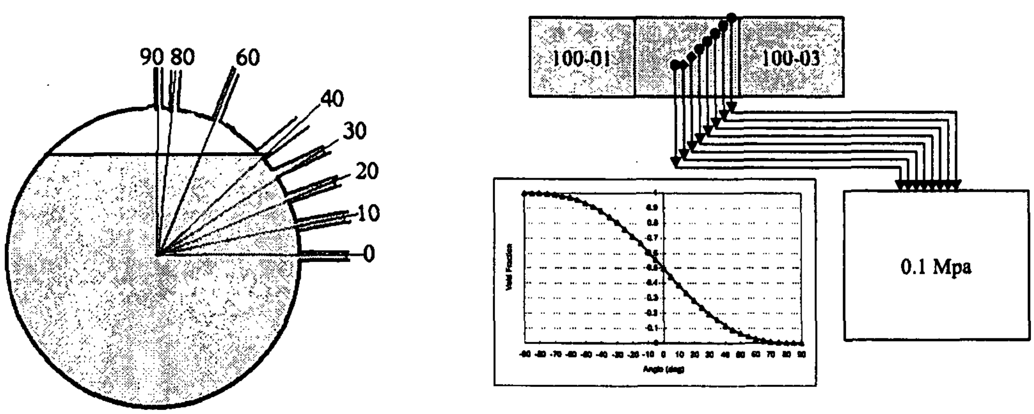


Figure 8 A Conceptual Problem for Model Verification

The pressure of tank decrease and void generate as a normal process of blowdown. Since the water inside the tank remains on a stagnant condition, phase separation occurs and water level formulate. The water level decrease continuously, as a consequence of blowdown process. If the water level reaches the elevation of branch, liquid flow should be changed into vapor flow. The calculation results are shown from Fig. 9 to 11.

Figure 9 shows header pressure which decreased with time. Figure 10 represents the void transients in the header and each branch junctions. It shows that the transition from liquid to vapor flow happens earlier in the top branch, and later in the branches with lower connection angles sequentially. The void fraction in a branch increase due to the vapor pull-through even before the water level reaches the elevation of the branch. On the other hand, the liquid flow is maintained due to the liquid entrainment model in the branch after the water level passed down the elevation of branch. Figure 11 shows the smooth transition of discharge flow from liquid to steam. From these results, it is concluded that the extended model is installed well and working as expected.

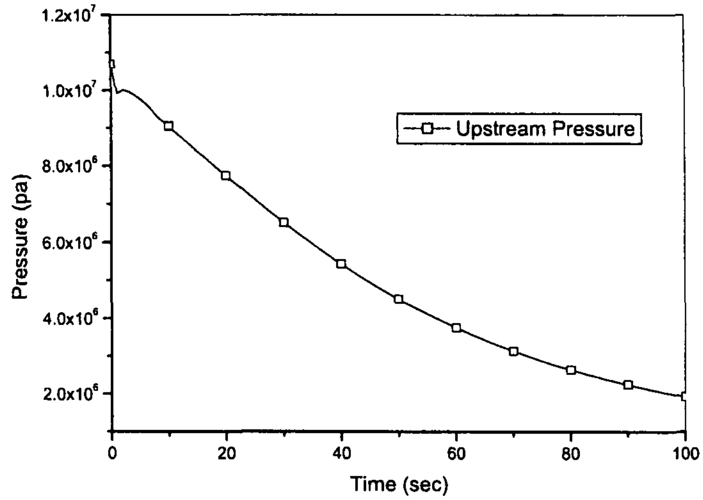


Figure 9 Header Pressure Transients

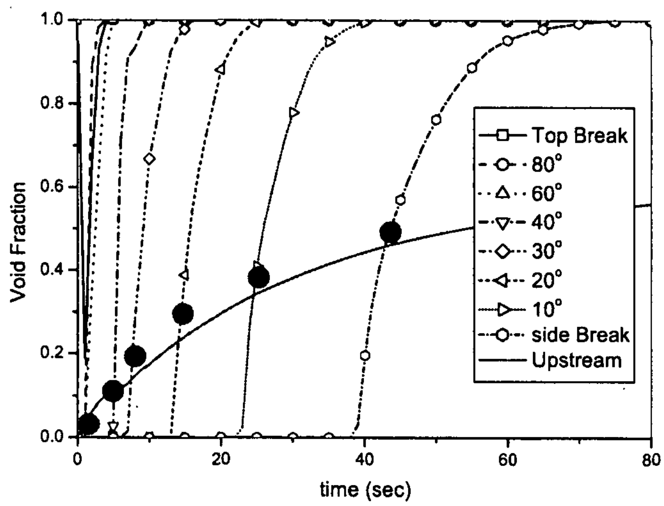


Figure 10 Void Fractions of the Header and Each Branch

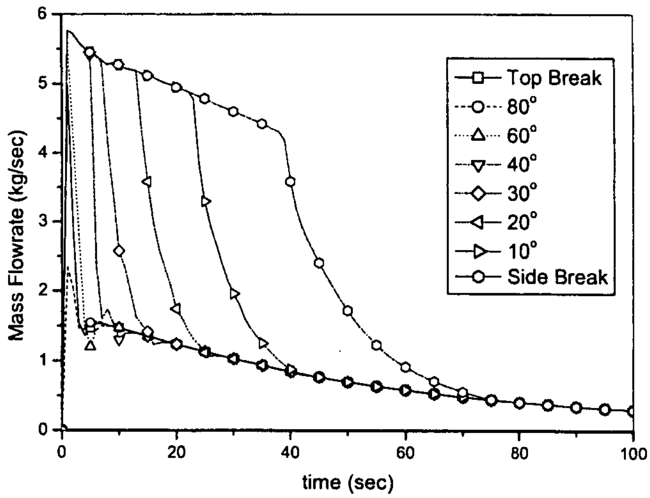


Figure 11 Mass Flow Rates of Each Branch

6. CONCLUDING REMARK

The liquid entrainment and vapor pull-through models of horizontal pipe of RELAP5/MOD3 have been improved for the better prediction of thermal-hydraulic between a header and feeder pipes in CANDU type reactor. The improved model enables to model the connection angle between horizontal pipe and branch as a user input value. Model implementation has been verified through the calculation of conceptual blowdown problem. Since the model was developed by extending the existing RELAP5 side off-take model without any experimental validation, careful consideration should be taken into account in the amount of liquid entrainment and vapor pull-through. It is recommended that the branch where the connection angle is more than ±60° should be modeled with the existing upward or downward off-take option. Experimental works should be done for the determination of inception criteria and flow quality of angled branch. Interference effect of vortex motion on flow discharge between many feeder branches in the horizontal header pipe is also an area of study for further improvements of the model.

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Appendix A

Lists of Subprogram Changes

Changes in 'hzflow'

```
SUBROUTINE hzflow(ichoke)
!define win32dvf
!define erf
!define fourbyt
!define hconden
!define impnon
!define in32
!define newnrc
!define ploc
!define sphaccm
.
.
.
INCLUDE 'voldat.h'
! candu HDR i1
     INCLUDE 'cons.h'
!  Local variables.
     INTEGER i,ik,j,k,kk,kx,ky,l,ll,lx,ly,m,nmap
     LOGICAL countc
     REAL(8) aj,ajth,alf,alg,alphef,alpham,arfg,argf
.
.
.
PARAMETER (grvmp2=0.634d0,grvp5=3.13d0)
     REAL(8) psinq,pcosq
! candu HDR i1
     REAL(8) voidgs,hangle
!
!  Data statements.
     DATA  ighsed,ighseh,ighsex/0,0,0/
.
.
.
! candu HDR+
! Consider the void fraction when free surface in on the junction (theta angle)
! void*pi= (pi/2-theta)-sin(pi/2-theta)*cos(pi/2-theta)
! where theta = jdissh(i)
             hangle=jdissh(i)*pi/180.0d0
             theta=pi/2.0d0-hangle
             voidgs=theta-sin(theta)*cos(theta)
             voidgs=voidgs/pi
! candu HDR-
!  Consider liquid entrainment.
!  This is the beginning of the liquid entrainment section which
!   covers    1. Upward-oriented,
!             2. Downward-oriented counter-current
.
.
.
!
! candu HDR r2
!                        IF(countc.or.j.eq.1.or.(j.eq.3.and.voidg( &
!                        kk).gt.0.5d0))then
                         IF(countc.or.j.eq.1.or.(j.eq.3.and.voidg( &
                         kk).gt.voidgs))then
!  Calculation of stratification angle.
                           alpham=min(voidf(kk),voidg(kk))
                           theta=htheta(alpham)
.
.
.
!  For normal horizontal main (doner) volume the liquid level is
!   calculated by using the stratification angle.
!
! candu HDR+ r1
!                               hcll=diamv(kk)*0.5d0*ctheta
                                hcll=diamv(kk)*0.5d0*(ctheta-sin(hangle))
                             ENDIF
!  Calculate common correlation parameter for j .eq. 1 2 3
                             x00=1.15d0/(1.0d0+sqrt(rhof(kk)/    &
                             rhog(kk)))
!
```

```
.
.
.
!  Reduce it as in old model.
!  voidx=min(voidx,0.49)*0.85
                                voidx=min(voidx,0.49d0)

! candu HDR+
! move voidx to adjust hangle elevation ( it is voidf, thus 1-voidgs)
                                voidx=voidx-0.5d0+1.0d0-voidgs
! candu HDR-
!  Test for entrainment or pullthrough.
!  This sub-section covers the liquid entrainment for side off-take when
!   the voidg.gt.0.5.  Cocurrent and countercurrent with main phase (gas
.
.
.
!   this subroutine.
! candu HDR r1
!                               IF(voidg(kk).gt.0.5d0)then
                                IF(voidg(kk).gt.voidgs)then
!  Voidg gt 0.5 -- liquid entrainment.
!  Calculate critical depth, limiting to a radius.
.
.
.
!
! candu HDR r2
!               IF(.not.countc.and.(j.eq.1.or.(j.eq.3.and.voidg(kk)   &
!               .gt.0.5d0))) GOTO 3000
                IF(.not.countc.and.(j.eq.1.or.(j.eq.3.and.voidg(kk)   &
                .gt.voidgs))) GOTO 3000
              ENDIF
!  Consider gas pull-through.
!  This is the beginning of the liquid entrainment section which
.
.
.
ELSE
! candu HDR r1
!                               hcll=diamv(kk) * 0.5d0*ctheta
                                hcll=diamv(kk)*0.5d0*(ctheta-sin(hangle))
                              ENDIF
!  Calculate correlation parameter
.
.
.
!  Reduce it as in old model.
!  voidx=min(voidx,0.49)*0.85.
                                voidx=min(voidx,0.49d0)
! candu HDR+
! move voidx to adjust hangle elevation
                                voidx=voidx-0.5d0+voidgs
! candu HDR-
!  Test for pullthrough or entrainment
!  This sub-section covers the gas pull through for side off-take when
!   the voidg.lt.0.5.  Cocurrent and countercurrent with main phase (gas
!   phase) moving out of main (doner) volume are considered in this sub-
!   section. For countercurrent with main phase moving into the main
!   (doner) volume is considered in the first half section of this
!   subroutine.
!
! candu HDR r1
!                               IF(voidg(kk).lt.0.5d0)then
                                IF(voidg(kk).lt.voidgs)then
!  Voidg lt 0.5  -- gas pullthrough
!  Calculate critical height, limiting to a radius
.
.
.
```

Changes in 'rbrnch'

```
SUBROUTINE rbrnch
!define win32dvf
!define erf
!define fourbyt
!define hconden
.
.
.
! candu HDR r1
!     IF((ist.gt.3.or..not.branch).and.(ist.ne.0.or.branch))then
      IF((ist.gt.4.or..not.branch).and.(ist.ne.0.or.branch))then
        ist=0
        tfail=.true.
      ENDIF
      IF(ick.ge.2)then
.
.
.
IF(ist.eq.3)isstratinpdat18(2,ij)=.true.
!candu HDR+
      IF(ist.eq.4)isstratinpdat17(2,ij)=.true.
      IF(ist.eq.4)isstratinpdat18(2,ij)=.true.
!candu HDR-
      isnpccflflg2(2,ij)=.false.
      isdonprespvwrk15(2,ij)=.false.
      IF(icc.eq.1)isnpccflflg2(2,ij)=.true.
.
.
.
!  The super-heated vapor discharge coeff is not used.
!  Trap the cases where there are 9 words on the card and
!  Henry-Fauske is being used so that the user does not use
!  an old critical flow model deck and get a bad non-equil. factor
! candu HDR+
! We are tring to use jdissh(ij) as feeder pipe connection angles with Header
! If ist=4 (added horizontal stratification entrainment/ pullthrough options)
! then use "word(9) R : superheated steam discharge coeff" as connection angle(deg)
! candu HDR-
! candu HDR i1
            IF(l3a(6).lt.9)xinit(9)=0.0d0
            IF(l3d(6).ge.9.and..not.isnochokflg4(2,ij))then
! candu HDR i1
              IF(ist.ne.4) then
!
               fail=.true.
               xinit(9)=9.87654d+99
               WRITE(output,2333)l3d(1)
 2333 FORMAT  ('0******** Henry-Fauske only requires 8 words on',      &
     & ' card ',i10,/,10x,'Make sure you are not using',              &
     & ' a card from the original RELAP5 choked flow model')
! candu HDR i1
              ENDIF
            ENDIF
            jdissh(ij)=xinit(9)
.
.
.
IF(isstratinpdat17(2,i).and.isstratinpdat18(2,i))ihf=ihf+&
               30000
! candu HDR i1
               IF(ist.eq.4) ihf=ihf+10000
               IF(.not.isstratinpdat17(2,i).and.isstratinpdat18(2,i))  &
               ihf=ihf+20000
               IF(isstratinpdat17(2,i).and.(.not.isstratinpdat18(2,i))) &
               ihf=ihf+10000
               IF(isnochokflg4(2,i))ihf=ihf+1000
               IF(isabrareachgflg8(2,i))ihf=ihf+100
.
.
.
```

Changes in 'rsngj'

```
SUBROUTINE rsngj
!define win32dvf
!define erf
!define fourbyt
!define hconden
!define impnon
!define in32
!define newnrc
!define ploc
!define sphaccm
!define unix
!define noselap
!define noextvol
!define noextv20
!define noextsys
!define noextjun
!define noextj20
!define noparcs
!define nonpa
!define nomap
!define logp
!deck rsngj
!
!  $Id: rsngj.ff,v 1.1 2001/02/01 23:17:28 r5qa Exp dbarber $
!
!  Process single junction input data.
!
!  Cognizant engineer: rjw.
.
.
.
!CANDU HDR r1
!     IF(ist.gt.3)then
      IF(ist.gt.4)then
         ist=0
         tfail=.true.
      ENDIF
.
.
.
!candu HDR+
      IF(ist.eq.4)isstratinpdat17(2,ij)=.true.
      IF(ist.eq.4)isstratinpdat18(2,ij)=.true.
!candu HDR-
      IF(ijt.ne.0)isjetjunflg25(2,ij)=.true.
.
.
.
! candu HDR+
! We are tring to use jdissh(ij) as feeder pipe connection angles with Header
! If ist=4 (added horizontal stratification entrainment/ pullthrough options)
! then use "word(9) R : superheated steam discharge coeff" as connection angle(deg)
! candu HDR-
! candu HDR i1
         IF(l3a(6).lt.9)xinit(9)=0.0d0
         IF(l3a(6).ge.9.and..not.isnochokflg4(2,ij))then
! candu HDR i1
          IF(ist.ne.4) then
!
            fail=.true.
xinit(9)=9.87654d+99
            WRITE(output,2333)l3a(1)
 2333 FORMAT ('0******** Henry-Fauske only requires 8 words on',      &
     & ' card ',i10,/,10x,'Make sure you are not using',             &
     & ' a card from the original RELAP5 choked flow model')
! candu HDR i1
          ENDIF
.
.
.
! candu HDR i1
         IF(ist.eq.4) ihf=ihf+10000
```

```
      IF(.not.isstratinpdat17(2,ij).and.isstratinpdat18(2,ij))ihf=   &
      ihf+20000
.
```

Changes in 'rvalve'

```
       SUBROUTINE rvalve
!
!  $Id: selap.s,v 1.52.1.2 1998/07/11 20:22:11 randyt Exp randyt $
!
!  Process valve input data. A valve has the same input as a single
!  junction in addition to valve data.
!  Valve types available are: trip valve, check valve, inertial swing
!  check valve, motor valve, servo valve and relief valve.
!
!  Cognizant engineer: dmk
!
       IMPLICIT none
       INCLUDE 'cmpdat.h'


!  Local variables.
!CANDU r1
!      INTEGER l3a(15),l3b(10),l3c(10),l3d(7),l3e(18),l3f(11),init(2,17)
       INTEGER l3a(15),l3b(10),l3c(10),l3d(7),l3e(18),l3f(12),init(2,17)
       INTEGER l3g(8),l3h(9),l3i(8),l3j(23)
       INTEGER lenvlv(6)
       REAL(8) xinit(17)
       EQUIVALENCE(init(1,1),xinit(1))


       DATA l3e/3 * 0,12,0,1,0,0,10 * 1/
!CANDU r1
!      DATA l3f/3 * 0,5,0,1,0,0,1,1,0/
       DATA l3f/3 * 0,6,0,1,0,0,1,1,0,1/
       DATA l3g/3 * 0,0,0,0,1,1/


!CANDU r1
!      DATA lenvlv/17,19,27,26,26,35/
       DATA lenvlv/17,19,27,27,26,35/
       DATA vname/'motor','servo'/

.
.
.
!CANDU HDR r1
!    IF(ist.gt.3)then
     IF(ist.gt.4)then
        ist=0
.
.
IF(ist.eq.3)isstratinpdat18(2,ij)=.true.
!candu HDR+
     IF(ist.eq.4)isstratinpdat17(2,ij)=.true.
     IF(ist.eq.4)isstratinpdat18(2,ij)=.true.
!candu HDR-
!blh-------------------------------------------
.
.
.
! candu HDR+
! We are tring to use jdissh(ij) as feeder pipe connection angles with Header
! If ist=4 (added horizontal stratification entrainment/ pullthrough options)
! then use "word(9) R : superheated steam discharge coeff" as connection angle(deg)
! candu HDR-
! candu HDR i1
        IF(l3a(6).lt.9)xinit(9)=0.0d0
        IF(l3a(6).ge.9.and..not.isnochokflg4(2,ij))then
! candu HDR i1
         IF(ist.ne.4) then
!
           fail=.true.
           xinit(9)=9.87654d+99
           WRITE(output,2333)l3a(1)
```

```
2333 FORMAT  ('0******** Henry-Fauske only requires 8 words on',      &
   & ' card ',i10,/,10x,'Make sure you are not using',             &
   & ' a card from the original RELAP5 choked flow model')
! candu HDR i1
         ENDIF
       ENDIF
.
.
.
        CALL inp2(fa(filndx(1)),init,l3f)
!CANDU r1
!        IF(l3f(6).eq.4.or.l3f(6).eq.5) GOTO 172
         IF(l3f(6).eq.4.or.l3f(6).eq.5.or.l3f(6).eq.6) GOTO 172
!   Not enough data for motor valve, assume 000 trips and no table
!   and continue processing.
        WRITE(output,3003)vtype(4),l3f(1),vtype(4)


        vlvslp(i)=0.0d0
        ! CANDU i1
        vlvslp(i+1)=0.0d0
        vlstm(i)=0.0d0
        vlstmo(i)=0.0d0
.
.
.
 3009 FORMAT  ('0******** Card',i10,' has negative or zero slope',1p,   &
     & e13.5)
        ENDIF
        ! CANDU Start
        IF(l3f(6).eq.6) then
           vlvslp(i+1)=xinit(6)
           IF(vlvslp(i+1).le.0.0d0)then
              tfail=.true.
              WRITE(output,3009)l3f(1),xinit(6)
           ENDIF
        ELSE
           vlvslp(i+1)=vlvslp(i)
        ENDIF
        ! End CANDU
        fail=fail.or.tfail
        ac=iand(jc(2,ij),256).ne.0

.
.
.
! candu HDR i1
       IF(ist.eq.4) ihf=ihf+10000
       IF(.not.isstratinpdat17(2,ij).and.isstratinpdat18(2,ij))ihf=   &
.
.
.

!  Motor valve.
 350    WRITE(output,3038)
!CANDU replace part
! 3038 FORMAT ('0  Jun.no.',25x,'open trip no. close trip no. table no.' &
!    &     ,5x,'slope',9x,'initial position')
!        WRITE(output,3040)
! 3040 FORMAT (78x,'(1.0/sec)')
!        WRITE(output,3041)l3c(1),opntrp(2,i),clstrp(2,i),tblnum(2,i),  &
!        vlvslp(i),vlstm(i)
! 3041 FORMAT (i10,19x,i9,5x,i9,4x,i9,10x,1p,2e14.5)
! CANDU Print start
3038 FORMAT ('0  Jun.no.',25x,'open trip no. close trip no. table no.' &
    &     ,5x,'open slope',2x,'initial position',2x,'close slope')

        WRITE(output,3040)
3040 FORMAT (78x,'(1.0/sec)',22x,'(1.0/sec)')
        WRITE(output,3041)l3c(1),opntrp(2,i),clstrp(2,i),tblnum(2,i),  &
        vlvslp(i),vlstm(i),vlvslp(i+1)
3041 FORMAT (i10,19x,i9,5x,i9,4x,i9,10x,1p,3e14.5)
! CANDU Print end
        GOTO 400
!  Servo valve.
```

```
 431 filsiz(3)=filsiz(3)+len-maxlen
     ncmps(2,filndx(3))=ncmps(2,filndx(3))+len
 438 CALL ftbsft(filid(3),filsiz(3),3,filndx(3))
1000 RETURN
     END SUBROUTINE rvalve
```

Appendix B

Input Deck for Model Verification

```
= Horizontal Stratification Take Off Model
*   running type
*----------------------
* option 14 : turn off constitutive relation
*1   14
100  new  transnt
101  run
102  si    si
105  2.  4.
110  nitrogen
115  1.0
*
120   100010000   0.0     d2o     channel
*
201  100.   1.0e-6  0.1   3   10   1000   10000
*201  500.   1.0e-6  0.1  3   10   1000   100000
*201  10.   1.0e-6  0.1   3   10   10000  10000
*201  300.   1.0e-6  0.01   7   200   50000  50000
***************************************************
*   minor edit volumes
*----------------------
*300   70.2  70.8
301   p  100010000
302   p  100020000
311   voidg   100010000
312   voidg   100020000
313   voidg   100030000
331   quale   100020000
332   quals   100020000
334   xej    101000000
341   voidgj  101000000
342   voidgj  102000000
343   voidgj  103000000
344   voidgj  104000000
345   voidgj  105000000
346   voidgj  106000000
347   voidgj  107000000
348   voidgj  108000000
361   mflowj  101000000
362   mflowj  102000000
363   mflowj  103000000
364   mflowj  104000000
365   mflowj  105000000
366   mflowj  106000000
367   mflowj  107000000
368   mflowj  108000000
*
*371   velgj   101000000
*372   velgj   102000000
*373   velgj   103000000
*374   velgj   104000000
*375   velgj   105000000
*376   velgj   106000000
*377   velgj   107000000
*378   velgj   108000000
*
501  time   0          ge   null   0     0.0      1
*
***************************************************
*  Heated Section Pipe
*
1000000   chan1    pipe
*1000000   chan1     canchan
```

```
1000001   3
1000101   1.0       3
1000201   0.0       2
1000301   1.0       3
1000401   0.0       3
1000501   0.0       3
1000601   0.0       3
1000701   0.0       3
1000801   0.0       0.0     3
1000901   0.939      0.939   2
1001001   100       3
1001101   100       2
1001201   002   10.69e6   0.0001    0. 0. 0.  3
1001300   1
1001301      0.0   0.0   0.0   2
*        Dj
1001401   0.00     0.0   1.0   1.0  2
************************************************
1010000   jun882  valve
1010101   100020003 200000000   0.0001   0.00    0.00  10100
1010102   1.00  0.14  *0.0
1010201   1  0.0   0.0   0.0
1010300   trpvlv
1010301   501
*
************************************************
1020000   jun882  valve
1020101   100020003 200000000   0.0001   0.00    0.00  40100
1020102   1.00  0.14  80.0
1020201   1  0.0   0.0   0.0
1020300   trpvlv
1020301   501
*
************************************************
1030000   jun882  valve
1030101   100020003 200000000   0.0001   0.00    0.00  40100
1030102   1.00  0.14  60.0
1030201   1  0.0   0.0   0.0
1030300   trpvlv
1030301   501
*
************************************************
1040000   jun882  sngljun
1040101   100020003 200000000   0.0001   0.00    0.00  40100
1040102   1.00  0.14  40.0
1040201   1  0.0   0.0   0.0
*1040300   trpvlv
*1040301   501
*
**********************************************
1050000   jun882  sngljun
1050101   100020003 200000000   0.0001   0.00    0.00  40100
1050102   1.00  0.14  30.0
1050201   1  0.0   0.0   0.0
*1050300   trpvlv
*1050301   501
*
************************************************
1060000   jun882  valve
1060101   100020003 200000000   0.0001   0.00    0.00  40100
1060102   1.00  0.14  20.0
1060201   1  0.0   0.0   0.0
1060300   trpvlv
```

```
1060301   501
*
*************************************************
1070000   jun882  valve
1070101   100020003 200000000   0.0001   0.00   0.00  40100
1070102   1.00  0.14   10.0
1070201   1   0.0   0.0   0.0
1070300   trpvlv
1070301   501
*
*************************************************
1080000   jun882  sngljun
1080101   100020003 200000000   0.0001   0.00   0.00  30100
1080102   1.00  0.14   *0.0
1080201   1   0.0   0.0   0.0
*1080300   trpvlv
*1080301   501
*
2000000  system   snglvol
*        Area       Length      Volume          ANGLE  Height    Rough
2000101  0.0         20.000      1000.000   0.0   -90.0  -20.000   0.00000
2000102  0.0         000000
2000200  002         1.0000e5   1.00
*
* termination card
.
```

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A. Calvo, NRC Project Manager

11. ABSTRACT *(200 words or less)*

The RELAP5 liquid entrainment and vapor pull-through models of horizontal pipe have been extended for the better prediction of thermal hydraulics in reactor header of CANDU plant. The model of RELAP5 accounts for the phase separation phenomena and computes the flux of mass and energy through an off-take attached to a horizontal pipe when stratified conditions occur in the horizontal pipe. This model is sometimes referred to as the off-take model. The importance of predicting the fluid conditions through an off-take in a small-break LOCA has been well known. In CANDU reactor, off-take model becomes so important that it controls the coolant flow of 95 feeders connected to the reactor header component where the horizontal stratification occurs. The current RELAP5 model is able to treat the only 3 directions junctions; vertical upward, downward, and side oriented junctions, thus improvements for the off-take model is needed for modeling the exact angles. The RELAP5 off-take model has been modified and generalized by considering the geometric effect of branching angles. Verification calculations have been performed for a conceptual blowdown problem in a pipe with different connected angles of branch. The calculated void fraction and mass flow rate of different location of branches shows the validity of implemented model. Experimental works have been also suggested for the further verification and improvement of models.

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