Condenser (CND) Package
Reference Manual

The purpose of the MELCOR CND Package is to model the effects of the Isolation Condenser System (ICS) and the Passive Containment Cooling System (PCCS), both of which use heat exchangers submerged in large water pools. Several older boiling water reactors (BWRs) and the new proposed simplified boiling water reactor (SBWR) contain isolation condensers to condense steam created in the core and return it to the primary system. Only the simplified boiling water reactor, however, contains the passive containment cooling system to provide steam suppression in the drywell in the event of a LOCA or when the depressurization valves are used to equalize the pressures of the reactor vessel and containment. This equalization is required so that water can drain to the reactor vessel from the gravity-driven cooling system pools located several meters above the top of the core. The CND Package constitutes a subpackage within the ESF Package. The removal or transport of fission product vapors and aerosols is not modeled. The Reference Manual gives a description of the subroutines used in the CND Package.

User input for running MELGEN and MELCOR with the CND Package activated is described separately in the Condenser Package Users' Guide.

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1. Introduction

This Package describes the Passive Containment Cooling System (PCCS) and Isolation Condenser System (ICS) models developed at Oak Ridge National Laboratory (ORNL) for use with MELCOR. This manual is divided into three sections. Section 2 describes the PCCS model, while Section 3 describes the extension of the basic PCCS model to provide calculational capability for the ICS. Finally, the interface with MELCOR for both the PCCS and ICS models is described in Section 4.

2. PCCS Model

2.1 Introduction and Concept

The PCCS is a safety-related passive system designed to remove the core decay heat that would be introduced into the SBWR containment during a loss-of-coolant accident (LOCA). The PCCS is described in Section 6.2 of the *SBWR Standard Safety Analysis Report (SSAR)* [1].

The basic operation of the PCCS derives from the induced flow of some of the drywell atmosphere to the wetwell airspace via the PCCS whenever the drywell-to-wetwell pressure differential is sufficient to clear the water from the vent line terminus within the pressure suppression pool. The venting pathway through the PCCS includes a heat exchanger in which the gases are cooled and some (or all) of the steam vapor is condensed; the condensate is drained to the Gravity-Driven Cooling System (GDCS) pool within the drywell. The noncondensible gases and any steam carryover through the vent line are released into the pressure suppression pool, where the gas bubbles rise to the pool surface. The intermittent nature of the venting process causes the thermal-hydraulic behavior of the PCCS to be much more complex than the normally encountered heat exchanger-condenser applications for which the flow is continuous.

The PCCS model described here is based upon the concept that the MELCOR code should adequately represent the effects of the PCCS under the boundary conditions that would be imposed by accidents. It is not intended that the MELCOR calculation should attempt to predict the performance of these heat exchanger-condenser systems based upon basic physical considerations; this is done by more sophisticated thermal-hydraulic codes. Furthermore, test calculations performed with MELCOR demonstrate that attempts to use the basic code "building block" approach to connect control volumes, flow paths, and heat sink structures as necessary to directly simulate the PCCS heat exchanger-condensers will result in code difficulties; these include oscillations in the predicted flows and energy exchanges, a demand for extremely small timesteps, and impractically large CPU and wall clock time consumption.

2.2 General PCCS Performance

Based upon the available information in the literature concerning the PCCS design and the results of equipment tests reported by the development consortium to date, it is clear that any PCCS component model must have the following basic attributes:

(1) Capacity limited to gravity drainage of steam condensing in the tubes until drywell pressure exceeds suppression chamber pressure by a margin [about 7.25 kPa (1.05 psid)] sufficient to overcome PCCS vent line submergence. With normal pressure suppression pool water level, the uppermost vent line exit hole lies at the depth of 0.75 m (2.5 ft). The pool water level may vary during the course of an accident and this must be considered in the model.

(2) For long-term cooling situations of practical interest for BWR accident calculations, the drywell-to-suppression chamber pressure differential is limited to the submergence of the drywell-to-pressure suppression pool vents.

(3) Capacity increases as the drywell-to-suppression pool pressure differential (vent line flow) increases over the small range between PCCS vent line clearance and clearance of the main horizontal vents.

(4) Capacity decreases with increasing partial pressure of noncondensible gases in the upper drywell because of the interference of the gas boundary layer within the PCCS tubes with the steam-to-wall heat transfer.

(5) Whenever the wetwell pressure approaches (or exceeds) the drywell pressure so that vent line flow is zero, the PCCS heat exchanger-condenser is subject to filling with noncondensible gases as the condensing steam is continuously replaced with a mixture of steam and noncondensible gas from the drywell. The PCCS is said to be “bound” when it contains only cool noncondensible gas so that all heat exchange and condensing operation is terminated.

(6) The average PCCS capacity over the long term is determined by the heat transfer from the outer surface of the PCCS heat exchanger tubes to the surrounding ICS/PCC pool. For the LOCA analysis presented in Section 6.2 of the SSAR, the General Electric Company has employed a constant heat transfer coefficient of 4500 W/(m^2-K) [792.5 Btu/(h-ft^2-F)] for the tube outer surface area.

(7) Capacity of the PCCS decreases as the pressure in the drywell falls below its optimum operational pressure. As the pressure drops in the drywell, the temperature of the steam and associated condensate drops, thereby lowering the heat transfer between the condenser wall and the steam. Heat transfer is determined by the heat transfer coefficient times the surface area times the difference between the steam temperature and the temperature of the condenser wall, which is very close to the surrounding pool temperature.

A general model interacting with MELCOR has been constructed from the available information and tested satisfactorily. Nevertheless, the most recent detailed information concerning experimental measurements or the results of sophisticated calculations of PCCS performance as a function of the ICS/PCC pool temperature, the drywell-to-wetwell atmosphere pressure differential, atmospheric pressure in the drywell, and the noncondensible gas fraction in the drywell atmosphere should be used to refine the input for this model (described in the CND Package Users' Guide) whenever production calculations are performed.

2.3 Operation of the PCCS Model

The PCCS model is contained within MELCOR Subroutine CNDRN1. In this section, the operation of the model is described as a 28-step process. Not all steps are executed each calculational timestep. One of the steps involves an iterative procedure, which is described in detail in Section 2.4. Those readers not interested in pursuing the level of understanding offered by a detailed discussion of model operation are encouraged to skip to Section 2.5, which provides an overview in the form of an example of calculated results.

It is important to recognize that the PCCS model operates on the assumption that the pressure within the PCCS remains equal to the drywell pressure and constant during a calculational timestep. Whenever material is removed, for example, when steam condenses and the condensate is transferred to the GDCS, a void is considered to be created within the PCCS. An uptake of mixture from the drywell atmosphere is required to fill this void at drywell pressure and the subsequent equilibrium conditions within the PCCS are calculated. This approach is taken to avoid the penalties (described in Section 2.1) of a mechanistic model for which mass transfers between the drywell and the relatively small PCCS would be based upon calculated pressure differentials.

The variable names mentioned in the following discussions and in Section 2.4 are the same as those used within Subroutine CNDRN1. The interested reader is encouraged to compare the stepwise operations described here with the actual FORTRAN in a listing of Subroutine CNDRN1; the COMMENT statements that will be obtained with the program listing will provide additional detailed information.

Before beginning the step-by-step discussion of model operation, it is necessary to define a few of the variable names that will be encountered (the meaning of the others will be obvious from the text).

NUMMAT	Is the total number of materials considered present (or potentially present) within a control volume. These include the water pool, fog droplets, steam, and the noncondensible gases.
I	I is the index of a particular material within a control volume.

Index	Material
1	water pool
2	fog
3	vapor
4 through NUMMAT	noncondensible gas

The control volume atmosphere is comprised of materials 2 through NUMMAT. The control volume total pressure is the sum of the partial pressures of materials 3 through NUMMAT.

CEFIC represents the running total kept within the model of the remaining PCCS heat exchanger capacity in Joules. The available capacity is established at the beginning of each timestep from tabular input supplied by the MELCOR user. This initial value depends upon the current ICS/PCC pool temperature, the current drywell-to-wetwell pressure differential, and the current mole fraction of noncondensible gas in the drywell atmosphere. It should be noted that the reduction in PCCS performance due to a buildup of noncondensible gas within the heat exchanger is not established from the tabular input, but rather is calculated by the PCCS model.

ENGIC(I) is the array containing the internal energies of the materials within the PCCS at the beginning of the timestep. During the timestep, the running values of these internal energies are contained in the array ETOTIC(I), which is copied to the ENGIC(I) array at the end of each timestep.

VLICMT is the volume of the materials (steam, fog, noncondensible gases) that constitute the atmosphere within the PCCS. Since the PCCS atmosphere is constrained to remain at a pressure equal to drywell pressure, this volume can be less than the actual PCCS structural volume if material is removed from the PCCS atmosphere during the calculation.

PCCS Model Steps

Steps 1 – 4: Establish Initial Conditions

These initial steps establish the equilibrium conditions within the PCCS with the volume filled at drywell pressure. Some of the available capacity is utilized to cool any noncondensible gas carried over from the previous timestep. Mixture is taken up from the drywell as required to maintain the PCCS at drywell pressure.

(1) Set the currently available heat removal capacity CEFIC based upon the drywell-to-wetwell pressure differential, the pressure in the drywell, and the noncondensible gas fraction in the drywell atmosphere. The dependence upon the pressure

differential and the source pressure are obtained from user-input tabular function IPCDPR and IPSRPR, respectively. The dependence upon the noncondensible gas mole fraction is obtained by interpolation between the user-input tabular functions IPLTMP (for 323.16 K) and IPCNCN (for 373.16 K), which correspond to ICS/PCC pool temperatures of 50 $^\circ$C and 100 $^\circ$C, respectively. (See Users' Guide for input record ESFCND0200.)

(2) Cool any noncondensible gases remaining within the PCCS at the end of the previous timestep. The gas temperature is reduced to the ICS/PCC pool temperature TICPL by calling the routine NCGPRO to obtain the internal energy of the gases at the new temperature.

- Reduce the internal energies ENGIC(I) accordingly.
- Reduce the available capacity CEFIC.

(3) Take up enough mixture from the drywell atmosphere to make the calculated PCCS equilibrium pressure equal to the drywell pressure. (Section 2.4 provides a discussion of the iterative procedure used.)

- Reduce the drywell gas, vapor, and fog masses and energies accordingly.
- Output of the equilibration routine includes
  ETOTIC(I) total internal energies and
  XMSICN(I) masses
  of the fog, vapor, and noncondensible gases.
- Set the PCCS material volume VLICMT equal to the internal volume of the PCCS structure.

(4) Determine if there will be vent line flow this timestep.

- If No, continue with Steps 5 – 9.
- If Yes, continue with Steps 10 – 27.

Steps 5 – 9: No Vent Line Flow

The PCCS is now full at drywell pressure with its contents at an equilibrium temperature. If there was a void remaining at the end of the previous timestep, or if some cooling of the noncondensible gases occurred, then some steam (and fog) taken up with the mixture from the drywell atmosphere will be included. CEFIC has already been reduced (Step 2) as necessary to account for the cooling of noncondensible gas.

(5) If no steam exists within the PCCS (No void at the end of the previous timestep and no noncondensible gas cooling or no steam in drywell atmosphere)

- Energy to ICS/PCC pool limited to that used to cool the noncondensible gases.

Go to Step 28.

(6) Condense the steam (and cool the fog) within the PCCS.

- May be limited because of insufficient capacity CEFIC remaining after the cooling of the noncondensible gas (Step 2).
- Add the masses and energies to the GDCS Pool.
- Reduce ETOTIC(I) and XMSICN(I) for steam and fog accordingly.
- Set RMVLIC equal to the accumulated void within the PCCS.
- Reduce the available capacity CEFIC accordingly.

(7) If CEFIC > 0.0 and RMVLIC > 0.0, take up enough mixture from the drywell atmosphere to use the available capacity and to partially fill the void (with noncondensible gas). On the other hand, it is possible that the noncondensible gas takeup will completely fill the void without using all of the available capacity.

- The steam and fog taken up are never actually added to the PCCS volume within the model but rather are removed from the drywell atmosphere and added directly to the GDCS Pool as saturated liquid.
- Reduce the available capacity CEFIC by the amount of energy used in condensing the steam and cooling the fog.
- For the noncondensible gas takeup: Increase XMSICN(I) and ETOTIC(I) for these gases and remove the associated masses and energies from the drywell.
- Reduce the void RMVLIC according to the takeup of noncondensible gas (only)—note that RMVLIC will remain greater than zero only if the takeup from the drywell atmosphere was limited by the available heat exchange and condensing capacity.

(8) Set VLICMT = VLICMT – RMVLIC. There will be a void within the PCCS at the beginning of the next timestep if RMVLIC > 0.0 here.

(9) Add the energy used in cooling the noncondensible gases (Step 2) and in condensing the steam/cooling the fog (Steps 6 and 7) to the ICS/PCC pools.

Go to Step 28.

Steps 10 – 27: With Vent Line Flow

At this point, the PCCS is full at drywell pressure with its contents at an equilibrium temperature. If a void remained at the end of the previous timestep or if some cooling of the noncondensible gases occurred, then some steam (and fog) taken up with the mixture from the drywell atmosphere will be included. CEFIC has already been reduced (Step 2) to account for any cooling of the noncondensible gas.

(10) Calculate the PCCS vent line mass transfer XMS2FL. The transfer is based upon the pressure differential between the drywell and the vent line terminus, which is submerged in the pressure suppression pool.

(11) Move noncondensible gases from PCCS to wetwell and reduce the running total for XMS2FL accordingly.

- RMVLIC is the associated PCCS void.
- Reduce the values of XMSICN(I) masses and ETOTIC(I) internal energies for the noncondensible gases.

- At this point, either:
  XMS2FL=0.0; some noncondensible gas remains in PCCS
  or
  XMS2FL>0.0; all noncondensible gas has been removed so that only steam and fog remain within the PCCS.

(12) Condense the steam within the PCCS up to the limits of the available capacity CEFIC. Place the liquids in the GDCS pool.

- XMSREM is the mass of steam condensed.
- Reduce CEFIC accordingly.
- Reduce XMSICN(I) and ETOTIC(I) for the steam.

(13) If some steam remains in the PCCS and if some vent line mass transfer remains (XMS2FL > 0.0) then

- Move the steam (uncondensed) through the vent line to the pressure suppression pool.
- Reduce XMS2FL accordingly.
- Increase XMSREM so it now represents both the condensed steam drained to the GDCS and the uncondensed steam moved to the pressure suppression pool.
- Reduce XMSICN(I) and ETOTIC(I) for the steam.

(14) Increase RMVLIC to account for the void created by both the steam condensed and drained to the GDCS pool and the steam moved to the pressure suppression pool via the PCCS vent line.

Note: Steps 12 – 14 are actually performed (in sequence) for fog, steam, and any water pool that has formed within the PCCS volume. The handling of steam is demonstrated in this discussion; the fog and water pool (if it exists) are treated in a similar manner.

(15) Reduce the PCCS material volume VLICMT by subtracting the void RMVLIC.

Set VOLINT = 0.0
VINTNC = 0.0
XMNNST = 0.0

(16) If both the remaining heat exchanger capacity CEFIC and the remaining vent line mass transfer XMS2FL have been reduced to zero.

Go to Step 28.

Steps 17 – 18: Heat Removal Capacity/Vent Line Mass Transfer Imbalance
It is unlikely that the amount of mixture that must be taken up from the drywell in order to use the remaining heat removal capacity will provide exactly the amount of noncondensible gas required to satisfy the remaining mass transfer requirement. These two steps determine the remaining model logic to be employed, based upon the sign of imbalance.

(17) Set VOLINT = Mixture volume required from drywell to use all remaining capacity CEFIC in condensing the associated steam and cooling the associated fog.

XMNNST = Mass of noncondensible gas associated with VOLINT.

VL2FL = 0.0

(18) Will XMNNST satisfy the remaining mass transfer requirement XMS2FL?

If No:

Go to Steps 19 – 21

If Yes:

Go to Steps 22 – 25

Steps 19 – 21: Mass Transfer Dominates
XMNNST (based upon use of all of the available heat exchanger-condenser capacity) is insufficient to satisfy the remaining mass transfer requirement XMS2FL.

(19) Set ADDRVL = mixed volume to be taken up from drywell solely to satisfy the mass transfer requirement.

(20) Add the steam (uncondensed) and fog associated with ADDRVL directly to the pressure suppression pool and remove them from the drywell atmosphere.

Transfer the noncondensible gases from the drywell to the wetwell atmosphere, while representing the heat transfer to the water that would occur during their bubbly passage through the pressure suppression pool.

(21) Set VLICMT = 0.0
CEFIC = 0.0

All material originally within the PCCS and all new material taken up from the drywell has been passed through the vent line. Also, all available heat exchanger capacity has been utilized.

Go to Step 26.

Note that VINTNC is 0.0 here while VOLINT is the mixture volume taken up from the drywell to satisfy the heat exchanger capacity.

Steps 22 – 25: Heat Removal Capacity Dominates

XMNNST (based upon satisfying the heat exchanger capacity requirement) exceeds the remaining mass transfer requirement XMS2FL. VOLINT (set in Step 17) is the mixture volume associated with XMNNST.

(22) Set VINTNC = noncondensible gas volume associated with VOLINT.

(23) Set VL2FL = noncondensible gas volume associated with XMS2FL. This is the volume that will flow through the PCCS vent line this timestep based upon XMS2FL.

(24) If VINTNC > (RMVLIC + VL2FL)

Cannot take up all of the mass XMNNST (associated with volume VINTNC).

- Reduce the mixed volume to be taken up from the drywell.

$$VOLINT = VOLINT \;\; x \;\; \left(\frac{RMVLIC + VL2FL}{VINTNC} \right)$$

- Reduce the available heat capacity by the amount used

$$CEFIC = CEFIC - CEFIC \;\; x \left(\frac{RMVLIC + VL2FL}{VINTNC} \right)$$

- Reduce VINTNC to a value sufficient to fill the available PCCS void plus provide the remaining vent line mass transfer.

$$VINTNC = RMVLIC + VL2FL$$

Else

CEFOC = 0.0

All available energy is utilized if VINTNC is less than or equal to (RMVLIC + VL2FL)

(25) Adjust the material volume within the PCCS

VLICMT = VLICMT + VINTNC - VL2FL

Here VINTNC is the noncondensible gas volume to be taken up from the drywell and added to the PCCS volume.

Steps 26 – 27: Transfer of Steam, Fog, and Gas from the Drywell Atmosphere

(26) Remove the noncondensible gases associated with VOLINT from the drywell atmosphere and add them to the PCCS volume and the wetwell airspace.

If VINTNC is greater than zero here, then some of the noncondensible gases taken up from the drywell to satisfy the available heat removal capacity are not passed through to the pressure suppression pool, but rather remain within the PCCS.

Increase XMSICN(I) and ETOTIC(I) for the noncondensible gases accordingly.

For the portion of the noncondensible gases (maybe all) that are passed to the pressure suppression pool, add the masses to the wetwell atmosphere and represent the heat transfer from the bubbles to the pool, adding the residual energies to the wetwell atmosphere.

(27) Remove the steam and fog associated with VOLINT from the drywell atmosphere and add the condensate to the GDCS pool.

Step 28: Set PCCS Internal Energies for the Next Timestep

(28) Set ENGIC(I) = ETOTIC(I) for the steam, fog, and noncondensible gases within the PCCS.

This is the last step in each calculation of PCCS operation. Any material remaining within the PCCS is considered to remain at drywell pressure and may or may not fill the PCCS volume.

2.4 The Iterative Procedure

2.4.1 Purpose

The objective of this iterative procedure is to fill the PCCS volume with the mixture of gases, fog, and vapor from the drywell atmosphere to make the PCCS pressure equal to the drywell pressure. The iteration constitutes Step 3 of the PCCS operation as described in Section 2.3 and may be performed at the beginning of each timestep, depending upon the initial conditions within the PCCS volume.

2.4.2 Initial Conditions

The initial conditions within the PCCS are those established at the end of the previous timestep, and fall into three categories.

(a) The PCCS may be bound (filled) with noncondensible gases at the temperature of the ICS/PCC pool and the pressure of the drywell atmosphere.

(b) The PCCS may be completely voided, or contain only steam and fog; in either event, there are no noncondensible gases within the PCCS.

(c) The PCCS may contain a mixture of noncondensible gas and steam. If the temperature of the mixture exceeds the temperature of the ICS/PCC pool, then the noncondensible gases are cooled to the pool temperature (as explained in Section 2.3) before the iteration begins.

Initial filling of the PCCS volume from the drywell atmosphere is necessary only for cases (b) and (c), and is accomplished by means of the steps described below:

2.4.3 Iterative Steps

(1) Call the MELCOR equilibrium routine CVTWGE with input

CVMS(I)	initial masses,
CVEM(I)	internal energies, and
XNMCLS x VOLIC	the total PCCS volume.

The calculated output includes the equilibrium values for

XMSICN(I)	masses,
ETOTIC(I)	internal energies,
PRIC	pressure, and
TEMPIC	temperature

For the equilibrium calculation, the index I represents fog (I=2), steam (I=3), and noncondensible gases (I=4, NUMMAT).

The first step is skipped in the first iteration if the PCCS is initially totally voided; in this case, the pressure PRIC is simply set to zero.

(2) Check to see if the pressure in the PCCS exceeds the pressure in the drywell after the initial equilibration calculation, which would indicate a current drywell pressure less than the pressure at the end of the previous timestep.

If the condition is met, then determine the expanded volume of the noncondensible gases at the new drywell pressure. If the expanded volume is greater than the volume of the condensers plus the source line volume, allow material to flow back from the PCCS to the drywell. The fraction of PCCS noncondensible gases to be removed from the condensers and transferred back to the drywell is:

$$F2FLBK = 1 - \frac{PCCS\ VOLUME}{VICDRY - PCCS\ VOLUME - PCCS\ SOURCE\ LINE\ VOLUME}$$

where VICDRY is the expanded volume of the noncondensible gases at the new drywell pressure:

$$VICDRY = \frac{PCCS\ \ PRESSURE\ x\ PCCS\ VOLUME}{DRYWELL\ PRESSURE}$$

FLMULT is then set to zero and the execution sequence is continued with Step 6.

(3) The mass transfer multiplier FLMULT is set depending upon the relative values of the PCCS pressure PRIC and the upper and lower boundaries of a pressure range centered on the drywell pressure PRES(IVPCSO) as follows,

....................PRES(IVPCSO) + 100

.....................PRES(IVPCSO)

....................PRES(IVPCSO) – 100.

As indicated, the total width of the acceptable pressure range is 200 Pa (about 0.03 psi).

If PRIC is less than the lower boundary limit, then FLMULT is set to a positive value. Conversely, if PRIC is greater than the upper boundary limit, then FLMULT is set to a negative value. In either case, the absolute value of FLMULT is reduced by a factor of two each trip through the iterative loop.

When PRIC finally lies within the acceptable boundaries, FLMULT is simply set to zero.

(4) The volume to be transferred from the drywell to the PCCS during this iterative step is calculated from

VOL2FL = [PCCS VOLUME – VLICMT] x FLMULT

where VLICMT is the material volume at the end of the previous timestep, reduced by 10 percent. The value of VLICMT set in the initial iterative pass is used without change during all subsequent passages through the loop.

Returning to a consideration of the possible initial conditions, it should be recognized that VLICMT will be zero at the end of the previous timestep if the PCCS is completely voided, in which case taking away ten percent would have no effect. The ten percent reduction is intended for cases in which noncondensible gases are present and are cooled before the iterative procedure is begun; some of the drywell atmospheric mixture must be brought into the PCCS to maintain a pressure equal to drywell pressure, and the iterative procedure accomplishes exactly this.

In fact, for the case with the PCCS completely voided at the end of the previous timestep, there is no need for iteration at all. The PCCS volume is very small in comparison with the drywell volume. Therefore, it is reasonable to assume that the PCCS will be filled with a material mass and energy composition identical to that of the drywell. One pass through the iteration loop is made to confirm that the calculated PCCS pressure after filling is equal (within limits) to the drywell pressure.

What about the case in which the PCCS is bound (filled with cooled noncondensible gas) and at drywell pressure? Reducing VLICMT by ten percent here has no effect since FLMULT is zero and hence VOL2FL is zero regardless of the value of VLICMT.

The upshot of this rather complicated discussion is that VOL2FL will normally be positive during the first pass through the iterative loop. An exception occurs if the PCCS pressure is already equal (within limits) to the drywell pressure. In that case, VOL2FL will be zero and the iteration will not be extended beyond a single pass through the loop.

(5) At this point, VOL2FL may be negative if the PCCS volume was overfilled during the previous pass through the iterative loop. Depending upon the sign of VOL2FL, the masses ADMS(I) and internal energies ADEM(I) of the steam, fog, and noncondensible gases within this volume of drywell atmosphere are added to (subtracted from) the PCCS volume. These masses and associated enthalpies are subtracted from (added to) the drywell control volume.

In these exchanges, portions of the drywell atmosphere are being transferred. Internal energy is added to or subtracted from the PCCS because a void is being either eliminated or created, as is the associated PV work term. For the drywell, gases entering or leaving do flow work upon (compression) or derive work from (expansion) the remaining gases. Hence enthalpy transfer is appropriate.

(6) CVEM(I) and CVMS(I) are adjusted depending upon the values of ADEM(I) and ADMS(I) for all materials within the PCCS atmosphere and the calculation returns to iterative step 1 unless FLMULT is zero. [FLMULT = 0 signifies that the PCCS pressure equals (within limits) the drywell pressure.]

(7) Once convergence is satisfied, VLICMT is set equal to the PCCS structural volume.

2.5 Example Results

This section provides, as an example, a discussion of the calculated PCCS operation for a MELCOR representation of the SBWR station blackout accident sequence. While reading this description, it is important to bear in mind that the available PCCS heat exchanger-condenser capacity (based upon current operation parameters) is assumed to be known each timestep; the purpose of the model is to determine the associated heat transfers and fluid flows, with due consideration of the current status of the PCCS with respect to binding. It is important to note that, for this example, no degradation in performance due to variations in the drywell pressure is assumed.

For an unmitigated station blackout accident sequence, reactor vessel depressurization would automatically occur when the vessel level reached a point about 3.6 m (12 ft) above the top of the core. The SBWR depressurization involves stepped opening of the safety relief valves, which discharge into the pressure suppression pool, followed by stepped opening of the six depressurization valves (DPVs), which discharge directly into the drywell atmosphere. The example results discussed here cover the period from just before the initial DPV actuation to five minutes thereafter.

Figure 2.1 shows the effect of the DPV openings, which begin at time 11161 seconds, upon the noncondensible gas fraction in the drywell. The actual DPV opening sequence is two valves at 11161 seconds, two valves at 11206 seconds, and two valves at 11251 seconds.

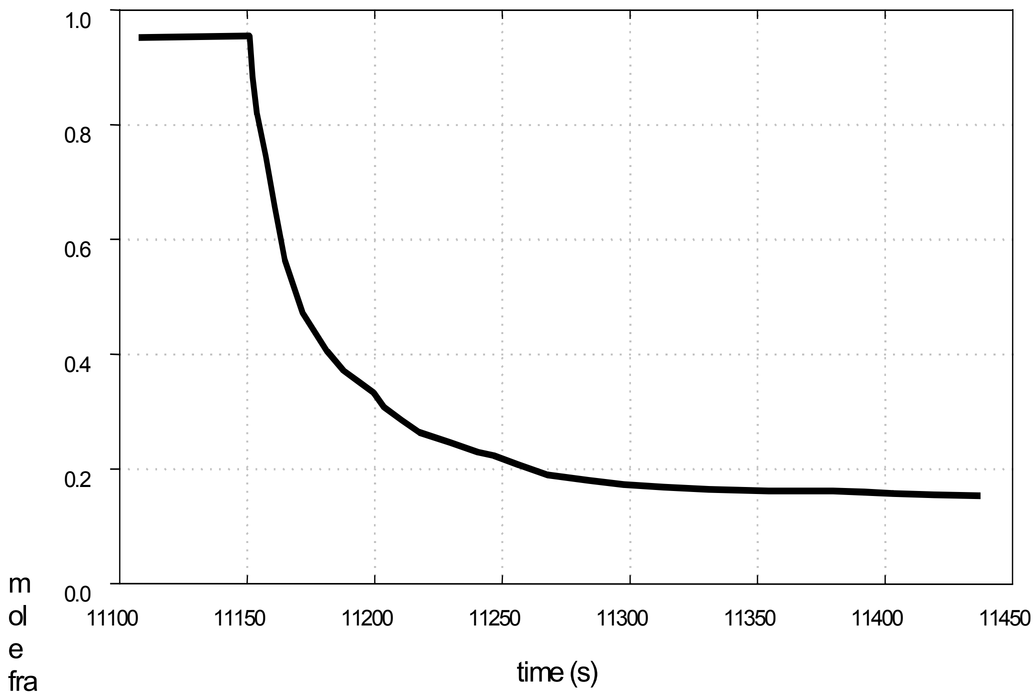

Figure 2.1 The noncondensible gas mole fraction decreases rapidly when steam is released directly into the drywell atmosphere during the final stage of an SBWR reactor vessel depressurization.

The reactor vessel depressurization also increases the drywell-to-wetwell differential pressure, as indicated by the response of variable **delpre**, shown in Figure 2.2. The variable **reqpre**, also plotted on this figure, represents the differential pressure required to induce flow through the PCCS vent line. It increases slightly during the period of the calculation as the height of the pressure suppression pool surface above the vent line terminus increases.

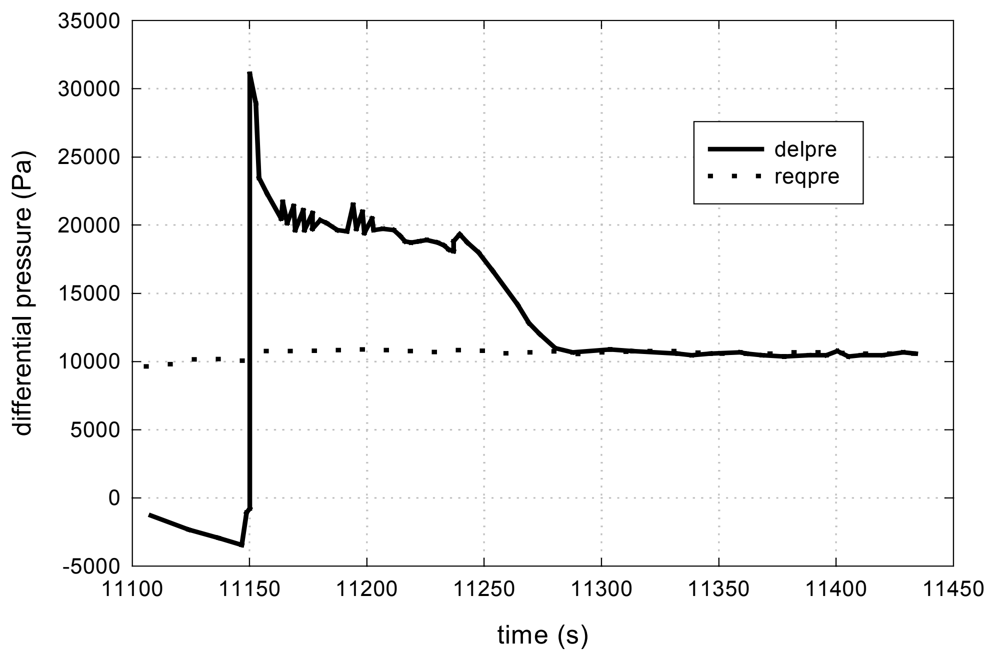

Figure 2.2 The drywell-to-wetwell pressure differential **delpre** and the differential pressure **reqpre** at which flow through the PCCS vent line is initiated.

At this point, it is necessary to consider the variation in PCCS performance in accordance with current conditions. The PCCS heat exchanger capacity is determined at the beginning of each timestep based (in order of increasing importance) upon (1) the current drywell-to-wetwell differential pressure, and (2) the current mole fraction of noncondensible gas in the drywell (considering the current ICS/PCC pool temperature and interpolating between values for two reference pool temperatures). The tabular input employed for this example calculation is listed in Tables 2.1 through 2.3. The basic capacity per PCCS unit is 10 MW_t at an ICS/PCC pool temperature (saturation) of 374.15 K (213.8 F), a drywell-to-wetwell pressure differential of 7239.5 Pa (1.05 psi), and a drywell noncondensible gas fraction of 0.0 (pure saturated steam). As stated above, the performance of the condenser is assumed to be constant over all source volume pressures.

Table 2.1 Tabular input example for variation of PCCS performance with drywell-wetwell differential pressure

Differential Pressure (Pa)	psi	Variation Factor
0.0	0.00	1.000
7239.5	1.05	1.000
8618.5	1.25	1.072
10342.1	1.50	1.153
12065.8	1.75	1.227
13789.5	2.00	1.294
15423.6	2.24	1.353

Table 2.2 Tabular input example for variation of PCCS performance with the drywell noncondensible gas mole fraction at an ICS/PCC pool temperature of 323.16 K

Noncondensible Gas Mole Fraction	Variation Factor
1.00	0.00
0.10	0.60
0.05	0.82
0.02	0.90
0.01	0.96
0.00	1.00

Table 2.3 Tabular input example for variation of PCCS performance with the drywell noncondensible gas mole fraction at an ICS/PCC pool temperature of 373.16 K

Noncondensible Gas Mole Fraction	Variation Factor
1.00	0.00
0.10	0.60
0.05	0.82
0.02	0.90
0.01	0.96
0.00	1.00

The example calculation represents the operation of all three PCCS units. Changes in the ICS/PCC pool temperature are assumed to have no effect upon the PCCS system performance, chiefly because the pool is sufficiently large that its temperature increase is small during the period of the calculation. It may be noted by comparing the variation factors listed in Table 2.2 and Table 2.3 that no credit has been given for an enhancement of the PCCS heat exchanger capacity for ICS/PCCS pool temperatures below saturation. At the time that this example calculation was performed, no information concerning this enhancement was available. Subsequently, it has become apparent that such enhancement should be represented by providing different values in Table 2.2 and Table 2.3. Similarly, the variation in performance due to source volume pressure changes were added when the need for such a reduction became apparent. (See the BH Package Users' Guide with respect to input card ESFCND0200 for additional information.)

The drywell-to-wetwell differential pressure affects the heat exchanger performance because it determines the (forced-convection) velocity within the heat exchanger tubes. The velocity, in turn, affects the heat transfer coefficient (h) at the inner surface of the tubes. A conventional expression commonly used has the form

$$h = (const.)\ x\ Re^{0.8},$$

where Re (the Reynolds number) includes the velocity. As a result, the heat transfer coefficient for various differential pressures between the drywell and the wetwell can be represented (assuming all other variables are constant) by

$$h = (const.)\ x\ (differential\ pressure)^{0.4}.$$

Thus, as indicated in Table 2.1, the PCCS capacity is enhanced as the differential pressure increases.

By far the largest effect upon PCCS capacity derives from changes in the noncondensible gas fraction of the gas entering the PCCS from the drywell. This large influence can be observed in Figure 2.3, which compares the current (three-unit) PCCS capacity to the drywell noncondensible gas mole fraction (also shown in Figure 2.1). It is obvious that the increase in available capacity shown in Figure 2.3 is inversely proportional to the decrease in noncondensible gas mole fraction. This large effect of the noncondensible gas fraction in reducing the condensation effectiveness is well known. The tabular input reproduced in Table 2.2 and Table 2.3 is derived from information provided in the paper, Heat Removal of Isolation Condenser Applied as a Passive Containment Cooling System by H. Nagasaka et al., of the Nuclear Energy Group, Toshiba Corporation. [2]

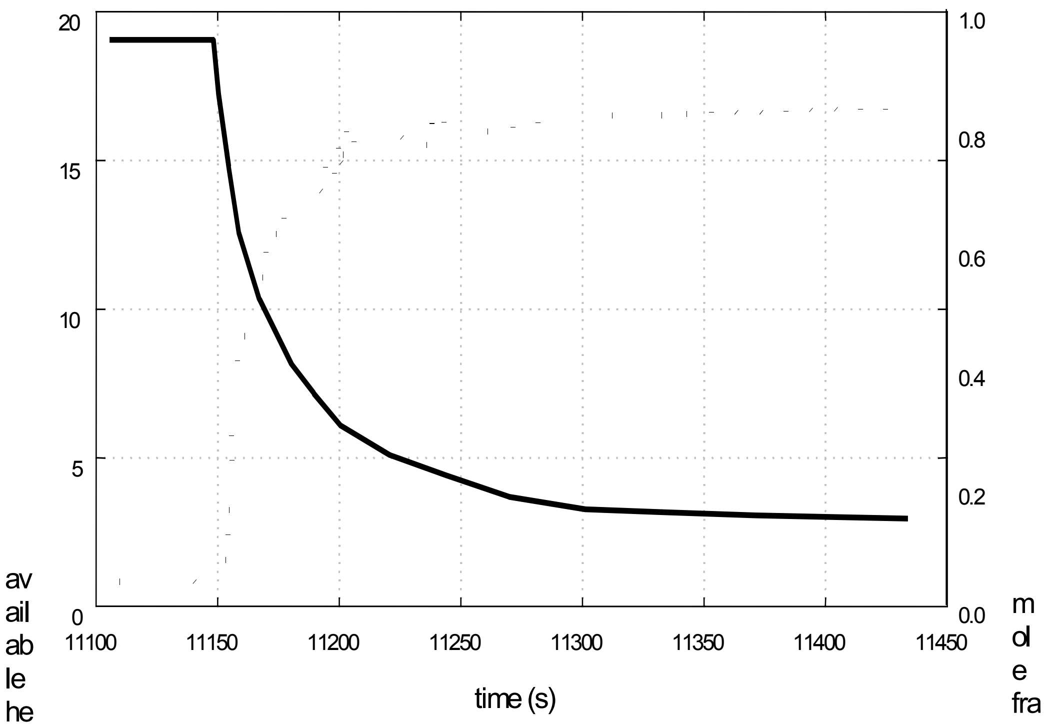

Figure 2.3 The available PCCS heat exchanger capacity (dots) is primarily determined by the drywell noncondensible gas mole fraction (solid line).

The available (three-unit) PCCS capacity is shown again, as variable **pitcef** on Figure 2.4. It should be recognized that three PCCS units operating under base conditions would have a combined capacity of 30 MW_t, whereas the maximum value of **pitcef** shown on Figure 2.4 is about 17 MW_t. Again, this reduction is primarily due to the presence of noncondensible gas in the drywell atmosphere, which will always be the case.

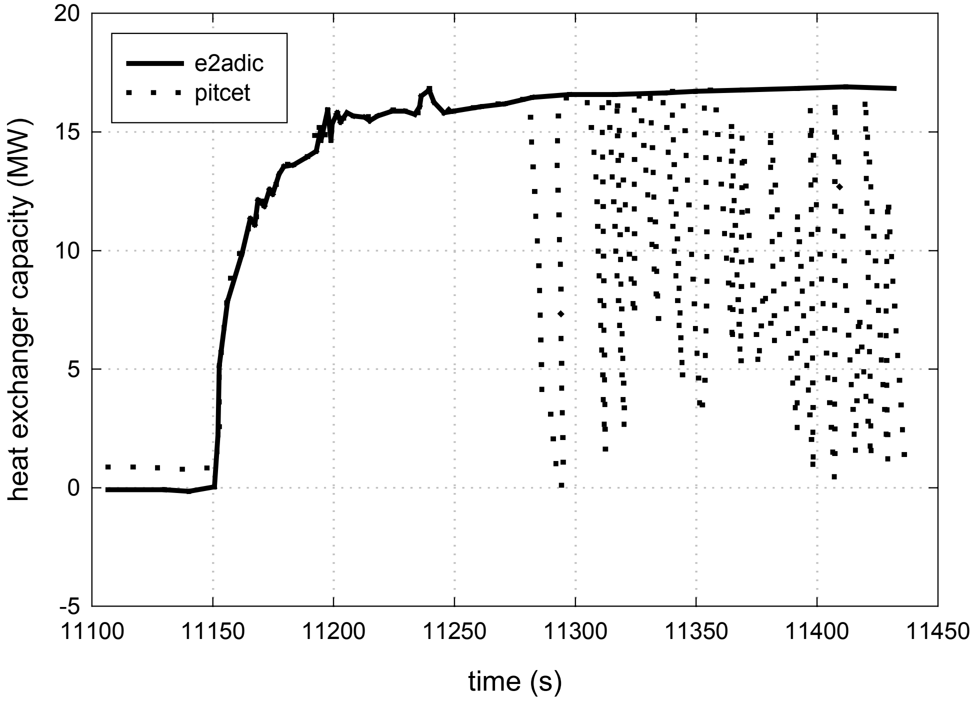

Figure 2.4 The available PCCS (three-unit) heat exchanger capacity **pitcet** and the power **e2adic** actually utilized.

Also shown in Figure 2.4 is the variable **e2adic**, which is the heat exchanger power actually being used. As indicated, none of the available capacity is utilized before the reactor vessel depressurization begins. This is because the PCCS heat exchanger tubes are "bound," or filled with noncondensible gas. Once reactor vessel depressurization begins, however, (1) the available heat exchanger capacity greatly increases, and (2) all of this capacity is used.

The reason that all of the available capacity is used during the period immediately after DPV opening is that the vent line flow induced by the increasing drywell pressure now sweeps the noncondensible gases from the PCCS each timestep, permitting the mixture of gases and steam within the drywell to enter. The total vent line flow **pltifl** and the noncondensible gas vent line flow **pltnfl** are shown in Figure 2.5. It should be noted that the vent line flow initially consists entirely of noncondensible gas; all of the steam entering the PCCS during this initial period is condensed.

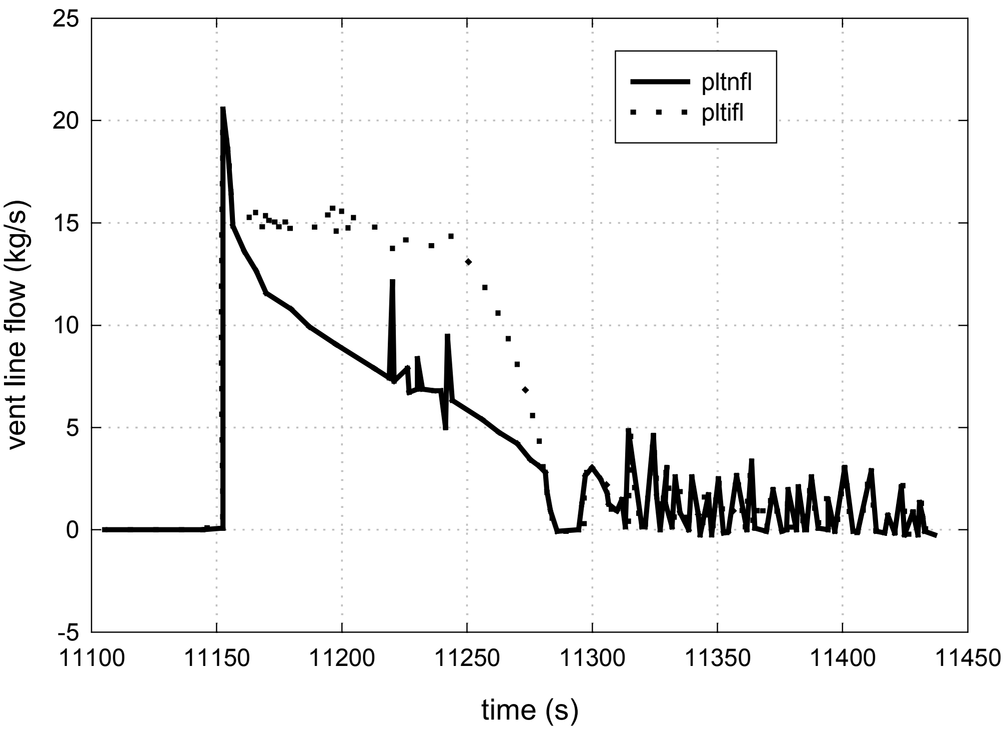

Figure 2.5 The total mass flow **pltifl** through the PCCS vent line and the associated flow **pltnfl** of noncondensible gases.

Steam flow through the vent (the difference between the two plotted variables) does not begin until about 20 seconds after vent line flow begins. Carryover of steam begins at this time because the concentration of steam in the drywell atmosphere has reached a level beyond the available heat exchanger capacity (even though the available capacity is also increasing; see Figure 2.3).

It is instructive to consider the events illustrated in these figures that occur just prior to time 11300 seconds. As shown on Figure 2.2, the drywell-to-wetwell differential pressure drops below the value needed to sustain PCCS vent line flow. This is substantiated by Figure 2.5, where the vent line flow is shown to be zero during this period. Figure 2.4 shows that the portion of available PCCS heat exchanger capacity actually used during this period decreases toward and ultimately reaches zero. This demonstrates that some time is required for the PCCS to fill with noncondensible gases and become bound after vent line flow ceases.

Almost exactly at time 11300 seconds, the drywell-to-wetwell differential pressure becomes sufficient to restore vent line flow (Figure 2.2), vent line flow (all noncondensible gas) is restored (Figure 2.5), and all available capacity is used (Figure 2.4) to condense the steam brought in with the mixed atmosphere from the drywell.

After time 11300 seconds, the drywell-to-wetwell differential pressure oscillates about the value required to induce vent line flow (Figure 2.2). During the periods when vent line flow occurs, this flow consists entirely of noncondensible gas (Figure 2.5). During the periods when vent line flow does not occur, the portion of the available capacity that is actually used decreases (Figure 2.4) as the PCCS tends to fill with cooled noncondensible gas. However, a fully bound condition is never attained.

That a fully bound condition is never attained during this final period of the example calculation is a testimony to the effectiveness of the PCCS system in controlling the drywell-to-wetwell differential pressure. Whenever the PCCS performance falters, this differential pressure increases, clearing the vent line and restoring the PCCS performance.

2.6 Effect of the Drywell Pressure on PCCS Operation

The nominal capacity of each PCCS heat exchanger-condenser is reported in the SSAR (Section 6.2.2.1) as 10 MW_t for conditions where the tubes are filled with pure saturated steam at 308 kPa (45 psia) and 407 K (273 °F), and the ICS/PCC pool temperature is 374 K (214 °F). The available capacity under accident conditions is, however, never more than about sixty percent of this because of the presence of noncondensible gases in the drywell atmosphere.

To estimate the variation in performance of the PCCS as a result of changes in the drywell pressure, the heat transfer (q) at the base condition is compared to the heat transfer rates at different pressures. The performance variation factor is thus calculated by dividing the heat transfer at the new condition by the heat transfer at the base condition. Ratios greater than one signify an improvement in performance.

The variation in performance = *q (new condition) / q (base condition)*

$$= \frac{h_{new} A \left(T_{steam}(new) - T_{wall}\right)}{h_{base} A \left(T_{steam}(base) - T_{wall}\right)}$$

where

h = heat transfer coefficient,

A = the surface area,

T_{steam} = temperature of the steam (saturation temperature at the pressure of the drywell), and

T_{wall} = temperature of the tube wall (assumed to be same as the temperature of the condenser pool, which is the saturation temperature at atmospheric conditions).

The heat transfer coefficient [3] for condensing steam in various geometries is examined next:

$$h = C\left[\frac{\rho_f\left(\rho_f - \rho_{steam}\right)k_f^{\,3} g \sin\theta \, h_{fg}}{\mu_f L\left(T_{steam} - T_{wall}\right)}\right]^{1/4}$$

where

ρ_f = the density of the liquid film,

ρ_{steam} = the density of the steam,

T_{steam} = temperature of the saturated steam,

T_{wall} = temperature of the wall, the temperature of the condenser pool,

$\sin\theta$ = sine of the angle of the tubes with the horizontal; for vertical tubes, the value is one,

h_{fg} = latent heat of the steam being condensed,

μ_f = viscosity of the film,

k_f = thermal conductivity of the film,

L = equivalent length,

g = gravitational constant, and

C = a constant value that must be calculated depending on the geometry, being either a vertical plate or a cylindrical tube.

It is important to note that this equation for the heat transfer coefficient is for condensers with relatively low vapor Reynolds numbers, less than 35,000. This equation will underestimate the heat transfer coefficient for condensers with a higher value; however, since the primary purpose of the equation as used here is to determine the variation in performance (and not the absolute value of the heat transfer) at low pressures, the use of the equation is appropriate.

The variation in performance becomes:

$$= \frac{h_{new}\left(T_{steam}(new) - T_{wall}\right)}{h_{base}\left(T_{steam}(base) - T_{wall}\right)}$$

$$= \frac{\left[\frac{\left[\rho_f\left(\rho_f - \rho_{steam}\right)k_f^{\,3}h_{fg}\right]}{\mu_f\left(T_{steam} - T_{wall}\right)}\right]_{(new)}^{1/4}\left(T_{steam}(new) - T_{wall}\right)}{\left[\frac{\rho_f\left(\rho_f - \rho_{steam}\right)k_f^{\,3}h_{fg}}{\mu_f\left(T_{steam} - T_{wall}\right)}\right]_{(base)}^{1/4}\left(T_{steam}(base) - T_{wall}\right)}$$

The performance variation factors for pressures are shown in Table 2.4. The base operating condition for the PCCS is at 0.3 MPa as noted in Table 2.4 by a value of unity for the multiplication factor. Also, as the pressure increases the performance of the PCCS improves. Thus, it is obvious why the ICS (which operates at a pressure of 7.4 MPa versus 0.3 MPa for the PCCS) has an energy removal capacity that is three times larger than the PCCS but has a smaller heat transfer surface area.

Table 2.4 Variation in PCCS Performance with Pressure in Drywell.

Pressure (Pa)	Multiplication Factors for PCCS Performance
0.000E + 00	0.0000
6.113E + 02	0.0000
5.000E + 04	0.0000
1.000E + 05	0.0000
1.500E + 05	0.4250
2.000E + 05	0.6660
2.500E + 05	0.8495
3.000E + 05	1.0000
3.500E + 05	1.1289
4.000E + 05	1.2425
4.500E + 05	1.3450
5.000E + 05	1.4386
6.500E + 05	1.6807
7.000E + 05	1.7518

Table 2.4 provides multiplication factors for performance variation for drywell pressures up to 0.7 MPa; however, it is recognized that the SBWR containment is predicted to fail at pressures greater than 0.65 MPa.

3. ICS Model

3.1 Introduction and Concept

The ICS (Isolation Condenser System) is a safety-related passive operating system designed to remove the core decay heat directly from the reactor vessel following reactor shutdown and isolation. It is described in Section 5.4.6 of the SBWR Standard Safety Analysis Report (SSAR) [1]. Unlike the PCCS, the ICS is not continuously in operation. A motor-operated valve must be opened (or, if power is lost, a nitrogen-operated bypass valve must open) in order to initiate operation of the ICS.

Flow through the ICS is first induced by the action of condensate draining from the condenser tubes into the reactor vessel annulus. The drainage draws in steam from the upper portion of the reactor vessel; this steam is condensed and returned to the vessel annulus. In the event that the ICS becomes "bound" by noncondensible gases, a vent line is provided to permit release of the gases trapped within the ICS to the pressure suppression pool.

The flow through the vent line is started and stopped by an active control system that continuously monitors the reactor vessel pressure. Once the vessel pressure reaches the vent opening setpoint (implying the ICS is bound), the valves on the vent line open allowing the accumulated noncondensible gases to escape to the pressure suppression pool, thereby reinitiating operation of the ICS.

The vent line valves are signaled to close once the vessel pressure has decreased below the reset (closing) setpoint for the vent. A time delay circuit is integrated into the logic to protect the vent valves from excessive cycling.

The ICS modeling concept is the same as for the PCCS in that it is recognized that it is not a purpose of the MELCOR code to predict ICS performance based upon first principles. Rather, based upon the available experiment evidence, MELCOR should adequately represent the effects of the ICS heat exchanger-condenser system under the boundary conditions that would be imposed by accidents.

3.2 Operation of the ICS Model

The same basic algorithms, contained in Subroutine CNDRN1, are used to model both the ICS and the PCCS. There is, however, a block of coding specific to the ICS. This coding block mimics the operation of the ICS vent line control logic, which has no counterpart within the PCCS (the flow through the PCCS vent line is limited only by the submergence depth of the vent line in the pressure suppression pool). The following is a description of the significant differences between the operating characteristics of the ICS and the PCCS and the logic enhancements required to represent the ICS.

The ICS operates at pressures near normal reactor vessel pressure, approximately 7 MPa, as compared to the PCCS, which operates at post accident drywell pressures of less than 0.50 MPa.

Because of the difference in operating pressures, allowances had to be made in the calculation of the vent line capacity to limit the flow to sonic velocity (choked flow) at the exit conditions. This was done by the use of the Modified Darcy Formula taken from the Crane Technical Paper No. 410.[4] The Darcy Formula estimates a mass flow rate for compressible flow using a net expansion factor through the pipe and the differential pressure between the reactor vessel and the choke point at the pipe exit. (The pressure at the exit condition can be easily determined if the flow is choked.) The determination of the net expansion factor serves to limit the flow through the pipe to sonic velocity at the pipe exit conditions.

The mass flow rate is determined in a subroutine CNDICF, which is used for both the PCCS and the ICS vent line flow calculations. CNDICF first determines the resistance coefficient for the vent line. Using the resistance coefficient, the maximum net expansion factor and the maximum $\Delta P/P$ for sonic velocity are found by interpolating between the values found on page A-22 of the Crane Technical Paper for a k value of 1.4. If the pressure in the PCCS/ICS minus the wetwell pressure divided by the PCCS/ICS pressure is greater than the value found for $(\Delta P)/P$, then the flow is choked. If the flow is not choked, then a linear interpolation is performed between zero and the calculated differential pressure to determine the net expansion factor. If the flow is choked, then the maximum $(\Delta P)/P$ is used to determine the pressure at the exit condition, and the net expansion factor is simply equal to its maximum value. The mass flow rate can then be estimated.

Because of the higher pressures at which the ICS condensers operate, the condenser tube walls are significantly thicker than for the PCCS condensers. This greater tube wall thickness may require a different performance degradation curve to represent system response to increases in noncondensible gas mole fractions. Provision is made for this new curve, when available, to be represented in the ICS set of user-input tabular functions, which are applied in a manner identical to the PCCS tabular functions described in detail in Section 2.3.

The heat removal capacity of a single ICS unit is at least 30 MW_t at a reactor pressure of 7.420 MPa (1050 psig) when fed by pure saturated steam. The large (factor of 3) increase in capacity over the PCCS is a direct result of the increase in steam density at reactor vessel pressure (where 1 m^3 of steam contains approximately 8 times the mass of the same volume at drywell conditions). Therefore, the ICS has a greater amount of stored energy within the fluid contained in the condenser tubes.

As described in Section 3.1, the vent line for each ICS unit contains a motor-operated valve, which is actuated upon a high pressure within the reactor vessel such as would occur whenever the condenser tubes become bound with noncondensible gases.

Unlike the PCCS, the ICS condensers are not expected to operate after the equalization of reactor vessel and drywell pressures that would occur under accident conditions as a result of ADS actuation and DPV sequencing. This conclusion is not stated explicitly in the SSAR, but follows from information contained in Section 5.4.6 and the control diagrams provided in Volume 15 of the SSAR. The control diagrams indicate that the controllers for the vent line valves receive their signals for automatic operation from reactor vessel pressure sensors exclusively.

After blowdown, these controllers would no longer receive a high pressure signal since the vessel would be at the same pressure as the drywell. Thus, the ICS would quickly become bound by noncondensible gases with no provision for venting except by means of operator intervention. However, no guidance to the operator concerning this action can be found in the SBWR Emergency Procedure Guidelines (EPGs).

The drain line from the ICS returns condensate directly to the reactor vessel annulus. The elevation of the ICS condensers provides a sufficient gravity head so that the condensate will drain to the vessel annulus even though the annulus water level may be several meters above the condensate return line. A loop seal is provided in the drain line to prevent steam from entering the condensers via this line should the water level fall below the connection point to the reactor vessel.

3.3 Example Results

Several test calculations have been performed using the ICS model with two units in operation for various accident sequences. The accident sequences considered are loss of offsite power (station blackout), a main steam line LOCA, and a break in the bottom head drain line. For the station blackout calculation, the ICS was predicted to operate continuously and to cause depressurization of the reactor vessel without SRV or ADS actuation, thus preventing loss of reactor coolant inventory and circumventing core degradation.

For the bottom head LOCA calculation, the ICS was predicted to operate until shortly after ADS actuation, when drywell atmosphere begins to be pulled into the reactor vessel (through the open DPVs) as the water drains from the bottom of the vessel. Subsequently, the presence of noncondensible gases within the reactor vessel causes rapid binding of the IC condenser tubes and without vent actuation, ICS operation terminates. The main steam line LOCA calculation shows a similar behavior with the ICS slowly becoming bound with the noncondensible gases that arise from hydrogen generation in the core and from the small amount of drywell atmosphere that mixes with the reactor vessel atmosphere after vessel depressurization.

To test the logic of the vent line control valve, additional calculations were performed in which a large amount of nitrogen was arbitrarily placed into the reactor vessel upper head for the station blackout and for the main steam line LOCA accident sequences. This provides an overpressure of noncondensible gas such that the vessel water is initially subcooled. The large noncondensible gas mole fraction at the isolation condenser inlet limits the ICS capacity (while operating) to a value insufficient to remove the decay heat. These test calculations show a very short period of ICS operation prior to binding.

Because of the inability of the ICS to remove any energy while bound, the calculated pressure in the reactor vessel increases until the vent valve opening setpoint is reached. The vent valve then opens to remove noncondensible gases from the ICS tubes to the wetwell and thereby restore ICS operation. While the vent line is open, the pressure in the reactor vessel decreases slightly, which leads to closing of the vent valve.

This predicted cyclic behavior continues with increasing frequency until the water within the reactor vessel reaches the saturation temperature and the rate of vessel pressurization increases markedly. Subsequent ICS vent actuation does not provide sufficient gas release through the small vent line to prevent the increasing vessel pressure from reaching the SRV opening setpoint. The action of opening the SRVs forces most of the nitrogen out of the reactor vessel and reduces the noncondensible gas mole fraction from approximately fifty percent to less than one percent. This produces a steam-rich environment within the ICS so that operation can resume.

For the main steam line LOCA, the ICS also becomes quickly bound, but flow through the break removes most of the imposed nitrogen from the reactor vessel. However, the break flow also serves to prevent the reactor vessel pressure from ever increasing above the vent valve opening setpoint; therefore, the ICS remains bound after operating for only a short time after the accident is initiated. (Possible operator action to remote-manually open the vent valve was not considered in this calculation.)

Similar to the PCCS, the ICS efficiency will degrade as the pressure in the reactor vessel decreases. To estimate this degradation, the same methodology described in Section 2.6 is utilized.

The multiplication factors for variation in performance for pressures are shown in Table 3.1. (Factors greater than unity signify an improvement in performance.) The base operating condition for the ICS is at 7.4 MPa as noted in Table 3.1 by a value of unity for the multiplication factor.

Table 3.1 Variation in ICS Performance with Pressure in the Reactor Vessel

Pressure (Pa)	Multiplication Factors for ICS Performance
0.000E + 00	0.0000
6.113E + 02	0.0000

Pressure (Pa)	Multiplication Factors for ICS Performance
5.000E + 04	0.0000
1.000E + 05	0.0000
1.500E + 05	0.1080
2.000E + 05	0.1692
2.500E + 05	0.2159
3.000E + 05	0.2541
3.500E + 05	0.2869
4.000E + 05	0.3157
4.500E + 05	0.3418
5.000E + 05	0.3655
6.500E + 05	0.4271
7.000E + 05	0.4451
7.500E + 05	0.4624
8.000E + 05	0.4787
8.500E + 05	0.4943
9.000E + 05	0.5092
9.500E + 05	0.5237
1.000E + 06	0.5376
1.100E + 06	0.5643
1.200E + 06	0.6507
1.300E + 06	0.6139
1.400E + 06	0.6368
1.500E + 06	0.6591
1.750E + 06	0.6661
2.000E + 06	0.6980
2.250E + 06	0.7259
2.500E + 06	0.7512
3.000E + 06	0.7956
3.500E + 06	0.8328
4.000E + 06	0.8645
5.000E + 06	0.9159
6.000E + 06	0.9556
7.000E + 06	0.9883
7.200E + 06	0.9942
7.400E + 06	1.0000
7.600E + 06	1.0054
7.800E + 06	1.0106
8.000E + 06	1.0156
8.200E + 06	1.0204
8.400E + 06	1.0252
8.600E + 06	1.0298
8.800E + 06	1.0340
9.000E + 06	1.0381
1.000E + 07	1.0568

4. Interface with MELCOR

The information for the condensers is stored in the ESF Package of the MELCOR database contiguous to the information for the FCL Package. A special routine to process PCCS/ICS model input has also been added for use in calculations for which these models are to be exercised. These modifications to the MELCOR database are bypassed (as are the PCCS/ICS model routine CNDRN1) unless the PCCS and/or ICS input cards are included in the MELGEN input deck.

If the user requests that the PCCS model be invoked for a calculation, then it is necessary that the control volume numbers representing the drywell, wetwell, ICS/PCC pool, and the Gravity-Driven Cooling System (GDCS) be provided on a dedicated MELGEN input card. If the user does not provide this card, the PCCS model will be bypassed. An additional dedicated card is required to indicate the tabular functions that represent the PCCS performance adjustments (depending upon operating parameters).

If the ICS model is to be exercised in a calculation, the user must provide the control volume numbers for the reactor vessel upper head and annulus, ICS/PCC pool(s), and the wetwell. Similar to the case for the PCCS, if the input card carrying this information is not provided, the ICS model will be bypassed.

A few simple descriptive input numbers for the PCCS and/or ICS are also required when these models are to be exercised. This special input consists of the volume of the condensers, the source line volume, the basic capacity of one unit of the condensers, and the dimensions of the vent line (minimum diameter and equivalent length) used in determining the mass flow. The user also inputs the number of units (maximum of three) that are to be considered to be operating.

For the ICS, the setpoints for the vent valve control logic are also required. The number of operating condensers may be changed during the course of a calculation. The CND Package Users' Guide describes the input to both MELGEN and MELCOR required for operation of the PCCS and/or ICS models, and the plot variables and associated special external data files that may be created.

Because the condenser is part of the ESF Package, the condenser energy balance does not have a separate listing under the GLOBAL energy balance edit, but rather is combined with the FCL Package so that an overall ESF energy balance is given. Currently, however, the FCL Package does not have a separate energy balance so the energy balance for the ESF Package represents the condenser package exclusively. For a typical calculation, a relative energy error of approximately 1×10^{-7} percent is produced.

References

1. SBWR Standard Safety Analysis Report (SSAR), GE Nuclear Energy, 25A5113 Rev. A, 1992.

2. H. Nagasaka et al., *Heat Removal of Isolation Condenser Applied as a Passive Containment Cooling System*, of the Nuclear Energy Group, Toshiba Corporation.

3 J.P. Holman, *Heat Transfer*, McGraw-Hill, Inc., New York, 1963.

4. Crane Technical Paper No. 410